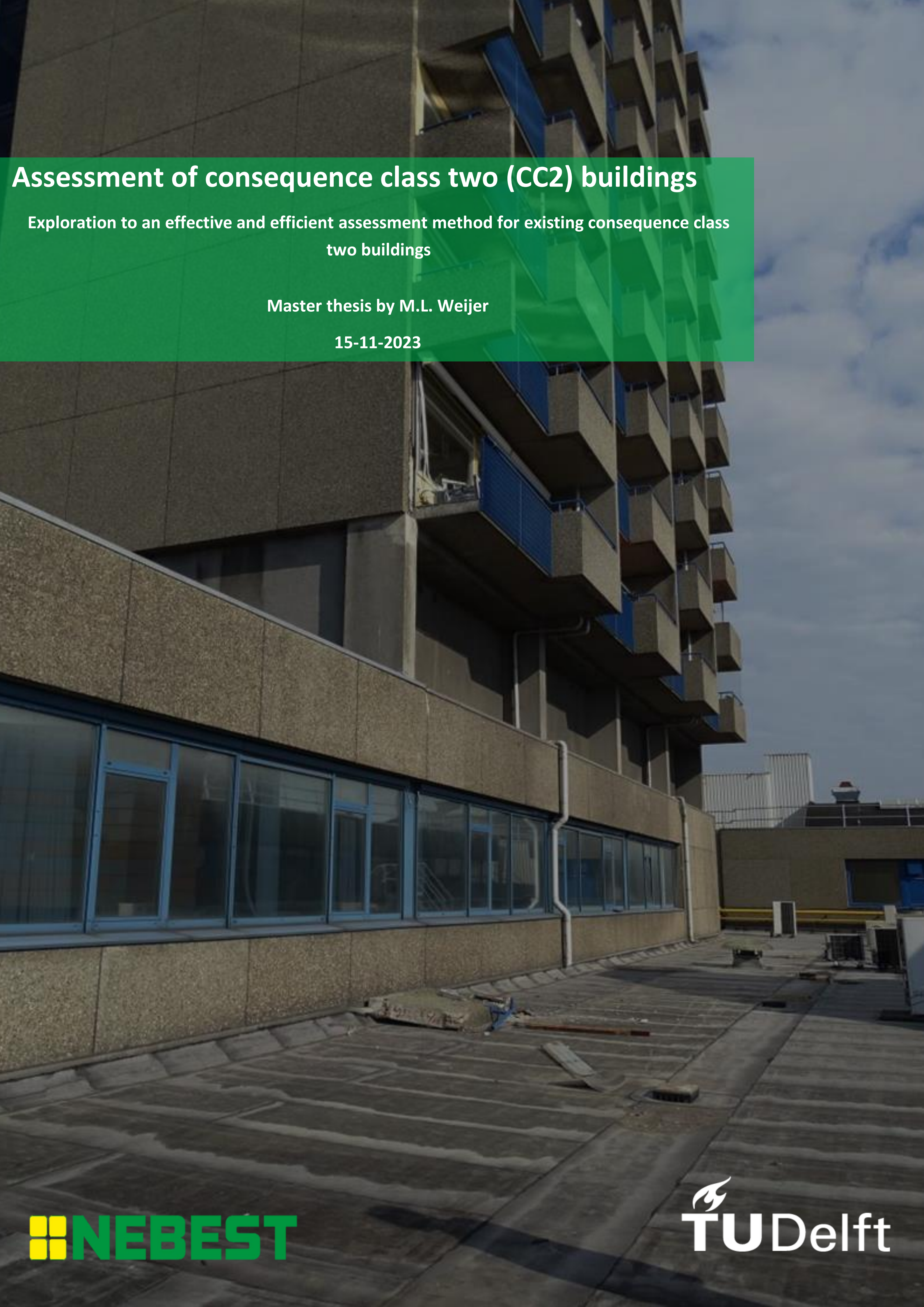

# Assessment of consequence class two (CC2) buildings

## Exploration to an effective and efficient assessment method for existing consequence class two buildings

Master thesis by M.L. Weijer

15-11-2023

Source title page figure: Inspected fallen spandrel from flat by Nebest (Kapteijn - Van Hennik, 2021).

# Assessment of consequence class two (CC2) buildings

## Exploration to an effective and efficient assessment method for existing consequence class two buildings

By

M.L. Weijer

In partial fulfilment of the requirements for the degree of
Master of Sciences in Civil Engineering
specialisation Building Engineering
at Delft University of Technology

*An electronic version of this thesis is available at https://repository.tudelft.nl/.*

| | | |
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| | Ing. W. H. J. van den Berg | Nebest |

# Preface

This thesis represents the conclusion of my studies at Delft University of Technology, which began six years ago with the bachelor Civil Engineering. After the bachelor it continued with a master's study in the same field, specialising in Building Engineering – Structural Design. Over the past year, I have been working on this thesis to complete my master's degree and apply the gained knowledge in practice.

The focus of this thesis is the development of an assessment process to evaluate the structural safety of existing CC2 buildings. This topic was chosen with the aim of enhancing safety for building users and those in close proximity, as well as gaining a deeper understanding of the existing building stock in the Netherlands. This research is primarily intended for engineers involved in assessment of existing buildings, but also provides insights for building owners or asset management organisations on how to maintain structural safety of their assets. Anyone interested in the assessment of existing structures, structural failure incidents, existing assessment methods or risk quantification is invited to read this report.

During my research I received support from engineering firm Nebest. I would like to express my gratitude to all my colleagues at the firm for their support, advice and network sharing. Special thanks go to ing. W.H.J. van den Berg for his guidance, knowledge sharing, encouragement and network provision.

I would also like to thank my committee at Delft University of Technology for their advice and feedback throughout this thesis. I am particularly grateful to dr. ir. K.C. Terwel for chairing this committee, providing valuable feedback and sharing his expert knowledge within forensic engineering sector; ir. A.C.B. Schuurman for his expert knowledge within structural engineering and IT; and prof. dr. ir. G.L.L. Reniers for his expert knowledge on risks and risk quantification.

This thesis includes interviews with asset managers and experts in the building sector. It also includes a survey and two case studies provided by organisations to validate the developed assessment process. I would like to express my gratitude to everyone in the building sector who contributed to this research.

Finally, I would like to extend my heartfelt thanks to my family and friends for their strong support throughout my studies and while writing this thesis. Their advice and discussions were inestimable, as their help with other aspects that enabled me to complete this study and thesis successfully. This thesis marks the beginning of my career in the building sector.

Menno Weijer
Kinderdijk, November 2023

# Abstract

**Problem:** Numerous structural failure incidents have occurred in the past years (Onderzoeksraad voor Veiligheid, 2020). It was found that current methods, such as NEN 2767, fall short in guaranteeing the structural safety of existing buildings. Although structural failure incidents infrequently result in casualties (Terwel, 2014), there are also social and economic consequences that impact both building user as owner. The interviewed asset managers have noted that the current lack of insight into a building's structural condition often leads to preventable maintenance and repair costs, and safety risks. When coupled with changes in the outdoor and built environment, such as a focus of continuity in use, these risks become increasingly challenging for owners to manage.

To ensure structural safety of significant public buildings within CC3[1], mandatory assessment via NTA 8790 must be performed. However, this method is exclusively tailored to CC3 buildings and only considers potential casualties as risk consequences. This strategy neglects CC2[1] buildings and other potential consequences, exposing them to elevated risks due to a lack of insight into their structural conditions. All the asset managers interviewed for this study, all managing CC2 buildings, reported these issues. The development of a method to assess a building's current structural state could mitigate these risks. This leads to the following **research question:**

In which way can consequence class two buildings be efficiently and effectively evaluated on structural safety to prevent incidents with structural failures?

**Scope research:** The scope of this research is limited to CC2 buildings during the use phase and focuses on structural safety. It is specific to normal conditions and pertains to the Dutch building industry.

**Building typologies:** A delineation of building types, intended for the assessment process, is established through a study of CC2 boundaries, an examination of the current building stock in the Netherlands and a structural failure incident study. This delineation is illustrated in figure 0.1. A combination of these depicted building types within a building is also considered. This approach facilitates an effective and efficient application of the assessment process to the most prevalent and/or vulnerable building types in the building stock.

However, the primary input of the developed assessment process is derived from a study to existing assessment methods, not the focus on different building types. This suggests that the developed assessment process could potentially be applied to non-selected building types within CC2 and CC3. Since the primary focus of this development was on the selected building types, its applicability to buildings outside this selection necessitates further investigation in future studies.

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[1] CC: Classification of constructions on the basis of consequences regrading failure of the structure or a part of it (NEN, 2015a).

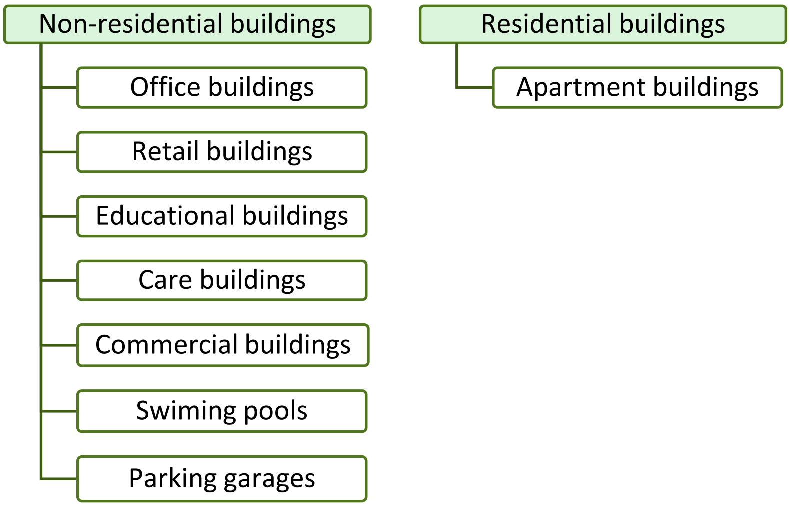

Figure 0.1: Building types considered in the thesis.

**Structural failure incidents**: In addition to examining the building types, structural failure incidents have been analyses to compile a list of common causes. This list must be considered during the assessment process to ensure the absence of these causes. However, due to the limited data availability, expert interviews and general literature this list is not exhaustive but rather an initial attempt. It can serve as a focus during the assessment but should not be solely relied upon.

**Assessment process:** Existing assessment methods are evaluated on the criteria of trustworthiness, effectivity and efficiency. The results of this evaluation have been integrated into the development of an efficient and effective assessment process, depicted in the flowchart on the next page. This process necessitates multiple iterations of object risk analyses (ORA), with risks quantified based on likelihood and consequences, both scaled from one to five. Risks are categorised into three levels: acceptable (green), undesirable (orange) and unacceptable (red).

Table 0.1: Quantification risks

| **Quantified level of risk** | | | | | | |
|---|---|---|---|---|---|---|
| **Chance** | 1 | 🟩 1 | 🟩 2 | 🟩 3 | 🟩 4 | 🟩 5 |
| | 2 | 🟩 2 | 🟩 4 | 🟧 6 | 🟧 8 | 🟧 10 |
| | 3 | 🟩 3 | 🟧 6 | 🟧 9 | 🟧 12 | 🟥 15 |
| | 4 | 🟩 4 | 🟧 8 | 🟧 12 | 🟥 16 | 🟥 20 |
| | 5 | 🟩 5 | 🟧 10 | 🟥 15 | 🟥 20 | 🟥 25 |
| | | 1 | 2 | 3 | 4 | 5 |
| | | **Consequence** | | | | |

Each risk is subject to a detection filter, ranging from one (easily visually detectable) to four (not detectable). This detection filter aids in categorising the outcomes in the first step of the ORA and in selecting appropriate actions or measures when the assessment is deemed insufficient. The detection filter is also given in the flowchart at the outcomes of ORA step one.

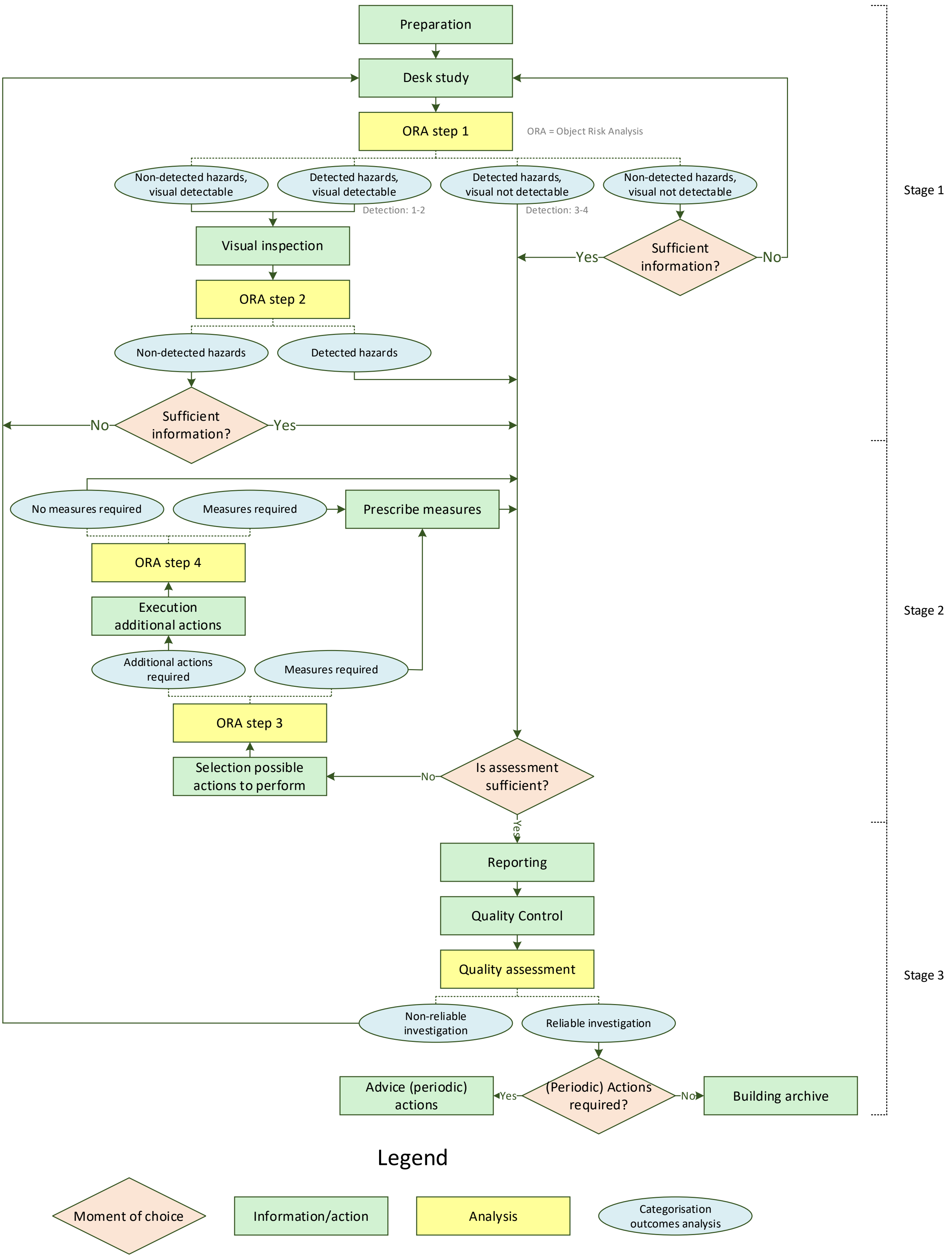

Figure 0.2: Developed assessment process

**Validation:** The assessment process developed in this study has been validated by applying it to two existing buildings. This validation demonstrates the method’s ability to detect both degradation mechanisms and design and execution errors, providing an efficient and effective approach to identify most existing problems. The process continues with more detailed investigations if required, until the root cause of the problem is identified.

However, it should be noted that a number of non-standard hidden defects or risks may not be detected. These are issues that could potentially only be identified through a comprehensive desk study, which involves a thorough examination of every element in all available drawings. These risks are also considered within the assessment process via the non-visual detectable hazards that are not detected, thereby acknowledging that there will always be residual risks that cannot be identified.

**Conclusion:** The assessment process developed in this study has proven effective in evaluating the structural safety of CC2 buildings, thereby preventing incidents relating to structural failures. While the necessity for comprehensive risk analyses does impact the time required for the assessment, these analyses have been optimised during the evaluation and validation stages to concentrate on the most critical aspects. The assessment itself is optimised by implementing specific actions based on different analysis outcomes. Along with other efficiency-enhancing aspects, it presents an efficient method within the parameters of effectivity and trustworthiness.

This was evident during the comparison of the developed assessment process with existing assessment methods on the criteria trustworthiness, effectivity and efficiency. The developed method primarily surpasses existing methods in terms of trustworthiness and effectiveness, while it is more closely matched to other methods in terms of efficiency.

When considering the detection of studied failure incidents, the method would be able to detect most of them. The list of common causes for structural failure incidents and general attention points, which must be considered in the assessment process, ensure that most incidents are detected. However, as revealed during validation, not all deficiencies can be detected using this method. There will always be hidden deficiencies that remain undetected and assessors are made aware of this limitation. Despite this constraint, the method provides an efficient and effective evaluation of the structural safety of buildings, thereby fulfilling the main objective of this study.

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# Glossary

| | |
|---|---|
| Apartment | Dwelling that forms a building with other houses or commercial premises (CBS, n.d.). |
| ASCE | The American Society of Civil Engineers. |
| BCA | Building and Construction Authority. |
| BZK | Ministry of the Interior and Kingdom Relations. |
| CBS | Central Bureau of Statistics. |
| Cobouw | An independent Dutch publication for the building sector. |
| Consequence class (CC) | Classification of constructions on the basis of consequences regarding failure of the structure or a part of it (NEN, 2015a). |
| Dutch Safety Board | An independent organisation which investigates practical as well as broader safety issues. In the investigations not only the direct causes are traced, but also more abstract issues are studied. The goal is to learn from incidents and provide recommendations to improve overall safety (Onderzoeksraad Voor Veiligheid, n.d.-b). |
| Effectiveness | Can be measured as the extent to which a goal is achieved from the client's perspective (Blokland & Reniers, 2013). |
| Efficiency | Refers to the ability to achieve maximum results with minimum expenditure of energy, effort, money and other resources (Cambridge Dictionary, 2023a). |
| EIB | Economic Institute for the Building Sector. |
| KPCV | The Knowledges Base Structural Safety. |
| Nebest | Consultancy and engineering firm specialising in the civil and building sector. |
| Housing association | Primarily to provide affordable living spaces for low-income citizens. While they may engage in commercial activities, these must be strictly separated from their social responsibilities (BZK, 2023). |
| MuWi floor | Floor composed of concrete beams with lightweight concrete filling elements in between (NOS, 2023). |
| NEHOBO floor | Floor consisting of hollow bricks bound together with reinforced mortar. |
| NEN | The Royal Dutch Standards Institute. |

| | |
|---|---|
| NL/SFB Codes | A classification system used for coding (structural) objects and layers in BIM/CAD systems, the NEN 2767 and other applications (Techniek Nederland, 2020). |
| NTA | Is a demand-determining agreement between two or more interested parties (Rijkswaterstaat, n.d.). |
| ORA | Object Risk Analysis. |
| Single-family house | Ground-floor dwelling not located in a building with multiple residences (NEN, 2019b). |
| Structural failure | The inability of a structure or structural member to meet the specified requirements (Terwel, 2014). |
| Use phase | Refers to the period during which a building serves its intended function(s). |
| VDI | Union of German Ingenieurs. |
| VROM | Former Ministry for Housing, Spatial Planning and Climate Policy. |

# 1 Introduction

## 1.1 Project motivation

Over the past years numerous incidents related to structural safety have occurred during the use phase of buildings within the Netherlands (Onderzoeksraad Voor Veiligheid, 2020). An example of such a failure includes a spandrel falling onto the roof of a shopping mall, as pictured on the title page. In fact, any structural safety deficiencies, whether they emerge post-completion or are undetected errors from the design or construction phase, can only be identified during a building's use phase (Onderzoeksraad Voor Veiligheid, 2020).

Nebest, a consultancy and engineering firm specialising in the civil and building sectors, initiated the development of an assessment method to get a better grip on the structural safety deficiencies in existing buildings. By detecting these deficiencies in time, structural failure incidents could be prevented. However, the pilot for this method has not yet been widely implemented in the building sector. As a result, many risks related to structural safety within existing buildings remain undetected.

The motivation of this thesis is to further develop Nebest's reassessment method to facilitate its widespread implementation in the building sector. This more refined reassessment method could help identify structural safety deficiencies and prevent incidents during the use phase of buildings. Consequently, the remaining risks within existing buildings could be detected and mitigated.

In addition to supporting Nebest and enhancing the structural safety of the building sector, this study aims to contribute to the scientific community. The development of the reassessment method involved a thorough exploration of various existing assessment methods via set criteria. By integrating the strengths of these methods, including those from other sectors, a new assessment approach has been developed. This approach not only offers a new way of assessment but also provides a comprehensive evaluation of existing methods, which could be beneficial to future scientific research.

Furthermore, structural failure incidents in the Netherlands have been examined to identify common causes. Efforts have been made to discern patterns within these causes, thereby shedding light on structural components and elements that are susceptible to failure.

## 1.2 Problem statement

As mentioned, numerous structural failure incidents have occurred in the past years (Onderzoeksraad Voor Veiligheid, 2020). The reason for these failures not being detected in a timely manner were revealed through interviews with asset managers and a survey among the building sector. Participants were asked about their methods for ensuring the structural safety of existing buildings and their views on the current situation. These interviews and the survey are detailed in appendix A.

It was found that current methods, such as NEN 2767, fall short in guaranteeing the structural safety for existing buildings as this aspect is underexposed. With the current implementation, building owners risk non-compliance with the duty of care towards building users and individuals in close proximity (Overheid, 2023). In this context, the term ''building owner'' also encompasses individuals authorised to make changes to the building.

The occurred structural failure incidents infrequently result in casualties (Terwel, 2014). However, these incidents also result in other consequences. These include social and economic impacts that affect not only the users but also the owners of the buildings. Asset managers have noted that the current lack of insight into a building's structural condition often leads to preventable maintenance and repair costs. This lack in understanding causes financial, social and safety risks. When coupled with changes in the outdoor and built environment, such as a focus of continuity in use, these risks become increasingly challenging for owners to manage.

To ensure the structural safety of significant public buildings within consequence class three (CC3), a National Technical Agreement (NTA) has been developed. This NTA 8790 guideline must be mandatorily applied to these existing buildings, due to the potential risk for a high number of casualties in the event of a collapse (Onderzoeksraad Voor Veiligheid, 2020). Visitors and other users of these buildings depend on the designers, builders and owners for their safety.

However, this method is exclusively tailored to CC3 buildings and only considers potential casualties as risk consequences. This strategy neglects CC2 buildings and other potential consequences, exposing them to elevated risks due to a lack of insight into their structural conditions. All the asset managers interviewed for this study, all managing CC2 buildings, reported these issues. The development of a method to assess a building's current structural state could mitigate these risks.

## 1.3 Research objective

This leads to the objective of developing a reassessment methodology. This methodology should be both effective, in terms of achieving the goals of the client (Blokland & Reniers, 2013), and efficient, in terms of maximising results with minimal resource expenditure (Cambridge Dictionary, 2023a). In this context, effectiveness is defined as the successful identification of significant risks related to structural safety of building occupants and those nearby. The object is defined as follows:

An efficient and effective assessment method to evaluate existing consequence class two buildings on structural safety to prevent incidents with structural failures.

## 1.4 Research questions

The research objective is translated in the formulation of the main research question of this thesis, which is depicted below.

In which way can consequence class two buildings be efficiently and effectively evaluated on structural safety to prevent incidents with structural failures?

Five sub-questions have been formulated to support this main question, with the second sub-question further divided into five additional questions due to its comprehensive nature. These supplementary questions aim to provide a more detailed understanding of the incidents involving structural failure. Each sub-question is accompanied by the type of investigation being conducted to answer it, such as a literature study or interviews.

Table 1.1: Sub-questions

| Sub-question | Investigation |
|---|---|
| Which building typologies are present in the Netherlands? | Literature study |
| What incidents are known within buildings?<br>- What building typology/typologies are featured most in these incidents?<br>- What was the age of these buildings when the incidents occurred?<br>- What are the critical structural components within these buildings?<br>- What are the vital locations of these components?<br>- Which parties are responsible for these components? | Database, interviews, literature study |
| Which reassessment methods are already available? | Literature study |
| What will the reassessment method look like? | Design |
| Is the method valid for the selected building typology/typologies within CC2? | Case study |

## 1.5 Scope and Limitations

The research presented in the thesis is subject to certain limitations. These limitations are necessary to maintain the efficiency and effectiveness of the methodology. Furthermore, the limitations ensure that the scope of the study aligns with the prescribed workload for a master's thesis. Most of the limitations are enumerated in table 1.2.

Table 1.2: Limitations of the study

| Topic | Limitation |
|---|---|
| Type of construction | *Building*<br>The scope of this thesis is confined to buildings. Infrastructure-type constructions are excluded. |
| Industry type | *Dutch building industry*<br>The reassessment method is intended for the Dutch building industry, incorporating its standards and characteristics. |
| Lifetime stage | *Use phase*<br>This method only considers buildings in the use phase of their life cycle. |
| Consequence class | *Two*<br>The method focusses on buildings within CC2. |
| Conditions | *Structural*<br>The method is designed for structural conditions pertaining to buildings in the Netherlands. Notably, fire conditions fall outside the scope of this method. |
| Incidents | *Structural safety*<br>The method developed primarily addresses incidents related to the structural safety of the building occupants and those nearby. |

All structures within the previously mentioned scope are included in this study. The reassessments conducted with the developed method must comply with the NEN 8700 standard.

The scope of the thesis is to devise a process for assessing an existing building, with the emphasis on the process rather than a fully developed method ready for implementation. Once the assessment process is established, the detailed implementation and fine-tuning, will be left for future studies. The study is considered complete once the assessment process is established. Further delineation of the study is provided in the first phases of the thesis.

## 1.6 State of the art

Several studies related to the subject matter of this thesis have been conducted. This section describes which information is already available and identifies gaps in relation to the thesis subject. First the discussion focusses on the most relevant sources pertaining to existing assessment methods, followed by sources that consider structural failure incidents. Both these topics are integral to the earlier stated sub-questions that need to be assessed.

### 1.6.1 Available sources related to existing assessment methods

In preparation for the development of the NTA 8790 periodic assessment method for CC3 buildings, three desk studies have been conducted. The content discussed in each of the three desk studies has been summarised in figure 1.1.

Desk study one: Existing guidelines, protocols etc. (Kuijer et al., 2022)

Desk study two: Inventerisation of the scope (Wijte et al., 2021)

Desk study three: Inventerisation of risky construction elements (Krijgsman et al., 2022)

Figure 1.1: Studies performed in advance of NTA 8790

The first desk study explores the information available for evaluating existing structures, including various established assessment methods (Kuijer et al., 2022). However, it does not interpret which aspects of these methods are efficient or effective in use. This missing information is important input in the development of an efficient and effective assessment method.

The latter two studies focus on structural risks that should be addressed by NTA 8790. However just as the assessment method itself, these studies are specific to CC3 buildings, leaving a knowledge gap in the consideration of structural risks for CC2 buildings. Further details on NTA 8790 are provided in section G.2.9 of appendix G.

Please note that the NTA version referenced in this document is not final. During the thesis writing and research period, only a feedback version was available from NEN. This version, along with a letter from the relevant Minister (source (de Jonge, 2023)), serves as the basis for this document. Therefore, there may be discrepancies between this document and the final version of NTA 8790.

### 1.6.2 Available sources to structural failure incidents

In 2014, Terwel completed a study aimed at identifying areas of improvement for factors in the design and construction process of the Dutch building industry with regard to structural safety (Terwel, 2014). This involved investigating the nature and extent of structural failures in the Netherlands (Terwel, 2012), leading to the creation of a structural incident database based on Cobouw articles.

A.R. Develi extended Terwel's research, expanding the database to cover incidents from 1993 to 2018, encompassing approximately 437 incidents. Develi sought to determine why many incidents occurred and which building elements were prone to incidents (Develi, 2020). An attempt was made to incorporate this information into a risk-based tool. However, due to insufficient data, the development of this tool was not feasible. The study did provide some insight into the frequency of these incidents, at least those reported in the news. Despite these insights, there remains a lack of information regarding the elements most prone to incidents and the common causes of structural failures. This missing data could be used as focal points within the assessment process to ensure these common causes are not present, thereby enhancing the effectiveness of the assessment.

## 1.7 Structure and research method

This section outlines the structure of the thesis and the research method. The figure below illustrates the entire process of this thesis through the sub-questions. The flowchart is divided into distinct phases, each of which is detailed further in this section.

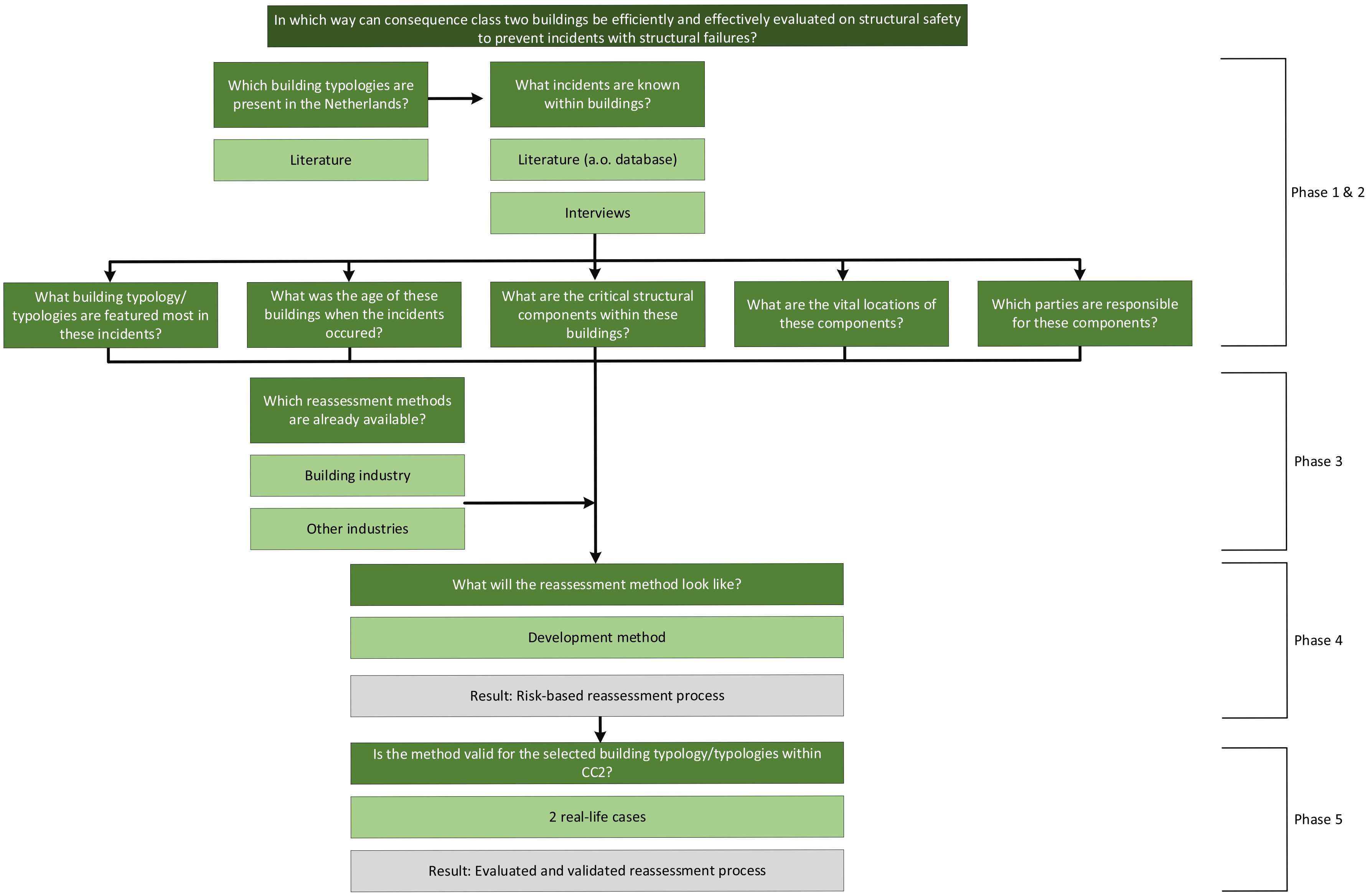


Figure 1.2: Flowchart process thesis

The phases given in the flowchart encompass the following subjects:

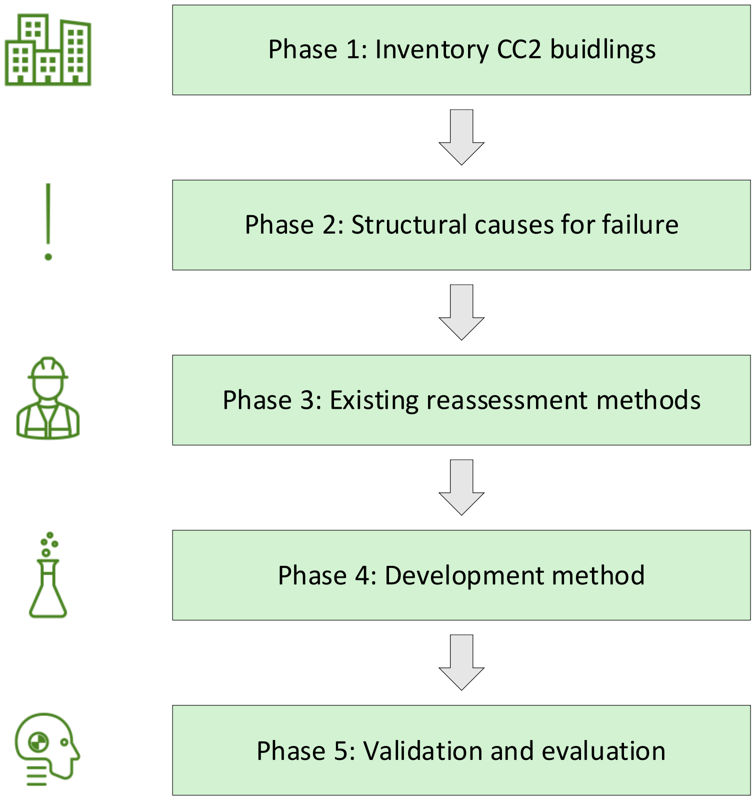


Figure 1.3: Parts thesis

### 1.7.1 Phase 1: Inventory CC2 buildings

The investigation for this phase is detailed in chapter 3. The existing building stock in the Netherlands is examined in this chapter. It involves a review of standards to delineate CC2 and identify buildings within this category. This process results in an inventory of various building types in the Netherlands, taking into account both their quantity and age.

### 1.7.2 Phase 2: Structural causes for failure

This investigation, presented in chapter 4, seeks to pinpoint the most common causes of structural failure in the Netherlands. This is accomplished by formulating a list of hypothetical causes derived from the Cobouw database by Terwel and Develi. This hypothetical list is then validated through interviews and a literature review with additional details gathered for the confirmed causes. These causes, which are present in multiple buildings in the Netherlands, help narrow down the focus of the method. Furthermore, general points of interest during an assessment of existing buildings, which emerged during the literature revied and interviews, are also noted. In addition, a delineation is made in building types based on the information from both chapters 3 and 4.

### 1.7.3 Phase 3: Existing reassessment methods

This section of the thesis is dedicated to information gathering for the development of the method. A comprehensive exploration of existing assessment methods, guidelines and other relevant sources is conducted. The first desk study for NTA 8790 is also reviewed to integrate its findings into this study. A selection of these sources is then examined for valuable insights, employing pre-defined criteria to structure and highlight the beneficial and less beneficial aspects. These beneficial aspects may be adapted or directly incorporated into the development of the method, as detailed in chapter 5.

### 1.7.4 Phase 4: Development method

The method is developed based on the output of the preliminary studies described in chapters 3, 4 and 5. The results of this development are presented in chapter 6. The structure of the assessment is first described using a series of steps. Subsequent sections provide information on the risk assessment, qualifications and advice on periodic actions.

### 1.7.5 Phase 5: Validation and evaluation

The method is validated and evaluated using existing cases. In total, two cases are used, for which certain criteria are given. Both the criteria and the selection process as well as the description of the cases are presented in chapter 7. The actual validation and evaluation are presented in chapter 8. This concludes the development of the assessment method for existing consequence two buildings.

# 2 Literature review

This chapter goes further into detail for the structural failure incidents in the use phase, the insurance of the duty of care by the building owner and changes within the built environment. In order to start the phases of the study to develop a reassessment process, it is important to first explore the details of the described problem.

## 2.1 Structural failure incidents in the use phase

The partial roof collapse at the AZ stadium on August 10, 2019, initiated an investigation by the Dutch Safety Board into the assurance of structural safety during the use phase of a building. This investigation concluded that numerous incidents occur during the use phase. Over a twenty-year period at least sixty serious structural problems were discovered during the use phase (Onderzoeksraad Voor Veiligheid, 2020). In half of these cases, problems relating to structural safety were identified in time to prevent an incident from occurring.

In the study by Terwel, among others, three databases of structural failure incidents were examined. The research considered the phase in which the primary cause of these incidents originated. Approximately 60% of the incidents were found to have originated from the design or construction phase, while only about 10% were attributed to the use phase (Terwel, 2014).

However, these percentages relate to the cause of failure. When examining the phase in which these incidents were discovered, two databases reported a discovery rate of 67% during use (Terwel, 2014). One database did not record any discoveries or cause of failure during the use phase. In conclusion, a significant number of structural safety incidents reported in the database were detected during the use phase of a building.

These incidents typically do not result in fatalities for citizens in non-working circumstances. According to the study by Terwel, the annual probability of death due to structural failure for this group is between $10^{-7}$ and $10^{-8}$ (Terwel, 2014). An acceptable limit of $10^{-5}$ is used, based on the study by Vrouwenvelder and Scholten, which provides this limit as it must be below the probability of death due to a traffic accident, which is $10^{-4}$ per year (Vrouwenvelder et al., 2011). The actual value is therefore below the acceptable limit.

However, as noted by Kleijn, while the overall probability may be below the limit, an individual building may fail to meet safety requirements (Kleijn, 2019). The results can also vary, as a low probability but high consequence incident can significantly affect this probability (Terwel, 2014). It is important to note that this paragraph only considers the probability of death. However, if such an incident occurs, social, economic and other consequences may also be significant.

## 2.2 Insurance of structural for existing buildings

A prior investigation by the Safety Board into the collapse of a multi-storey car park in Eindhoven resulted in an action plan to improve structural safety during the design and construction phase. However, the question remains what is done in the use phase to assure the structural safety and why is it falling short.

First it was investigated what legislation is available for assuring the structural safety in the use phase.

### 2.2.1 Legislation

In the Netherlands, the responsibility for ensuring structural safety primarily lies with the building owners, as mandated by Section 1A of the Dutch Housing Act (Overheid, 2023). This legislation requires that the condition of buildings does not pose any health or safety risks. The NEN 8700 standard provides guidelines for assessing existing structures, especially during reconstruction or disapproval. However, its application in other scenarios largely depends on the knowledge and/or willingness of the owner (Onderzoeksraad Voor Veiligheid, 2020). The safety Board has observed that specific details on maintaining the (structural) condition of a building are not readily available.

Municipalities are responsible for ensuring compliance with building regulations. However, inspections are typically initiated only when there is a suspicion of non-compliance (Onderzoeksraad Voor Veiligheid, 2020). The government also imposes investigative duties on certain buildings that could potentially pose health or safety risks (Bouwbesluit, n.d.). These duties specifically pertain to external cantilevered gallery floors, roof suspension in swimming pools and plank floors. While these investigative duties enhance structural safety, they are reactive measures addressing specific issues that have already surfaced.

### 2.2.2 CC3 buildings

The Dutch Safety Board concluded that periodic assurance of structural safety during the use phase of buildings is not adequately ensured (Onderzoeksraad Voor Veiligheid, 2020). As a result, the Board recommended mandatory periodic assessments of structural safety for significant public buildings within CC3. These buildings were selected due to the potential for a high number of casualties in the event of a collapse (Onderzoeksraad Voor Veiligheid, 2020). Visitors and other users of these buildings depend on the designers, builders and owners for their safety. The Minister accepted this recommendation, thereby making the duty of care for these building owners more specific (Ollongren, 2021).

To establish a clear methodology for the reassessment of these buildings, the Minister commissioned the Royal Dutch Standards Institute (NEN) to develop the earlier mentioned NTA (Ollongren, 2021). The mandate for the NTA development specified a proportionate, risk-based assessment focussing solely on structural safety in the use phase (Ollongren, 2021). This NTA 8790 provides a methodology for assessing significant existing public buildings within CC3. CC2 buildings are thus not considered for the development of NTA 8790.

## 2.3 Changes in built environment

Next to the insufficient insurance of structural safety in the use phase, changes within the built environment increase the load on existing buildings. Climate change, for instance, can result in increased rainfall, higher wind loads and other extreme weather phenomena (Krijgsman et al., 2022). According to NEN 8700, the effects of climate change must be adequately considered for existing structures, including buildings.

Economic conditions, historic preservation concerns, emphasis on structure utilisation, space shortages and rising materials and product costs have also necessitated a more thorough evaluation and utilisation of the building stock (ASCE, 2000). This has led to a shift from replacement to preservation/rehabilitation, particularly in older cities.

However, new activities in existing buildings often impose increased loads and require adaptations to the structure (Wijte et al., 2021). Moreover, building codes have become more stringent.

With an increasing focus on preservation and worsening climate conditions, these changes will progressively affect the condition of buildings and compliance with stricter codes. Via reassessment of existing buildings, these changes can be accounted for and structural safety ensured.

# Phase 1. Inventory CC2 buildings

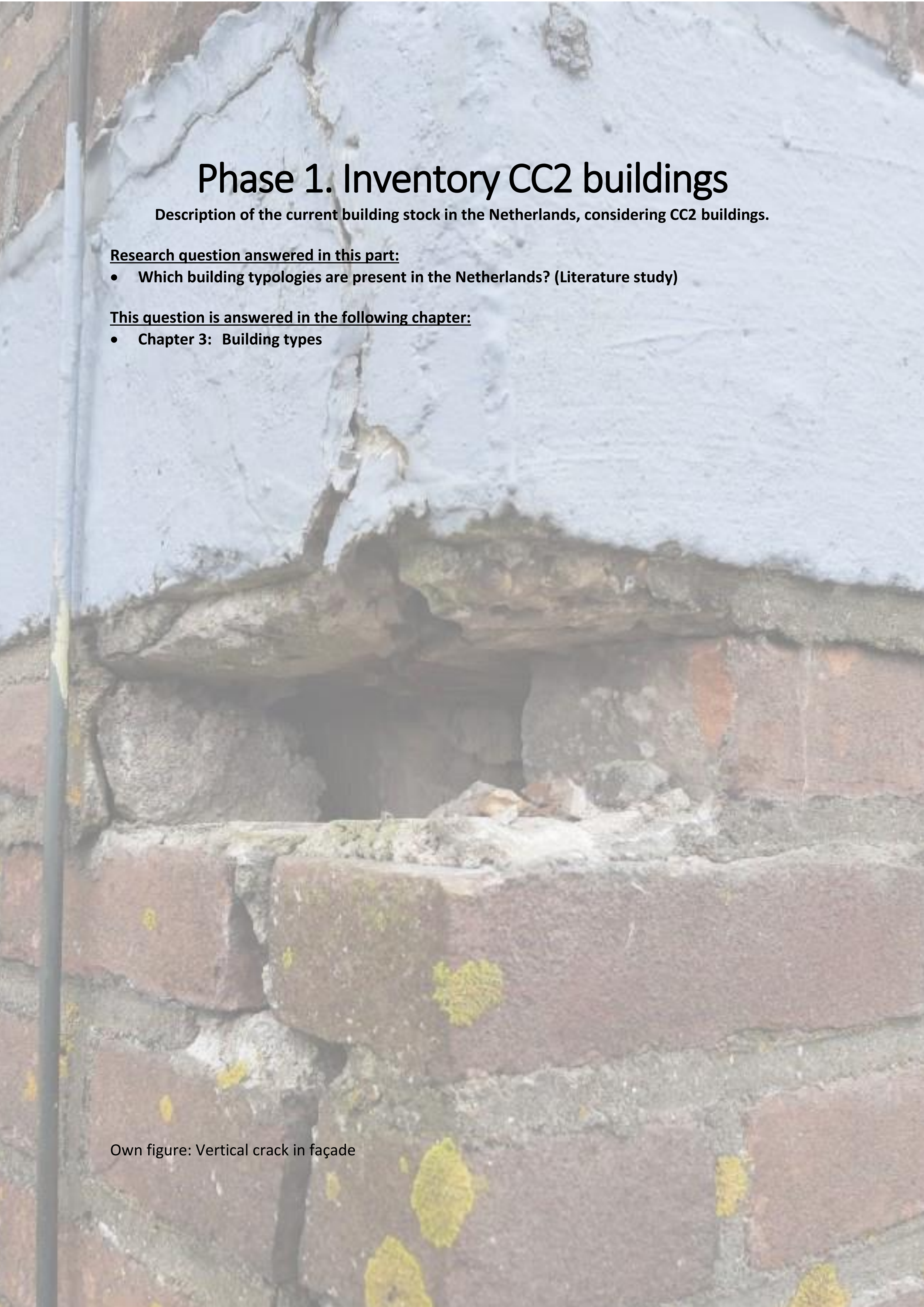
**Description of the current building stock in the Netherlands, considering CC2 buildings.**

**Research question answered in this part:**

- **Which building typologies are present in the Netherlands? (Literature study)**

**This question is answered in the following chapter:**

- **Chapter 3: Building types**



Own figure: Vertical crack in façade

# 3 Building types

With a funded overview of the problems that need to be addressed in this thesis, the first phase within the study can be conducted. In this phase the CC2 building stock within the Netherlands is investigated for its numbers and different types available. This knowledge enables a more systematic approach to the subsequent studies detailed in this document. For instance, the common causes outlined in chapter 4 are categorised according to the building types obtained in this chapter. The building stock is quantified to be able to focus the assessment process on the building types which are most common.

First there is investigated which type of buildings are present within CC2. This leads to the categorisation of building types, which are used for the examination of the existing building stock.

## 3.1 CC2 buildings

This section explores the types of buildings that fall under the CC2 category. To gain a deeper understanding of these consequence classes, first the general classification is explained.

### 3.1.1 Consequence classification

The consequence classes (CC) are used to categorise an object based on the potential consequences of a (partial) structural failure (NEN, 2015a). These consequences are divided into the following categories (NEN, 2019b):

1. Consequences in terms of loss of human life.
2. Social, economic and other consequences that may impact the surrounding area.

A three-level scale is employed to classify objects according to these consequence categories. CC1 represents the lowest level, indicating minimal consequences in the event of a (partial) structural failure. In contrast, CC3 represents the highest level of consequences. Examples of buildings corresponding to each class are provided below.

Figure 3.1: Example of CC1 building (Waard, 2023)

Figure 3.2: Example CC2 building

Figure 3.3: Example CC3 building (Fabrique, n.d.)

An object is assigned to a specific consequence class if it meets either of the two consequence categories. For instance, an object would be classified as CC2 if a (partial) structural failure would lead to significant economic consequences. The specifics of each consequence class are detailed in table 3.1. CC1 is further divided into subcategories 'a' and 'b', representing low risk (a) and high risk (b). This distinction could also be made for the other classes.

Table 3.1: Definition consequence classes (NEN, 2019b)

| Consequence class | Consequences category 1 | Consequences category 2 |
|---|---|---|
| CC3 | High | Very high |
| CC2 | Medium | Significant |
| CC1b | Low | Small/negligible |
| CC1a | Virtually excluded | Very small/negligible |

### 3.1.2 Consequence class two

This study only considers buildings within CC2. However, using table 3.1 to identify existing buildings as CC2 may pose challenges. What misses are specific boundaries to accurately determine what kind of buildings are included in CC2.

The national annex of NEN-EN 1990 and the standard NEN-EN 1991-1-7 provide an indication of the types of buildings that fall within the different consequence classes. This information is combined and aligned within table 3.2, where CC2 is further divided into low (CC2a) and high-risk (CC2b) categories. This subdivision, adopted from NEN-EN 1991-1-7, offers a more precise representation of the risks associated with each building type just as done above for CC1.

Table 3.2: Indication building types within CC2 (NEN, 2015a & 2019a)

| Consequence class | Indication of boundaries |
|---|---|
| 2a (Low risk) | • Residential buildings, hotels and offices lower as five storeys.<br>• Single storey educational buildings.<br>• Public buildings of maximum two storeys and a floor area that does not exceed 2000 m$^2$ per storey. In case of failure less than 500 people are in danger.<br>• Retail buildings lower as four storeys and less than 1000 m$^2$ floor area per storey.<br>• Industrial buildings no higher as three storeys with unlimited number of persons (no dangerous substances/processes).<br>• Single-family houses with four or more floors. |
| 2b (High risk) | • Residential buildings, hotels and offices with more than four but no more as fifteen storeys/70 metres.<br>• Educational buildings with more than one but no more as fifteen storeys/70 metres. No more as 500 people can be in danger due to structural failure.<br>• Public buildings with floor areas higher as 2000 m$^2$ but lower as 5000 m$^2$ per storey. Building not higher as 70 metres from ground level and no more as 500 people in danger due to structural failure.<br>• Retail buildings with more than three but no more as fifteen storeys/70 metres.<br>• Industrial buildings with more than three layers.<br>• Prisons, hospitals and other care buildings below four storeys.<br>• Car parking with at maximum six storeys. |

The table sets limits on the number of storeys within a building. Both standards provide a definition of which storeys to consider and which not. The definition of the national annex is followed: All storeys from the top of the foundation marked with a use function, as defined in the Dutch building decree, until the upper storey must be considered (NEN, 2019b).

The boundaries indicated in the table serve as the delineation for CC2 buildings. Buildings that fall within these boundaries are subsequently included in the study.

For further help in this classification, a flowchart for selecting the consequence class for buildings is included in figure b.1. While it provides a comprehensive overview of the boundaries between various consequence classes, there are some deviations from the standards. These deviations are detailed in appendix B.

## 3.2 Building types

The table above distinguishes buildings based on their functional use. The categorisation of building types must align with the functional distinctions outlined in this table to determine whether a building falls within CC2.

The Economic Institute for the Building Sector (EIB) has devised a categorisation for the building stock in the Netherlands. Initially, buildings are classified as either residential or non-residential. Residential buildings are further divided into single-family houses and apartment buildings. Non-residential buildings are further subdivided based on their functional purpose. The EIB building categorisation, which is used in this document, is shown in figure 3.4. It is important to note that the EIB provides only a limited number of categories for non-residential buildings, with the remaining structures grouped under the 'other' category.

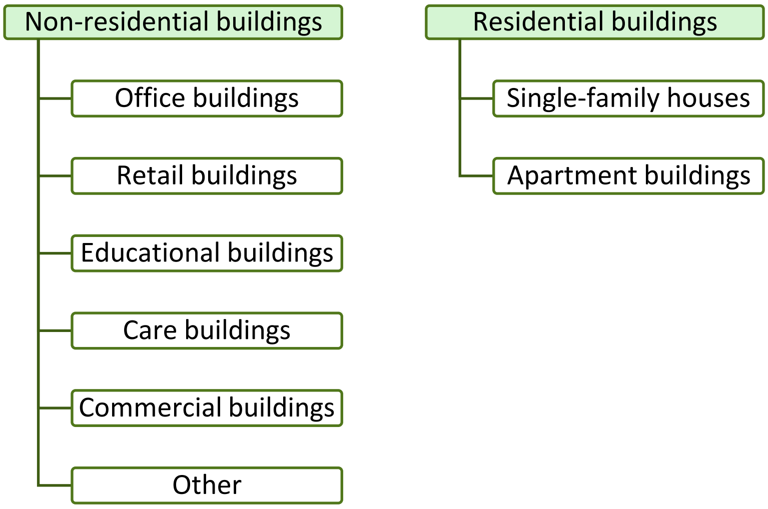


Figure 3.4: Building types used in the study (EIB, 2015)

Buildings serving multiple functions, such as a shopping centre with apartments above, are classified as hybrid. However, these buildings must facilitate a combination of building types given above.

The building typology categorisation by the EIB supports the differentiation of buildings in table 3.2, making these building types suitable for the remainder of this study. These types are necessary for examining the existing building stock in the Netherlands. Moreover, they facilitate a more detailed investigation of structural failure incidents and assist in identifying vulnerable structural elements in chapter 4. Consequently, these building types allow for a higher level of detail within the assessment method.

## 3.3 Existing building stock

The EIB study, conducted in 2010, is not employed for the actual number of buildings within these categories due to its outdated representation of the building stock. Instead, two studies by the Central Bureau of Statistics (CBS) are utilised for the quantification. One study for the residential and another for the non-residential building stock.

The non-residential building stock study provides insight as of January 1st, 2021. However, it does not employ the same building categorisation as this document. The adaptation of the CBS study to the building types in this document is presented in appendix C. The residential building stock study provides data as of January 1st, 2022. The subsequent subsections provide an overview of the current building stock in the Netherlands using the predefined categories listed in figure 3.4.

### 3.3.1 Non-residential building stock

Table 3.3, which displays the floor area per building type, is derived by categorising the figures presented in table c.2. Within the non-residential building stock, commercial buildings account for the largest floor area, followed by office buildings.

Table 3.3: Building stock non-residential buildings (CBS, 2022a)

| **Building type** | **Floor area [x1000 m$^2$]** |
|---|---|
| Office buildings | 62,663 |
| Retail buildings | 48,286 |
| Educational buildings | 34,059 |
| Care buildings | 27,250 |
| Commercial buildings | 294,998 |
| Other buildings | 61,718 |
| **Total** | **528,974** |

The CBS study does not provide information on the construction year for these building types. The research framework requires an examination on the age of the building at the time of structural failure incidents. Therefore, the 2010 EIB study is used for the construction year, with the final results depicted in figure c.1.

### 3.3.2 Residential building stock

CBS also maintains a record of the number of dwellings in the Netherlands. As of January 1st, 2022, there were a total of 8.0 million dwellings (CBS, 2023). This figure comprises 5.1 million single-family houses and 2.9 million apartments, indicating that 36% of all dwellings are apartments.

In appendix C, the single-family houses are further classified into several subcategories, which are essential for the delineation made in the subsequent chapter. Additionally, this appendix provides information on the construction periods for different types of dwellings, including apartments.

### 3.3.3 Conclusions

The defined building types provide a framework for examining and categorising the causes of structural failure incidents, which are explored in the following chapter. These building types are further delineated at the end of this chapter drawing on the building stock examined. As the study indicated which building types are most prevalent, the method could be employed more frequent for these buildings.

## 3.4 Delineation building types

Based on the investigation of the building stock, some of the defined building types are excluded from the remainder of the study. These buildings will thus not be considered in the developed assessment process. This approach allows for an effective application of the assessment process to the building types that are most prevalent in the building stock. It is important to note that the building types under consideration must fall within the boundaries of CC2, as indicated in table 3.2.

First, a rationale is provided for excluding certain building types from the study. This is followed by an overview of common structures for the building types considered in this document.

### 3.4.1 Single-family houses

Single-family houses, which make up the majority of the building stock with 5.1 million dwellings (CBS, 2023), are only classified as CC2 if they consist of four or more storeys (see table 3.2). To determine the proportion of single-family houses that fall within this consequence class, the number of storeys for the houses is examined.

Single-family houses can be further subdivided into detached, semi-detached, terraced and other houses. Table C.3 presents the actual number of houses for each category, showing that the majority of single-family houses are terraced houses.

An inventory conducted by Agentschap NL in 2011 provides a distribution of the number of storeys per single-family house category up to 2005. Despite its dated nature, figure c.2 shows that the majority of house construction occurred before 2005. The inventory indicates that terraced houses in general and most other house categories consists of three or fewer stories (Agentschap NL, 2011). This indicates that most single-family houses are classified as CC1.

In addition, Terwel's study concluded that residential buildings suffer relatively less from structural failures than other building types (Terwel, 2014). This could be attributed to the fact that in the Netherlands, houses are often produced in series and/or larger dimensions than structurally required for walls and floors are implemented to meet sound and heat insulation requirements.

Given that most single-family houses fall within CC1 and may possess more redundancy as other buildings, they are excluded from the rest of this study. Consequently, a small portion of single-family houses within CC2 is not accounted for. The remaining 2.9 million apartments within the residential building stock are included in the rest of the study (CBS, 2022b).

### 3.4.2 Commercial buildings

This category encompasses buildings such as car dealerships, industrial halls, agricultural buildings and data centres, as detailed in table c.2. Industrial halls represent the largest group within this category, accounting for approximately 82% of the total floor area of commercial buildings. Industrial and agricultural buildings designed for production purposes with a limited number of occupants and one or two storeys are classified as CC1 (NEN, 2019b). However, a number of halls fall within the CC2 classification, as determined through the expert interviews for the validation detailed above. Only halls classified as CC2 are included in the study.

It is worth noting that major retail entities such as Ikea and Gamma, which resemble industrial halls, are classified as retail functions in the BAG viewer. This viewer is used along with other sources by the CBS to compile all figures stated in table c.2 and table 3.3. As such, it is assumed that entities like IKEA and Gamma form part of the retail buildings and not the commercial buildings.

Data centres represent a relatively small and specialised group within the commercial building category, as shown in table c.2, and are excluded in the study.

In conclusion, only commercial buildings classified within CC2 are considered in this study, with the data centre group being excluded. The exact proportion of commercial buildings included in the study is unknown. However, given that this was the most significant category within non-residential buildings, a substantial number of buildings will still be present.

### 3.4.3 Other buildings

This category includes a diverse array of buildings, ranging from hotels and restaurants to sport facilities, each representing relatively small areas as indicated in table c.2. Given the variety of building types within this category and their smaller proportions, these buildings are generally excluded from the focus of the study. However, the susceptibility of any subcategories within these buildings to structural failure incidents is examined in the subsequent chapter. On the basis of this study there is decided which buildings of this category are considered in the remainder of the study.

### 3.4.4 Conclusions

The study examined buildings classified under CC2 and the current building stock, leading to the exclusion of categories single-family houses, other buildings and commercial buildings classified as CC1. In fact, all building types within CC1 are excluded. However, before these (CC2) types are excluded from the study, an investigation into their susceptibility to structural failure incidents is conducted. The results of this investigation are detailed in section 4.3.

### 3.4.5 Typical load bearing structures for delineated building types

For the delineated building types, it is possible to obtain preliminary insights into the typical load-bearing structures used in both non-residential and residential buildings. A distinction is made between low-rise and multi-storey buildings. Multi-storey buildings are further categorised on their structure: column structures or a wall structures (Oosterhoff, 2013), see figure 3.5.

In a column structure, the assembly of floors, beams (if present) and columns form an assembly that transfers the building’s loads to the foundation (Kamerling & Kamerling, 2004). In contrast, in a wall structure, the floors and walls provide this load transfer. Wall structures are primarily used in residential buildings, while column structures are predominantly used in offices and other sectors such as education and healthcare (Oosterhoff, 2013). This makes column structures a defining feature for utility buildings (Kamerling & Kamerling, 2004).

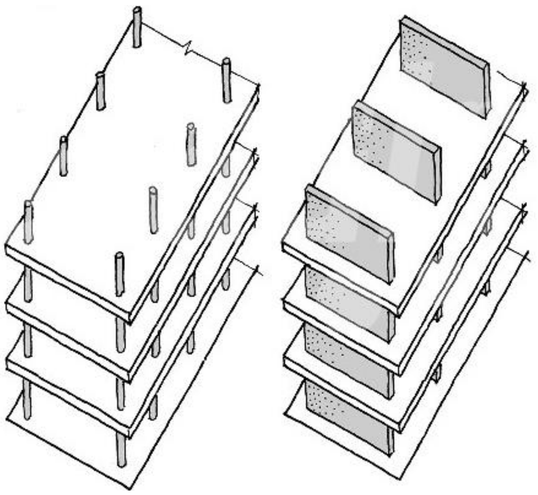


Figure 3.5: Column structure (left) and wall structure (right) (Oosterhoff, 2013)

Low-rise buildings primarily comprise halls (Oosterhoff, 2013). These halls can be classified as either long or central. Long halls have a distinct longitudinal direction, with forces being transported to the foundation in a single direction. In contrast, central halls have similar longitudinal and latitudinal directions, with forces being transported to the foundation in two or multiple directions. Examples of both types of halls are provided in figure 3.6 and figure 3.7.

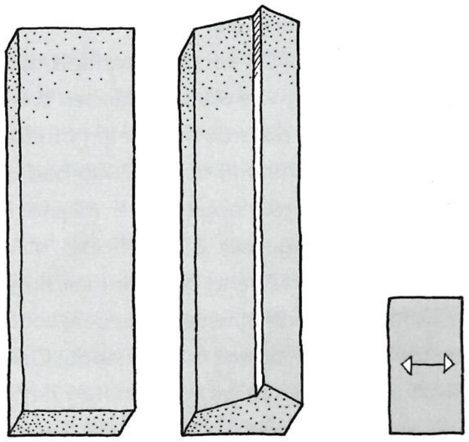


Figure 3.6: Example long hall (Oosterhoff, 2013)

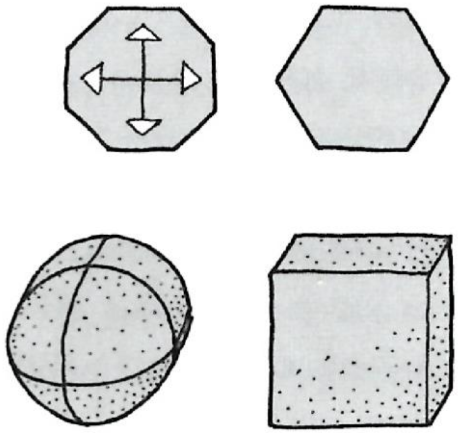


Figure 3.7: Example central hall (Oosterhoff, 2013)

It is important to note that this subsection primarily discusses the vertical load-bearing structure. Additional structural elements may be required for stability (horizontal load bearing).

# Phase 2. Structural causes for failure

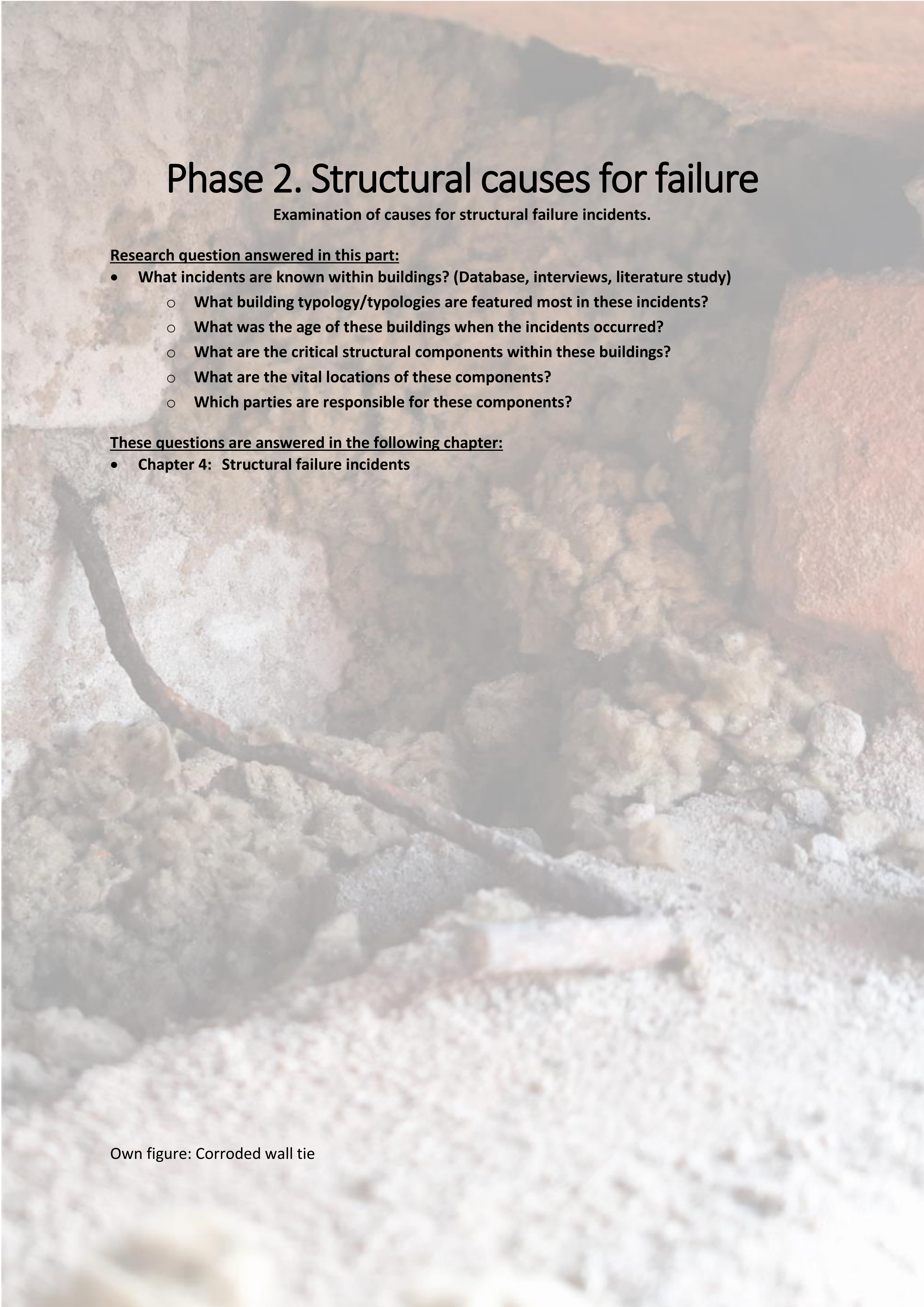
**Examination of causes for structural failure incidents.**

**<u>Research question answered in this part:</u>**

- **What incidents are known within buildings? (Database, interviews, literature study)**
    - **What building typology/typologies are featured most in these incidents?**
    - **What was the age of these buildings when the incidents occurred?**
    - **What are the critical structural components within these buildings?**
    - **What are the vital locations of these components?**
    - **Which parties are responsible for these components?**

**<u>These questions are answered in the following chapter:</u>**

- **Chapter 4: Structural failure incidents**



Own figure: Corroded wall tie

# 4 Structural failure incidents

To develop an efficient and effective reassessment method that pinpoints the most significant risks, an attempt is made to investigate the most common causes for structural failure incidents. These causes must be taken into consideration when performing an assessment of an existing building.

Section 4.1 outlines the setup of the investigation and presents the final list of common causes for structural failure incidents in the Netherlands. Further details pertaining to this investigation are also discussed.

The validation study of these common causes also identified more general points of attention that should be addressed during assessments. These points are presented in section 4.2.

In conclusion, the information gathered about the building stock and the building types susceptible to structural failure incidents have led to a delineation of building types. These are the types that are considered in the developed method. The final section of this chapter provides this delineation.

## 4.1 List of common causes for structural failure incidents

In this section the validated list of common causes is presented, with each cause examined in detail for detection purposes. Prior to delving into these causes, the setup of this investigation is discussed in the following subsection.

### 4.1.1 Setup investigation

As a starting point, all incidents listed in the Cobouw database by Develi and Terwel have been analysed. Via this analysis, a hypothetical list of common causes for structural failure incidents is generated. These incidents are not exclusive to CC2 buildings but encompass all available buildings, as the incidents are largely not specific to the consequence classification. The incidents could be linked to materials or certain construction methods that are also used within CC2.

Incidents could be coupled to materials or certain building methods which are also applied within CC2.

This hypothetical list is validated through expert interviews and a literature review to obtain a more accurate understanding of the common causes. Experts were primarily selected from the commission for the development of standard NTA 8790. In these interviews the experts were consulted about the relevance of each cause on the hypothetical list and potential additions to it.

The entire process, from generation of the hypothetical list to its validation through expert consultations and literature reviews, is detailed in appendix D.

### 4.1.2 Common causes for structural failure incidents

The final validated list of common causes for structural failure incidents is presented in table 4.1. Each cause is accompanied by an example for clarity. However, it is important to note that these examples do not cover all aspects of the listed causes. This list of common causes should be viewed as a preliminary attempt rather than a comprehensive one, primarily due to the limited data available. A more detailed explanation regarding the incompleteness of the list can be found in the discussion (chapter 9) and recommendations (chapter 11).

Table 4.1: Common cause for structural failure incidents in the Netherlands

| No. | Cause | Example |
|---|---|---|
| 1 | Realised object deviates from design. | Construction elements found to be missing/applied with properties deviating from design. |
| 2 | Reinforcement in concrete experiences (pitting) corrosion due to presence of chlorides, dampness and oxygen. Common sources of chlorides in concrete structures include the use of de-icing salts and the inclusion of calcium chlorides in the concrete mixture to improve the curing process. | Gallery floors are for instance vulnerable to the effects of de-icing salts. In the case of the inclusion of calcium chlorides, examples of affected structures include consoles and 'Kwaaitaal' floors. |
| 3 | Incorrect wind load calculation. | Façade panels blown away due to inadequate calculation of the applied wind force. |
| 4 | Deterioration timber pile foundation. | Degradation due to bacteria, moulds and other mechanisms. |
| 5 | Problems relating to floors which are prestressed without bond. | The prestress cables in the floors experience corrosion due to ingress of moisture during construction or during use. |
| 6 | Seams plank floors incapable of transferring a positive bending moment. | Plank floors, such as those in the parking garage in Eindhoven, were designed to transfer positive bending moments across the seams but it was insufficient. |
| 7 | Higher permanent load on/lower position of the upper reinforcement in (external) cantilevering floors. | These issues have been observed in relation to gallery and balcony floors. |
| 8 | Corrosion of steel structure supporting balconies. | Consoles corroding near the (masonry) façade. |
| 9 | Too little/corrosion/insufficient anchorage of balconies. | The anchors intended for the connection did not attach properly. |
| 10 | Corrosion of (stainless) steel in swimming pools. | Corrosion in the suspension of the ceiling. |
| 11 | Roofs overloading due to water accumulation. | This could for instance be attributed to the lack of insufficient emergency drainages or the insufficient slope of the roof. |
| 12 | Incorrect snow load calculation/Roofs overloading due to snow accumulation. | Roof collapses under the weight of the accumulated snow. |
| 13 | Too little/incorrect application/corrosion of wall ties in façade. | Corrosion of wall ties of the façade. |
| 14 | Façade panels letting go. | Façade Panels of the 'Achmeatoren' letting go. |
| 15 | Glass fracture in façade/roof panels due to nickel sulphide inclusions/bad quality/thermal stress and more. | Nickel sulphide inclusions in the glass panel cause the glass to shatter. |
| 16 | Filled/ too small/ missing horizontal and vertical dilatations. | The filling of dilatations resulted in deformations and formation of cracks. |
| 17 | Corrosion of the connectors of prefab elements. | Corrosion of the reinforcement connecting the spandrel to the rest of the structure. |
| 18 | Settlement of the foundation. | Uneven settlement of peat subsoil. |
| 19 | Incompetent renovation/adaptation. | Removal of load bearing wall. |

|  |  |  |
|---|---|---|
| 20 | Change in use. | Office is changed to storage area. |
| 21 | Incorrect installation of MuWi floors in schools. | Due to incorrect appliance, floor sections are broken, after many years these pieces come loose. |
| 22 | Corbel for connection prefab beam to column has wrong detailing/too little reinforcement. | Corbel in garage rips off due to wrong detailing reinforcement. |
| 23 | Fall protection not connected/insufficiently secured. | Steel fall protection connections corroded. |

The list of common causes includes three issues that necessitate mandatory investigation: monolithically connected concrete cantilevering balcony and gallery floors, stainless steel suspension in swimming pools and plank floors with the primary load direction across the seams. These issues correspond to causes six, seven and ten. In addition, cause two, which pertains to chloride damages of concrete, is partly encompassed by the mandatory investigation to the cantilevering balcony and gallery floors. The frequency of these causes along with expert opinions can be found in appendix D. Further information on these mandatory investigations is provided in appendix E.

### 4.1.3 Details for common causes

The research sub-questions, outlined in section 1.4, necessitate the consideration of several factors for the validated causes: building typology, critical structural components, their vital locations and the responsible parties. Additionally, the extent of damage caused by these causes is examined to judge their potential impact and associated risk.

Appendix D provides supplementary information about these causes, aiding in answering the aforementioned questions. However, it should be noted that for some causes, this may not be feasible due to factors such as applicability to all building types, absence of critical structural components or unavailability of information. Where possible, additional details for the common causes are retrieved.

For this information retrieval of the validated common causes, the database is also consulted. The causes in the database are studied in section E.1 appendix E. The further specifications of the common causes are provided in section E.2. This section also provides more information for the mandatory investigations and references existing documents for investigation when applicable. These are only the documents that have been found during the study of the common causes.

## 4.2 General attention points

The preceding section outlines common causes of structural failure incidents, which are important considerations when assessing existing buildings in the Netherlands. However, these are not the only factors to consider. This section presents additional more general points that emerged during the validation process and should be considered during the assessment or inspection of a building. The section is organised according to the sources providing these points of attention.

### 4.2.1 Expert interviews

First, several general points emerged from the expert interviews conducted to validate the list of common causes. These points include:

- Material degradation and other deficiencies.
- Every old damage/reparation.
- Over-maintained buildings.
- Poor maintenance.
- Old buildings inspected in the past.
- Determination condition when corrosion is identified.
- Robustness of the structure.

More details on these points, including justifications for their inclusion are given in subsection D.3.2. The information given in the following subsection is also further discussed in appendix D.

### 4.2.2 KPCV

In addition to expert opinions, literature also offers general points worth considering. Specifically, the Knowledge Base Structural Safety (KPCV) provides valuable insights, namely (KPCV, 2022a):

- Damage leading to a reduction in material properties (for instance corrosion).
- Cracks and/or deformations resulting from force distribution.
- Cracks caused by impended or imposed deformations.
- Loose or broken anchors, bolts and/or nuts.
- Reduction in the support length of structural elements.
- Damage attributable to external factors.
- Methods of water disposal (since water is involved in most forms of degradation).

### 4.2.3 VDI 6200

The VDI 6200 German standard, developed by the Union of German Ingenieurs (VDI), also offers useful lists according to an expert. This is an assessment method to periodically inspect existing buildings. The method is divided into three levels: owner-led, expert-led and special expert-led. The first two levels have available attention points in the form of two lists, which are provided in appendix F. Some points may overlap with those mentioned in this chapter, but in general most points could be helpful for those conducting the inspection or assessment.

The VDI 6200 standard is further explored within the subsequent chapter evaluating the existing assessment methods.

## 4.3 Conclusions

This section begins with the final conclusions related to the common causes of structural failure incidents and general attention points. It then proceeds to the final conclusions regarding the delineation of building types. Chapter 3 excludes certain building types from the remainder of the study. However, before this exclusion, an investigation was conducted to determine if any of the excluded categories are more susceptible to structural failure incidents. The final subsection presents building types that are included in the study, considering the structural failure incidents.

### 4.3.1 Common causes and general attention points

Next to a list of common causes, this chapter also provides more general attention (bullet) points in the preceding section. Both sections offer key points to consider during the assessment or inspection of an existing building. These points facilitate effective and efficient detection, thereby enhancing the efficiency and effectivity of the assessment method. However, it is important to ensure that potential issues not included in the list are still identified during inspection or assessment. There are also some limitations regarding the content of these sections which must be considered. These limitations are described in the discussion (chapter 9) and recommendations (chapter 11).

### 4.3.2 Delineation building types

In chapter 3 the category ‘other buildings’ among other types, is excluded from the study. However, the investigation into structural failure incidents revealed that swimming pools and parking garages should be considered in the subsequent stages of the study.

Swimming pools are included due to multiple recorded incidents related to structural safety in the database. One of the identified common causes is specifically related to swimming pools, warranting the inclusion in the study.

Similarly, parking garages are considered due to numerous structural safety issues identified during expert interviews conducted in section D.3. These issues were found in a significant number of parking garages investigated, thus justifying their inclusion in the remainder of the study.

The remaining building types which are included in the rest of the thesis are depicted in figure 4.1. Hybrid buildings with mixed functions are also within the scope of this work. The delineation focusses on the most common building types within the CC2 building for this assessment process. Additionally, building types that are more susceptible to structural failure incidents, such as swimming pools and parking garages, are included in this focus.

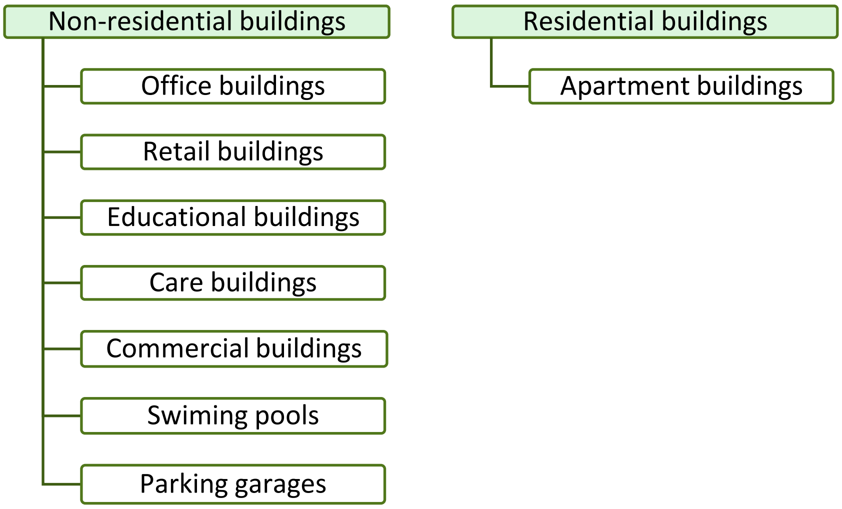


Figure 4.1: Building types considered in the thesis.

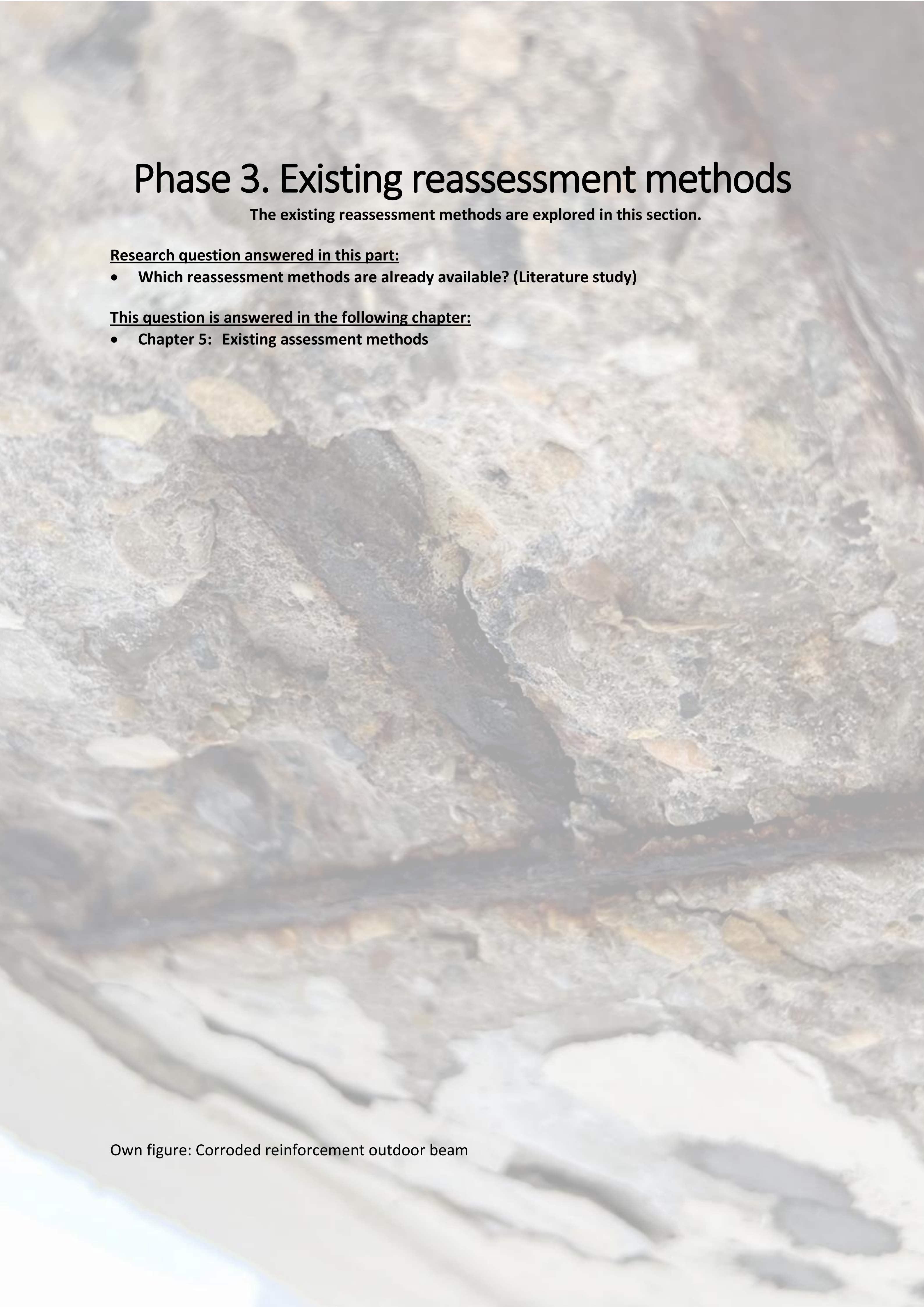
These buildings will thus be considered in the developed assessment process. This approach allows for an effective application of the assessment process to the building types that are most prevalent in the building stock and/or vulnerable. It is important to note that the building types under consideration must fall within the boundaries of CC2, as indicated in table 3.2.

# Phase 3. Existing reassessment methods

**The existing reassessment methods are explored in this section.**

**Research question answered in this part:**
- **Which reassessment methods are already available? (Literature study)**

**This question is answered in the following chapter:**
- **Chapter 5: Existing assessment methods**



Own figure: Corroded reinforcement outdoor beam

# 5 Existing assessment methods

The development of an assessment method for existing CC2 buildings is not an isolated endeavour, as there are other assessment methods available. By examining existing methods, their shortcomings can be highlighted and their strengths can be integrated into the new method.

As mentioned in section 1.6, a preliminary study was conducted for the development of NTA 8790, in which existing guidelines, protocols and other resources were reviewed. This study serves as a foundation for further exploration, detailed in section 5.1, where the need for further exploration is also justified.

Section 5.2 introduces additional resources to be explored and outlines the more detailed exploration process. The findings of this exploration are presented in section 5.3, taking into account the results of the initial desk study for NTA 8790. These findings form the basis for the development of the new assessment method.

## 5.1 First desk study NTA 8790

This desk study examined 24 sources pertaining to the inspection or assessment of existing structures for structural safety (Kuijer et al., 2022). A systematic inventory was conducted based on the points outlined in figure 5.1.

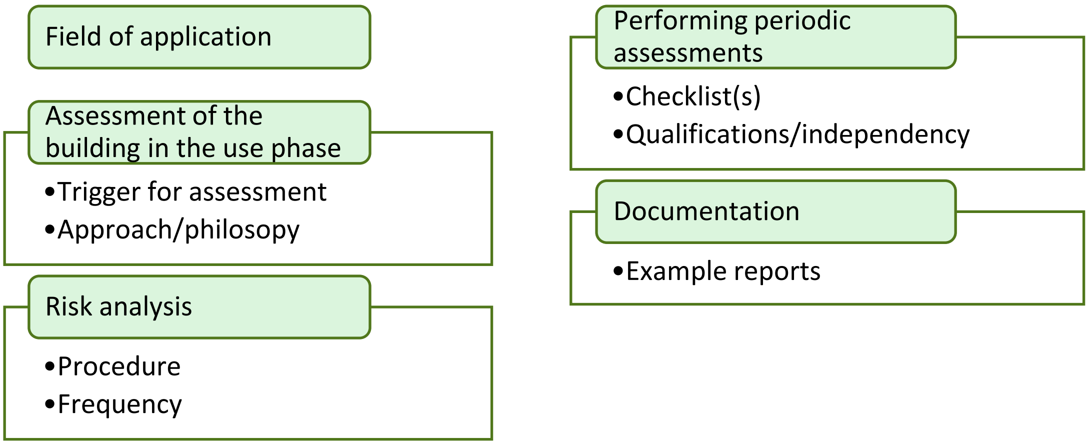


Figure 5.1: Subjects Inventerisation first desk study (Kuijer et al., 2022)

Through this inventory of information, it is unclear which parts of the 24 considered sources contribute to an efficient and/or effective assessment of existing buildings. In addition to the effectivity and efficiency, the inventory does not clarify which aspects enhance the trustworthiness of an assessment. These aspects are crucial to the development of the method. Moreover, the inventory does not provide a comprehensive overview of the sources under consideration. For example, it lacks detail regarding risk identification and evaluation.

Therefore, additional information is needed regarding efficiency, effectivity and trustworthiness. More detailed information in general needs to be obtained from these sources for the development of the method. This information can only be collected using a clear evaluation process, which is detailed in the following section.

## 5.2 Set up exploration assessment methods

The existing sources are explored to gather input for the development of the assessment method for CC2 buildings. If certain elements of existing methods have potential, they can be adapted or directly integrated into the new method.

In addition to the 24 sources from the desk study, the following sources were included due to their relevance:

1. NEN-EN 8700: A standard for evaluating existing structures for reconstruction and disapproval.
2. Master thesis by Sarah Kleijn: A study on quantitative risk assessment concerning additional actions.
3. NTA8790: A periodic assessment of structural safety in existing structures.
4. Risk based assessment by Nebest: A risk-based method that provides control measures to mitigate risks if necessary.

This exploration aims to extract valuable information from existing methods. All types of information could be beneficial, provided that they can be applied for the development of the CC2 method. Therefore, the next subsection filters out the sources relevant for further exploration.

### 5.2.1 Selection reassessment methods

To evaluate the content of the various available sources, the presence of certain aspects in these sources was examined. These aspects represent the necessary information for the development and are as follows:

- Does the source provide a reassessment method?
- Is the method applicable for CC2 buildings?
- Does the considered method provide a stepwise/risk-driven approach?
- Are multiple risks considered?
- Does the method provide additional information regarding inspections/damages/material properties?
- Are there examples given regarding the risk evaluation?
- Are there critical damage patterns/(structural) elements stated?
- Are there examples given regarding reporting/report formats?
- Are qualifications/independency stated?

These aspects guide the selection of sources relevant for further exploration. Ensuring that a wide variety of information is available from the selected sources allows for a comprehensive consideration of different aspects for the method development. An overview of the aspect availability within the sources and the selection process of the sources is provided in appendix G.

This delineation resulted in ten assessment methods that are further explored to gather information for the development of an assessment method. The methods considered in this exploration are listed in the table below. In the table, the abbreviation ORA stands for object risk analysis. Each of the ten methods is briefly described in section G.2 of appendix G.

Table 5.1: Reassessment methods considered in exploration

| **Method** | **Institution** | **Source** |
|---|---|---|
| Guideline for Structural Assessment of Existing Buildings | The American Society of Civil Engineers (ASCE) | (ASCE, 2000) |
| Periodic Structural Inspection of Existing Buildings – Guidelines for Structural Engineers | Building and Construction Authority (BCA) | (BCA, 2022) |
| CUR-aanbeveling 124, Constructieve veiligheid bestaande bruggen en viaducten van decentrale overheden | CROW - CUR | (CROW-CUR, 2019) |
| NEN-ISO 13822 | NEN – ISO | (NEN-ISO, 2010) |
| Appraisal of Existing Structures | The Institution of Structural Engineers | (ISTRUCTE, 2010) |
| VDI 6200, Standsicherheit von Bauwerken Regelmaβige Uberprufung | VDI - GBG | (VDI, 2010) |
| NEN 2767 Conditiemeting gebouwde omgeving | NEN | (NEN, 2019a)<br>(NEN, 2008) |
| ORA, eenvoudige objectrisicoanalyse – werkomschrijving | Rijkswaterstaat | (Rijkswaterstaat, 2016) |
| NTA 8790 | NEN | (NEN, 2023) |
| Risicogestuurde inspectie | Nebest | Not able to reference |

The ABT method and the source by the KPCV are not included in the exploration. Both methods lack the necessary level of information required to be fully considered in the exploration. However, they do offer valuable insights that should be considered during development. These points are discussed in section H.4 of appendix H.

The structure of the exploration process is explained in the following subsection.

### 5.2.2 Criteria used in evaluation

As previously mentioned, this study aims to devise an efficient and effective method to address the research objective and question. In addition, the trustworthiness is considered as it is important that an assessment can be trusted.

To structure the exploration of existing assessment methods, the following criteria are employed:

1. Trustworthy
2. Effective
3. Efficient

Each criterion is assessed by examining its associated tangible aspects, which are further elaborated in the subsequent paragraphs. These aspects enable the measurement of the somewhat abstract criteria within the assessment methods, thereby facilitating an exploration of information that impacts these criteria.

### 1. Trustworthy

The University of Technology in Delft, has developed new criteria for conducting trustworthy investigations, addressing the challenges associated with the abstract concepts of reliability and validity in forensic investigations (Terwel et al., 2018). This resulted in the 'Ring of Trustworthiness' (figure 5.2) which provides a more detailed understanding of the characteristics that constitute a trustworthy method.

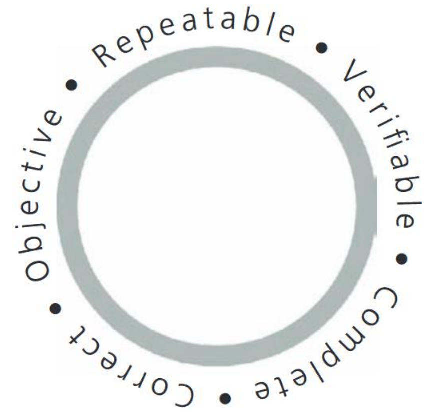


Figure 5.2: Ring of Trustworthiness (Terwel et al., 2018)

While the aspects of the 'ring of trustworthiness' offers valuable insights into the characteristics of a trustworthy method, its application in evaluating existing assessment method presents challenges as it is still too abstract. To address this, several tangible aspects have been identified that align with the 'Ring of Trustworthiness'. These aspects include:

- **Multi-person principle:** Assesses whether the method necessitates multiple individuals for execution or verification.
- **User qualification requirements:** Ensures that individuals conducting the assessment are competent.
- **Structure of the approach:** Guides users through the entire evaluation process and provides additional resources such as tools, manuals and other information to perform the assessment.

These aspects stimulate all subjects in the 'Ring of Trustworthiness' and must be employed to evaluate the trustworthiness of the method.

### 2. Effectivity

Effectivity is measured by the extent to which a goal is achieved from the perspective of the client (Blokland & Reniers, 2013). This is realised when the most significant risks regarding structural safety are identified. The tangible aspects for this criterion are:

- **Structured risk assessment:** Determines how risks are evaluated and whether they are deemed acceptable.
- **Critical factors:** These factors aid in identifying the major risks.
- **Identification number of risks:** Shows whether only the most significant risks are evaluated or also less relevant ones.

**3. Efficiency**

Efficiency refers to achieving maximum results with minimum resources (Cambridge Dictionary, 2023a). User qualifications, previously mentioned under trustworthiness, are also considered for efficiency but in a different context. This and the other aspects for this criterion are:

- **Right qualifications for right work:** Using appropriately qualified individuals for the right work can result in cost savings compared to overqualified personnel.
- **Working from coarse to fine:** By employing this aspect and stopping when risks are sufficiently identified or reduced, only the necessary work is performed.
- **Time efficiency:** Not only encompasses the time required to execute the method, but also factors such as inspection times, prioritisation within buildings or a group of buildings and the frequency of method execution.
- **Tables and tools for selecting the right inspections and more:** Allow for selecting the appropriate actions for the problems presented.

Figure 5.3 provides an overview of the three criteria and their tangible aspects. Essential information for the development of the method, not detected by the criteria, is also considered in the exploration.

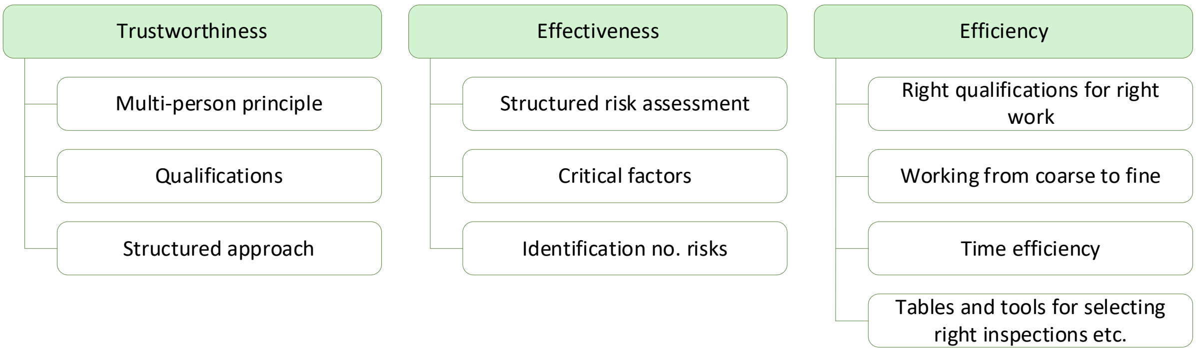


Figure 5.3:Criteria used for evaluation with tangible aspects

A three-point scale is used to provide a to-the-point overview of the relative value of each aspect of the method, with one representing the lowest score and three the highest. For instance, in case of time efficiency, a score of one signifies that the method is time-consuming, while a score of three indicates the method is optimised in terms of time. This exploration does not assign an overall score for the criteria. Instead, the three-point scale serves to highlight the strengths and weaknesses of the different aspects of the selected methods.

The evaluation, along with all aspect scores for the selected methods, is presented in appendix H. The findings from this exploration are discussed in the following section.

## 5.3 Results

Before delving into the results of the exploration of useful aspects within existing assessment methods, as detailed in appendix H, the insights from the initial desk study for the NTA are summarised. Subsequently, this section provides a concise overview of the key findings from the conducted exploration.

### 5.3.1 Conclusions first desk study

The first desk study for NTA 8790 offers advice for each of the subjects listed in figure 5.1. The most important recommendations, which are also employed in the development of the new assessment process, are as follows (Kuijer et al., 2022):

- **Approach/philosophy**: Adopt introductory texts from Appraisal of Existing Structures.
- **Procedure**: Assume a multi-layered assessment and provide a clear flowchart. Use robustness class for the extent of assessment and frequency.
- **Checklist(s)**: Use checklists to establish a structured workflow. The checklist is not the risk-based approach.
- **Qualifications/independency**: The qualification for experts with relevant working experience needs to be reported. In addition, the inspection and assessment should be performed by one team, and the individual responsible for the assessment must have on-site knowledge of the object. At last, there must be transparency regarding any prior involvement of experts.
- **Example reports**: These aid in providing guidance and achieve a uniform way of performing the assessment. There is recommended to use the report format form NEN-ISO 13822 as it aligns with the standard on reassessment.

The desk study thus recommends using checklists to establish a structured workflow. This can be beneficial if it refers to a checklist for ensuring all steps within the assessment procedure are completed. However, if it refers to a checklist for inspecting defects, there is a risk that only the defects listed in the checklist will be considered, without further investigation. Aside from this note, these points, along with those mentioned in the previous subsection, are considered in the development of the assessment process.

### 5.3.2 Results exploration

The key findings form the existing assessment methods are summarised in figure 5.4 and figure 5.5. These salient points, derived from sources discussed in this chapter, are considered during the development of the assessment process. In certain cases, it may be feasible to directly incorporate data from these sources. Alternatively, some information may require minor adaptations but will reflect the content presented in the original sources.

In addition to the exploration, this evaluation reveals that current methods do not perform optimally across the various aspects used to evaluate the criteria trustworthiness, effectivity and efficiency. To get an overview for what aspects the different methods fall short, appendix H, can be accessed. However, for each aspect, some method achieves a maximum score. By integrating the strengths of the explored methods, the assessment process could potentially achieve optimal performance for each aspect. This would result in a process that scores highly in terms of both efficiency and effectivity, as well as trustworthiness. The developed process is discussed in the next chapter.

**ASCE method**

- Qualifications for engineer and equipment.
- Tables for tests with a.o. purpose, principle, user expertise, advantages and limitations.
- Tables coupling defect/property to evaluation method (tests).
- Report format available.
- Information regarding materials and damage patterns given.
- Preliminary assessment only considers critical parts.

**BCA method**

- Qualifications engineer stated.
- Engineer must perform the site visit.
- Coverage requirements stated for visual inspection.
- Report format given for visual inspection.
- Checklists for assessment.
- Frequency assessment based on fact residential building or not.

**CUR 124**

- Detailed flowchart for approach indicating iterative steps.
- Prioritisation within group of objects via small ORA for most important risks.
- ORA via traffic -, consequence class and deficiencies.
- Tables provided with main material properties.
- Per type of object stated what information required.
- More information like iterative approach in calculation models given.

**NEN-ISO 13822**

- Future performance must be discussed before assessment.
- Assessment in two steps with a loop for detailed assessment.
- Assesment detailed in flowchart.
- Fact that structure proves itself over years, conisdered in this method.
- Report format available.

**Appraisal of existing structures**

- Assessment consists of three stages with multiple steps.
- Extensive flowchart for assessment available with yes or no choices.
- Report format available.
- Tables given with indiciations possible causes, suggested investigations and references applicable tests.
- Tests and materials extensively described.
- Statement that points where small energy leads to collapse significant mass are critical.
- Brief must be written before assessment.

**NEN 2767**

- Lists with deficeincies along with codes for objects and type of defects given.
- Clear examples and tables given for (quantitative) assessment via intensity, extent and severity.

*ORA stands for Object Risk Analysis.

Figure 5.4: Main points explored methods (1/2)

**VDI 6200**

- Different qualifications for the three levels of assessment via years of experience.
- First level of assesment via technical staff owner.
- Table available describing changing building characteristics due to environmental influences.
- For first two assessment levels checklists available.
- Classification via consequence and robustness classes determines which and when the assesment level is perfomed.
- Report headers with indications stated.

**ORA Rijkswaterstaat**

- In advance decided what level of analysis required via tables and graphs.
- Assessment consists of desk study, inspection and proposed measures.
- Detailed description given for steps assesment along with lots of examples.
- Excel format available for quantitative ORA via chances and consequences.
- (R)AMSHEEP to help quantification consequences.
- Mandatory quality assesment of analysis by other individual as the one performing the assessment.

**Nebest method**

- Assesment consists of desk study, visual inpsection and proposed control measures.
- After each step a risk assesment is performed.
- More detailed assesment only applicable for most important risks.
- Excel format for quantitative assessment which consits of chance x detection x consequence.
- Most urgent risks must be solved within one year and risk level below within five years.

**ABT method**

- Stated where to find what infomation.
- It is a risk based approach, where first entire buidling parts are considered.
- Desk study divided into three parts: surroundings, material properties and structural assembly.
- Must use reference projects in desk study.
- Yearly inspections and multi year assesments based on first assessment.
- Different qualifications given for yearly inspections and multi-year assessments.

**KPCV method**

- Reasons for assesment given.
- Stated that one year after completion, inspection must be performed to design and construction errors.
- Stated that every five to ten year an inspection must be performed to cover the aging aspect.
- Important points for existing buildings given.

**NTA 8790**

- Qualifications given for engineer and organisation performing the assessment.
- Important points given on inspection plan and reporting.
- Clear flowchart and good description of steps, providing valid points.
- Risks quantified via people exposed to danger.
- Assessment seen as sufficient when risks are acceptable or no more detail can be obtained on the specific risk.
- Actions and frequency periodic part is based on severity risk.
- Vulnerable structures/structural elements stated.
- Help in estimation extent damage.
- Independency organistion perfoming the assesment listed.

*ORA stands for Object Risk Analysis.

Figure 5.5: Most important aspects for the explored methods (2/2)

# Phase 4. Development method

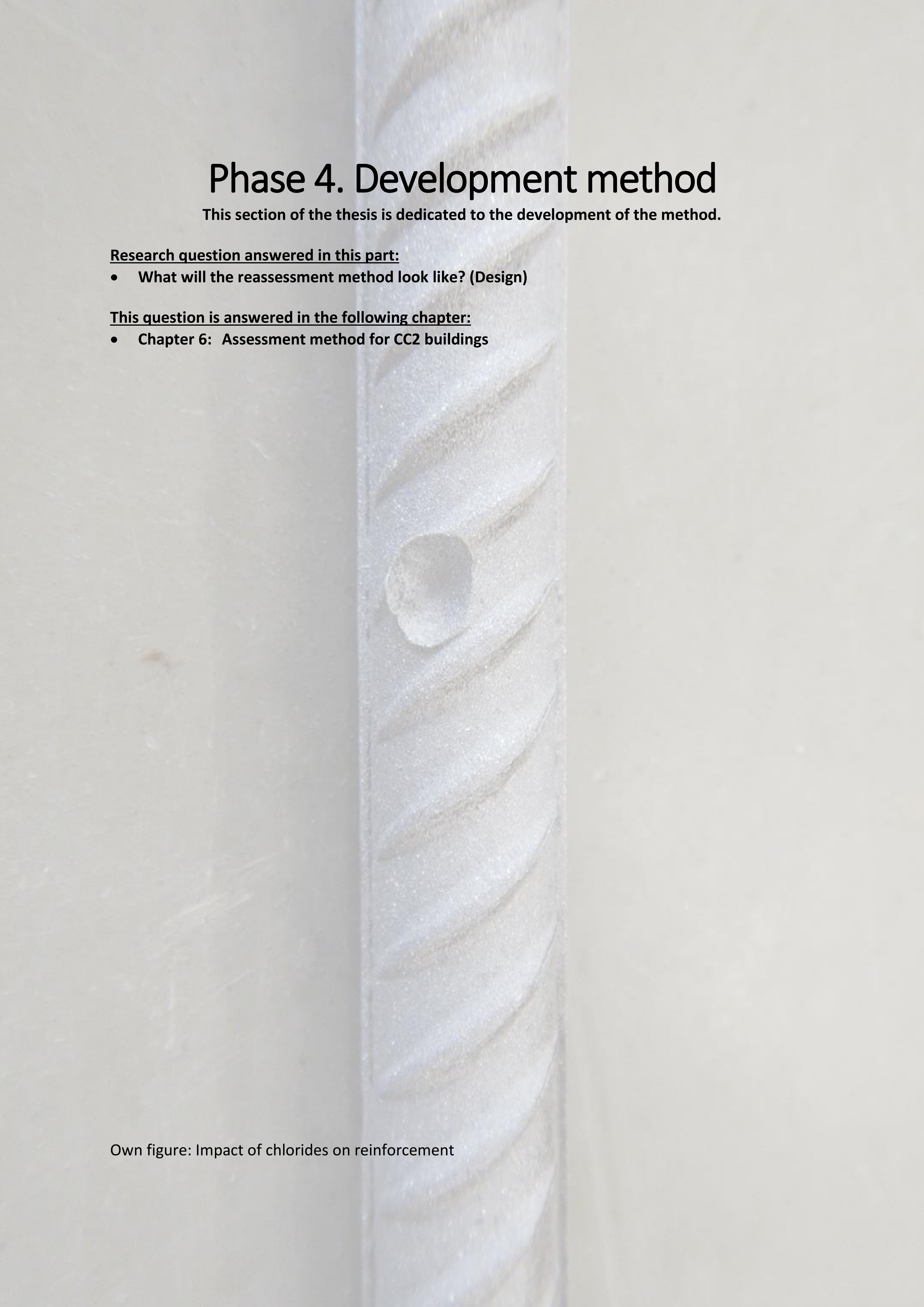
**This section of the thesis is dedicated to the development of the method.**

**Research question answered in this part:**

- **What will the reassessment method look like? (Design)**

**This question is answered in the following chapter:**

- **Chapter 6: Assessment method for CC2 buildings**



Own figure: Impact of chlorides on reinforcement

# 6 Assessment method for CC2 buildings

This chapter presents a new process for assessing existing CC2 buildings, based on the studies conducted in chapters 3, 4 and 5. The assessment is introduced in the first section. Following this introduction, the developed assessment process is described step-by-step in 6.2. The risk analyses that need to be performed in the assessment are further detailed in the subsequent section. Qualifications for all individuals involved in the assessment are outlined in section 6.4. At last, additional information that supports the assessment method is referenced, and the developed method is compared to the methods evaluated in the previous chapter.

## 6.1 Introduction assessment method

This section serves as an introduction to the assessment method. First, the mindset required for the assessor(s) is discussed. Next, general points of consideration for the assessment process are provided.

### 6.1.1 Mindset for assessment of existing structures

Structural reassessment differs from structural design as it involves evaluating the current condition and adequacy of an existing structure (ISTRUCTE, 2010). This process introduces other uncertainties, such as those related to aging, which often necessitate a return to basic principles. Consequently, a different mindset from that applied in structural design is required, even though some calculation steps may be identical. To guide the assessor in the assessment, several key questions should be considered (ISTRUCTE, 2010):

- What mechanism(s) could render the structure inadequate?
- What are the consequences of a local failure on the overall structure, its users, the building owner and others in close proximity?
- Is the structure sufficiently safe and usable now and till next assessment?
- Can the building serve its intended purpose now and till next assessment?

These questions facilitate an understanding of the potential consequences of a local failure. An important consideration in this context is the robustness of the structure. As noted in the Appraisal of Existing structures, a small local failure leading to significant material loss poses the greatest risks (ISTRUCTE, 2010).

This process is designed to aid users in their assessments, potentially requiring engineering judgement beyond the detailed follow-up from the standards. Standards and regulations offer a general level of safety but do not guarantee absolute safety (ISTRUCTE, 2010). Due to the complexity of detailed clauses in the standards, there are instances where engineering judgement may supersede (ISTRUCTE, 2010). This engineering judgement must also be employed when performing an assessment via this process.

### 6.1.2 Working from coarse to fine

Focussing on the assessment process, it primarily consists of an initial assessment. This initial assessment determines the structural condition of the building at a specific point in time, providing recommendations for potential periodic actions based on this assessment.

The assessment process involves information retrieval and risk review. It begins at a more abstract level of information, gradually uncovering more details as required during the process. This approach ensures that the building components without problems do not require detailed calculations or further detailed information gathering, contributing to a more efficient method. The information gathering process is illustrated in the figure below.

Figure 6.1: Process of assessment from abstract to fine details (ABT, 2020)

## 6.2 Assessment process

The assessment process is encapsulated in a flowchart presented in figure 6.2. The flowchart includes various headers, each represented by a different colour. A brief legend explaining these headers is provided below the flowchart. The first header, indicated by a red triangle, marks a decision point in the assessment process. The green boxes represent steps where information is gathered or an action is performed. This typically leads to an analysis step, which is depicted in a yellow box. At last, the blue boxes, which always appear after an analysis, categorise the different outcomes from this analysis.

The steps in the flowchart are captured within three stages: preliminary assessment, the loop and reporting stage. The steps to be conducted within these stages, are further detailed in subsequent subsections. The risk analyses to be performed in the method are not detailed in these subsections. Only what needs to be analysed and a description of the result categorisation are provided. The risk assessment itself is discussed in section 6.3. However, to provide preliminary insight into when an assessment can be deemed sufficient there are two applicable criteria. One of these criteria must be met for an assessment to be considered as sufficient (NEN, 2023):

- Risks are categorised as acceptable and it is likely they cannot be classified higher.
- It is likely that retrieving more information cannot lower the classification.

The risk itself is composed as the product of likelihood times consequence. In addition to the risk, the detection filter is also quantified in section 6.3. As depicted in the flowchart, this detection filter is used, among other things, to determine whether a hazard from the first step of the risk analysis is visually detectable. If the filter is one or two, the hazard is visually detectable, otherwise, it is not. More information on the filter can be found in the section specified above.

As this chapter progresses, it will become evident that this method is a complication of aspects within the existing assessment methods that have been assigned a maximum score. These scores can be accessed in appendix H.

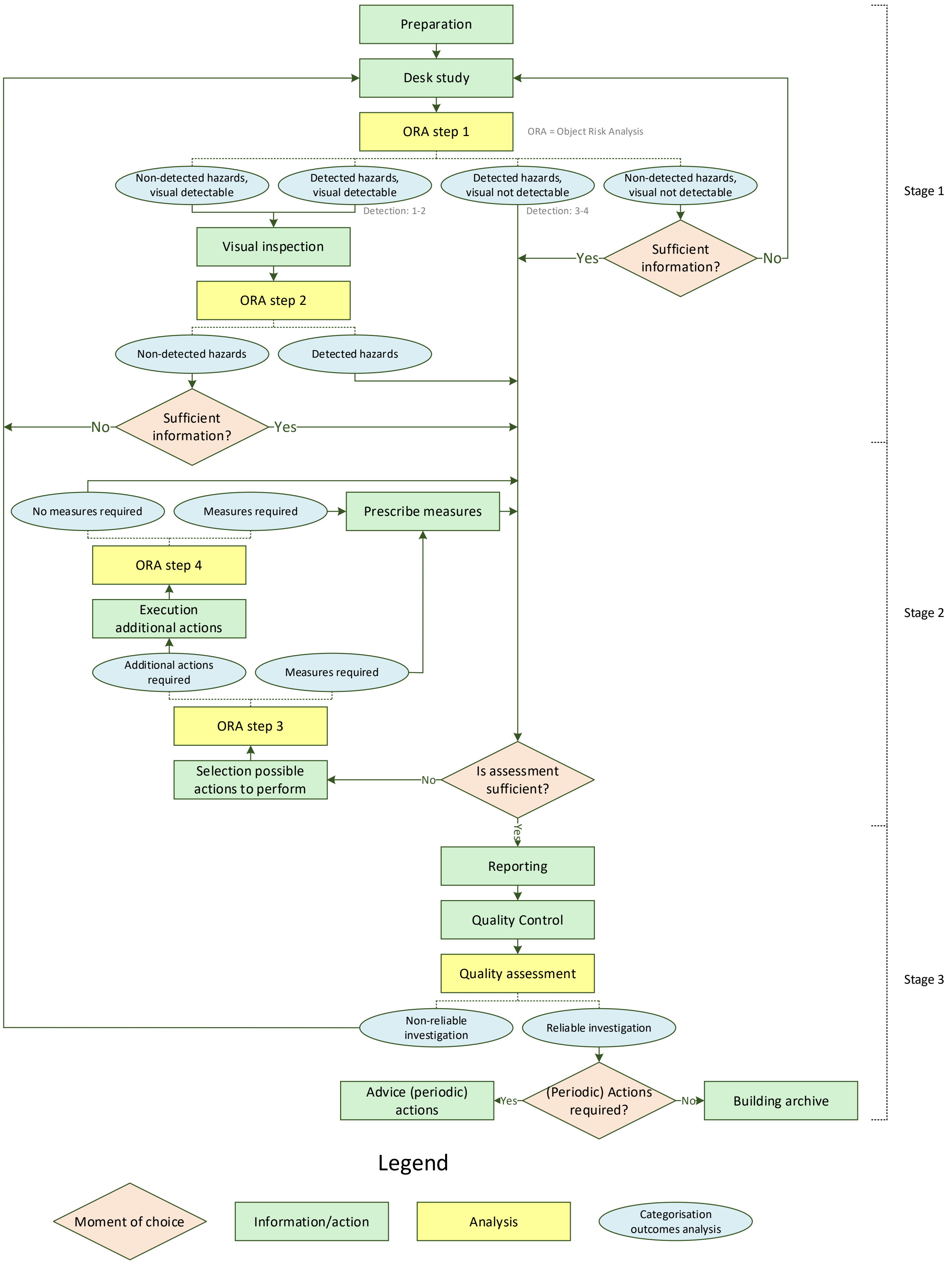


Figure 6.2: Flowchart process assessment existing buildings

### 6.2.1 Preparation

The first step in the assessment process is the preparation phase, during which several important points of information must be gathered:

- Initial building overview
- Client alignment
- Desk study information retrieval

**Initial building overview**

Before delving into the more detailed steps, an initial overview of the building and its surroundings should be obtained. The aim is to familiarise oneself with the object. This overview could be achieved by physically walking around the building or exploring it in an online environment. The surroundings should be considered not only in close proximity to the building, but also on a larger scale. For instance, buildings near the sea are more exposed to salts, which can accelerate material degradation. This kind of factors should be detected in this step of the assessment.

**Client alignment**

Once the initial overview is obtained, the next step is to align the assessment with the client. This step serves two important purposes: ensuring that both parties have the same expectations and understanding of what is required. In addition, information related to the building must be gathered. If there is limited documentation available for the desk study, obtaining information from the client becomes vital for the assessment. Even when ample documentation is available, this information retrieval helps focus the desk study.

Appendix I provides a set of questions that can be used during client alignment. This list is not exhaustive and may be supplemented with additional questions as needed. It is important to explain the working of the assessment process and the stapes to be taken prior to posing these questions.

Considering the maintenance history, it is important to note that the assessment should not be conducted too soon after maintenance. Coatings and paint applied during maintenance can obscure deficiencies. Over time, if not addressed, these deficiencies will reappear and can be detected during assessment. Therefore, it is recommended to perform the assessment at least three years after maintenance.

In conclusion, the client should be asked to provide all relevant documents for the desk study.

**Desk study information retrieval**

In addition to the client, there are other sources from which the required information for the desk study can be obtained. These potential sources for the desk study are outlined in section I.1.

Once an initial building overview is obtained, alignment with the client is completed and the documents for the desk study are retrieved, the preparation phase is concluded. The desk study step of the assessment process can commence.

### 6.2.2 Desk study

As previously mentioned, the desk study should not be performed at an overly detailed level, as there has not yet been any elimination of elements to study. This approach ensures that more detailed studies are only performed for structural elements that pose a significant risk. The aim of this phase is to gain insight into the building and its potential hazards through available documents.

In the stadium assessment method by ABT, the desk study is divided into three parts: surroundings, structural/technical assembly and material properties. The surroundings primarily encompass the wind calculation leading to wind loads. This aspect is not considered in this desk study phase as it can be addressed in a later action when a risk in the wind calculation or in parts exposed to winds is identified. The other two components, structural assembly and material properties are considered and will be explained in more detail.

**Structural assembly**

This part of the desk study involves reviewing the structural assembly of the building. Both the ABT method and NTA 8790 provide points that should be addressed in this section. These points are detailed in section I.2 of appendix I. Please not that these lists are not exhaustive and additional points may need to be considered as appropriate.

**Material properties**

This section of the desk study investigates information related to the structural materials. It is verified whether sufficient information on the materials is available (ABT, 2020). If not, this could pose a risk and should be listed in the first step of the object risk analysis. At this stage no actions are described or performed. It is merely a check to ensure enough information is available on the materials used in the structure.

**Common causes and other attention points**

The desk study also considers the list of common causes and other attention points outlined in chapter 4. There must be determined whether any of these causes or attention points pose a potential risk that needs to be addressed. Elements necessitating mandatory investigation, as specified in the list of common causes, should be assigned a higher risk score. This ensures their consideration in additional actions, during which the required investigations are conducted.

**Robustness classification**

As part of the desk study, a robustness class must also be defined. For this classification, table g.9 from the VDI method can be used. A structure with a low robustness poses more risk than a robust structure. This robustness classification is limited to the main load bearing structure and is used to provide more focus for the assessor(s).

**Division into structure into components**

To provide more structure for the desk study and subsequent steps in the assessment, the building should be divided into building components. These components should be assessed in the desk study. If more detail is required on these components, individual elements or oven details within these components could be investigated.

The process employs the NL/SFB codes for the components. A classification system used for coding (structural) objects and layers in BIM/CAD systems, the NEN 2767 and other applications (Techniek Nederland, 2020). Most housing associations utilise the NEN 2767 and base their multi-year maintenance planning on the outcomes, using these codes.

These codes are thus integrated in the process to accommodate the multi-year maintenance scheme and BIM usage. The required codes for the method are provided in the standard NEN 2767-2 (NEN, 2008). The codes for the decomposition are provided in table 6.1.

Table 6.1: decomposition building with NL/SFB codes (DigiGo BIM Loket, n.d.)

| **NL-SFB** | **Description** | **NL-SFB** | **Description** |
|---|---|---|---|
| 11 | Ground | 33 | Secondary elements to floors |
| 13 | Floor beds | 34 | Secondary elements to stairs |
| 16 | Retaining walls, Foundations | 37 | Secondary elements to roofs |
| 17 | Pile foundations | 38 | Other secondary elements |
| 21 | External walls | 41 | Wall finishes, external |
| 22 | Internal walls | 42 | Wall finishes, internal |
| 23 | Floors, galleries | 43 | Floor finishes |
| 24 | Stairs, ramps | 44 | Stair and ramp finishes |
| 27 | Roofs | 45 | Ceiling finishes |
| 28 | Building frames, other primary elements | 47 | Roof finishes |
| 31 | External wall openings | 48 | Finishing packages |
| 32 | Internal wall openings | | |

At the end of the desk study, the client should be consulted to validate that indeed all components present within the building are considered.

### 6.2.3 Object Risk Analysis (ORA) step 1

The information gathered during the preparation phase and the desk study serves as the foundation for the first step of the Object Risk Analysis. This stage brings forth the risks identified in these two steps. Some of these risks may be high due to incomplete information, as only the desk study and preparation have been conducted so far. For instance, during the desk study, it was observed that an older balcony is supported by steel profiles exposed to outdoor conditions. These beams could potentially be corroded, a condition that can only be confirmed through visual inspection.

The method distinguishes results based on detection, because it is inefficient to conduct a visual inspection for hazards that are not visually detectable. In this context, a hazard is defined as a potential danger. The first step of the analysis can yield four different possible outcomes which are illustrated in the figure below.

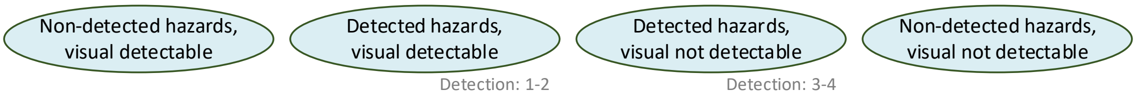


Figure 6.3: Possible results for ORA step 1

By distinguishing between visually detectability of hazards and if they are already detected or not, appropriate actions can be implemented for each hazard category. This categorisation also shows the residual uncertainty inherent in the assessment of existing buildings.

The use of a quantified detection filter guides the assessor towards the specific result categories, as each is assigned a corresponding number. To provide more clarity, each of the four categories is further explained with examples in the following paragraphs.

**Non-detected hazards, visual detectable**
An example of such a hazard is corrosion of exposed reinforcement in an outdoor concrete beam due frost damage. In this instance, neither the client nor the desk study detected this damage, meaning it does not surface in the first step of the ORA. However, this hazard is visually detectable and can thus be identified during visual inspection. This category underscores the importance of considering all potential hazards during the visual inspection, not just those identified in the first step of the risk analysis.

**Detected hazards, visual detectable**
The only difference with the previous category is that these hazards are already known from the preparation and/or the desk study. The example of potentially corroded steel support beams for a cantilevering outdoor balcony of an older building applies here. The issue can be detected during the desk study as it is also listed in the common causes (see chapter 4). Subsequently, the visual inspection can confirm this hazard and provide more information.

**Detected hazards, non-visual detectable**
This category includes hazards that cannot be identified through visual inspection. An example is the corrosion of wall ties inside a fifty-year old masonry façade near the coast. The risk can be identified during the desk study, as it is listed as a common cause in chapter 4. However, it cannot be visually detected. Bricks can be removed in stage two to check the quality of the wall ties. If a visual inspection is required for other hazards, the removal of bricks or other actions can be conducted the same day to maximise the efficiency of site visits.

**Non-detected hazards, non-visual detectable**
These are hazards that are not covered by the method. They are not detected during the preparation and desk study and cannot be identified through visual inspection. To address these hazards, it is important to ensure enough information is gathered during the preparation and desk study phase.

Despite these efforts, it is important to acknowledge that you can never be sure if all risks are detected. If sufficient depth has been applied within the preparation and desk study, these risks must be accepted.

Examples of such hazards include an old mineshaft under the object, different concrete mixtures applied in a foundation block during execution and missing reinforcement in a foundation beam. If no report is made during the desk study for the first example or during execution for the latter two examples, these hazards are not visually detectable until damage has already occurred.

### 6.2.4 Visual inspection and ORA step 2

For hazards that are visually detectable and have been identified, a visual inspection is necessary to gather more information and refine the risks outlined in the first step of the ORA. In addition, there are undetected hazards that are visually detectable. Since these hazards can only be identified through a visual inspection, this step is always required within the assessment. It is important to not focus solely on the points from ORA step one, but also look for additional attention points within the building. The goal of this inspection and accompanying second step of the ORA is to identify all visually detectable hazards present within the object.

**Inspection plan**

Before conducting any inspection, including a visual one, a plan should be composed outlining how the investigation is performed safely. This is the first step in the visual inspection phase and must be completed before the inspection beings. The points to consider in each inspection plan are detailed in subsection 6.2.5.

**Coverage visual inspection**

It is important to note that a visual inspection cannot cover 100% of a building's area. Professional judgement is required to obtain a representative sample of the building. To assist in this judgement, some guidelines are provided below. These points come from the BCA method and are slightly adapted. A distinction is made in residential and non-residential buildings.

<u>Residential buildings (BCA, 2022):</u>

- Special and critical structures, as well as structures without redundancies must be visually inspected. Chapter 4 can assist in identifying critical structures. If concealed by architectural finishes, when seen necessary access should be made for inspection.
- All unconcealed structural elements should be visually inspected.
- All structural elements in common areas (lift, lobby etc.) must be inspected.
- At least 20% (for < 30-year-old building) or 30% of the dwellings should be accessed for inspection. The selected dwellings must represent the building's structural condition and be well distributed throughout the building. The following requirements are given:
  - At least one dwelling per storey.
  - All rooftop dwellings.
  - Selected dwellings well distributed.
  - Consider attention points in selection.
- Concealed elements within the selected dwellings should be inspected via appropriate access points like access panels, lighting points, etc.

The BCA method suggests that with these guidelines, a visual inspection can cover a minimum of 70% - 80% of the building's structure (BCA, 2022).

Non-residential buildings (BCA, 2022):

- The points regarding special and critical structures, as well as structures without redundancies, are the same as in residential buildings.
- All unconcealed structural elements and units should be visually inspected.
- For indoor areas not exposed to weather and covered by suspended ceilings, the ceiling must be accessed for at least one point every 500 $m^2$.
- For outdoor areas exposed to weather and covered by suspended ceilings, the ceiling must be accessed every 250$m^2$.

If the minimum aspects stated above are not met, professional judgement must be applied to ensure a comprehensive overview is obtained. There are also factors that may necessitate a higher coverage rate, see chapter 4.

These guidelines can assist in conducting a thorough visual inspection where most hazards are detected or further refined. The appropriate tools for this inspection, also listed in this subsection, can further enhance the effectiveness of the inspection.

**Tools for visual inspection**

Tools to be used during the visual inspection are detalied in section I.3.

**ORA step 2**

Following the visual inspection, the second step of the ORA must be conducted. In this analysis, risks must be quantified or updated, along with the detection filter. Two outcomes can emerge from the risk analysis after the visual inspection.

The first type of outcome is a detected hazard which is thus included in the ORA. These hazards are all quantified in terms of risks, allowing for a judgement on whether the risks are acceptable or not.

It is also possible hazards are not detected. Some non-detected hazards are only visually detectable. If these hazards are not detected during the visual inspection, they will not be present in the risk analysis and thus not covered by the assessment. In this case it is important to ensure sufficient information is gathered during the preparation, desk study and visual inspection.

Despite these efforts, it is important to acknowledge that not all risks can be detected. If sufficient depth has been applied within the preparation, desk study and visual inspection, these risks must be accepted.

For all detected hazards that emerged in the first stage of the assessment, it must be determined if they are acceptable or not. If one of the two following cases apply, the assessment is seen as sufficient:

- Risks are categorised as acceptable and it is likely they cannot be classified higher.
- It is likely that retrieving more information cannot lower the classification.

If the assessment is not deemed sufficient, the second stage in the form of the loop in the flowchart must be accessed. It is likely that if risks are not acceptable after the first stage, additional actions could lower the quantified risk.

### 6.2.5 Stage two: the loop

Figure 6.4 presents the iterative loop for additional actions or advice on measures. The detected hazards, based on the previously described input, are evaluated for acceptability and sufficiency of information. If neither criterion is met, the loop is entered. The process conducted within this loop is discussed in this subsection. Even within the loop, the assessor(s) should first attempt to perform more abstract actions and then progress to finer details if required.

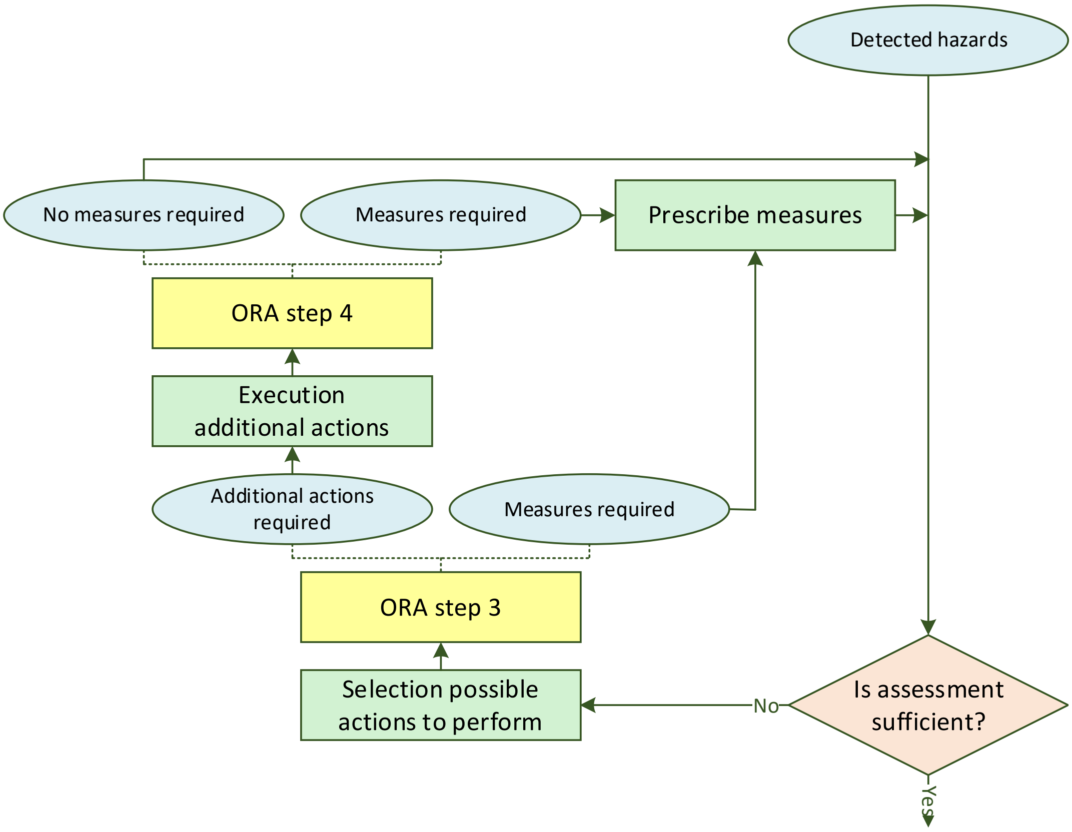


Figure 6.4: Iterative loop for additional actions and measures

**Selection possible action to perform**

This is the initial step when the assessment is deemed insufficient. Only the risks that render the assessment insufficient are considered in this loop. In this step, potential actions to mitigate the risks are considered. Examples of actions that could be included in this section are (NEN, 2023): performing inspections, making control calculations and/or conducting (material) investigations.

In this method, risk is defined as the product of likelihood and consequence. The potential actions should address the likelihood of occurrence or the consequence of the risks, thereby reducing the risk. For example, a possible action is listed for both aspects to mitigate the non-visible risk of wall ties in a masonry façade:

Likelihood: By removing some bricks, the application, quantity and condition of the wall ties can be assessed. This information allows for a more accurate estimation of the likelihood score.

Consequence: By erecting fences around the façade, people or other objects can be protected from injury or damage due to falling bricks resulting from failed wall ties. In this case, the consequence side of the risk is mitigated.

There is a distinction between these two examples. In the likelihood example, an action is proposed to gather further information for a more accurate risk estimate. In contrast, in the second example, a measure is prescribed to the client. Both actions and measures should be listed in this step.

**ORA step 3**

Once the potential actions or measures are identified, their impact on the risks must be quantified in the third step of the ORA. This analysis quantifies the efficiency of the next step, providing an overview of the most effective alternatives to pursue. The outcome of this analysis could either be a required action to gather more detailed information or a necessary measure to be prescribed to the client. The costs of different alternatives might also influence this decision, a factor that can be discussed between the assessor(s) and the client.

**Execution additional actions**

If the outcome of ORA step three necessitates additional actions, these actions must be executed in this step. Prior to conducting any actions, an inspection plan must be completed. The NTA 8790 provides key points for this inspection plan (NEN, 2023):

- Which elements are assessed.
- Which aspects are assessed.
- Define the level of detail of the inspection/investigation.
- Specify the required level of measurement accuracy (if applicable).
- List whether the investigation is destructive or non-destructive.
- If existing (architectural) finishes are damaged for inspection, specify the necessary level of recovery.
- State materials and tools required for inspection.
- Outline how the inspection can be conducted safely.

Subsequently, the selected actions in the previous step can be performed. The findings from these actions must be documented. In case of an inspection/investigation, the report should include (NEN, 2023):

- Purpose of the inspection/investigation.
- Individual who performed it.
- Date it was performed.
- Elements considered.
- Findings of the inspection/investigation.
- Conclusions and recommendations derived from these findings.

The NTA also provides information on checking calculations, stating that significant structural systems, individual elements or even structural details can be calculated (NEN, 2023). For these calculations the NEN 8700 standard, specifically section E.5, must be applied. All inspections and additional investigations must ensure compliance with the NEN8700 standard as it is applicable to existing buildings.

All the documents resulting from these additional actions must be uploaded into the building archive.

**ORA step 4**

The results of the additional actions could lead to a reduction, increase or continuity in risks. For instance, if bricks are removed to inspect the wall ties and it is found that they are almost non-existent due to corrosion, the risk is higher and measures need to be prescribed. To gain insight into the actual risks after the additional actions have been performed, the fourth step in the ORA is required. This quantification determines whether measures are necessary.

If no measures are required, it does not necessarily mean that the assessment is sufficient. There could still be insufficient information on the risk, necessitating another iteration within the loop.

If measures are required, they should be prescribed to the client in the form of advice. This ensures that the client immediately knows what measures should be taken to mitigate the risk.

When the assessment is deemed sufficient, the final steps of the initial assessment can be accessed. Therse final steps are captured in stage three and shown in the figure below.

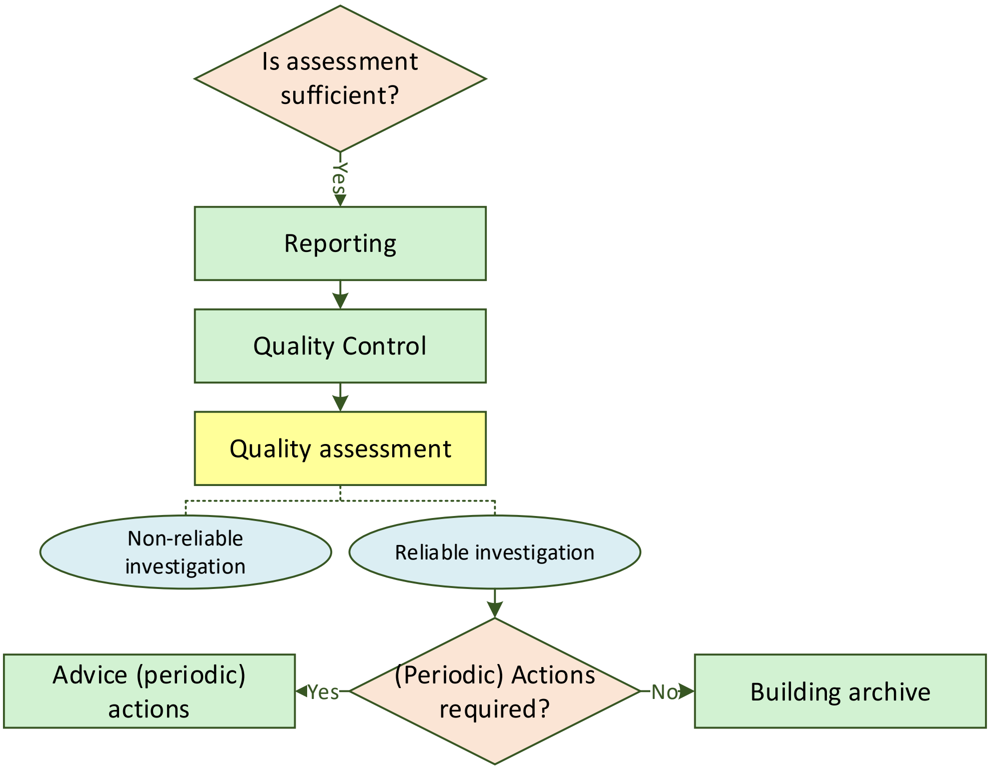


Figure 6.5: final steps assessment

### 6.2.6 Reporting

There are multiple methods available which provide report formats. Specifically, the format provided by NEN-ISO 13822 offers a good example to document all findings form the initial assessment. Although the scope of this thesis focusses primarily on the process of assessment, an attempt has been made to adjust the NEN-ISO 13822 format to suit the assessment performed in this method. The first version of this adjusted report format is provided in appendix J. In case periodic actions are undertaken, there are also documentation formats available for these actions.

### 6.2.7 Quality assessment

The quality assessment provided by Rijkswaterstaat is used in this method, with minor adaptations, as it offers a sound solution to ensure that the assessment is reviewed by another individual. The questions that should be asked for this quality assessment are (Rijkswaterstaat, 2016):

- Does the assessment provide the appropriate level of detail for the object?
- Are all functions of the object considered?
- Is the chosen physical decomposition appropriate? This checks if too many parts of the structure are bundled or if excessive differentiation is applied.
- Is the decomposition of the object chosen correctly? This checks if any parts are missing or wrongly placed.
- Are the correct failure patterns identified in the report? Check if dominant failure modes that could occur in the building are missing.
- Are the likelihood, consequence and detection scores estimated correctly? Rijkswaterstaat noted that a negative finding during inspection could lead to a more unfavourable likelihood score. Additionally, it is cautioned that the consequence score sometimes implicitly considers the likelihood. For instance, for a failure mode with a small likelihood, a small consequence is chosen as the chance of occurrence is almost non-existent (Rijkswaterstaat, 2016).
- Are there mistakes in the risk assessment?
- Are measures proposed for all non-acceptable risks and if so, are the appropriate measures proposed?

The quality assessment must be performed by an individual different form the one(s) who conducted the assessment. As indicated in appendix J, the reviewer must also sign the opening pages of the report once it meets the expected standard. At a minimum, the reviewer must work through the questions listed above. However, this is not an exhaustive list and additional relevant questions should be posed and reviewed (Rijkswaterstaat, 2016). After review, the assessor(s) have an opportunity to respond to each question. Following this process, the reviewer provides their agreement per question if satisfied with the response. If not, any unsatisfactory sections must be revised and checked again by the reviewer to ensure they meet the required standards.

This process is also reflected in the final part of the flowchart, where there is questioned whether or not the investigation is seen as reliable. If deemed unreliable, previously mentioned actions must be performed. If deemed reliable, all is clear and the assessment can be concluded.

At last, there must be decided whether advice on periodic actions should be given or whether all documents related to the assessment should be placed in the building archive. The latter option means there is no follow-up action on this initial assessment. However, even if all risks are deemed acceptable, this does not mean no periodic actions have to be assigned. For instance, if acceptable risks include degradation mechanisms, conditions could deteriorate resulting in a higher risk.

### 6.2.8 Advice on periodic actions

This final step involves advising the client on periodic actions that can be taken to monitor the structural condition of the building over time. Three levels of periodic actions are used, similar to the VDI 6200 standard. This differentiation in levels enables efficient monitoring, with different qualifications assigned to each level. The timing and necessity of each of the three levels is given in section 6.3. The first two levels primarily check if the structural safety, compared to the initial assessment, is still applicable, similar to the ABT method (ABT, 2020).

If advise on periodic actions is chosen, an assessment plan must be written. This plan should highlight the most important points during the period assessment, considering the initial assessment. It should also specify whether and when any of the three periodic actions should take place.

The three periodic actions that could be performed are (VDI, 2010):

- Visual inspection by client or client's representative.
- Visual inspection by an expert.
- Periodic assessment of the structure.

The first to levels consist of a visual inspection, with the only difference being the qualifications of the assessor. In the first level, the owner or a representative of the owner performs the inspection. Most housing associations use the NEN 2767 standard as a visual inspection. However, as concluded in chapter 5, this standard does not sufficiently capture risks relating to structural safety. As for the periodic assessment two more levels are available to compensate for the shortcomings of NEN 2767 its use is less problematic. By providing this opportunity housing associations do not have to adapt their entire asset management structure. However, in the NEN 2767 extra work must be conducted to quantify the condition score of each building part. It is thus advised to perform a visual inspection with the points given in subsection 6.2.4 and fill in the notation form appendix J, but NEN 2767 could also be used.

The visual inspection by an expert is the second level. The information provided in subsection 6.2.4, should be considered for the first and second level. For the final level, the full periodic assessment, the same procedure as the initial assessment should be followed. However, since the initial assessment has already gathered a lot of information, not all of it needs to be reconsidered. The main focus should be on changes or degradation in relation to this initial assessment, making this procedure more time efficient. More information on the contents of this periodic assessment is provided in the report format of appendix J.

Further information on the qualifications of the periodic assessment levels is provided in section 6.4. In addition, attention points outlined in chapter 4 should be considered during all inspection levels. A wealth of information is already available from the initial assessment, which should guide and streamline the periodic assessments.

A quality assessment, similar to that described in subsection 6.2.7, should be conducted for all levels. However, questions that are not applicable to these periodic assessments do not need to be considered. The quality assessment should be proportionate to the effort undertaken in each level.

If all aspects are found to comply with the expected level of quality, the periodic assessments can be used to update the periodic assessment plan.

## 6.3 Risk assessment

The assessment process, as outlined in the preceding section, necessitates the execution of an object risk analysis at several stages. This analysis quantifies the risk and requires the application of a detection filter. This filter aids in categorising the results of the first step of the ORA (see figure 6.3). In addition, it assists in selecting appropriate actions or measures when the assessment is deemed inadequate. As aforementioned, the risk is composed of likelihood times consequence.

The focus of this section is on risk quantification and determining whether risks are acceptable. If periodic actions are recommended, the final subsection provides guidance on potential frequencies for which these actions could be performed.

### 6.3.1 Quantification of risk and detection filter

All elements, including risks and the detection filter, are quantified. First, the likelihood and consequence are considered. Both of these aspects use a five-point scale, as illustrated in figure 6.6. The scale ranges from one to five to ensure sufficient differentiation and detail within the risks.

| **Five point scale chance and consequence** | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

Figure 6.6: Five-point scale for likelihood and consequence

To facilitate this quantification process, both the likelihood and consequence aspect utilise a slightly adapted quantification mechanism from the risk analysis conducted by Rijkswaterstaat. The likelihood quantification mechanism is presented first, followed by the mechanism for the consequence.

**Likelihood**

The likelihood is quantified by the time until first moment of failure, denoted as ‘t’. Failures are categorised into those resulting from aging and those that do not. For failures where the likelihood remains constant over time, the likelihood score is interpreted as mean frequencies of occurrence (Rijkswaterstaat, 2016). The same time periods apply to both categories and er given in table 6.2.

Table 6.2: Quantification mechanism likelihood (Rijkswaterstaat, 2016)

| **Chance quantification** | | |
|---|---|---|
| 1 | Negligible | t > 20 years |
| 2 | Small | 6 years < t ≤ 20 years |
| 3 | Medium | 2 years < t ≤ 6 years |
| 4 | Significant | 0.5 year < t ≤ 2 years |
| 5 | Certain | t ≤ 0.5 year |

**Consequence**

The quantification of consequences is executed through the (R)AMSSHE€P framework, where each letter represents a consequence category that is assigned a score from one to five. The first letter ‘R’ for reliability, is enclosed in brackets as it is already accounted for in the likelihood score and thus excluded from the consequences (Rijkswaterstaat, 2016). The remaining letters represent: Availability, Maintainability, Safety, Security, Health, Environment, Economics and Politics.

During the validation process, which is detailed in chapter 8, it became clear not all categories are relevant for the assessments conducted with this method. To save time in quantification, only useful categories are considered, resulting in the following configuration: AMS€P. The full categorisation and quantification mechanisms for the consequences is provided within table k.2. This appendix also provides a more detailed explanation of the (R)AMSSHE€P framework.

**Detection filter**

In addition, to quantifying risks by multiplying likelihood with consequences, this method also incorporated a detection filter. This detection aspect was considered within the risks of the Nebest method. However, the detection aspect is not included in the risk calculation to maintain a clear prioritisation based on likelihood and consequences. This approach ensures clarity in defining likelihood, as the detection score must be distinct from it. Moreover, detection is already accounted for in the hazard categorisation process during the first step of the ORA. By prescribing suitable actions for these hazards, risks associated with detection are inherently mitigated.

Nevertheless, a detection filter proves useful in distinguishing between visual and non-visual detectable hazards. For these two categories, a binary scale (visual or non-visual) would suffice. However, if the assessment is deemed insufficient, appropriate actions or measures must be implemented to mitigate the risk. In this context, the detection filter aids in determining suitable actions or measures.

To provide more insight, a four-point scale is employed for the detection filter. With an even number of points, levels one and two can be categorised as visually detectable hazards, while levels three and four can be classified as non-visual detectable hazards. Via this detection filter more information is obtained thereby making sure the appropriate follow up actions or measures are implemented. The quantification of the detection filter is presented in table 6.3.

Table 6.3: Quantification detection filter

| Quantification detection filter | |
|---|---|
| 1 | Easy to visually detect |
| 2 | Likely to visually detect |
| 3 | Hard to detect |
| 4 | Not detectable |

To interpret each of the four levels, brief examples are provided. The first category encompasses easily visual detectable risks that are visually identifiable, such as a broken glass façade panel. The second category includes risks that are likely to be visually detected but require additional effort. For instance, removable plates in the lowered ceiling need to be taken out to inspect the concrete beams supporting the floors. Another example is to check the underside of the ground floor and the foundation beams via access points.

The third and fourth category are not visually detectable. In the third category, if assessment is deemed insufficient, additional actions in the form of non-destructive or even destructive tests must be performed. An example would be removing bricks to check wall ties.

The final category risks that are almost undetectable. An example is verifying the consistency of in-situ formed piles in the ground all the way to the bottom.

In conclusion, each step of the risk analysis must involve risk composition via likelihood and consequences. In addition, a detection filter must be assigned to each risk.

### 6.3.2 Acceptable risks

The ability to quantify risks allows for a more nuanced understanding of what level of risk is deemed acceptable. As indicated in the previous subsection, certain colours such as green and red are used to denote acceptable and unacceptable risks.

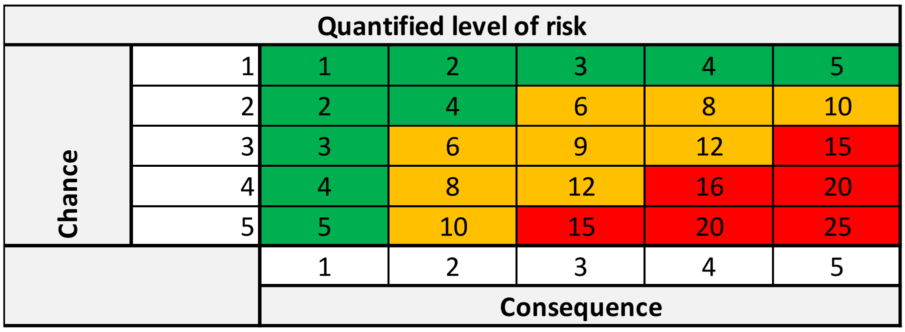
Table G.13 of Rijkswaterstaat provides an indication of which risks are considered acceptable and which are not. It also introduces an intermediate level of undesirable risks. Consequently, a three-level scale for risks is employed in the Rijkswaterstaat. This scale has been incorporated into the current method and is presented in table 6.4.

Table 6.4: Risk categories

| Risk categories |
|---|
| Acceptable risks |
| Undesirable risks |
| Unacceptable risks |

The product of likelihood and consequence is thus categorised into these three levels. This categorisation of quantified risks is presented in table 6.5. The sufficiency of the assessment is determined by whether all risks are acceptable or if no further information can be gathered to reduce the risks. Therefore, if the risks are deemed undesirable and additional information can still be collected, the loop in the flowchart must be implemented.

Table 6.5: Quantified and categorised risks



| | | Quantified level of risk | | | | |
|---|---|---|---|---|---|---|
| Chance | 1 | 1 | 2 | 3 | 4 | 5 |
| | 2 | 2 | 4 | 6 | 8 | 10 |
| | 3 | 3 | 6 | 9 | 12 | 15 |
| | 4 | 4 | 8 | 12 | 16 | 20 |
| | 5 | 5 | 10 | 15 | 20 | 25 |
| | | 1 | 2 | 3 | 4 | 5 |
| | | Consequence | | | | |

If the assessment identifies measures that are necessary as the risk remains unacceptable, these measures must be implemented as soon as possible. Similar to the Nebest method, it is advised that these measures be completed in one year. For the undesirable risks measures must be completed within a five-year timeframe.

### 6.3.3 Frequency periodic actions

This subsection provides guidance on the frequency at which periodic actions could be performed. It should be noted that this advice on frequency is merely indicative. The intervals do not reflect individual risks or degradation mechanisms, nor do they account for risks over time. The frequencies are general suggestions for intervals at which periodic action could be undertaken.

The periodic actions of the VDI 6200, which are also used in the method, have associated intervals. In this standard, the intervals depend on the consequence class of the structure. Specifically, for CC2 buildings, the VDI standard suggests the following intervals (VDI, 2010):

- Periodic action level 1: 2 – 3years
- Periodic action level 2: 4 – 5 years
- Periodic action level 3: 12 – 15 years

NTA 8790 prescribes two types of periodic tasks: general tasks to verify the correctness of the initial assessment every ten years, and specific tasks based on their risk level. For the risks the specific tasks must be performed every five to ten years with exception of high risks. These risks must be performed every three to five years (NEN, 2023).

In this method, the frequency mechanisms of both methods are combined. Similar to the NTA, the intervals of periodic actions are based on the final risks in the assessment. The times for different actions consider both the VDI standard and NTA.

| | |
|---|---|
| **Acceptable risks** | •Level 1 in three years<br>•Level 2 in ten years<br>•Level 3 if required |
| **Undesirable risks** | •Level 1 in three years<br>•Level 2 in five years<br>•Level 3 in fifteen years |
| **Unacceptable risks** | •Level 1 in two years<br>•Level 2 in four years<br>•Level 3 in twelve years |

Figure 6.7: Advised frequencies for periodic actions

This method encounters the same issue as the NTA, where different risks yield different intervals. If there are significant gaps, the risks can be grouped under the highest applicable risk level. For instance, if there are numerous undesirable risks and some acceptable risks, the first two levels of periodic actions could be combined. The third level for acceptable risks only needs to be performed when deemed necessary based on the outcomes of the first two levels.

## 6.4 Qualifications

As highlighted in chapter 5, it is important to specify different qualifications, particularly when differentiating between various types of work. This aspect is considered under both the trustworthy and efficiency criteria. By delineating these differences, the method aims to be efficient yet reliable.

The periodic actions align with the VDI 6200 standards, and its qualifications are adopted with minor modifications. The NTA 8790 is also consulted. The qualification levels used in this assessment method are:

- **Client/Representative:** Individuals who have some affinity towards building management/technical service (ABT, 2020).

- **Expert:** Civil engineers/architects with at least five years of relevant experience in structural analyses, technical site supervision and similar areas (VDI, 2010). In addition, at least three years of experience in compiling structural analysis are required.

Ideally, this experience should be related to buildings similar to the object being assessed. Alternatively, civil engineers/architects could have a minimum of three years' experience inspecting constructions similar to the object under consideration (VDI, 2010).

- **Special expert:** Civil engineers with a minimum of 10 years' experience in technical site supervision, compilation of structural analyses and similar areas (VDI, 2010). In addition, at least five years of experience in compiling structural safety verifications are required.

- **Specialists:** Individuals with ten years of relevant experience for more specialised inspections and investigations (NEN, 2023).

The qualifications outlined above can be assigned to different aspects within the method. The qualifications required for tasks in the method are presented in table 6.6. The qualifications for the periodic part of the method align with those of the VDI 6200. For the initial assessment, the same qualification level as for the periodic assessment is chosen.

Table 6.6: Qualifications required for what task

| Task to be performed | Qualification |
|---|---|
| Initial assessment | Special expert |
| Periodic inspection (level one) | Client/Representative |
| Periodic inspection (level two) | Expert |
| Periodic assessment (level three) | Special expert |
| Detailed inspections/investigations | Specialist |

The qualifications of the reviewer conducting the quality assessment should at least be equivalent to those of the individual performing the task. Therefore, if a special expert is required to perform the initial assessment, the reviewer should also be qualified as a special expert.

In scenarios where multiple individuals are involved in the building assessment, the person with the appropriate qualifications is responsible for all steps and bears any consequences. This individual must also conduct the on-site visual inspection to gain an accurate understanding of the building's condition.

If more detailed inspections and investigations are needed, other parties with relevant expertise or tools may be consulted. As indicated in table 6.6, individuals conducting these inspections and investigations must have specialist qualifications. This may also apply to certain structural analyses. The outcomes must always be verified by a suitable qualified individual performing the task.

## 6.5 Final considerations

This section presents additional sources that could provide further specification when using this assessment method. Furthermore, the method developed in this chapter is compared to the methods evaluated in chapter 5 based on the criteria trustworthy, effectivity and efficiency. At last, conclusions drawn from the development of the assessment process are provided.

### 6.5.1 Additional information

The study of various available methods in chapter 5 revealed that an assessment method for existing buildings could provide a wealth of additional information. This information is not included in the study as the focus is on the assessment process. However, it is known where this information can be found.

For this reason, the sources containing this additional information, along with brief content descriptions, are elaborated upon in appendix L. The content from these sources could be used in addition to the developed assessment process to improve its assessment. Future studies could consider incorporating this content into the assessment process.

### 6.5.2 Comparison with evaluated methods

A comprehensive comparison of the developed method with those evaluated in chapter 5 is provided in appendix H. It is important to bear in mind that these methods have not been applied to cases for the comparison with the developed assessment process. The content of the methods is compared via the criteria trustworthiness, effectivity and efficiency and their defined tangible aspects in chapter 5. At the time of this comparison, NTA 8790 was not finalised and no assessments had been conducted with the method. Therefore, these scores may not align with the final used for assessments. Each criterion’s results are discussed, with special attention given to NTA 8790.

**Trustworthiness**

The method achieves maximum scores for the multi-person principle and qualifications, as expected, since the content of the methods achieving the maximum score is directly incorporated into the assessment process. Other methods score better for the structure approach, as they contain some information not considered in the process. This information, referenced in the preceding section, could still be implemented.

Despite scoring highest overall among the considered methods, there is room for improvement to maximise performance on all aspects within the trustworthiness criterion.

The main distinction of this method compared to NTA 8790 is the multi-person principle. The quality assessment to verify the reliability of the investigation in the developed assessment process is an addition to the team collaboration in NTA 8790.

**Effectivity**

For the effectivity criterion, two of the three aspects receive maximum scores: the structure of the risk assessment and the critical factors. The aspect scoring intermediate pertains to risk identification. Risks are assessed at each stage, focusing on the most significant for further identification, limiting the risks considered in subsequent stages. However, all risks are considered with the analyses at the start of the assessment.

Despite this intermediate score, the developed assessment process proves more effective over the aspects considered in this criterion.

Compared to NTA 8790, the developed assessment process provides a more structured risk assessment. Both the quantification of risks and the selection of next steps for different outcomes of the analyses provide a more structured risk assessment that more effectively identifies risks.

In addition, NTA 8790 only considers casualties in the consequence part of the risks, while the developed process considers the AMS€P. For the other two aspects within the criterium both methods have the same scores as there are not a lot of differences

**Efficiency**
In terms of efficiency, the developed assessment process does not rank highest. It receives maximum scores for two aspects: qualifications and the coarse to fine approach, followed by intermediate scores for the tools and time aspects. The first aspect pertains to tools or specifications that enhance efficiency. Some evaluated methods provide more applicable information, which could enhance the developed method. These tools and specifications are referenced in the preceding section.

The second aspect relates to the time-intensive nature of the extensive risk quantification via the AMS€P categories and the assessment process itself. While this ensures effectivity and trustworthiness, it impacts efficiency. However, by optimising actions for different applicable outcomes, the time required for this method is minimised. However, not to the extent of achieving the maximum score for the time aspect.

When compared to other methods, particularly the CUR 124 used to assess civil structures, scores better across almost all aspects. However, some of its aspects, such as the prioritisation of a group of objects, are more applicable to uniform infrastructural objects. Moreover, CUR 124 has one aspect with the minimum score as it does not distinguish qualifications. In conclusion, while attempts have been made to optimise the method for efficiency, it does not emerge as the most efficient compared to other methods.

Considering NTA 8790, the methods do not differ significantly, except for the distinction in qualifications for different tasks. This distinction is more extensive in the developed assessment process, thereby enhancing efficiency.

### 6.5.3 Conclusions

The theoretical comparison suggests that the assessment process developed in this study holds more promise in terms of trustworthiness and effectivity than existing methods. These aspects influence the efficiency criterion, as the method is more comprehensive than some other existing methods. However, by performing actions specific to different outcomes for various analyses, the time required for the assessment is optimised. Other efficiency aspects, such as different qualifications for different tasks and a coarse to fine approach, also contribute to the method’s efficiency.

When comparing with NTA 8790, several differences emerge, including the quality assessment, the structure of the risk assessment and the differentiation in qualifications for different tasks. These differences, represent improvements for the developed assessment process. For other aspects, no significant differences are observed. To truly compare the method, Once NTA 8790 is finalised, it could be contrasted with the developed assessment process using an existing case.

In conclusion, the comparison reveals a trustworthy and effective method for assessing existing buildings. This impacts the time aspect of the assessment and, consequently, its efficiency. However, the steps within the assessment are optimised to minimise the time required for each step, thereby presenting an efficient method within the boundaries of effectivity and trustworthiness criteria.

This section only presents a theoretical comparison of the content of the developed assessment method. The method is also evaluated and validated using existing cases, a process described in subsequent phase. During this process some improvements were identified and directly incorporated into the method. Thus, the method presented in this chapter is the improved version following validation and evaluation with existing cases.

# Phase 5. Validation and evaluation

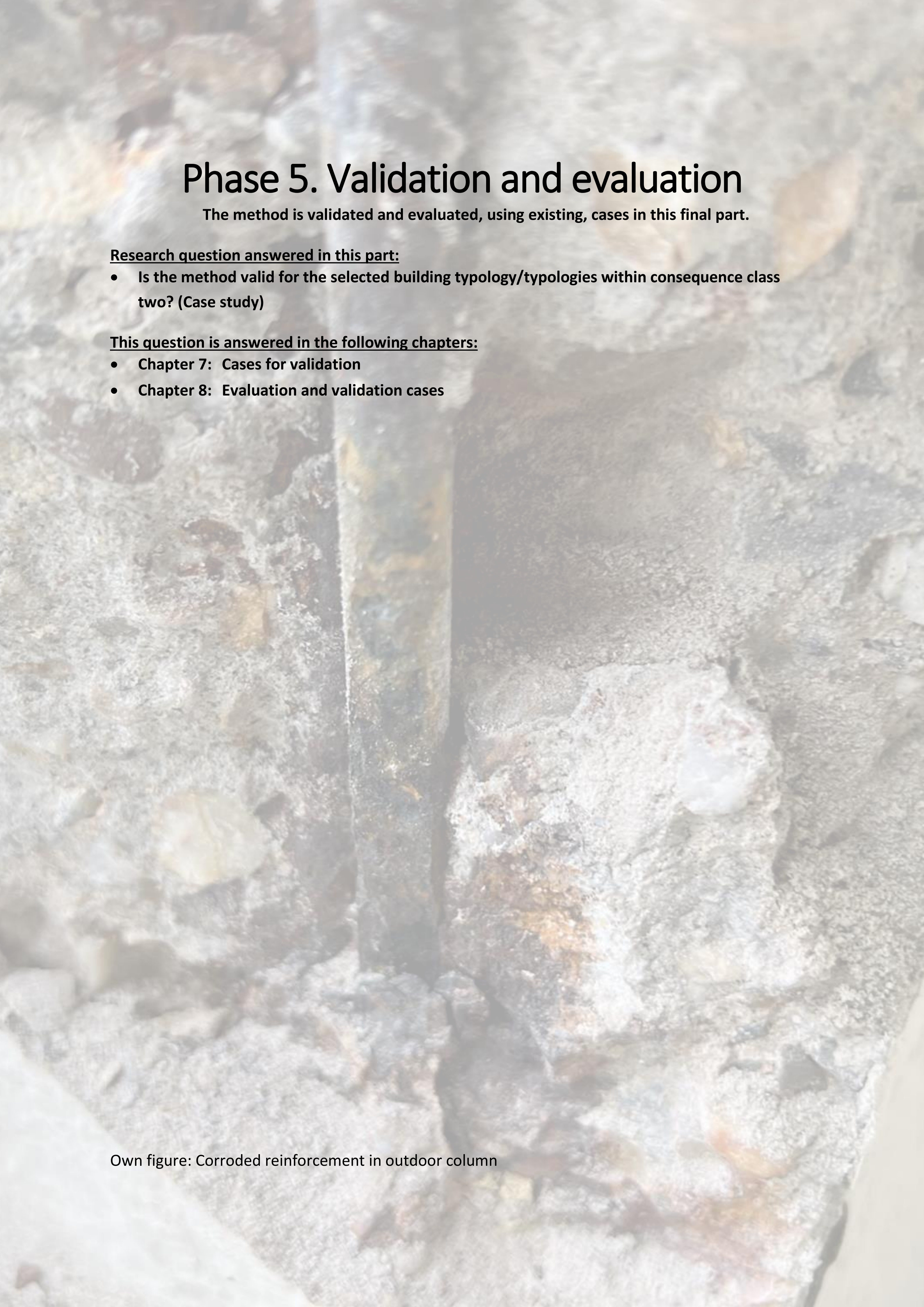
**The method is validated and evaluated, using existing, cases in this final part.**

**Research question answered in this part:**

- **Is the method valid for the selected building typology/typologies within consequence class two? (Case study)**

**This question is answered in the following chapters:**

- **Chapter 7: Cases for validation**
- **Chapter 8: Evaluation and validation cases**



Own figure: Corroded reinforcement in outdoor column

# 7 Cases for validation

The method developed in chapter 6, requires evaluation and validation to assess its practical performance. As outlined in chapter 7, this evaluation and validation is conducted using two existing cases. These cases are detailed in this chapter, preceded by a description of the selection process for the cases in the first section.

## 7.1 Selection process

This section outlines the process used to retrieve two suitable causes for validating the method. The first subsection defines the criteria used for case selection, while the second subsection details how the cases were retrieved.

### 7.1.1 Criteria for selection

The first criterion requires that both cases have assessments available for the respective buildings. These assessments allow for a comparison of the test outcomes with the available results, thereby validating both cases and allowing for variety in other aspects. To ensure the method's unambiguous operation, the available assessments should not be reviewed prior to testing the method on the building. This approach prevents the available results from influencing the method's test procedure.

**Type of failure/error**

A distinction is made between different type of structural failures. These are design and construction errors and failures due to degradation mechanisms, which could occur due to user errors. The method must be able to detect risks coming from all these types of errors. As indicated by the KPCV, the design and construction errors can be detected early after the completion of a building (KPCV, 2022a). For degradation mechanisms it is better to have a building which is more towards the end of its theoretical design life. So, a distinction in age of the building needs to be made for the two cases.

**Building typology**

The building typology is also considered. The housing associations play a major role in this study, with CC2 apartment buildings being the most applicable typology. A representative apartment building from the Dutch building stock is selected, considering periods where most apartment buildings were constructed (1965 – 1985 and 1985 – 2005), see figure c.2. These buildings are later in their lifespan, possibly highlighting degradation patterns. This aligns with the requirement to consider degradation as part of a case.

For the second case, there is no specific building typology requirement. While testing a different typology form an apartment building could provide a broader evaluation of the method, selecting another apartment building could allow for a more experienced validation, given the learnings from the first case. Both options have their merits and drawbacks. Therefore, no explicit criteria for building typology are set for the second case, the selection will be based on which case best fits the validation process. For this case, a newer building between one and ten years should be evaluated to validate the fact the method can detect design and execution errors.

The selection criteria for the two causes are summarised within table 7.1. As evident, there is considerable variation between the cases. This diversity in criteria is intended to test the method's applicability across different situations within the scope of the study. Despite these differences, both cases have an available assessment, allowing for validation of the method.

Table 7.1: Criteria for two validation causes

| Cause | Assessment available | Type of failure/error | Building typology | Completion date |
|---|---|---|---|---|
| 1 | Yes | Degradation | Apartment | 1965 - 2005 |
| 2 | Yes | Design/construction | Any seen fit | 2013 - 2022 |

The cases under consideration are existing buildings owned by either organisations or individuals. For a case to be eligible for the method's evaluation, the owner or representative must agree to the following terms:

- Access to building must be facilitated if required. Certain parts may not be accessible, but this should not hinder the validation process.
- The owner should provide all relevant information that is available.
- Some information, including the risk format, may be published in the TU Delft repository for public consultation. Building information will be kept to a minimum and anonymised.
- The Assessment is solely for the purpose of evaluating and validating the method, not for providing the client with insight into the risks of the building. This is due to the fact that this method is developed by student for his thesis, not an engineer with the experience outlined in the method.

If the owner/representative agrees to these conditions and the building meets the aforementioned criteria, it can be selected as a case for validating the developed method.

### 7.1.2 Retrieval cases

Cases were retrieved through a video released on Nebest outlets, targeting building owners, consultation with colleagues and contact with the asset managers interviewed for the problem statement.

The first case, referred to as 'Building A', was obtained through one of the asset managers. Nebest had already performed a risk-based assessment on this apartment building via the method evaluated in chapter 5. The risks are assessed after the desk study, the visual inspection and listing of possible actions. This allows for comparison and validation of the similar steps within the developed method. One limitation in the case is the fact that the dwellings could not be visually inspected. This was not an issue as sufficient building area is present to validate the method.

The second case, 'Building B', was retrieved through a Nebest colleague. While a full assessment is not available in writing for this building, the colleague has a complete overview of it. After testing the method on the building, the results are discussed with this colleague, providing validation for the method and concluding the validation process.

## 7.2 Description case building A

This building is an apartment complex completed in 1970, which consist of a semi-prefabricated concrete load-bearing structure. The load-bearing structure comprises concrete walls on concrete foundation strips which divide the load over concrete piles.

Access to the dwellings is facilitated via outdoor prefab concrete gallery floors, supported by prefab concrete consoles. These gallery floors connect the three different complexes comprising the building. A support structure was developed for these galleries between the complexes. The galleries are accessible via stairs or elevators. The appartements also feature balconies, which are supported by walls instead of being cantilevered.

The facades of the building primarily consist prefabricated masonry parts which are connected to the inner concrete walls via doves. On façade corners, prefab concrete elements are in place.

One of the apartment complexes has undergone adaptations, with ground-floor storage boxes replaced by shops, adding commercial activity to the primarily residential functions. In another complex, storage spaces have been converted into a communal area for residents. A passage was created at ground level in the third complex to improve access from one end to the other. Generally, storage space is located at ground level with apartments situated on the floors above. The building stands seven stories tall.

In terms of renovation history, an exterior renovation was conducted in the mid-2000s, following an earlier renovation of the dwellings. Regular maintenance has been performed on the building since then, although recent maintenance has been deferred in anticipation of preservation actions.

At last, the building is not situated in a coastal municipality, it is subject to standard land-level conditions.

## 7.3 Description Building B

Building B is a recently completed multifunctional complex. The upper floors of the various building sections house appartements, supported by an in-situ concrete wall structure. These apartments are accessible via prefabricated concrete gallery plates, which are either cantilevering or supported by beams and columns. The beams consist of steel and the columns are mostly made of prefabricated concrete (a small parts consist of steel). The prefabricated concrete balconies also vary in support.

The lower three floors comprise storage, commercial and parking area. The vertical load-bearing structure consists of both in-situ walls and prefabricated concrete beams and columns that transfer the forces to the foundation. Prefabricated walls housing the central staircases and elevators span all floors and function as the horizontal load-bearing structure. The parts of the parking garage that are not topped by apartments serve as a roof garden.

The foundation comprises of concrete strips and pads that distribute the loads over the concrete piles which are formed in the ground. Floor construction varies between in-situ, plank floors and hollow core slabs. The facades primarily consist of masonry which is supported by steel beams every two floors. In some instances, timber or glass panels are implemented.

# 8 Validation process

This chapter validates the assessment process outlined in chapter 6, using two case studies detailed in chapter 7. The aim is to evaluate the practical application of the designed assessment and compare its performance with existing assessments. One case study involves an assessment using the previously evaluated Nebest method, while the other involves an interview with an expert who assessed the building.

## 8.1 Set up validation

It is important to note that this study is conducted as part of a master's degree in civil engineering, which means the validation cannot be performed with the qualifications specified in section 6.4. Effort has been made to minimise this qualification factor and focus on validating the core process.

Not all components of the assessment process can be validated through these case studies. The parts that can be validated are illustrated in figure 8.1.The final section of the loop, which includes the additional actions and prescription of measures, is excluded from this validation due to its focus on validation only and the lack of correct qualifications. Consequently, steps to be taken once the assessment is deemed complete, including advice on periodic actions, are not included in this validation. These remaining steps are straightforward and can be validated in future studies when the entire process is validated.

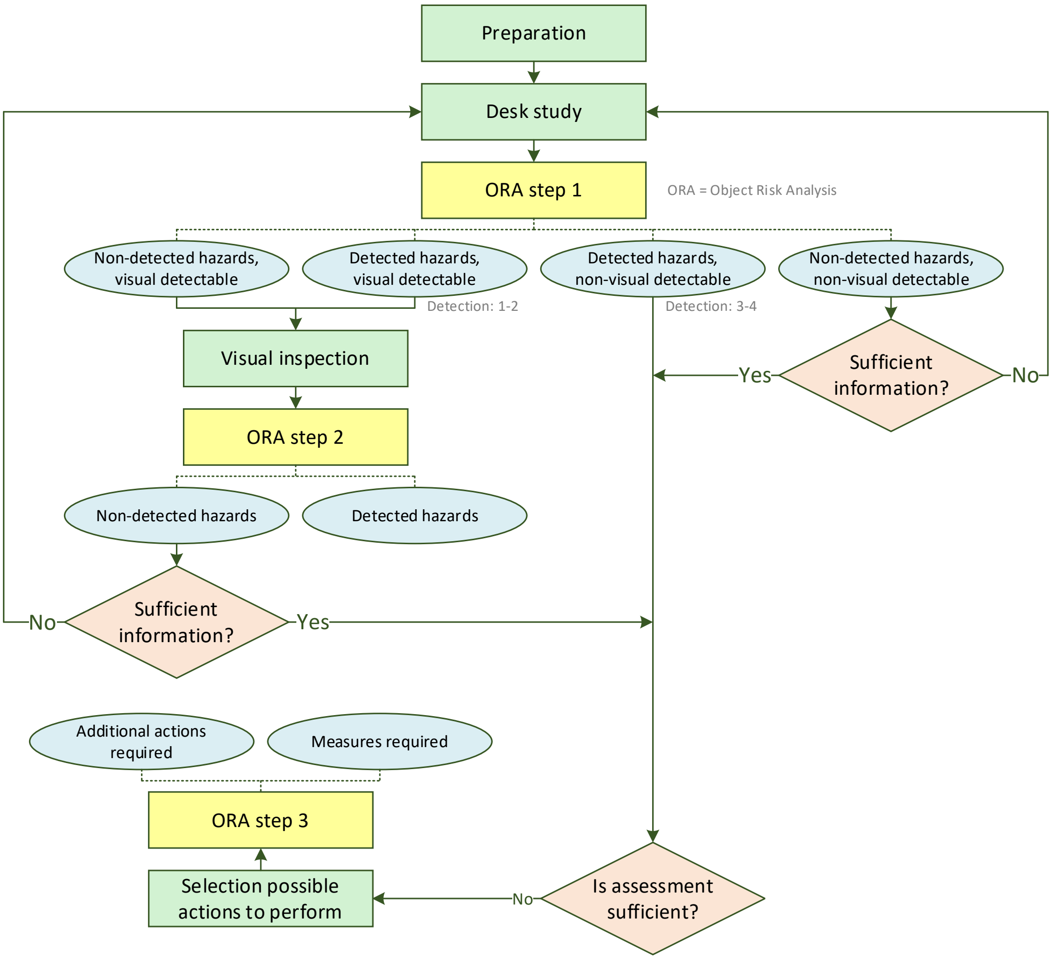


Figure 8.1: Part assessment process validated

## 8.2 Validation via case A

The assessment process is first applied to Building A. A brief overview of the assessment process, including the sheets on quantified risks, is provided in appendix M. The key areas for improvement identified during this assessment are discussed in the following subsection.

The results of this assessment are then compared with those obtained using the Nebest method, with the main points of comparison highlighted. For both aspects, the method is broken down into steps and points are provided for each step. This structured approach allows for a comprehensive evaluation and comparison of the different assessment method.

### 8.2.1 Validation process

Table 8.1 succinctly outlines the key findings from the assessment process of case A, per applicable step in the assessment. Further elaboration on these findings with improvement actions or recommendations are given below the table. Only areas of improvement have been considered.

Table 8.1: Improvement points found in assessment process case A

| Step assessment | Important points |
|---|---|
| Desk study | - Material properties should be examined post-structural assembly. |
| ORA step 1,2 and 3 | - Challenge to distinguish detection filters for building components.<br>- Quantifying the likelihood remains difficult at times.<br>- Security, health and environment consequences are not critical.<br>- Miss distinction between one or multiple casualties in consequences. |
| Visual inspection | - Not able to verify coverage prescription as no access dwellings. |
| Selection actions/ measures | - Determining the selection of actions or measures to implement is challenging. |

**Desk study**

The desk study revealed that the examination of material properties should be conducted after the structural assembly is known. This finding has led to a reordering of these steps in chapter 6.

**ORA step 1,2 and 3**

An important point pertains to the different risks which might be present within building components. Some of these risks are visually detectable while others are not. In the assessment a detection filter was applied to the entire building component, while it should be applied per detected risk. Multiple detection filters should thus be applied within a component, each pertaining to a risk.

Despite incorporating the time component, estimating the likelihood score accurately remains challenging. The NEN 2767 provides a general degradation curve based on the condition score. Future studies could explore additional support for this score, possibly through a general degradation curve.

For the quantification of the consequence score, AMSSHE€P was used via table k.1. During this quantification it became clear that the categories security, health and environment were not critical in any of the risks considered. Given that each letter per risk requires a score, this process can be time consuming. As these categories are not critical for structural safety, the framework has been revised to AMS€P for efficiency, as shown in table k.2.

Within the remaining categories (AMS€P), there is room for improvement in the safety aspect. The highest category includes sustaining injuries to multiple persons or a fatal injury to one person. This often resulted in the maximum consequence score due to a possible fatality. No differentiation could be made within single or multiple fatalities. This differentiation would allow for a more accurate estimation of the consequence score. This aspect has been revised in table k.2.

**Selection actions/measures**

The final point of improvement pertains to the difficulty in determining actions or measures to reduce risk levels. This was anticipated and is listed as a recommendation for future research.

**Conclusion**

Aside from these points, the assessment process proved practical in identifying risks and conducting assessments. In the next subsection the results are compared with the assessment from Nebest.

### 8.2.2 Validation versus available assessment

Table 8.2 provides a brief overview of the key points identified during the validation with the available assessment, conducted using the Nebest method. These points are categorised into general points and specific points related to trustworthiness, effectivity and efficiency. These criteria offer a structured approach to compare the assessments.

Table 8.2: Key points comparing assessments case A

| **Step** | **General points** | **Specific points** |
|---|---|---|
| Desk study | - Not all building components were detected. | - Nebest includes elements less relevant to structural safety. |
| ORA step 1 | - The likelihood was mostly consistent.<br>- The detection was largely consistent.<br>- Differences consequence score often due to letters and safety category.<br>- Detection score in quantification resulted in different form of prioritisation. | - The consequence classification is more time consuming in developed method.<br>- More consequences are addressed through the multiple consequence categories. |
| Visual inspection | - Not all building components were detected. | |
| ORA step 2 | - Same points as step one. | - Nebest considers all risks, while developed method only considers visually detectable risks in this step. |
| Assessment sufficient | | - Only undesirable and unacceptable risks are further considered in developed method, Nebest considers all risks. |
| Selection actions/ measures | - Selection of actions/measures more uniform in Nebest method. | |
| ORA step 3 | - Same points as step one.<br>- Nebest assessment adapted detection for actions, developed method adjusted both likelihood and detection. | - The impact of actions/measures on multiple aspects can be observed through the consequence categories for the developed method. |

**Desk study**
Within the desk study, it was noted that not all building components mentioned in the Nebest method were detected by the developed assessment process. To address this issue, the asset manager or building owner could be contacted after the inventory of components to ensure all components are accounted for.

Nebest also considers hazards unrelated to structural safety such as installations, fire safety, making the assessment more extensive and thus less efficient. In addition, Nebest also considered window frames with no impact on structural safety. As these elements do not pose significant risks, the consideration of these elements makes the method less effective.

**ORA step one**
The most significant differences between the two assessments lie in the risks they compose. Although both have similar outcomes for likelihood and detection, they diverge in their treatment of consequences. This is largely due to the categorisation process of AMSSHE€P in the developed method. While quantifying risks via AMSSHE€P is more time consuming, as it requires consideration of all categories, it provides a more comprehensive overview of potential consequences. This occasionally results in higher consequence scores than Nebest but enhances the trustworthiness of the method. Efficiency could be improved by eliminating the categories mentioned in the previous subsection. The consequence score is also elevated due to the lack of distinction between one and multiple casualties.

The most notable difference is the inclusion of detection in the risk quantification. This discrepancy leads to variations in risk prioritisation between the two assessments. In certain instances, a risk is elevated in the Nebest method, even if its consequence and likelihood are within acceptable limits.

Detection is an important factor to consider as undetectable risks can pose significant challenges. However, the actual failure depends on its likelihood, quantified through time factors. The severity of the failure is quantified via the consequence scores. By quantifying detection separately but still considering it, risks can be prioritised if detection issues arise. However, as the risk is represented by the likelihood of failure and its potential consequences, this leads to a clear prioritisation which is not influenced by too many factors.

**Visual inspection**
The issue of undetected building components recurs in the visual inspection. However, this issue is already solved in the section above.

**ORA step two**
Nebest considers all hazards during the visual inspection. The developed method is more efficient and effective as it only considers visual detectable hazards in this inspection. Apar from this comparison the same points apply as given in ORA step one.

**Assessment sufficient?**
When determining the sufficiency of the assessment, only undesirable and unacceptable risks are considered in the assessment process. The Nebest method, however, considers all risks, even those deemed acceptable, making the method less effective in the second stage.

The extra considered risks also take up time but this is also the case for the more extensive AMS€P consequence categories applied in the undesirable and unacceptable risks within the developed assessment process.

**Selection actions/measures**

The selection of actions or measures echoes the points raised during the process validation. The process could offer more assistance in implementing follow-up actions or measures. As the Nebest method is conducted by an expert, these actions are more uniformly applied.

**ORA step 3**

In quantifying the potential impact of these actions or measures on the risks, there is a difference in the risk adaptation. In the Nebest method, most actions, such as additional investigation, affect the detection aspect of the risk.

In contrast, such an action in the developed process both impacts the detection filter and likelihood, as additional information allows for a more precise estimation of the time interval for the likelihood. The different consequence categories also provide more insight into the impact of actions or measures on consequences, making the new process superior in this step.

**Conclusion**

In general, while there are areas of improvement in the assessment process compared to the Nebest method, this validation demonstrates that this process has potential to develop into a more trustworthy, effective and efficient method for building assessment.

## 8.3 Validation Building B

The assessment process for the second case was conducted in the same manner as for case A, which is outlined in appendix M. However, some of the identified improvements during case A were incorporated into this assessment. These improvements involved scoring consequences using the AMS€P system, distinguishing between single and multiple casualties, investigating material properties after the structural assembly in the desk study and applying the detection filter per risk. Despite these modifications, the overall structure of the assessment remained largely unchanged. As the previous assessment has already been documented and due to privacy considerations, the details of this assessment are not published.

The validation followed the same structure as the previous section, beginning with a validation of the process and then further validation through comparison with an existing assessment for the building. The primary focus of the validation was on the differences implemented in case B compared to case A. Additionally, any new points that emerged during this validation were examined.

### 8.3.1 Validation process

The table below presents new insights that emerged during the assessment process, as well as a validation of the changes implemented following case A. This validation not only includes areas for improvement but also positive observations. Again, only the assessment steps for which these points were found are mentioned in the table.

Table 8.3: Important points validation process case B

| Step assessment | Important points |
|---|---|
| Preparation | - Aligning with client yields valuable information. |
| Desk study | - Proportionality at abstract level is established from start.<br>- Robustness classification aids in quantifying consequences. |
| ORA step 1 | - Distinguishing in casualties allows for more accurate risks estimation.<br>- Applying a detection filter per risk offers a clearer overview.<br>- The AMS€P system enables a more efficient risk evaluation. |
| ORA step 2 | - Points quantification risks aligns with those identified in ORA step 1.<br>- Risks were properly adjusted based on findings. |
| Assessment sufficient | - Only a small selection of risks required for further assessment. |
| ORA step 3 | - Points quantification risks aligns with those identified in ORA step 1.<br>- Different aspects AMS€P still provide a good consideration of the impact of possible actions/measures. |

**Preparation**

During the preparation phase, it became evident that aligning with the client is crucial. In several instances, this alignment led to the early detection of risk during the desk study phase. For building B, some of the most significant risks were identified during this alignment. This point was also observed during the validation process for case A.

**Desk study**

It is important to note that the desk study is conducted in a proportionate manner, beginning at an abstract level. This point will be further discussed in subsection 8.3.2. Additionally, the robustness classification for the load bearing structure assists in estimating whether certain failures could lead to a more progressive collapse.

**ORA steps one, two and three**

For the object risk analyses, adaptations regarding casualty distinction, application of the detection filter per risk and AMS€P proved beneficial. The casualty distinction provides a more accurate representation of real-world risks. The fewer categories for AMS€P proved more efficient as it takes less time and still provides a comprehensive consideration of the impact of actions or measures on consequences in ORA step 3. The detection filter also proved more effective when applied per risk.

In ORA step 2, it was found that risks could be properly adjusted based on findings from the visual inspection. Moreover, only a small selection of risks required further consideration for this building. This makes the assessment effective as more detail is only required for the most significant risks.

**Conclusion**

Overall, the assessment process improved following the adaptations made after the validation process of case A. However, there were also points where recommendations were made for further studies, such as difficulties in quantifying likelihood and selecting actions/measures for insufficient risks. These points were also echoed in the validation of case B.

### 8.3.2 Validation via available form of assessment

The available form of assessment available for this building, is an expert who thoroughly investigated the object. The findings from the assessment with the method were subsequently discussed with the expert. The outcomes of this discussion are presented in this subsection.

The inclusion of a client interview and visual inspection, in addition to the desk study, adds depth and focus to the assessment, which is evident in the evaluation of this building. The assessment demonstrates that the method can effectively identify real-world issues and facilitate appropriate follow-up actions to investigate their root cause. The method serves the purpose of performing an assessment in short time to retrieve maximum results, thereby implying that the method does provide an efficient and effective assessment.

However, there was an issue in this building that could only have been identified through a comprehensive desk study. This problem had already manifested as visible damage. The method could have identified this issue through a more detailed investigation into the origin of the damage. However, if no damages were present, this risk would have gone undetected. This indicates that 20-30% of hidden deficiencies cannot be detected by the method as they are unique and cannot be covered by prior knowledge.

Therefore, while this method can identify many risks present in the building, there will always be deficiencies that it cannot detect. These undetected risks must be accepted in the assessment as they will remain in the building.

## 8.4 Final conclusions

The validation conducted in this chapter demonstrates that the developed method can detect both degradation mechanisms and design and execution errors. It provides an efficient and effective approach to identify most of the existing problems and continues the assessment to more detailed investigations until the root cause oof the problem is identified. This implies that the assessor(s) must persist with this assessment until they are satisfied with the identified cause of the problem.

However, it should be noted that 20-30% of non-standard hidden defects/risks may not be detected. These are issues that could potentially only be identified through a thorough desk study, which involves a comprehensive examination of every element in all available drawings. These risks are also considered within the assessment process via the non-visual detectable hazards that are not detected. This way there is acknowledged that there will always be residual risks that cannot be identified.

In addition to these points, several recommendations have been made throughout this validation for further improvement of the assessment process in future studies. The method has thus far only been validated for two apartment buildings. in future studies the assessment could also be tested for other building typologies present within CC2. Nevertheless, the validation demonstrates that this assessment process is practical for efficiently and effectively assessing existing buildings to gain deeper insights into the structural condition thereby retrieving more grip on the structural safety of existing buildings.

# 9 Discussion

This chapter discusses the findings of the study, first linking them back to the problem detected in the problem statement and subsequent literature review. This is followed by a addressing the limitations of the study.

## 9.1 Reflection

This section dissects various aspects of the problem reflecting on the impact of the study on each specific part. Furthermore, the application of the method to buildings other than CC2 is explored.

**Occurrence of structural failure incidents in use phase**

Literature revealed numerous structural failure incidents over the years. By investigating the structural failure incidents within the Cobouw database, it can be confirmed that these failures are not incidental. However, due to limited data conclusions may vary with different sets of structural failure incidents.

Terwel used more databases to retrieve more funded conclusions. In two of the three database 67% of the incidents were discovered in the use phase (Terwel, 2014). In the other database there were no incidents recorded in the use phase. This study thus also shows that numerous structural failure incidents do occur within the use phase.

In short, the conducted studies in this thesis support the fact that numerous structural failure incidents do occur in the use phase.

**Current methods fall short in guaranteeing structural safety**

Interviews with asset managers and a survey of the building sector indicate that current methods fall short in guaranteeing structural safety. Most of the respondents apply the NEN 2767, which they deem insufficient, for this aspect.

In this study available existing assessment methods have been evaluated. In this evaluation it is confirmed that the NEN 2767 fall short in detecting risks relating to structural safety. However, it also identifies existing methods that offer more assurance regarding structural safety. These methods could also be implemented to secure the structural safety aspect of existing buildings.

Yet, all considered methods fall short on the evaluated criteria trustworthiness, effectivity and efficiency. The newly developed method exhibits strong performance in terms of trustworthiness and effectivity. Within the boundaries of these two criteria, the efficiency criterion is optimised. This could potentially result in higher costs compared to methods such as NEN 2767, particularly due to imposed qualification requirements and more extensive time commitment. However, it is worth noting that many other methods also impose similar qualifications and require more time to implement. This is logical considering, for instance, that NEN 2767 is inadequate in ensuring structural safety. The new method still outscores most existing methods in terms of efficiency, thereby providing a more trustworthy and effective solution.

**Gap CC2 buildings**
While NTA 8790 provides a mandatory assessment for CC3 buildings, a suitable method for assessing CC2 buildings was lacking. The newly developed method surpasses NTA 8790 in terms of trustworthiness and effectivity, and scores slightly better in efficiency. During the validation and evaluation phase, which utilised CC2 buildings, it was evident that the method is practical, offering an effective and efficient assessment. Consequently, this method can be chosen over NTA 8790 to bridge the gap in available assessment methods for CC2 buildings.

While NTA 8790 remains mandatory for significant public buildings within the CC3 category, the newly developed method can coexist with it for CC2 buildings. Furthermore, the implementation of the developed assessment method for CC3 buildings could also be considered. However, it should be noted that the final version of NTA 8790 has not been considered and no assessments have been conducted using this method yet. To obtain a more substantiated comparison of NTA 8790 with the developed assessment process, both methods should be applied in the assessment of a case, and the results should be compared.

**Appliance to CC3 buildings and other building types within CC2**
For the development of the method a selection in building types within CC2 has been made, as depicted in figure 4.1. However, the primary input for the new method stems from the study of existing assessment methods. In addition, the incident study has been incorporated into the developed assessment process. This incident study considers all building types, not just the selected ones, and does not differentiate between consequence classes. For example, buildings such as hotels, which are not considered in the developed method, are included in the incident study. A case in point is the incident involving the fallen façade panel at the Hilton hotel Rotterdam. As this type of incident is included in the list of common causes to be considered during assessment, this problem could have been identified with this assessment process.

This indicates that the developed assessment process could potentially be applied to non-selected building types within CC2 and CC3 buildings. However, since the primary focus of this development was on the selected building types within CC2, its applicability to buildings outside this selection requires further investigation in future studies.

## 9.2 Limitations assessment process

The primary limitations of the research are the scope boundaries delineated in section 1.5. In addition to these boundaries, further limitations emerged during the development process of the method. These limitations are discussed in detail below.

**List of common causes and attention points**
The study on common causes for structural failure incidents in the Netherlands has yielded a list of causes and more general attention points. However, due to the limited data availability, expert interviews and general literature this list is not exhaustive but rather an initial attempt. It can serve as a focus during the assessment but should not be solely relied upon.

The same applies to the general attention points listed in this chapter. The points made by KPCV and VDI provide good focus during assessment, but additional risks should be actively sought.

**Advice frequency periodic actions**

The developed assessment method provides advice on the frequency of specified periodic actions. These frequencies are not based on degradation mechanisms or risk development over time, but on sources implying general frequencies. They should be seen as general advice to cover risks identified in the initial assessment. For risks influenced by time, adapted periodic actions may be necessary.

**Report format**

The newly developed report format for the method is based on NEN-ISO 13822. However, this format has undergone no validation within this study, potentially leading to shortcomings during practical implementation.

**Operability assessment process**

The assessment process could include more detailed information, such as specification what tests for what problems, to improve the trustworthiness, effectiveness and efficiency of the assessment. All additional information that could be incorporated is provided in section 6.5. The fact that the process is not fully developed should be considered when used in practice.

**Does not detect all problems**

The validation showed that the method can detect most of the risks present. However, 20-30% of hidden deficiencies cannot be detected as they are not visible and require a detailed investigation at element or detail level. These deficiencies must be accepted when performing an assessment with this method.

**Appliance in regular conditions**

The method is designed to inspect existing buildings under regular conditions. If a problem has already been detected and a detailed investigation is immediately required, this method may not be suitable.

**Validation**

For the validation, two cases were used: a multifunctional building (including, parking, apartments and commercial activities) and an apartment building which partly commercial activities in the plinth. This demonstrates that the assessment process can be applied to multiple building typologies. However, not all types within CC2 were considered in the validation. In addition, the assessment of the developed method was only compared to an available assessment via the Nebest method. Other types of available assessments could also be used in future studies for future validation. Moreover, not the entire process was validated. Only the pars of the process given in figure 8.1 were considered.

In general, the assessment cannot be validated with 100% certainty via these two cases and used setup. However, these cases were suitable for the validation process proving the assessment process is fit to assess existing buildings.

# 10 Conclusions

This chapter presents the conclusions of the study. The primary objective of the thesis was defined as the following:

An efficient and effective assessment method to evaluate existing consequence class two buildings on structural safety to prevent incidents with structural failures.

This objective underpinned the main research question which was further divided into several sub-questions. All questions, from sub-questions to main research question, are addressed in this chapter, thereby fulfilling the main research objective. The responses to the sub-questions are first provided, leading to the answer for the main research question.

## 10.1 Sub-questions

In this section responses are given to all sub-questions for this study.

**Which building typologies are present in the Netherlands?**

Chapter 3 and appendix C treat this sub-question by examining the building stock in the Netherlands. The building typologies present in the Netherlands are depicted in figure 3.4. The category of 'other buildings' includes functions such as restaurants, cafés, hotels and other forms of lodging, day care, sports facilities, swimming pools and congregation areas. The latter is often also found within other building typologies like offices. Furthermore, the Netherlands also features hybrid building typologies, which consist of a combination of the typologies mentioned below.

**What incidents are known within buildings?**

Chapter 4, in conjunction with appendices D and E, investigated structural failure incidents. The known incidents have been compiled into a validated list of common causes for structural failure incidents, as presented in table 4.1. Detailed questions to further explore these causes are answered in table e.1 and table e.2.

**Which reassessment methods are already available?**

Chapter 5 along appendices G and H, focus on the selection and evaluation of available assessment methods. Initially, 28 sources were considered. These were subsequently narrowed down to ten assessment methods for evaluation, as presented in the subsequent table.

Table 10.1: Available methods selected for evaluation

| Method | Institution |
|---|---|
| Guideline for Structural Assessment of Existing Buildings | The American Society of Civil Engineers (ASCE) |
| Periodic Structural Inspection of Existing Buildings – Guidelines for Structural Engineers | Building and Construction Authority (BCA) |
| CUR-aanbeveling 124, Constructieve veiligheid bestaande bruggen en viaducten van decentrale overheden | CROW - CUR |
| NEN-ISO 13822 | NEN – ISO |
| Appraisal of Existing Structures | The Institution of Structural Engineers |

| | |
|---|---|
| VDI 6200, Standsicherheit von Bauwerken Regelmaβige Uberprufung | VDI - GBG |
| NEN 2767 Conditiemeting gebouwde omgeving | NEN |
| ORA, eenvoudige objectrisicoanalyse – werkomschrijving | Rijkswaterstaat |
| NTA 8790 | NEN |
| Risicogestuurde inspectie | Nebest |

Not all available assessment methods were selected for evaluation in these chapters. The following assessment methods are available but were not considered:

- Protocol Beoordeling constructieve veiligheid Stadions betaald voetbal ABT.
- CUR-aanbeveling 121.
- Structural Condition Assessments of Existing Buildings and Designated Structures Guideline, Professional Engineers Ontario.
- Handboek RVBBOEI inspecties.
- Analysekader vaste kunstwerken – Analysekader voor Viaducten, Vaste bruggen, Rijkswaterstaat.

The reasons for excluding these available assessment methods from the evaluation are provided in table g.4.

**What will the reassessment method look like?**
Chapter 6 presents the developed assessment method for existing buildings. For an overview of the assessment, see figure 6.2, which encapsulates the entire assessment process within a flowchart. This chart should be followed when assessing an existing building.

**Is the method valid for the selected building typology/typologies within consequence class two?**
The building typologies within CC2 that are considered by the method are depicted in figure 4.1. The validation process is conducted in chapter 8, where two cases were used for validation. A multifunctional building, which includes parking, apartments and commercial activities and an apartment building where a part of the plinth consists of commercial activities. It shows the method is able to assess these existing buildings effectively and efficiently.

This demonstrates that the assessment process can be applied to multiple building typologies, although not all types within CC2 were considered in the validation. While the assessment cannot be validated with absolute certainty using these two cases and the given set up, it does demonstrate the applicability for the selected building typologies within CC2.

## 10.2 Main research question

The main research question addressed in this study is:

> In which way can consequence class two buildings be efficiently and effectively evaluated on structural safety to prevent incidents with structural failures?

It can be concluded that the assessment process developed in this study can be used to effectively evaluate the structural safety of CC2 buildings to prevent incidents with structural failures. While the need for extensive risk analyses does impact the time required for the assessment, these analyses have been optimised during evaluation and validation to focus on the most critical aspects. The assessment itself is also optimised by performing specific actions based on different analyses outcomes. Coupled with other efficiency-enhancing aspects, it presents an efficient method within the confines of effectiveness and trustworthiness criteria.

However, as revealed during validation, not all deficiencies can be detected using this method. There will always be hidden deficiencies that remain undetected. Assessors are made aware of this limitation within the developed method.

# 11 Recommendations

This chapter presents the final recommendations for further studies, thereby concluding this study on an assessment process for existing buildings in CC2. The initial four sections propose suggestions for further research. The final two sections offer advice to Nebest and building owners for the application of this method.

## 11.1 Structural failure incidents

This section outlines recommendations for sturdies to develop a more definitive list of common causes for structural failure incidents. The list presented in this study can only be seen as a first attempt.

- **Expand database of structural failure incidents**

The conclusions drawn in this study were tentative due to the limited number of structural failure incidents available in the database. Expanding the database would allow for a more accurate estimation of common causes and enable the study of patterns within these causes. One way to gather more data is to implement a mandatory reporting system for structural failure incidents, ensuring all specifics of an incident are recorded in a database.

- **Expand expert interviews**

In addition to expanding the available data, the accuracy of the list of common causes could also be improved by conducting more expert interviews. These experts, with their day-to-day insights into real life problems, can provide valuable information to further validate the list.

- **Regular updates**

The initial list developed in this study should be adapted via the aforementioned actions. In addition, the list should be updated periodically to ensure its relevance to the current and future building stock.

- **Consider indirect causes**

This study focused on direct technical causes of structural failure incidents. Future studies could also examine more indirect causes, as suggested in the study by Terwel.

## 11.2 Developed assessment process

In addition to structural failure incidents, further study is required to refine the developed assessment process for real life application.

- **Non-detected hazards (non-visual detectable)**

These hazards are considered in the outcomes of the object risk analysis. However, future study could be conducted to determine the appropriate follow-up actions to limit these outcomes.

- **Likelihood score**

During the validation process it was observed that determining the time interval, and consequently the score for the likelihood aspect of risk, posed a challenge. NEN 2767 offers a general degradation curve based on the condition score. Future research could investigate further support for this score, potentially through the development of a general degradation cure, for example.

- **Further detailing in assessment process**

The steps in the assessment process described in this document need to be further detailed to provide more guidance during assessment. Additionally, the components available in the sources, given in section 6.5, need to be adapted to fit the developed assessment process.

- **Frequency of periodic actions**

Currently, a more general advice is given by merging the available information from the VDI 6200 and NTA 8790. The advised frequency could be given more detail by examining degradation mechanisms and how common risks behave over time.

- **Efficiency**

During the validation process, it was observed that the developed assessment method is still quite extensive in terms of time commitment. However, the efficiency could be enhanced by further automating the assessment and risk analyses through programming. Within Nebest, the automation of risk analyses within tools has demonstrated potential. Future studies should investigate the automation of the assessment process.

## 11.3 Validation

Next to recommendations about the assessment process itself, there are also some considerations about the validation process for future studies.

- **Use more case for further validation**

To ensure the reliability of the method, more cases need to be used for validation. These causes should include different typologies, preferably those not used in this study’s validation. Additionally, it would be beneficial if the available assessments for validation came from different assessment methods. This would allow for a more comprehensive comparison of the developed method based on criteria such as trustworthiness, effectivity and efficiency.

- **Validate entire assessment method**

The parts of the assessment process validated via the two cases in this study are depicted in figure 8.1. However, not all aspects of the assessment have been validated in this document. Future studies should consider validating the entire process.

- **Appliance to CC3 buildings and other building types within CC2**

The developed assessment process could potentially be applied to non-selected building types within CC2 and CC3 buildings. This should be further investigated in future studies.

## 11.4 Comparison NTA 8790

At the time this study was undertaken, the final version of NTA 8790 was not yet available. As a result, no assessments have been conducted using this method. In this study the comparison with the draft NTA was limited to comparing its content to the developed assessment process for the criteria trustworthiness, effectivity and efficiency. For a more substantiated comparison between the methods, both the definitive version and the developed method should be applied to an existing case. Subsequently, the results of both assessments should be compared to obtain a well-founded overview.

## 11.5 Nebest

Before Nebest can implement the developed assessment process in practice, the following steps should be taken:

- **Finalise the development and validation of the method**

As discussed in section 11.2, certain aspects of the method still require refinement before it can be considered complete. Nebest should conduct further studies on these points to ensure the method's practical applicability. This also applies to the further validation of the method described in section 11.3.

- **Develop an automated tool**

As suggested in the efficiency recommendation, it is advisable to develop a tool that automates the assessment process as much as possible. This will not only make the method more efficient by reducing the time required, but also increases its trustworthiness by minimising user errors in the automated parts. For example, once the scores have been correctly determined, the risk of miscalculations is eliminated.

- **Ensure proper qualifications**

Nebest must make sure that its employees have the necessary qualifications, stated in section 6.4, to carry out the assessment method. In addition, the personnel who will use the method should receive adequate training and familiarise themselves with its procedures and workings.

## 11.6 Building owners

In addition to Nebest, building owners who wish to implement the assessment method for their assets should consider the following recommendations:

- **Adapt asset management process**

Building owners are recommended to adjust their asset managements to accommodate the results of the assessment method. This allows the results to be incorporated into the multi-year maintenance scheme and facilitates the implementation of recommended periodic actions.

- **Acquire appropriately qualified assessment party**

Buildings owners should also consider the qualifications outlined in section 6.4. Only parties that meet the criteria specified in this section should be considered for building assessment. In addition, the building owner should ensure the availability of employees with some affinity towards building management/technical service.

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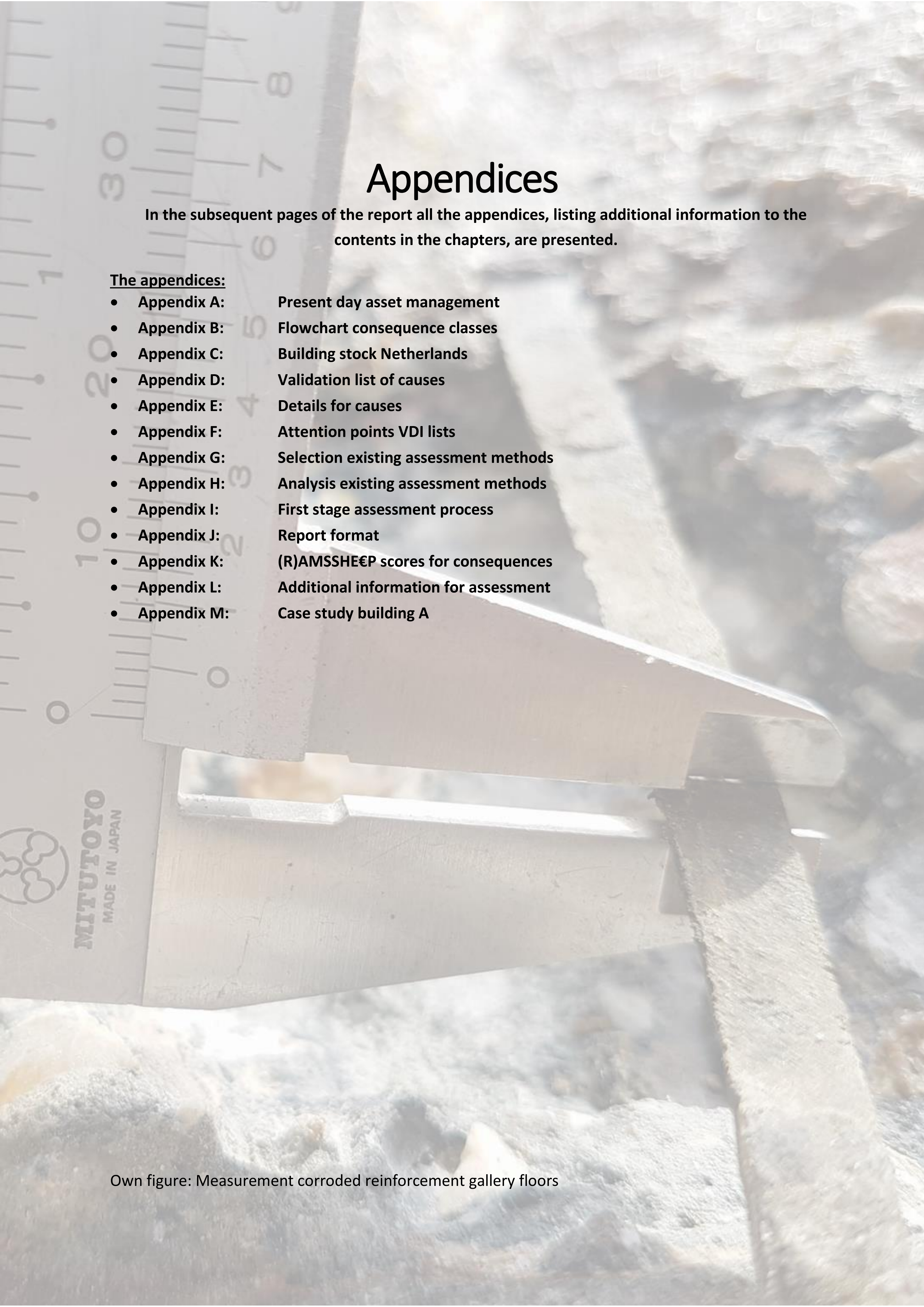
# Appendices

**In the subsequent pages of the report all the appendices, listing additional information to the contents in the chapters, are presented.**

**The appendices:**

- **Appendix A: Present day asset management**
- **Appendix B: Flowchart consequence classes**
- **Appendix C: Building stock Netherlands**
- **Appendix D: Validation list of causes**
- **Appendix E: Details for causes**
- **Appendix F: Attention points VDI lists**
- **Appendix G: Selection existing assessment methods**
- **Appendix H: Analysis existing assessment methods**
- **Appendix I: First stage assessment process**
- **Appendix J: Report format**
- **Appendix K: (R)AMSSHE€P scores for consequences**
- **Appendix L: Additional information for assessment**
- **Appendix M: Case study building A**



Own figure: Measurement corroded reinforcement gallery floors

# A. Present day asset management

To ascertain the current state of asset management (for buildings) and verify the findings of the Dutch Safety Board, interviews were conducted with asset managers. The outcomes of these interviews are detailed in the section below. To supplement these findings and gain a better overview, a survey was disseminated across the sector. The results of the survey are elaborated in section A.2. At last, the key takeaways from this investigation are summarised in the conclusion section.

## A.1 Results interviews asset managers

The interviews were mainly conducted within the field of asset management, to determine whether the implementation of the duty of care for structural safety was causing any problems. The respondents were also asked whether an assessment method for existing buildings would be a useful tool in implementing the duty of care. In five out of eight cases, the interviewee was employed by a housing association and was involved in some way with asset management. Housing associations primarily provide affordable living spaces for low-income citizens. While they may engage in commercial activities, these must be strictly separated from their social responsibilities (BZK, 2023). In the remaining cases, the respondents worked for an asset management company, a homeowner association management company and the asset management for the Dutch government.

As the majority of respondents worked at housing associations, the primary building typology considered was apartment buildings. However, other buildings such as care buildings, schools and other social or even non-social buildings were also managed by the interviewees. More information on building typologies can be found in chapter 3.

The first question posed to the respondents was whether they were familiar with the duty of care for buildings. Fortunately, all respondents indicated they were. However, the question remained whether the implementation of the duty of care is adequate and consistent among the respondents.

### A.1.1 Implementation duty of care

Of the respondents, the majority (five out of eight) reported that they assess the condition of the structure and the rest of the building using the NEN 2767 condition assessment standard. Some respondents also mentioned they consider signals from building users, as well as messages from the former Ministry of Housing, Spatial Planning and Climate Policy (VROM). This ministry has since been split between the Ministry of the Interior and Kingdom Relations (BZK), and other ministries.

One respondent reported that they had developed a safety group in addition to using the NEN 2767, while another was developing their own policy to better understand the condition of the structure and the associated risks. The respondent involved in asset management within the government reported using their own assessment method, the BOEI format, which is part of the sources considered at the start of chapter 5.

The remaining two respondents reported consulting specialists to assess the condition of their buildings or addressing known problems as they arise. Thus, while the majority of respondents use the NEN 2767 standard, additional measures are often taken. The implementations of these additional measures, in combination with the fact not all respondents use the NEN 2767 standard, indicates that there is no consistent approach to implementing the duty of care among the asset managers questioned.

Four of the interviewees expressed criticism of the NEN 2767, stating among other things that it did not adequately cover the risks as the problems had to be severe to be noted in the assessment. One respondent even stated that the standard had little to do with safety, as acute problems were not even signalled. Of these four individuals, three indicated that they used the NEN 2767 standard as part of their duty of care implementation. This means that three out of five respondents, who used the NEN 2767, were not satisfied with the results it provided. Chapter 5 discusses the limitations of the NEN 2767 for assessing the structural safety of existing buildings.

In addition to concerns about the NEN 2767, two respondents mentioned that the necessary knowledge for conducting assessments was sometimes lacking. Two respondents who did not use the NEN 2767 standard, but instead relied on the BOEI format or consulted specialists, mentioned the absence of a standard protocol. While there are many rules and standards, they are not always easy to find. The government employee stated that there was a need for an active rather than reactive standard protocol. These comments align with previous conclusions that there is currently no consistent approach to implementing the duty of care among asset managers. Finally, two respondents reported that their organisations were in the process of establishing a safety group or developing their own protocol to gain a better overview. In conclusion, most respondents did not consider the current situation, for identifying and addressing risks, to be sufficient.

When asked whether they had a sufficient overview of the condition of the structure of their buildings, the responses were more positive. Six out of eight respondents reported having sufficient understanding of their assets. Another respondent stated that their understanding of the exterior of the building was sufficient, but the difficulties arose within the dwellings. The final respondent gave a clear ‘no’ and stated that problems often emerged during renovations, and that it would be better if they were identified earlier so that more appropriate action could be taken.

Among the six respondents who reported having a sufficient understanding of their assets, several points were raised. One respondent had a few buildings that had already been inspected by Nebest as a part of a pilot program for risk-based inspection. Another respondent stated that their sufficient understanding was due to their experience and the repetition of managing similar buildings. These factors, combined with the inconsistent implementation of the duty of care, suggest that a combination of approaches is currently required to achieve a sufficient understanding of the structural condition of buildings. It should also be noted that respondents were asked about the assets they manage, this may have introduced some bias.

Chapter 4 discusses common structural failure incidents in the Netherlands (during the use phase) and concludes that most of these causes could result in structural damage or even (partial) collapse of (a part of) the structure. These causes could lead to potentially dangerous situations. Further information about this study and an explanation on the scale for severity of incidents can be found in chapter 4. However, there is still the potential for hazardous situations to arise in existing buildings. This finding is consistent with the conclusion that the current implementation of the duty of care is insufficient and contradicts the notion that there is a sufficient overview of the structural condition of buildings.

The NTA8790 could provide a framework for the assessment of existing buildings. Although the focus of the NTA is on CC3 buildings, it could be applied to all building types. However, there are significant public buildings within CC3 for which the use of the NTA is mandatory. None of the housing association employees questioned had CC3 buildings in their building stock. This means the focus of the NTA is not on the building group addressed in this investigation. In addition, the NTA only considers the consequences of structural failure in terms of the number of people at risk and does not consider other important factors such as economic or social consequences that may be relevant to asset managers.

The majority of the individuals (five out of eight) were not aware of the NTA 8790. One respondent only had heard about it through Nebest, while another was involved in its development as part of commission. This individual also had a more structural background and was responsible for addressing structural problems within governmental buildings. In conclusion, most respondents were not even aware of the development of the NTA 8790. More information about this NTA including an analysis of the method is given in section 1.6 and chapter 5.

### A.1.2 Opinion development new assessment process

In addition to questions about the current situation, respondents were also asked about the development of a new efficient and effective method specific to CC2 buildings and its potential implementation in practice. The terms for efficient and effective are defined in section 1.3. Six out of eight respondents believed that such a method could be of added value. The seventh respondent stated that it must be an umbrella term, as another new method would not provide any additional clarity. The last respondent stated that despite the introduction of another method, the problem of inspecting inside the dwellings would remain unsolved.

Those who believed that the method could be useful, mainly addressed its potential to identify risks while initially implementing non-invasive, less costly measures. They also noted its potential to aid in the durability process until 2025, as many buildings are approaching the end of their indicative design life, which is 50 years (NEN, 2019c). The method could assist in the question if buildings should be renovated or demolished. If there is chosen for renovation, the respondent stated that in such cases the durability must be increased, which would result in additional loading on the building. Chapter 3 discusses the age of the building stock in the Netherlands.

Overall, respondents identified several important points that are currently lacking and that could be solved by implementing a new method. When asked if such a method would truly be of added value in practice, most respondents agreed that it would be, as it concerns safety and is the duty of the owner. However, they also raised concerns about the costs of implementing such a method and its practicability. Some respondents suggested that it could complement NEN 2767. In conclusion, respondents generally believed that such a method could contribute to asset management and improve building safety.

## A.2 Results survey

A survey was conducted to support the findings of the interviews, with the same questions being asked. In total 20 individuals responded to the survey. The respondents had diverse occupations, with three working in asset management and two belonging to owner associations. However, one of the individuals in asset management worked in infrastructure, which is not applicable to this study. Additionally, one of the owner associations focussed solely on single-family houses, which are mostly classified as CC1 (as described in chapter 3) and was therefore not considered. The remaining respondents included nine experts, two advisors, one contractor, one project developer and one individual with the authority to make changes to buildings. One individual who mentioned to be a structural designer is also considered as an expert. Thus, 18 respondents had the qualifications to be relevant of the investigation, but there were little asset managers among them.

### A.2.1 implementation duty of care via survey

All respondents were familiar with the duty of care. However, one expert and one advisor did not provide any implementations. Another expert was only consulted when damages were already present, which could be considered a form of implementation of the duty of care. The remaining respondents provided various implementations, sometimes in an advisory capacity.

The survey revealed a wide range of ways in which the duty of care was implemented. One respondent stated that they provided advice on structural safety, but this was considered too abstract to be included as a result in this section. Out of the thirteen valid responses, the least form of implantation was a visual inspection (in two cases) or a condition assessment via NEN 2767 (in one case). It is worth noting that the NEN standard was applied by an asset manager, while the visual inspections were performed by an individual with the authority to make changes to buildings and a developer. In one case, the contractor stated that they performed their own visual inspection and consulted an expert if they were in any doubt. Three respondents (an asset manager, a member of an owner association and an expert) stated that specific inspections were performed. One advisor and one expert even mentioned a full reassessment as their implementation. One expert implemented a multiple of the aspects given above. Two individuals stated that they did not implement the duty of care earlier but used the NEN 2767 and specific inspections.

What does become clear, as in the interviews, there is a wide variety in the implementation of the duty of care. However, the results are less valuable due to the significant spread in professions representing different roles within the building sector. In contrast, the interviews were more uniform and targeted to the focus group of asset managers. The NEN 2767 standard was only mentioned twice in the survey, which could be attributed to the limited number of asset managers among the respondents.

When asked if risks relating to the structural safety of buildings were sufficiently considered in the current situation, the responses were mixed. Eight out of 18 respondents stated ''no'', five stated ''yes'', and the remaining five either did not know or said it depended on the building. While there were more ''no'' responses, it was not a clear majority, indicating that there is no clear consensus among the survey respondents on whether the risks relating to structural safety are sufficiently considered. However, when asked if there was a sufficient understanding of the true state of buildings, a majority of the respondents (13 out of 18) stated that this was not the case. Only three respondents said ''yes'', while two did not know. That suggests that, according to the survey respondents, there is not a sufficient understanding of the current condition of buildings.

### A.2.2 Opinion design method

In the second part of the survey, respondents were asked for their opinions on the design of an efficient and effective method to provide a better understanding of the true state of CC2 buildings. A clear majority (13 out of 18) responded with a ''yes''. Four respondents said ''no'', while one requested a clear explanation of important structural points for special or deviating structures. Thus, most respondents were positive about the idea of a new method to improve understanding of the building, supporting the claim made in interviews.

When asked if the proposed method would be of added value and truly used in practice, the responses were more varied, as was also observed in the interviews. Four respondents gave a clear ''yes'' answer. However, others provided more nuanced responses, mentioning factors such as ease of use, affordability, sufficient education and coercive measures. One respondent stated that a change in behaviour would be required before the method could be implemented and that more incidents might need to occur before it would be widely adopted. Another respondent confirmed this by stating that a considerable number of owners would not consider the method, while another said that only significant organisations or associations would implement it. Two respondents stated it was difficult to estimate beforehand if the method would be used, while three others gave a clear ''no'' answer. Thus, it is not possible to give a clear ''yes'' or ''no'' answer to whether the respondents of the survey think the method will be truly used in practice. This has some similarity to the concerns raised by the interviewees. Most of the interviewees gave a yes but also foresaw some challenges.

Finally, the survey also assessed how many respondents were aware of the development of NTA 8790. As expected, a higher number of respondents (10 out of 18) were familiar with it compared to the interviews. This is likely due to the considerable number of experts and advisors among the respondents, who were the only ones to answer ''yes'' to this question.

## A.3 Conclusion

In conclusion, all respondents of the interviews and survey were aware of the duty of care, but there was a variety of activities implemented to fulfil this duty. The most commonly used was the NEN 2767 standard, often in combination with other activities, as most respondents found it insufficient for assessing the current structural condition of buildings. In the survey there was even more variety in the implementation, but this has likely to do with the large spread in professions among the respondents of this survey.

The majority of the respondents viewed the current situation as inadequate. However, there was a contradiction in the interviews, where most respondents believed that they had obtained a sufficient understanding of the condition of the buildings they managed. This was mainly due to their individual activities and experience. This was not the case in the survey, were most respondents felt that there was not a sufficient understanding of the current condition of structures. This could be due to the potential bias of the interviewees as the respondents are asked about the state of the assets they manage. This contradiction could also be due to difference in professions between the interviewees and the respondents of the survey. In the survey the dominant group is experts over the asset managers in the interviews. Furthermore, a study on common structural failure incidents in the Netherlands (discussed in a later chapter of this thesis) revealed that structural damages or even partial collapses do occur, leading to potentially dangerous situations. This indicates that the current situation is seen as not sufficient.

When asked about the development of a method as implementation of the duty of care, respondents from both the interviews and the survey were positive about this development and saw its potential. However, concerns were raised about the costs of this method and its ease and practicality of use. These concerns were also reflected in the survey, where it was debated whether this new method would be used in practice. This suggested that the method must be efficient and effective (later the definitions for these aspects are given) to be widely adapted and presented a challenge to overcome during its development. If this method could meet the demands of the respondents, it could help ensure more uniform implementation of the duty of care and prevent dangerous situations from arising, while ensuring that the building continues to meet the standards even when subject to changes.

# B. Flowchart consequence classes

Figure B.1 presents a flowchart for determining the appropriate consequence class for a building. The flowchart deviates from the national annex of NEN-EN 1990 for industrial and retail building types. For retail buildings, there is a 2000 m$^2$ per storey limit for CC2b, which serves as a useful criterion for distinguishing between CC2b and CC3. This criterion is not specified in the national annex. For industrial buildings, the flowchart indicates that CC3 is assumed for buildings with more than three storeys. However, the national annex of NEN-EN 1990 specifies that industrial buildings with three or more storeys fall under CC2. The standard is followed in this study. Overall, aside from these deviations, the flowchart provides a clear overview of the boundaries between the consequence classes.

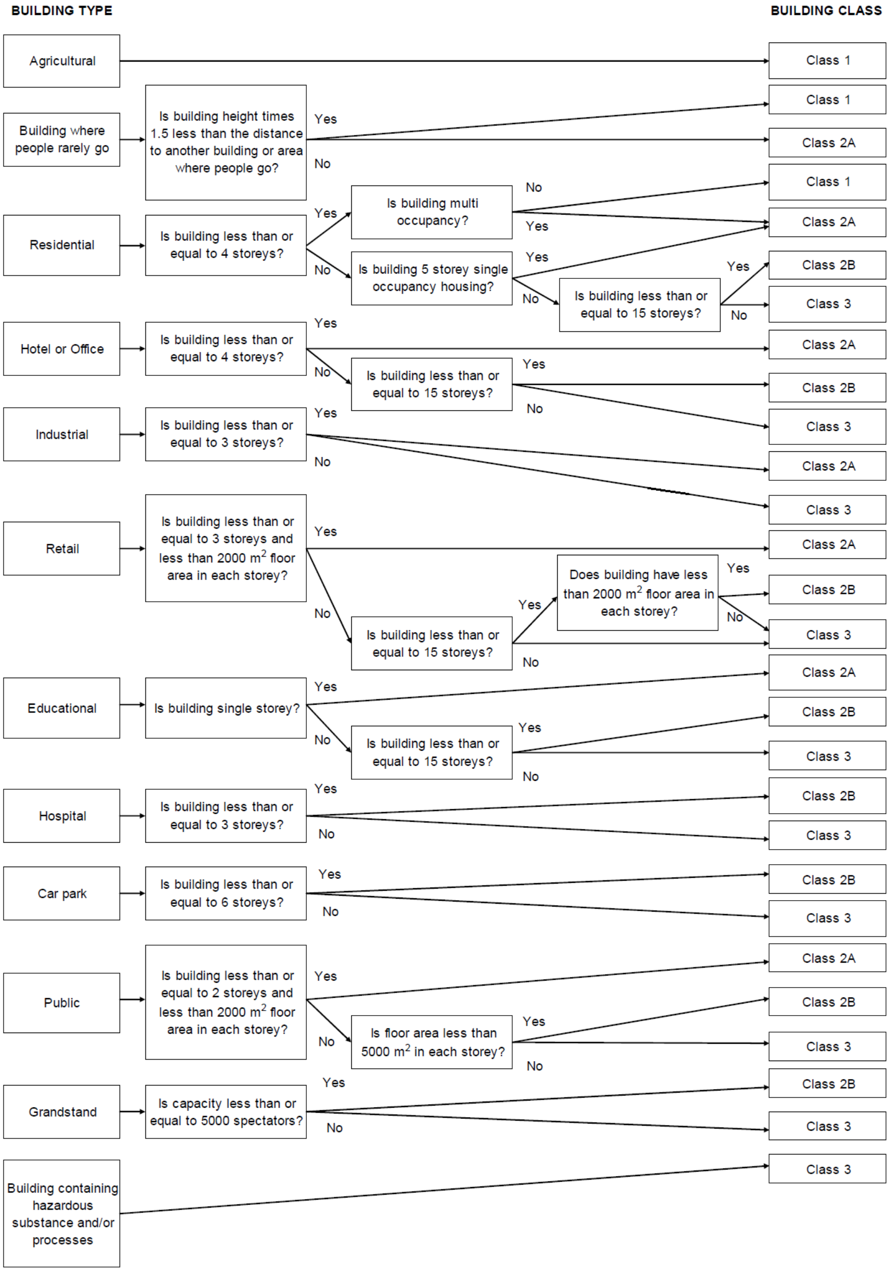


Figure B.1: Flowchart consequence classes (Steelconstruction.info, n.d.)

# C. Building stock Netherlands

This appendix provides supplementary information on the building stock in the Netherlands, complementing chapter 3. Similar to chapter 3, this appendix is divided into sections on the non-residential and the residential building stock. In addition to the more detailed information on the categorisation of the building stock, the years of construction for the predefined building types are also included.

## C.1 Non-residential building stock

In this section, the figures for the non-residential building stock, provided by the CBS, are presented in table c.2. This table shows a different categorisation of buildings compared to the building types used in this document. It is therefore necessary to convert these figures to match the building types used in this document. In table c.1, these building types are assigned a colour, which is used to match the figures from the CBS study. The amount of floor area per building type is provided in table 3.3.

Table C.2: Non-residential building stock per 1-1-2021 (CBS, 2022a)

| Building type | Amount [x1000 m$^2$] |
|---|---|
| Office | 62,663 |
| Retail without cooling | 44,087 |
| Supermarket | 4,199 |
| Café, restaurant | 7,584 |
| Congregation | 19,968 |
| Day care | 2,158 |
| Hotel | 7,833 |
| Lodging, other | 5,732 |
| Education, primary | 12,182 |
| Education, secondary | 10,850 |
| Education, vocational | 1,410 |
| Education, higher | 2,085 |
| Education, other/unknown | 7,532 |
| Practices | 7,695 |
| Laboratory | 583 |
| Hospital | 6,007 |
| Nursing home | 12,105 |
| Penitentiary institution | 860 |
| Sport, inside | 10,307 |
| Sport, outside | 5,519 |
| Swimming pool/wellness | 2,617 |
| Car dealership | 20,905 |
| industrial hall | 240,450 |
| Agriculture | 32,603 |
| Data centre | 1,040 |
| **Total** | **528,974** |

Table C.1: Building categories thesis

| Building type |
|---|
| Office buildings |
| Retail buildings |
| Educational buildings |
| Care buildings |
| Other buildings |
| Commercial buildings |

One building type that presented a challenge for classification was the car dealership. Although the function of the building is more similar to that of a retail building, its characteristics are more align with those of a commercial building. Therefore, car dealerships have been classified as commercial buildings.

As mentioned in chapter 3, the EIB study provides an overview of the years of construction by building type. Figure C.1 depicts the building stock plotted by year of construction, showing that the majority of buildings were constructed after 1965. The office stock was primarily built after 1985 (EIB, 2015). The social sectors follow a similar trend of development after 1965, with care and educational buildings mainly developed around the 1970s and after 2000 (EIB, 2015). In the early 1980s, the Operating Reduction Initiative (EVI) was introduced for the health sector to increase construction output while reducing healthcare costs (EIB, 2012). However, interviews conducted by the EIB revealed that buildings constructed during this initiative were of low quality (EIB, 2012), resulting in a sharp decline in hospital construction in the early 1980s (EIB, 2015).

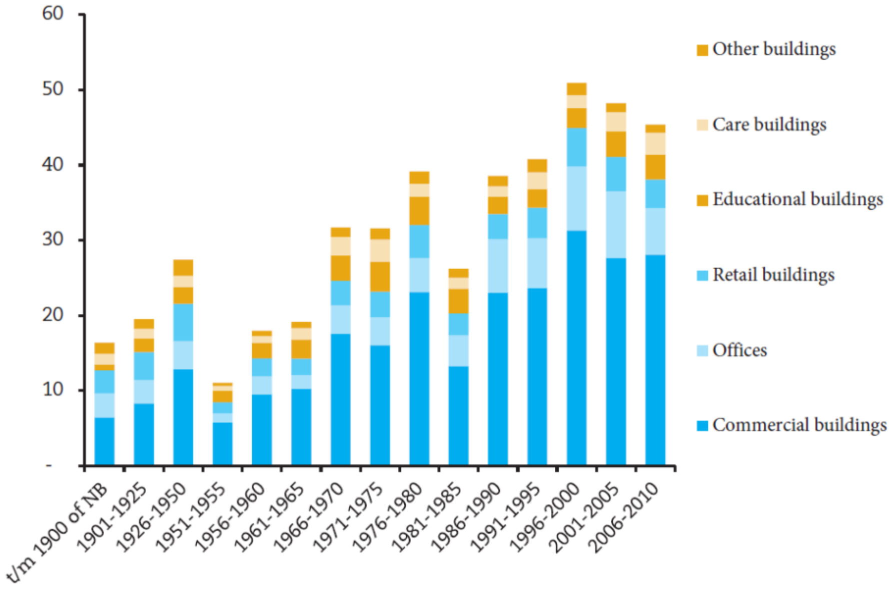


Figure C.1: Non-residential buildings per year of construction (EIB, 2015)

## C.2 Residential building stock

Single-family houses can be further classified into several subcategories. The inventory for these subcategories is presented in table c.3. According to the table, the majority of single-family houses in the Netherlands are categorised as terraced houses.

Table C.3: Categorised single-family houses (CBS, 2023)

| Single-family houses | Stock | % total |
|---|---|---|
| Detached house | 1,042,650 | 20.3 |
| Semi-detached house | 704,055 | 13.7 |
| Terraced house (corner) | 1,018,885 | 19.9 |
| Terraced house | 2,361,261 | 46.0 |
| Other | 2,836 | 0.1 |

Figure C.2 plots the housing stock against different construction periods. The graph shows four categories of dwellings: terraced, semi-detached and detached houses within the single-family housing category and apartments. The graph indicates that the majority of houses were constructed between 1965 and 1985. This is due to the housing shortage that affected the Netherlands after World War ll. From the 1950s to the 1970s, this shortage led to a focus on fast and inexpensive construction (EIB, 2015). The graph shows that during this period, more single-family houses were built than apartments. It is also noteworthy that 19% of the housing stock consists of pre-war dwellings (CBS, 2022b).

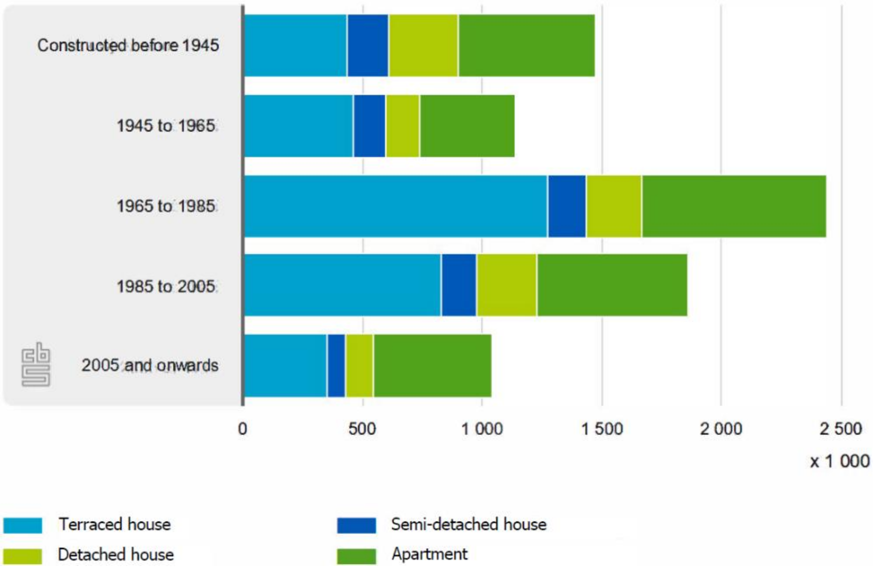


Figure C.2: Number of dwellings by type and construction period (CBS, 2022b)

# D. Validation list of causes

As stated in chapter 4, this appendix first presents a hypothetical list of frequently occurring causes for structural failure incidents. These hypothetical causes are validated via interviews and a review of relevant literature. As a preliminary step in this validation, the frequency in which these causes appear in the database is documented. It should be noted that if new incidents are uncovered during this validation process, they are appended to the list in the final section if deemed appropriate. This validation procedure leads to the final validated list of causes, as presented in section 4.1.

## D.1 Hypothetical list of causes

The hypothetical list of common causes for structural failure incidents in the Netherlands is presented below. This list has been compiled through a thorough examination of the articles contained in the Cobouw database, as discussed in section 1.6. It is important to remark that these are solely the direct technical causes for the failure incidents, the indirect causes for failure incidents are not considered in this study. To provide further clarity on the causes, some examples are provided. However, these examples are not exclusive, other phenomena within each cause may also occur.

Table D.1:Hypothetical list of causes with accompanying examples

| No. | Cause | Example |
|---|---|---|
| 1 | Realised object deviates from design | Construction elements found to be missing/applied with properties deviating from design |
| 2 | Reinforcement in concrete experiences (pitting) corrosion due to presence of chlorides, dampness and oxygen. Common sources of chlorides in concrete structures include the use of de-icing salts, swimming pools and the inclusion of calcium chlorides in the concrete mixture to improve the curing process | Gallery floors are, for instance, vulnerable to the effects of de-icing salts. In the case of the calcium chloride inclusions, examples of affected structures include consoles and 'Kwaaitaal' floors |
| 3 | Incorrect wind load calculation | Façade panels blown away due to inadequate calculation of the applied wind load |
| 4 | Deterioration timber pile foundation | Degradation due to bacteria, moulds or other mechanisms |
| 5 | Problems relating to floors which are prestressed without bond | The prestress cables in the floors of houses in Heerhugowaard were corroded due to ingress of moisture during construction |
| 6 | Seams plank floors incapable of transferring a positive bending moment | Plank floors, such as those in the parking garage in Eindhoven, were designed to transfer positive bending moments across the seams |
| 7 | Higher permanent load on/lower position of the upper reinforcement in (external) cantilevering floors | These issues have been observed in relation to gallery and balcony floors |
| 8 | Corrosion of steel structure supporting balconies | Consoles corroding near the (masonry) façade |

| | | |
|---|---|---|
| 9 | Too little/corrosion/insufficient anchorage of balconies | The anchors intended for the connection did not attach properly |
| 10 | Corrosion of (stainless) steel in swimming pools | Corrosion in the suspension of the ceiling |
| 11 | Roofs overloading due to water accumulation | This could, for instance, be attributed to the lack of insufficient emergency drainages or the slope of the roof |
| 12 | Incorrect snow load calculation/Roofs overloading due to snow accumulation | Roof collapses under the weight of the accumulated snow |
| 13 | Too little/incorrect application/corrosion of wall ties in façade | Corrosion of wall ties of the façade |
| 14 | Façade panels letting go | Façade Panels of the 'Achmeatoren' letting go |
| 15 | Glass fracture in façade/roof panels due to nickel sulphide inclusions/bad quality/thermal stress/sealant | The presence of nickel sulphide inclusions in the glass panel causes the glass to shatter |
| 16 | Filled/ too small/ missing horizontal and vertical dilatations | The filling of dilatations resulted in deformations and formation of cracks |
| 17 | Corrosion of the connectors of prefab elements | Corrosion of the reinforcement connecting the spandrel to the rest of the structure |
| 18 | Settlement of the foundation | Uneven settlement of peat subsoil |

This list was compiled after a thorough review of the articles, thus forming a hypothesis. The validation of this hypothesis is achieved by assessing the frequency of the causes mentioned in the database, expert interviews and literature. This validation process is documented in the subsequent sections. It should be noted that new causes may emerge during this validation. In the final section there is determined what the definitive list of common causes is for this study.

## D.2 Validation with incident database

As aforementioned, this hypothetical list of causes has been compiled by examining the articles in the incident database to identify recurring or pertinent causes in the Netherlands. However, no assessment has been made of the frequency of these causes within the Cobouw database itself. This task is complicated by the fact that not all incidents outlined in the fault tree by Develi, as described in section 1.6, are relevant or applicable to this study.

Given that the database information does not align with the study requirements, the fault tree has been filtered to retain only pertinent causes. Furthermore, some data in the fault tree has been adjusted based on personal insights after determining that the article did not correspond with the description given by Develi. Criteria for determining the relevance of an incidents to this study are outlined below. The validation is then carried out using only those incidents deemed relevant. However, to ensure comprehensiveness, incidents deemed non-relevant are also reviewed to avoid overlooking any potentially useful information.

### D.2.1 Relevance incidents

The incidents are deemed irrelevant to this study if they meet any of the following criteria:

- The damage was identified at the moment the incident occurred. These incidents cannot be prevented through inspection or reassessment. For instance, damage to a building caused by groundwork is immediately apparent during the groundwork process.
- The Incident occurred or was identified during construction work. As the method of this study is specific for the use phase, such incidents are not applicable. However, it should be noted that incidents detected during an inspection following another incident, or in preparation for renovation, are considered relevant.
- The incident is specific to an object that falls outside the scope of this study. For example, if bridges are damaged due to higher traffic loads than those stipulated in old codes, such incidents are not applicable to this study.
- There is insufficient information available about the incident, or the true case is not provided.
- The incident is a special case. The developed method does not apply to special cases such as moveable ceilings in swimming pools, unique roof constructions for speed skating rings or sinkable caissons for sea locks.

If none of these factors apply, the incident is considered relevant and is used in the validation of the hypothetical list of causes. It should be repeated that the description of the fault tree by Develi is sometimes modified based on insights gained from studying the specific articles.

### D.2.2 Causes in database

The adapted fault tree comprises a total of 391 technical causes related to incidents concerning structural safety. Out of these 391 causes, 228 are deemed relevant to this study. An examination was conducted to determine how many of the hypothetical causes are included within these 228 causes. It should be noted, that for a single incident, multiple causes may be listed. All these causes are taken into account in the study. There may be instances where some incidents are not included in the table below, despite suspicions that they may be linked to common causes. In such cases, there was insufficient information to confirm this.

Table D.2: Times hypothetical causes mentioned in database

| Cause | Number in source | Cause | number in source |
|---|---|---|---|
| 1 | 18 | 10 | 13 |
| 2 | 8 | 11 | 16 |
| 3 | 4 | 12 | 6 |
| 4 | 5 | 13 | 16 |
| 5 | 1 | 14 | 14 |
| 6 | 1 | 15 | 8 |
| 7 | 5 | 16 | 10 |
| 8 | 2 | 17 | 3 |
| 9 | 5 | 18 | 9 |

After this examination of the frequency of the causes in the database, it was found that causes number five and six are each mentioned only once in the revised fault tree. In addition, cause number eight is only mentioned twice. However, this cause encompasses a lot of balconies constructed with a steel support structure in the cities of Rotterdam and Utrecht. The other two cases, despite their infrequent mentions, are seen as important. Cause number six pertains to plank floor incidents, which require a mandatory investigation and for cause number five a VROM notation is available. These arguments, however, are more suited for the literature validation discussed in section D.5. consequently, no pattern for these causes can be identified in the database.

Several other causes are infrequently mentioned, with four or five notations found in the database. Despite this, they exhibit a more frequent pattern than the causes listed above. Given the relatively small selection in the database, these causes are regarded as validated in this study. The reaming causes are considered to be recurring as they are mentioned multiple times throughout the database.

In total, approximately 144 of the 228 relevant causes are covered by the aforementioned list of hypotheses, accounting for about 63% of the relevant causes. Causes five, six, eight and seventeen are not deemed validated through the database as their frequency in the database is less than three times.

### D.2.3 Other points relevant causes database

In addition to verifying how many of the hypothetical causes are listed in the database, an investigation was conducted to identify other causes that are frequently mentioned in the database. This applies to causes deemed relevant as explained in subsection D.2.1. Only cases mentioned more than twice are considered in this section. The causes that were identified during this investigation are listed in the table below.

Table D.3: Other relevant causes from database

| Cause | Number in source |
|---|---|
| Not enough reinforcement in element | 5 |
| Concrete degradation in general, could also be due to bad maintenance | 9 |
| Problems relating to renovation | 3 |
| Timber degradation in general, for instance due to moisture penetration or due to bad maintenance | 6 |
| Too little mortar fixation for bricks | 3 |
| Problems relating to glue, not façade panels letting go | 4 |
| Problems relating to connections | 10 |
| Too low load resistance of floors | 4 |

It can be observed that several more general causes are mentioned in the table, such as degradation of concrete and timber and issues with connections. In the cases of concrete and timber degradation, lacking maintenance is mentioned. These general causes must be considered in the desk study and visual inspection but are not listed as additional focus points. If issues relating to lacking maintenance or problems relating to glue emerge in the other validation processes, they can be included in the attention points.

It should be noted that for problems relating to glue, incidents involving façade panels detaching are not considered as this is covered by hypothetical cause number 14. There is also a cause for the use of wrong-quality glue in glass façade panels leading to fractures, which is more aligned with cause number 15. In another case, a ceiling panel fell instead of a façade panel. There was also an instance of a stone strip falling from a façade due to a glued connection. If this can be considered as a façade panel, this case is also more applicable to cause number 14, suggesting that problems relating to glue are not a new common cause given the significant variance in problems demonstrated by these described cases.

Furthermore, there is the cause that not enough reinforcement was applied in elements and the load resistance of floors was too low. The former is mentioned five times and the latter four times in the database. Therse could be considered as attention points. There are also two causes with a frequency of three: incompetent renovation and insufficient mortar fixation of bricks. As these causes only recur three times, they are not worth mentioning in this validation part. However, as previously stated, if these causes emerge during the other validation aspects, they can be considered in the final list of common causes. The same applies for the lack of sufficient reinforcement and the load resistance of floors as new causes must be supported by another validation technique to be recorded in the final list.

### D.2.4 Other points from non-relevant causes database

In the precedent sections, causes deemed non-relevant were not considered for reasons previously stated. To ensure no significant points in the database were overlooked, this subsection explores these non-relevant causes. As there are reasons these causes are not considered, they will only be used in the attention points if valid argumentation is provided.

The first point that came forward during this exploration is that within these non-relevant causes, more causes relating to the hypothetical list are given. More mentions are made for causes:

- Roofs collapsing due to snow load.
- Glass panels bursting.
- Differences between design and completed object.
- Façade panels letting go.
- Incorrect wind load calculations.
- Settlement, among others due to nearby groundwork or construction.
- Problems relating to dilatations.
- Balconies.
- Wind calculation.

There are also more causes available for the relevant causes mentioned in subsection D.2.3. Among these causes, there are buildings within CC1 and stadiums. The following causes are mentioned:

- Renovation
- Degradation concrete
- Degradation timber connection
- Connections

- Floor elements in torsion
- Bricks came loose

Finally, there are some recurring points that are not mentioned in the list of hypothetical causes and in subsection D.2.3. From three of the causes reporting the same problem onward, the causes are discussed. If it becomes clear beforehand that the cause is really not applicable to buildings in the use phase or out of scope, the cause is still not taken into account. Examples include fire safety and sinkable caissons for sea locks.

The first causes that comes to attention is the structure being hit by an object. In two cases a boat crashed into a restaurant. As this case can be seen as rather unique with not a lot of buildings located on the water, it is justified that these causes are seen as not relevant. Then there are two causes where a column is hit by a vehicle. As one is a viaduct over a highway and the other a canopy of a tank station, both buildings not considered in this study and more exposed to traffic, these causes are also seen as not relevant. There is also a deliberate cause as a building was hit by an object for burglary reasons, this is also not taken into account. At last, there is a single-family house that was hit by a falling tree. This would be difficult to inspect as it involves more of the surroundings. In addition, such a cause is only mentioned once in the database. The hit by an object cause is thus not considered in the final list for common causes.

Problems relating to pile driving also recur six times in the database. However, five causes occurred during construction work and one had too little information. As none occurred during the use phase, this aspect is not considered in the list of common causes for structural failure incidents.

This is followed by causes related to soil mechanics, where three causes have been reported. One of these causes is related to an old mineshaft that was overlooked during the design phase. Another cause arose due to an inadequate soil test, and yet another was attributed to a miscalculation of the horizontal soil mechanics. This demonstrates that within the cause soil mechanics, each of the three causes has a different cause for the structural failure. Consequently, this aspect is not taken into account.

At last, structural failure incidents caused by whirlwinds or strung gusts are considered. A total of four of such causes were identified, each indicating that a part or the whole of the structure collapsed due to one of these phenomena. All these causes were deemed irrelevant as it was concluded that either insufficient information was available or the true cause was not provided. The collapse due to whirlwinds or strong gusts suggests that the resistance of the structure to these loads was inadequate. However, no technical cause for this lack of resistance has been identified. Could it be due to a miscalculation of the wind forces? The answer remains unknown. Therefore, this phenomenon is not included in the list of common causes.

In conclusion, after examining all the cases marked as non-relevant, it is determined that none of these causes are considered in the list for common causes for structural failure incidents.

## D.3 Validation via interviews with experts

As aforementioned this database is based on a collection of articles published over several years in a professional journal. To ensure that the identified common causes accurately reflect the real-world causes of structural failure incidents, interviews with experts in the building sector have been conducted. It is important to note that not all experts have experience with all types of buildings. For instance, the experience of one expert is primarily with stations. However, most of the interviewed experts have experience with a broad spectrum of building types. In total, nine interviews were conducted.

First, the hypothetical list of causes is discussed, followed by additional points of consideration that emerged from these interviews. At last, other important information gathered from these interviews is presented.

### D.3.1 Validation hypothetical list of causes

In this validation process, there is evaluated whether the experts think a particular factor is a common cause for structural failure incidents or not. Following this assessment, important information related to this cause is concisely described. Table D.4, indicates how many experts consider each hypothetical cause a common cause of structural failure incidents.

Table D.4: Opinion on common causes by experts

| Cause | Number in source | Cause | Number in source |
|---|---|---|---|
| 1 | 9 | 10 | 6 |
| 2 | 5 | 11 | 7 |
| 3 | 7 | 12 | 5 |
| 4 | 8 | 13 | 7 |
| 5 | 5 | 14 | 8 |
| 6 | 6 | 15 | 7 |
| 7 | 7 | 16 | 8 |
| 8 | 5 | 17 | 4 |
| 9 | 5 | 18 | 8 |

As observed in the table, all experts unanimously agree that cause one is a common cause for structural failure incidents. Moreover, for nearly all the hypothetical causes listed, a majority of experts believe it is valid to include them as common causes. The only exception is hypothetical cause 17, which pertains to the corrosion of connectors of prefab elements. This could be attributed to the fact that an expert from Nebest recently published an article outlining the risks associated with this cause. The article is described in subsection D.5.2. However, this particular cause cannot be seen as validated through interviews with experts.

There are several causes on which five experts agree to be common causes. At first cause two only pertained to concrete damage due to calcium chloride being added to the admixture. The adaptation of the cause, to considering all chloride damage of concrete, was revised following the interviews. So, in the interviews it solely covers damage resulting from the admixture with calcium chlorides. One expert encountered this issue primarily within Kwaaitaalfloors and asserts that this type of flooring is predominantly used in CC1 buildings, except of the auxiliary structures within CC2.

The experts who agree with this cause state that it is not exclusive to this type of structures, but affects all prefab elements constructed during a specific time period. This time period will be discussed later in this section. Therefore, this cause is seen as validated by the interviews.

The fifth cause mentioned, describing the issue of floors prestressed without bond, is also validated by five experts. Some experts have noted that despite multiple inspections, no damage was found. However, others counter this by asserting that these floors do present problems and lack any robustness.

Regarding causes eight and nine, it should be noted that two experts lack experience with apartment buildings, thereby reducing the number of eligible experts to seven. Given this limitation, the validation provided by five expert is a strong endorsement. These causes are thus seen as validated.

At last, cause twelve, which discusses the overloading of roofs due to snow, is also validated by five experts. Those who consider it an important factor cite issues such as snow accumulation against an object or higher building parts and problems arising when the snow thaws. These arguments in combination with the fact that a majority of experts validates this cause, justifies further consideration of this cause in the analysis.

While causes six and ten are well recognised by all experts, only six experts identify them as common causes. In case of cause six, some experts state that no problems were detected during mandatory inspections. However, most experts still rank it as a common cause, with some nothing that strengthening measures had to be implemented.

As for cause ten, all experts agreed that it is common, but some argue the issue is currently well managed due to mandatory inspections of stainless steel used in ceiling suspensions of swimming pools. However, other structural components within swimming pools could still pose a risk, as noted by the experts who did identify this problem as a common cause.

In conclusion, all causes with the exception of cause seventeen, have been validated through these interviews. Cause seventeen is discussed in the subsequent section in the validation by literature, where it may be validated. However, as only a minority of experts agree that it is a common cause, it cannot be considered validated based on the interviews alone.

During the interviews, additional information relating to these causes was also gathered. This information has been summarised in brief points in figure d.1 and figure d.2, as it can be used to gather more details on the validated list of causes.

**1**

- Difficult to inspect
- Ask question if execution same as design after desk study
- Problems when transfer project within parties
- Insufficient reinforcement in, for instance, parking garages
- Question is extent problem and if mulitple objects are missing

**2**

- Not only kwaaitaal, which more CC1
- All prefab concrete within 1962 and 1980 can have this problem, in some rare cases in situ too
- Consoles
- Also chlroide damage swimming pools
- Sometimes even material from sea used in mixture concrete
- Needs to be enough oxygen and moisture to occur

**3**

- Due to change in surrounding, currently in standards more rules
- Incorrect calculation
- Sometimes other cases copied, but surroundings important
- Higher wind suction on corners facade and roof. Newer standards take this into account but olders not

**4**

- Could also be in good condition when use of tar
- Lot in Amsterdam/Zaanstreek
- Not due to bacteria but due to decrease groundwater level and oxygen
- Also molds
- Detect via cracks and then something can still be done

**5**

- VZA floors not robust, if drill in floor it breaks
- For buildings with significant span like shopping malls and parking garages
- Could use high water pressure to chip concrete and check reinforcement

**6**

- Use VROM inspection document

**7**

- Mainly for balconies and galleries with no thermal break in moist environment. Crack located where drainage is
- Also concrete coverage
- CUR 248 available
- For galleries and balconies besides lower position also chlorides, put in two

**8**

- Steel inside to outside always problem
- More in older parts cities for 1900 - 1930 and small balconies
- Concrete also in bad state
- pre war and in war staircase accesible flats
- UNP with balstrude often changed earlier, not the consoles
- Most vital point corrosion is at facade

**9**

- Standards on chemical and glued anchors have improved since coming on market
- Lime sandstone/concrete anchors often used for non cantilivering balconies on steel profiles. Near stairs or landings higher forces, these locations for anchors critical
- Difficult in order of execution as reinforcement in place but balconies connected at last
- Chemcial anchor always attention point as often not well connected

**10**

- Ceiling suspension well covered by existing rules
- Are other parts swimming pools however as dressing rooms, facades, slide structure etc.
- Also basement around pool, floor often leaking, leading to corrosion steel columns underneath

Figure D.1:Most important points for hypothetical causes from experts (1/2)

**11**

- Old buildings do not comply with standards (also 80's and 90's)
- Newer buildings accounted for (for sure last five years)

**12**

- Same with standards as 11
- When snow thaws and frozen underneath,drainage via certain zone, leads to non uniform load
- Accumulation snow against objects or higher building parts is in standard, but often not done right

**13**

- There is notition
- Less in last years

**14**

- Corners mainly critical due to wind suction
- Often not well assembled
- No coating leading to corrosion
- Multiple problems with corrosion and moisture
- Glue problem as must apply well and degradation issue + not good in tension only shear
- Anchors also risk as thin and moving plates due to thermal changes

**15**

- Connection glass panel estimation deforms due to thermal changes
- Nickel sulphide
- Vandalism
- Heatsoke test so also look further
- (Difference in) Deformation support structure

**16**

- Not only masonry also concrete, can even knock over columns
- Imposed and wringing deformations
- (Z) dilatation concrete (for lengthened beams) also required for shrinkages
- Also important are parking garages due to thermal changes and penetrationof moisture and chlordies in these dilatations
- If dilatations there is damage to finishing, if not damages strcuture
- Difficult in moist environments as could pollute/corrode
- Stuffed dilatations
- Horizontal and vertical! Horizontal have bearing beams carrying facade, dilatation stuffed which makes the wall continuous

**17**

- Could also be prefab to in situ
- Most of these problems are bolts

**18**

- Different kind of soils
- After building
- Construction/ground work nearby
- Old shallow foundations
- Changing load on foundation
- Building errors due to compacting or leakages under foundatoin

Figure D.2: Most important points validated list experts (2/2)

### D.3.2 Additional attention points

The validation of the hypothetical causes via interviews is not complete. The experts identified an additional 24 points of attention that could be incorporated into the method or included in the list of common causes.

First, there are several general points of attention that must be considered during the assessment process but are not included in the final list of common causes. As one expert pointed out, all standard deficiencies such as material degradation should be taken into account. All points of material degradation should be of interest to the assessor, as they might influence the structural safety of the object. This also applies to any old damage or repair of such damage, excessively well- or poor maintained buildings, previously inspected buildings and the assessment of the rest capacity of the element when corrosion is detected.

Every old damage or repair of such damage is important as it shows the element (or structure) has failed at this location before. It is necessary to verify whether the damage can no longer occur. This can be achieved by checking if the damage did not progress any further and the repair has been carried out adequately. An expert pointed out that excessively well-maintained buildings are also a point of attention because cracks and other potential problems are immediately visually concealed by paint or coatings, making the damages invisible for a visual inspection. Therefore, this expert suggested that inspections should be performed at least three years after any maintenance.

Poor maintenance could also be a cause for structural failure incidents, but in this context, it is considered in a different way. If maintenance is poor or non-existent, degradation may become so extensive that critical points can no longer be identified during inspection. In such cases, the critical points must come from the desk study which is performed in an earlier stage of the assessment. More details of the assessment process can be found in chapter 6.

Old buildings that have already been inspected in the past could also be considered a point of attention. There are areas within these inspections thar are not reached and can still pose a risk to the building. During the initial assessment of this building, this must be considered with more care.

At last, an expert stated that determining the extent of corrosion when detected is also a point of attention. How can the remaining quality of this corrosion be determined? By using a factor? But how should this factor be considered? There is advised to consult a specialist on this aspect once this problem has been detected. Another expert also stated that the robustness in general is important. This robustness is classified in the VDI 6200 method and also considered in the developed method for this study.

In summary, the more general attention points listed by the experts are:

- Material degradation and other deficiencies.
- Every old damage/reparation.
- Excessively well and poor maintained building.
- Previously inspected old buildings.
- Assessment conditions when corrosion is identified.
- Robustness of the structure.

As can be seen in section D.2, in the database these more general attention points are also listed. Examples are material degradation and poor maintenance.

Then there are the common causes for structural failure incidents, as identified by the experts, that warrant inclusion in the list. These causes, along with the number of experts citing each, are presented in table d.5. The subsequent sections provide a detailed discussion of these causes, Additional insights pertaining to these cases are also included for further context.

Table D.5: Other common causes by experts

| Cause | Amount in source |
|---|---|
| Incompetent renovation/adaptation | 7 |
| Corrosion (reinforcement) in parking garages | 5 |
| Change in use | 3 |
| MuWi floors schools | 2 |
| Corrosion reinforcement due to insufficient coverage | 2 |
| Problems relating to thermal bridges for balconies | 1 |
| Alkali silica reaction in concrete | 1 |
| Specials | 1 |
| Connection prefab beam on prefab corbel column, problems with reinforcement in corbel | 2 |
| Problems with too thin plank floors or cracks located above the beams for these floors | 1 |
| Floors like Manta and Hebobo floors also have problems | 1 |
| Problems for joints with sealant | 1 |
| Problems with plate constructions | 1 |
| Thermal changes due to isolation of existing buildings | 1 |
| Fall protection not connected | 1 |

The first considered common causes to structural failure incidents, as identified by seven experts, is incompetent renovation or adaptation. This cause was also highlighted three times in the database, see subsection D.2.3. Therefore, this factor is included in the list of common causes for structural failure incidents. One expert further specified this issue, citing the creation of recesses for elements such as ducts as an example. However, this specific concern is encompassed within the broader category of incompetent renovation.

The second cause of corrosion in parking garages can be linked to the second hypothetical common cause, as vehicles introduce chlorides and moisture into the structure due to de-icing salts. This can lead to the corrosion of reinforcement in concrete parking garages. In some instances, steel plates used in composite floors, which serve a structural function, also have a significant risk of corrosion in this building typology. In addition, floor coatings can result in delayed detection of corrosion, or if detected, merely lead to the application of a new coating as a repair measure. Insufficient coverage is also mentioned as a contributing factor, but this will be discussed later. Therefore, if the damage is due to chlorides, it falls under hypothetical cause number to. However, if this is not the case, it should be considered as a separate cause. If no further mention is made in the validation in the subsequent chapters of this appendix, this chloride aspect is incorporated into hypothetical cause number two. This approach of further validation from other sources also applies to the causes that follow.

Chance in use, with three mentions, is a clear factor, though no further information is provided. An issue also arises with MuWi floors in schools built during the 1950s and 1960s. These floors were cracked during construction but remained in place. Today, pieces of floor can fall off. One expert suggested that this problem could be common in similar schools.

As previously mentioned in the context of parking garages, insufficient coverage of reinforcement in concrete is also identified as a common cause by two experts. A moist environment often exacerbated this issue, leading to corrosion of the reinforcement. This is why locations such as parking garages or basements can pose problems. The issue could stem from the concrete coverage being lower, due to pouring of concrete or from an overlap in reinforcement, which also results in less coverage. Furthermore, less coverage was prescribed 60 years ago and even less so a hundred years ago. One expert noted that this cause occurred frequently.

Thermal breaks for balconies were also suggested to be a common cause for failure. One expert mentioned that there was a search for different types of stoppages for thermal bridges. However, this cause pertains to the connection of balconies to the load-bearing structure and is thus considered under hypothetical cause number nine.

One expert also observed multiple instances of the alkali-silica reaction in concrete, particularly in older buildings constructed before 1980. Modern concrete suppliers now take this issue into account. This expert also suggested that so-called ‘’specials’’ should be listed. These ‘’specials’’ refer to standard details or other solutions that exceed their boundaries.

Two experts have highlighted the issue of corbels used to connect prefabricated beams to prefabricated columns in parking garages. These corbels can crack or even fall due to incorrect detailing of reinforcement, often resulting from insufficient reinforcement during execution. Alongside hypothetical cause six concerning plank floors, an expert also reported issues with plank floors that were so thin, and with heating combined with reinforcement, that it is questionable whether al reinforcement is present. Cracks in these floors at the location of the supporting beams were also noted by an expert. If these floors are present in parking garages, chlorides could penetrate the structure.

Various other types of floors can also pose problems. The first is the Manta floor, which shares the same issue as the Kwaaitaal floor regarding calcium chlorides in the concrete admixture. This floor should therefore be considered under hypothetical cause number two. The expert stated that the NEHOBO floor also causes problems as it contains mortar and reinforcement within the bricks. The poor quality of the mortar leads to carbonation and thus carrion of the reinforcement in these floors.

Issues also arise for joints with sealants. This coincides with hypothetical causes 14, 15 and 16, which concern façade panels, glass fracture and dilatations. However, sealant could be a point of attention if not considered in the façade, otherwise, it is covered by the causes mentioned above. For plate constructions an expert also reported it as a common cause. No further information on the problem was specified by this particular expert. As the main reference was about earthquakes, this cause is not further considered.

This leads to problems with applying insulation in existing buildings. Initially, thermal bridges and lack of insulation facilitated help with thermal changes in the outer wall. With insulation, these thermal changes become more significant, leading to cracks and in worst-case scenario, collapse of the façade. At last, there is the issue of fall protection which is not connected (anymore).

All the causes mentioned above have not yet been included in the list of hypothetical causes. A validation with literature is performed first to further check for common causes with structural failure incidents. However, during interviews with experts, some other aspects were considered. These points are discussed in the next subsection.

### D.3.3 Other important information

In addition to the common causes for structural failure incidents, other questions were raised during the interviews with experts. The first point pertains to the building types, which are discussed in chapter 3. Through these interviews, it was determined whether commercial building types should be considered for the new assessment method and whether any other building types were missing. As studied in section 3.1, consequence classes are not solely dependent on the risk to life but also consider economic and other consequences. Commercial buildings, as noted by an expert, can sometimes hold such economic value that a number of these buildings are categorised in CC2. These buildings can also experience considerable movement and occupancy inside. One expert even suggested that these buildings are important to consider due to minimal maintenance, frequent changes, lack of municipal oversight and absence of nearby residences providing social control. Aggressive substances within these buildings can negatively impact the structure. This building typology should thus be considered by the assessment method. The experts also concluded during the interviews that parking garages should also be include on the list as this typology is vulnerable to structural failure incidents due to exposure to weather conditions. Even if the garage is enclosed, cars can still introduce moisture and potentially de-icing salts.

The initial steps of the assessment method were also a topic of discussion among the experts. The majority suggested that a desk study prior to the inspection would be a more effective approach as it allows for a more focussed inspection. A preliminary preparation phase could precede this desk study, during which an overview of the building could be obtained, for instance, online. This preparatory phase could also involve asking the client questions about the building's history, changes in use, future changes in use and the renovation history. It was noted there is often an interaction between two elements, with the process moving from the desk study to the inspection and then back to the desk study if further information is required and so forth. However, some experts highlighted the commercial aspect at the beginning of such a method. They pointed out that nine times out of ten, a site visit is required, which could serve as an initial general inspection.

The subsequent question pertained to the inspection methods or tests that should be incorporated into this assessment. The majority of experts agreed that a visual inspection is the appropriate starting point for the assessment. A selection of tools could be employed for this inspection and the inspector should have access to elevated areas within the buildings. Tools such as crack width measurement equipment and endoscopes could also be utilised. The NEN 2767 provides a list of tools that should be used during the inspection. One expert suggested that if there is suspicion, a simple non-destructive test could be performed during the visual inspection.

Two experts emphasised that experienced individuals should conduct this inspection. One expert even advocated for collaboration between inspector and constructors, as they possess different types of knowledge., for instance, the inspector is more accustomed to identifying deficiencies. This expert believes it would be best if the inspector and constructor conducted the inspection together. The next step should be an iterative information gathering process, potentially involving destructive material investigation.

In conclusion, one expert stated that the list provided by the VDI 6200 method is comprehensive and can complement the list of common causes compiled in this thesis. However, other experts cautioned against relying solely on standards lists, as there are issues that cannot be addressed within such a list and each object may present unique problems. Therefore, there is a risk that issues not accounted on the list may be overlooked.

In their final thoughts on the subject, the experts highlighted several key points that are deemed relevant and are briefly described in this paragraph. The condition of the structure of existing buildings is largely about the robustness of the structure. One expert explained that modern structures are so robust that three to four things need to go wrong for a collapse to occur, indicating that there are still many unknowns within the structures that did not have any consequences. The robustness classification by the VDI is considered a good option.

Related to this, the warning capacity of structures is also important. One expert suggested dividing the causes into warning and non-warning causes on the list. It should always be remembered that this list of common causes is not exhaustive and will never be. This list must also be updated. However, it serves as a useful reference as most causes can be quickly checked. It might also be beneficial to include the severity of the structural failure due to the listed causes.

Regrettably, the ABC point where structural failures must be reported is no longer available. However, a new possibility for a central point to collect structural failure incidents has emerged with the new branch governance codes being discussed, including learning ability as subject.

During some interviews, the aspect of prioritisation for a group of objects was also discussed. It was stated that this is not for a periodic assessment. Ultimately, the method should guide buildings into the future. It is hoped that the method will stimulate craftmanship and critical thinking, but it should also be recognised that an expert already has all this information at their disposal.

As a final note, one expert stated that not all companies should be able to perform such a method. But this is can already be addressed requiring qualifications for those conducting the assessment. Lastly, numerous experts mentioned fire safety as a factor to incorporate into the method. As this is outside the scope of the thesis, this subject is also addressed in the recommendations. All the points mentioned above have been taken into account for this study.

## D.4 Survey

In the survey conducted for the problem statement, as detailed in section A.2, participants were also asked about their familiarity with various types of structural failure incidents. The results of this question are presented in figure d.3. This section provides an enumeration of these results.

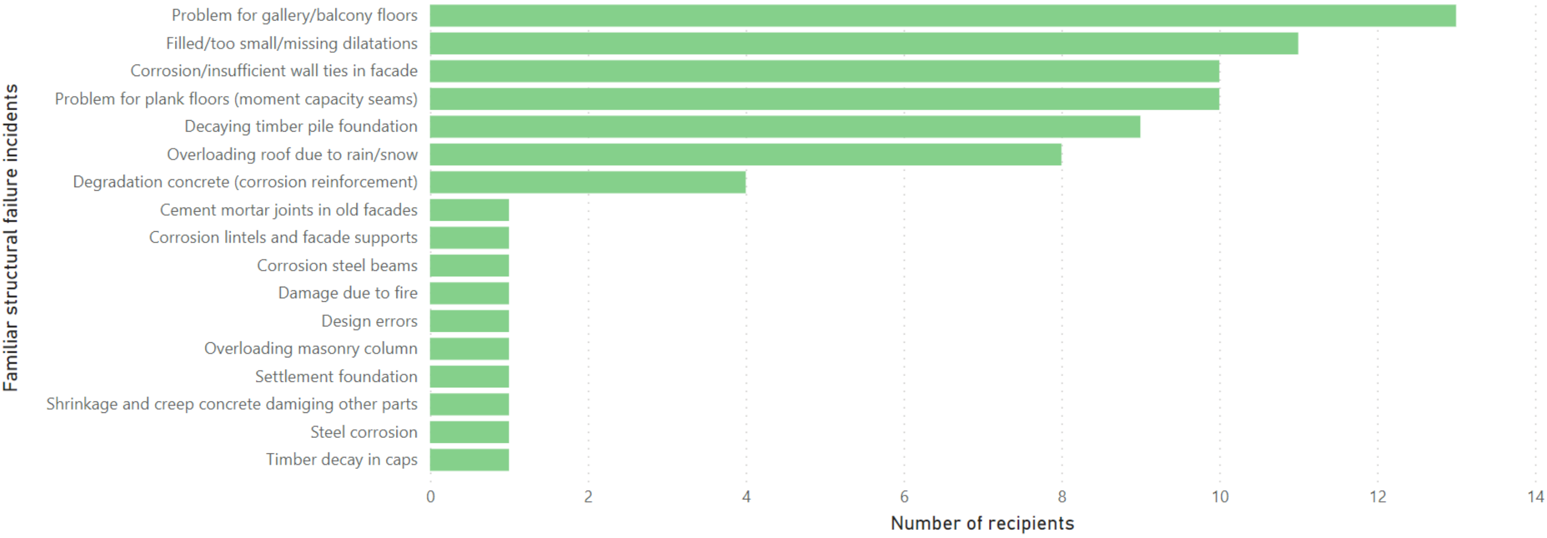


Figure D.3: Familiar structural failure incidents by survey recipients

The graph illustrates those issues pertaining to gallery and balcony floors, as discussed in hypothetical causes two and seven, are the most prevalent among the respondents. These are closely followed by problems related to dilatation and wall ties, which are addressed in hypothetical causes 13 and 17. Hypothetical causes mentioned by multiple respondents also include decaying timber pile foundations (4) and roof overloading due to rain or snow (11/12). The settlement of the foundation, hypothetical cause number 18, was only cited by a single expert.

In addition to the causes for structural failure incidents listed, respondents reported other causes which were not included in the list. One of these causes is mentioned by multiple respondents, four to be clear, was concrete degradation (corrosion of reinforcement). This more general cause also appeared in relation to the other points listed in the database outside the hypothetical list. As stated in that section, since this is a more general cause, it could be addressed in the desk study or visual inspection conducted in the method. There were also other causes mentioned by only one respondent. These are not considered further due to their limited occurrence.

Given the limited control over the information obtained through the survey, the data presented is not directly utilised in the validation process. For instance, the qualifications of the respondents could not be controlled and fully known for the survey results. There may also be a slight bias, as some examples were already provided within the survey. Therefore, this section primarily serves to enhance the understanding of failure incidents within the building sector, rather than as a direct source of validation data.

## D.5 Validation with literature

Literature plays an important role in this validation process. First, sources discovered during research, such as existing assessment methods discussed in chapter 5, are used. These sources provide valuable information for the validation process and are elaborated upon in the following subsections. These sources include the KPCV, Cement and NTA 8790.

For the hypothetical causes that have not been validated by the aforementioned sources, as well as causes identified by the database and experts, other literature sources are explored in the final subsection. In certain instances, supplementary information is provided, if available, to help further focus the common causes.

### D.5.1 KPCV

The KPCV provides several sources that highlight important factors to consider when evaluating an existing building. First, the following points of attention are given for periodic inspections (KPCV, 2022a):

- Damage leading to a reduction in material properties, for instance corrosion.
- Cracks and/or deformations resulting from distribution of forces.
- Cracks caused by impended or imposed deformations.
- Loose or broken anchors, bolts and/or nuts.
- Reduction in the support length of structural elements.
- Damage attributable to external factors.
- Methods of water disposal, as water is involved in most forms of degradation.

As these points are somewhat general, they are difficult to relate to the specific points in the hypothetical list of causes mentioned in section D.1. These points cannot be used in the validation process. However, they could serve as general points of attention as they represent warning mechanisms of the structure, see section 4.2.

The KPCV also provides additional points of attention that can be incorporated into the validation process, see table d.6. these primarily include problems that do not exhibit any warning signals prior to collapse.

Table D.6: Problems specified by KPCV (KPCV, 2022b, 2022c & 2022d)

| **Description** | **Cause** | **Additional information** |
|---|---|---|
| Kwaaitaal and Manta floors exhibiting corrosion due to inclusion of calcium chloride in the concrete admixture | 2 | These floors were mainly applied in housing and commercial buildings for the period 1965 – 1983. Document available is CUR 79 |
| Plank floors with a positive moment at the seam between the plates | 6 | Mainly for objects realised after 1999. This problem has a mandatory inspection, see (Wijte, 2018) |
| RVS suspension construction in swimming pools not able to withstand indoor climate | 10 | Here also a mandatory inspection is applied via document NPR 9200:2015 |
| Insufficiently assembled fall through protection for both residential as non-residential buildings | New | This problem also applies to railings and balustrades |

| | | |
|---|---|---|
| Continuous masonry facades with insufficient/corroded wall ties. | 13 | The document SBR publication ‘Protocol voor het inspecteren, beoordelen en herstellen; Constructieve veiligheid bestaande metselwerk buitenspouwbladen’ is available |
| Water accumulation on roofs due to no/insufficient drainage | 11 | Stated that the drainage system must be regularly inspected and maintained. More information for assessment light plat roofs via a risk-based inspection is available in (VROM Inspectie, 2003) |
| Stated that snow accumulation can also lead to problems for roofs | 12 | When in doubt, clear the snow of the roof |
| Change in use | New | Must check to which extent problems arise relating to structural safety |
| Adaptation structure | New | Incompetent measures could result in loss or change of load bearing capacity. Dilatations must also be considered |
| The too low position of the reinforcement in cantilevering gallery and balcony floors which are monolithically connected to the load bearing structure | 7 | Problem for apartment buildings with galleries built in the period 1950 – 1975. Mandatory inspection via CUR 248 |

The table reveals that certain causes have been validated through this literature source. However, it also presents three points not listed in the hypothetical list of causes. The first point pertains to the insufficient assembly of fall protection, railings and balustrades. This problem could be considered in the attention points, as one expert also identified this as a concern, see table d.5. The second point involves changes in the use of a structure or a part of it. This problem was also highlighted during expert interviews, with three experts mentioning it. The final point relates to adaptations of the structure, categorised under incompetent renovation/adaptation. This cause is also noted in the additional points from the database and expert interviews. In addition, the table also provides supporting documents for mandatory and other inspections.

Delving deeper into CUR 79, mentioned in the first row of the table, it is stated that approximately 25% of Kwaaitaal floors and about 10% of Manta floors require (partly) structural measures roughly 20 years after production (Van Der Wegen & Wijte, 2016). However, the CUR also specifies that is particularly suited for ground floors of CC1b buildings where the upper side of the floor cannot be assessed. One expert also suggested that these floors are primarily found in CC1 type buildings and not in CC2 buildings. Nevertheless, if these elements are present in CC2 buildings, they pose a risk that must be evaluated. At last, the CUS states that its assessment can also be applied to storey floors within houses composed of Kwaaitaal and Manta elements (Van Der Wegen & Wijte, 2016), implying that these floors are sometimes not only used as ground but also as storey floors.

### D.5.2 Cement

There are two articles by the journal Cement used in this subsection. The first article discusses the insufficient load resistance and the lower position of the reinforcement in the cantilevering gallery and balcony floors. It also considers chloride damage to these floors. An inventory was conducted on 552 monolithically connected cantilevering floors that were inspected. Out of these 552 cases, 158 were gallery floors, 229 were balcony floors and in 165 cases both type of floors were inspected (van den Berg et al., 2021). The figure below illustrates that a significant number of floors did not meet both short-term as long-term standards. Furthermore, in 176 cases elevated chloride content was detected and in 46 cases actual corrosion of the reinforcement was discovered.

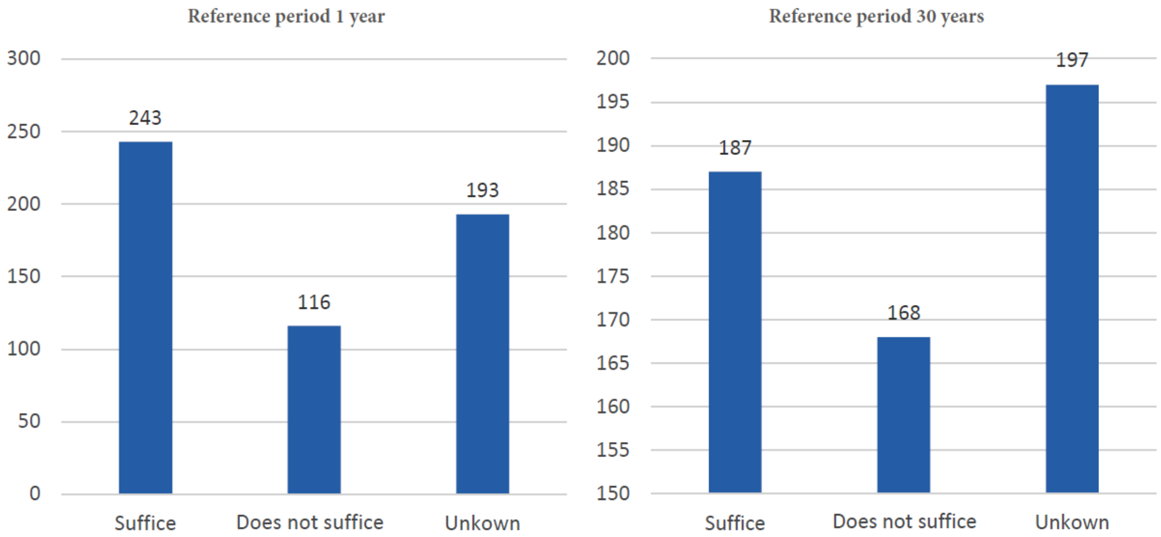


Figure D.4: Study to apartment buildings for short (left) and long term (right) (van den Berg et al., 2021)

The article also provides data to demonstrate that balcony floors pose a problem. In total, 46 floors did not meet short-term standards and 61 failed to meet long-term standards (van den Berg et al., 2021). In addition, 38 of these floors exhibited elevated chloride content.

Given the substantial figures presented above, it is evident that causes two and seven are justifiably included in the list of common causes for structural failure incidents in the Netherlands, as previously established via the KPCV source.

The second article validates hypothetical cause 17, which pertains to the corrosion of connectors in prefab elements. It is stated that prefab elements, with regular occurrence, fall from buildings due to corrosion of the connectors in the void between elements (Kapteijn - van Hennik, 2021). Four cases related to this issue are discussed in the article. In summary, the following problems associated with this cause were identified (Kapteijn - van Hennik, 2021):

- A spandrel fell from a gallery flat.
- Silting of mortar occurred in the connection between outside columns of balconies.
- Bolts connecting a concrete spandrel to a staircase accessible flat failed.
- A spandrel fell from a flat.

The document provides detailed information regarding these four cases. It also outlines general causes and suggests particular attention should be paid to structures within 25 to 30 years old (Kapteijn - van Hennik, 2021). Furthermore, it recommends conducting a risk-based inspection for apartment buildings after approximately 30 years of use. A desk study is proposed to determine whether the following elements should be investigated: gallery and balcony structures, concrete spandrels in the external environment, connection mortars and coupling reinforcement structures with prestress without bond and facades with wall ties (Kapteijn - van Hennik, 2021). here hypothetical causes five, seven, nine and thirteen are mentioned, providing some validation for these points.

### D.5.3 NTA 8790

The NTA report identifies structures and structural elements that are vulnerable to damage. First, the information is categorised based on the different materials used. Subsequently, for each structural component, potential issues are enumerated and methods of assessment are provided under the following headers: Example, structural errors, aging, inspection signals and calculation check (NEN, 2023).

In this subsection the vulnerable parts are analysed, to validate the hypothetical list of common causes. To facilitate this, table d.7 documents the cases by listing the two cause categories used in the NTA. It should be noted that the inspection signals and calculation checks are not considered in this appendix. This information may become relevant if a hypothetical cause is validated and additional information is required.

Table D.7: Vulnerable structural components NTA 8790 (NEN, 2023)

| Case | Structural error | Aging |
|---|---|---|
| Steel trusses with welded or bolted nodes | Wrong calculations, insufficient welds, use of wrong bolt quality or not securing bolts, forcing non fitting connection, wrong detailing and truss not complying with design | The truss can corrode in a moist environment |
| Frames with a kink | Realised object supported while only lateral support in design or removal of ties | Corrosion of steel frame or steel ties in moist environment |
| Lightweight flat roofs supported by steel beams | Could be due to stiffness, slope and amount of emergency drainages influencing the water load on the roof | Not an issue as rain load on roofs before 1990 not mandatory and till 2004 less common |
| Steel connections in general | Mistakes in calculation reduce load bearing capacity. Also vulnerable for eccentricities from design and/or execution | Could corrode in moist environment |
| Stainless steel construction in chloride environment | Wrong choice of material in aggressive environment | Corrosion over time due to chlorides and other acids |
| Deficiencies hollow steel sections | Water retention in profiles, lengthening of profiles via weld which could have less capacity. | Not an issue |

|  |  |  |
|---|---|---|
| Steel top hat beams | Composed of steel plates. Weld not good accessible, must be considered in design. Executed welds could deviate from calculations/design | Less relevant |
| Concrete structures in chloride environment | Insufficient coverage reinforcement, deviation in implementation or significant crack widths | Corrosion of (prestress) reinforcement and more chance pitting corrosion |
| Concrete structures using concrete half joints in connection | Reinforcement not placed as indicated in drawing. If significant diameters this means significant sections of concrete are unreinforced at the bent bars. Also, too high resistance in dilatations to move, not considering resistance of movement or wrong detailing of suspension reinforcement | Due to the aforementioned structural error significant crack withs can occur. Danger of durability in moist environment |
| Plank floors with positive moment at seams | Incorrect assessment of moment resistance at seam. Mainly between 2000 and 2019 | Redistribution of moment can lead to cracks in other parts floor. In moist environment this can lead to corrosion |
| Floors with prestress without bond | In starting stage of this system not always sufficient corrosion protection. From starting 1980's strongly improved | Water can penetrate concrete to the prestressing reinforcement during and after built. Due to corrosion the cables can break. If infiltration during built, must happen within 10 years. Can also happen later in moist environment. Also, danger for drilling in floor |
| Objects with prefab concrete elements | Not or only limited robustness. Can thus lead to progressive collapse | Less relevant |
| Timber structures in general | Timber loses part strength in moist environment. Also, more susceptible for decay and fungus. Must have right durability class to check if covering sufficiently protects against moisture | Decay of timber and fungus in moist environment. Also, insects can cause decay |
| Timber trusses with steel nodes | Wrong calculations/ schematisation. For instance, not resembling realised object. From static determined to static indetermined | Corrosion of steel nodes or decay timber |
| Laminated beams and frames | For bent frame, same as steel frame, designed with lateral support but realised with full support | Decay timber, glue losing strangt and overaging of slats possible in moist environment. Corrosion of steel supports also option |
| Timber beams loaded with tension tangible to the fibres | Insufficiently considered during design | Again, decay and more, but also effect of long-lasting loading leading to reduction strength |

| | | |
|---|---|---|
| Load bearing masonry | Not full and sufficient working of the bed joint reducing the compressive strength. This strength could also be lower as in design, for instance due to switch in stone type | For inside environment no threats. In outside environment degradation due to frost/thaw can occur |
| Non-load bearing masonry | Deficiencies dilations and misalignment detailing with other materials can cause cracks. Also, corrosion of incorrect appliance of wall ties. Can cause insufficient resistance to pressure difference with inside environment | Until recently, steel wall ties being corroded, mainly in west and south orientated facades. Damage due to insufficient dilatations are often damages due to temperature influences which increase over time |
| Composite and plastic structures in general | Nothing detected yet | Can age when exposed to temperatures, moisture and/or UV. The material gets more brittle |
| Shallow foundations | Mainly unequal settlements, local ground conditions not sufficiently considered, insufficient load bearing capacity, settling of dilations, unforeseeable excavation work or extensions | Settlement during build but also after some time, especially for clay grounds. Also, a temporary lowered ground water table can lead to more settlement |
| Pile foundations | Mainly unequal settlements, local ground conditions not sufficiently considered, insufficient load bearing capacity, settling of dilations, unforeseeable excavation work or extensions | Mainly on more solid grounds, exceptions are piles on resistance. Decay timber piles also factor to consider. |
| Structural glass | Nickel sulphide inclusions, stress in glass due to wrong detailing, cracks in laminated glass and thermal stress | Not hardened glass can mainly appose subcritical cracks which could lower the strength of the glass |
| Façade elements | Insufficient capacity anchors, corrosion or letting go of panels | Corrosion anchors and frost/thaw damage |

Based on the data provided in the table, several hypothetical causes can be confirmed. The table presents numerous instances where there is a discrepancy between the design and completed object (hypothetical cause one). For instance, the types of support differ in the steel and timber frames, incorrect bolt quality used, change in static determinacy for timber trusses with steel nodes and the removal of ties. Other hypothetical causes mentioned, include the plank floors (6), prestressing without bond (5), stainless steel connections in swimming pools (10), water accumulation for light flat roofs (11), wall ties (13) and dilatations (16).

The table also indicates that concrete structural parts are vulnerable to a chloride environment. There are also the crack widths which are attributed to the coverage for concrete. Due to these crack widths moisture, which might contain chlorides, can penetrate the structure and cause degradation.

The issue of concrete in a chloride environment is covered within cause two. Part of cause two is the use of chlorides in the admixture of concrete to improve the curing process. This issue is not mentioned by the NTA.

This lack of complete overlap between causes and the information in the table can also be applied to prefab structures and hypothetical cause 17 related to the connections of prefab elements. The NTA stats that prefab elements are vulnerable due to the absence of a secondary way of bearing and the hypothetical cause focusses on the corrosion of the connectors in prefab.

Façade elements are also identified as vulnerable construction elements in the table. This validates the hypothesis that façade panels detaching or falling must be considered as common cause (14). In conclusion, causes for settlement (18), glass fracture (15) and decay of timber piles (4) also come forward in the table by the NTA.

The table also reinstates several newly proposed causes, as mentioned in the database and by experts during interviews. Both the connections and timber in general, are highlighted in the extra points in the database and in the NTA. Timber is more vulnerable for decay and fungus than other materials and loses strengths in moist environments (NEN, 2023). This can be verified through the appropriate robustness class of the material applied. The table also mentions half joints in concrete structures. Two experts have identified corbels for column beam connections in parking garages as critical, which is a type of half joint. The database also includes an incident involving a failing half joint at Bos and Lommer Plaza in Amsterdam.

In addition to the validation of the hypothetical causes and the new points from the database and interviews, table d.7 provides new insights into vulnerable building parts/components. These new insights include the problems with hollow sections and top hat beams, issues with detailing, laminated timber and timber beams loaded in tension parallel to the fibres. With laminated timber there is a risk of glue losing strength. For tension loading parallel to the fibres, this issue is sometimes not adequately considered during design (NEN, 2023). The point of detailing is still too general to include in the list of common causes for structural failure incidents.

Design calculations are evident in other issues as well, such as with steel trusses, steel connections and timber trusses with steel nodes. However, these points are more often consider under the general point of connections. In addition, the functioning of the bed joint and potential degradation from frost and thaw damage could pose a problem for the compressive strength of load bearing masonry. At last, the factor of age combined with exposure to temperatures, moisture and/or UV light pose a risk to composite/plastic structures (NEN, 2023). As this material is not commonly used for structures within buildings, this problem is not listed among the common causes.

While several new problems are introduced above, they are not considered for the common causes without validation from the database or interviews with experts. This does not imply that these issues cannot occur frequently in practice or poses a threat to existing CC2 buildings, they are simply not listed as common causes in this study. Future studies could examine these aspects in greater detail to further focus the list of common causes for structural failure incidents in the Netherlands.

### D.5.4 Other sources hypothetical causes

The conclusions drawn from the database are verified by sources describing vulnerable construction parts and/or common incidents, as discussed in the previous three subsections. However, hypothetical causes three, eight and nine which pertain to balconies supported by steel structures, anchorage of balconies and incorrect wind calculations, respectively, are not mentioned in these sources.

In 2021, the municipality of Utrecht announced an investigation into 6400 old balconies (NOS, 2021). This investigation pertains to cause number eight, which involves corrosion of the steel support structure. The corrosion can occur in the connection with the wall and may not always be visible (NOS, 2021). The article states that balconies built between 1850 and 1945 will be investigated due to dozens of reports of deformation or settlement. It is suspected that more municipalities will inspect this problem.

Present day, there are no immediate sources of information beyond the database content that support the validation of causes number three and nine. Therefore, these two causes cannot be validated with literature at this time.

Additional literature is available for some of these hypothetical causes. For instance, cause number 4 refers to timber pile foundations. The SBRCUR guideline for timber pile foundations under the buildings indicates that a significant number of all structures on these foundations are at risk due to factors such as overloading, being above ground water level or degradation under water (F3O, 2016). As timber structures are often constructed well beyond the current standards, these standards are subordinate for assessment. This source provides a guideline for assessing these structures.

Additional information is also provided on floors with prestressing without bond. These floors have been used in the Netherlands since 1970 (VROM Inspectie, n.d.). The source indicates that corrosion can originate from moisture present during construction or later penetration. Other problems include inaccurate design/execution and failure of the anchorage. These floors are primarily used in apartment and non-residential buildings as a low coverage on the reinforcement is sufficient and due to the prestress, relatively thin floors can be realised (Hordijk et al., 2011). As this problem became apparent over time, VROM stated that buildings with these floors constructed between 1970 and 1980 are of particular interest (VROM Inspectie, n.d.). Damage occurrence does not necessarily imply that these floors pose a risk of collapse. Even without a significant number of the prestress cables, the structure could still be safe and there is extra load bearing capacity available which is not used in the calculations (VROM Inspectie, n.d.). It is also stated that these floors provide warning signs before collapse via additional reinforcement and formation of cracks.

Plank floors pose problems when the primary load bearing direction is via the seams between the floors and where the coupling reinforcement, for the connection, is loaded in tension (Steenbergen et al., 2022). A study conducted by TNO in 2022 provides more in-depth information for the assessment of plank floors. This structural system was applied up to 2017 (Steenbergen et al., 2022). However, as there is a mandatory investigation in place for this cause, the details form the document, stated in (Wijte, 2019) and (Wijte, 2018), must be followed. To ensure accuracy, the 2019 date by NTA 8790, as seen in table d.7, is used.

Mandatory investigations are also required for cantilevering gallery and balcony floors, as well as swimming pool suspensions, where the documents stated in table d.6 must be adhered to. This table also references valuable documents for non-mandatory investigations for causes 11, 13 and partially for cause two.

The relevance of causes 11 and 12, related to snow accumulation, us further reinforced by a report of an insurance company. In the reported there is stated that 15 to 20 roofs collapse annually due to water/snow accumulation or a combination thereof (ZeerZeker, 2021). A previous investigation by VROM concluded that out of 1467 investigated roofs, 775 were at risk (Dekker, 2004). The insurance company also provides a description of at-risk roofs and indications during inspection that may signal potential issues. Commercial and public buildings like sport halls and swimming pools with relatively large spans, buildings with flat roofs along with roof panels without beams and buildings with lightweight flat roofs with a steel construction are identified as problematic. The document by the insurance company also confirms the problems stated in the database: non-functioning or absent emergency drainages, insufficient stiffness, insufficient slope or a combination of these factors (ZeerZeker, 2021). An additional factor is the strength of the roof. For snow pressure on the roof, the structural connections between the structural parts are deemed important (ZeerZeker, 2021).

The Dutch Safety Board reports that for falling façade elements (cause 14), four incidents occurred within three months in 2005 (Onderzoeksraad Voor Veiligheid, n.d.-c). There was concluded that this is a more common issue. This leaves hypothetical causes three and nine, for which no supporting literature has been found at this time to substantiate their classification as common cause.

### D.5.5 Other information possible causes

During the validation process, both the database and the experts proposed new additions to the list of causes. This subsection attempts to validate the remining proposed causes, as some have already been validated. The VDI 6200 contains general material degradation tables and checklists for two of the three inspection levels, see chapter 5. This includes the more general points for concrete and timber degradation. Changes in usage and constructional changes, referred to as incompetent renovation/adaptation in this study, are also stated. The fact that these causes are mentioned on a checklist for inspections in the German Standard reaffirms, these are important causes to consider.

The guideline for the assessment of glued facades reports that multiple damages for this phenomenon have been observed in recent years (van Beek- van der Toorn et al., 2022). For instance, the detachment of glue from the surface due to the expansion and shrinkage of panels (de Jong, 2018). Another problem is the exceeding of the maximum measurements of panels for the glue. Variations in the amount of glue over the length of the connection, which impacts the strength of the connection, have also been observed. As demonstrated in these examples, this primarily concerns façade panels becoming detached, which is already covered under hypothetical cause 14.

In addition, there is potential delamination of timber beams as stated within NTA 8790, which also involves glue. However, no cases involving delamination in timber beams were found in the database for problems with delamination. Experts did not identify this as a common cause of structural failure incidents in the Netherlands. In consequence, this aspect is not included in this study. Future studies should conduct more comprehensive research to provide a more accurate list of common causes.

The validation interviews discussed in subsection D.3.1 referenced the MuWi flooring system. This is supported by a news article reporting that the Minister of Housing and Spatial Planning ordered the inspection for schools with this system (NOS, 2023). The Minister suspects that approximately a hundred schools in the Netherlands were constructed using this system, which was prevalent between 1951 and 1973. The system comprises concrete beams interspersed with lightweight concrete filling elements (NOS, 2023). TNO, which conducted the initial investigation where parts of the concrete detached, reported two similar cases in Rotterdam alone.

Experts have identified multiple issues related to corrosion in parking garages. These structures are exposed to external environmental conditions, with all floors subjected to water and de-icing salts (containing chlorides). Often, the structure is minimised for cost-effectiveness per meter, inadvertently increasing risks (Swinkels, 2017). This source also highlights a lack of attention to quality and maintenance.

The first issue with this type of construction relates to the exposure class of concrete. Frequently, an inappropriate exposure class is selected, leading to too low concrete quality, inadequate concrete coverage and significant cracking (Swinkels, 2017). As previously mentioned, de-icing salts and moisture contribute to corrosion can penetrate the element via cracks and crack formation often occurs in parking garage floors (Adviesbureau ir. J.G. Hageman B.V., n.d.). These cracks can result from insufficiently assembled monolithic floors, shrinkage or the use of prefab parts (Swinkels, 2017). The document provides an example that plank floors often crack above seams and between beams and columns. This crack formation aligns with expert statements. While significant reinforced toppings can prevent these cracks, they are often not applied (Swinkels, 2017). If cracks do occur, coatings can be applied. However, the risk of corrosion persists as the coating does not halt this process but merely slows it down.

At last, the source specifies that floors with prestressing without bond are also used in parking garages. It states that many of such floors are still in use and have not yet been investigated (Swinkels, 2017).

The two sources discussed highlight the significance of parking garages as a building type prone to multiple issues. However, the primary cause of structural failure is predominantly corrosion due to moisture combined with chlorides, a factor already covered by hypothetical cause two. Insufficient coverage is also mentioned in this context, but the corrosion of reinforcement is often attributed to chlorides.

Damage due to alkali-silica reaction can occur under specific conditions: the presence of an admixture sensitive to this reaction, sufficient alkali in concrete and adequate moisture. The source indicates that among the 50 concrete structures where this damage was detected, most are civil structures constructed with Portland cement and are relatively older.

The issues with Manta floors were previously mentioned in the KPCV section, but sources are also available for NEHOBO floors. These floors were commonly used as ground floors during the period 1954 – 1984 (Goossens, 2023). It is mentioned that the reinforcement can lead to further damage. However, it remains uncertain whether these floors are used in CC2 buildings and whether this problem is widespread. The only validation available is the information provided above.

In conclusion, there is the issue of insulating existing buildings with a cavity wall. An insulation expert describes this problem in an article (DPG Media Privacy Gate, n.d.), providing additional validation. However, a comprehensive overview of this problem is lacking.

The above descriptions are the result of a literature study conducted on these causes within the context of the Netherlands.

## D.6 Overview validation

This section concludes the validation process for common causes of structural failures in the Netherlands. Previous sections provided additional information on the causes, but this section focuses solely on their validation, which will be useful for the causes validated in chapter 4.

First, there is assessed whether the hypothetical list of causes has been sufficiently validated to be implemented. Subsequently, there is discussed if additional points raised during the process should be included. This discussion culminates in a final list of common causes for structural failures in the Netherlands.

It should be noted that further research is necessary to complete this list. This is an initial attempt to compile a list of common causes that should be addressed more carefully during assessment.

### D.6.1 Validation hypothetical list of causes

The validation process used the database, the interviews with experts and literature. Table D.6 indicates whether each of these three aspects validates the specific hypothetical cause. In general, most causes are mentioned in all three aspects. However, causes three, five and nine are mentioned by only two of the three sources as indicated by a yellow marked cell. Notably, experts deemed that all these three causes are relevant for the list of common causes, hence their inclusion in the list.

At last, cause 17 is validated solely through literature. Despite only having three mentions in the database and being validated by three experts, it is considered validated due to a referenced article in the Cement, see subsection D.5.2. This article, coupled with the fact that this causes was just below the threshold for both database and expert validation, justifies its consideration. Consequently, all hypothetical causes are represented in the final list of common causes, which serves as the starting point for chapter 4. Future studies should examine these causes more closely.

Table D.8: Results validation hypothetical causes

| No. | Validation database | Validation experts | Validation literature |
|---|---|---|---|
| 1 | X | X | X |
| 2 | X | X | X |
| 3 | X | X | |
| 4 | X | X | X |
| 5 | | X | X |
| 6 | | X | X |
| 7 | X | X | X |
| 8 | | X | X |
| 9 | X | X | |
| 10 | X | X | X |
| 11 | X | X | X |
| 12 | X | X | X |
| 13 | X | X | X |
| 14 | X | X | X |
| 15 | X | X | X |
| 16 | X | X | X |
| 17 | | | X |
| 18 | X | X | X |

### D.6.2 Additional proposed causes

As is evident in this appendix, additional causes are proposed at each of the three stages. These proposed causes are all listed in table d.9, which indicates the number of sources that mention each cause. For further insight into why certain proposed causes were considered or disregarded, please refer to the preceding sections.

Table D.9: Final proposed causes for list

| Proposed causes | Database | Experts | Literature |
|---|---|---|---|
| Not enough reinforcement in element | X | | |
| Too little load bearing capacity floors | X | | |
| Incompetent renovation | | X | X |
| Change in use | | X | X |
| Incorrect appliance MuWi floors schools | | X | X |
| Corbel for connection prefab beam to column connection has wrong detailing/too little reinforcement | | X | X |
| Too little coverage on reinforcement | | X | |
| Alkali silica reaction in concrete | | X | |
| Specials | | X | |
| Corrosion reinforcement in NEHOBO floors | | X | |
| Isolation of existing buildings leading to thermal changes in façade | | X | |
| Problems with hollow sections and top hat beams | | | X |
| Loading tangible to the fibres of timber beams insufficiently considered | | | X |
| Problems with the bed joint for load bearing masonry | | | X |
| Fall protection not connected/ insufficiently assembled | | X | X |

The database only mentions the first two additional causes. The first cause, the missing reinforcement is considered within the discrepancy between design and realised object. The second cause, insufficient load bearing capacity for floors, is mentioned four times in the database but not elsewhere, hence it is not included in the list of common causes.

Incompetent renovation is a common cause, sited by seven out of nine experts and mentioned three times in the Cobouw database. It is also listed in the VDI 6200 checklist. Other common causes include issues with MuWi floors for schools and connections for prefab beams on prefab columns with corbels due to incorrect detailing or insufficient reinforcement. The extent of the problem with MuWi floors is unclear and may be reassessed by the end of 2023. Corbel connections, a type of half joint connection, are highlighted as an issue by NTA 8790 and two experts.

Five causes were proposed by experts to be included in the list. The first is insufficient coverage on reinforcement for concrete leading to corrosion. In literature there can be seen that this cause is also present in parking garages but leads to chloride infested corrosion, which is covered by an already final cause. Besides the interviews, no further validation is available. The second cause is Alkali Silica reaction, proposed by one expert who observed this damage in older buildings pre-1980s. However, literature suggests this damage is mostly found in civil structures, hence it is not considered for this study. The cause with specials, where boundaries of standard solution are crossed, is also not in the list as it is given by one expert and not validated through literature or the database.

Two causes were proposed by one expert and some information was available in literature: issues with NEHOBO floors and insulation of existing buildings. However, these are not highlighted in assessment methods like NTA 8790 or VDI 6200 and lack concrete data on the extent of the issues. The literature available for the NEHOBO floors is a site for an inspection firm and with the isolation there is an interview with an insulation expert available. As the extent of the problem does not become clear, both causes are not included in the study.

In addition, two causes were only mentioned as attention points in NTA 8790. As these causes are not validated via experts or the database, they are also excluded from the list.

The final cause, unconnected fall protection, is proposed by an expert and highlighted as an attention point by the KPCV. Given its mentions in two different validation sources and its presence in the KPCV list, which includes other validated common causes, this cause is included in the final list.

The validated list of common causes for structural failure incidents in section 4.1, include:

- Incompetent renovation.
- Change in use.
- Incorrect appliance of MuWi floors in schools.
- Incorrect detailing or insufficient reinforcement in corbel connections for prefab beams to column connections.
- Fall protection not connected or insufficiently assembled.

This addition to the list concludes the validation process for common causes of structural failure incidents in the Netherlands for this study. It should be noted that this list is a preliminary attempt due to the lack of a national database for incidents and varying working conditions among experts. The limited information available in literature due to the reluctance of owners and other parties to publicise such incidents further complicates the process. Future studies are required to refine this list and provide more detailed information on each cause.

In addition to the common causes, more general attention points were identified throughout this chapter. These are not included in the list of common causes but are incorporated into the attention points discussed in section 4.2.

# E. Details for causes

This appendix provides a detailed examination of the common causes identified in section 4.1, utilising the database to discern patterns and incorporating supplementary information form appendix D. The required data, as outlined in subsection 4.1.3, encompasses building typology, age, critical structural components, their vital locations, extent damage and the responsible parties. Section E.1 delves into the pattern analysis of the database which subsequently informs the details presented in section E.2. This section also offers a more detailed review of the mandatory investigations and references additional documents containing available investigations.

## E.1 Investigation patterns database

To investigate patterns within the database, multiple cases with corresponding information must be available for the cause. Causes five and six cannot be studied as there is only one case available see table d.2. In the table there can also be seen that, in general, little cases are available for this study. This makes it difficult to discover any patterns. This is the reason that any information solely based on this stud is within yellow marked cells in section E.2. In future studies this information must be further validated and adapted.

Age categories are assigned to the incidents considered, to retrieve further insight into the age of the building the moment the incident occurred. The following categories are used:

- 0 – 5 years
- 5 – 25 years
- 25 – 50 years
- > 50 years

The date, age and age category for the structure at the moment the incident occurred, is sometimes estimated via the date of the Cobouw article. For the building types, the defined typologies from chapter 3 are used.

In case of the responsibility, it is difficult to truly state who is responsible for which common cause. However, in the database, there is stated what kind of error is made (Develi, 2020):

- Design error
- Construction error
- User error
- Combination
- Other, also with force majeure
- Unknown

These error types are thus available and do state something on the responsibility of the cause. In the future more studies can be performed to get a more exact overview on the responsibility.

In the database by Terwel and Develi there also is a five-level scale used to describe the extent of the damage. This extent of damage is also used in this study. From significant to no extent of damage, the following scale is used (Develi, 2020):

- (Partial) collapse ((P.) c.)
- Structural damage (S. d.)
- Material deterioration (M. d.)
- Insufficient functionality (I. f.)
- No consequences (N. c.)

Below the common causes are examined for patterns on the required details stated above.

**Cause 1: Difference design and completed object, 18 causes available**
Within these cases, there are four mentions of apartments or single-family houses and 3 within the building type other. In conclusion, for some building types two mentions are available, but overall there is no clear pattern for this problem. The same accounts for the completion date, with at max three mentions for 1996, and the age of the structure as there is no double mention. Here the relevance of the age category becomes evident as a better indication of the age within these cases can be obtained. For the group 0 – 5 years there are 8 cases, which is followed by the 5 – 25 category with 5 cases. At last, there is the 25 – 50 group with four cases. There are no cases with structures older than 50 years old. In conclusion, most cases are present within the first years after completion.

When looking at the structural elements stated in these causes, the most are façade panels, with five mentions, and to be specific the connection of these panels. There are also four cases where there was a difference in the supports of beams or columns. No vital locations are found for these problems.

But what is the severity of the incidents within this cause? Most cases, eight to be specific, have structural damage as a result of the incident. In six cases this causes resulted in (partial)collapse. For these cases, three consisted of façade panels. At last, in 15 of the 18 cases the described error type is construction. In the other cases the error type is unknown. As in most cases the cause was a construction error, this is seen as the applicable error type.

**Cause 2: Chloride damage concrete, 8 causes available**
Within these 8 causes, there are four apartment building types and two swimming pools. There are three possible manners in which the chlorides could be present in the structure (as found in literature and the database):

- Admitted in concrete mixture to speed up hardening process.
- Via de-icing salts.
- Chloride environment in swimming pools.

The admittance of chlorides in the concrete mixture is mentioned in 4 of the 8 cases. In three of these cases Kwaaitaal floors were the cause. These floors were present in educational, single-family house and swimming pool building types. These cases thus also show that Kwaaitaal floors could be available in CC2 buildings. In the remaining case it was a balcony within an apartment complex.

For the chloride admittance in the concrete mixture, there are three completion dates in the period 1970 – 1975 and one in 1950. Not a lot can be said about the age categories except for the fact none are found within 0 -5 years after completion.

In three other cases, the chlorides were present in the galleries of apartment buildings. It is assumed the source of these chlorides is de-icing salts. For the completion date and age of the structure, no patterns could be discovered. At last, there is one case available for the chloride environment in swimming pools as a column was affected.

But what about the error types for the different types of chloride damage? For the admixture in most cases a construction error was listed. In one case for a Kwaaitaal floor it was marked as a design error, but in general for this chloride type of damage is seen as a construction error.

For the use of de-icing salts on balcony/gallery floors, the error is with the user. In one case it is also seen as design as the cracks make it easier for chloride to penetrate. However, the use of de-icing salts on structures is seen as an user error. For the swimming pool case there is listed that the error type is unknown. Thus, for this final category no conclusions regarding the error type can be taken.

Overall, there can be seen that chloride-initiated damage to concrete is not present in the years 0 – 5 after completion. In most cases, the period of 25 – 50 years is valid. However, in one case it was discovered for a 23-year-old which is just outside this period.

When considering the extent of the damage, there are four cases resulting in structural damage, two cases with material deterioration and two cases which resulted in (partial) collapse.

**Cause 3: Incorrect wind calculation, 4 cases available**
Four cases make it difficult to retrieve any funded patterns. However, for these four cases, three of them occurred in office buildings. Looking at the structural components, all cases consist of panels, three for the façade and one for the roof.

Looking at the time aspects, there are three cases, with completion dates 2001, 2002 and 2003, which all collapsed within 0 – 5 years after completion. The other case comes from 1987 and was within the 25 – 50-year category.

For the severity of the incidents there is again the 3:1 distinction with three cases of (partial) collapse and one case with no consequences. As the wind calculation is performed in the design, it is in line with expectations that three of the four cases are marked as a design error. For one case the error type is marked as other, as the surroundings changed over time.

**Cause 4: Degradation timber foundation piles, 5 cases available**
With only five cases, the same difficulties apply as mentioned in the previous paragraph. However, in this case there is no pattern detected for building types. There are three residential buildings mentioned for which one apartment complex, the other two are unknown.

The dates validate the information in literature that till 1970 these types of piles where used (RVO, 2019). 1950 is the last known case in the database, followed by 1930, 1620, 1500 and one case for which it is unknown.

This also shows that in three of the five cases the building was more than 50 years old the moment the incident occurred. Four of the five cases had structural damage and in one case there was a (partial) collapse. As this cause is about degradation with buildings being older as 50 years, in four of the five cases the error is applicable to the user. In one case it is marked as a construction error.

**Cause 7: Higher permanent load on/lower position of the upper reinforcement in (external) cantilevering floors, 5 cases available**
In this case there is already quite some information available in literature as also a mandatory investigation to this cause is required. This problem is solely applicable for residential and to be specific, apartment buildings. This comes back in the database with 4 of the 5 cases being apartments and the remaining one being housing unknown.

This cause can have its origin in the loading not complying to the building codes or the too low carrying capacity of the structure. For these phenomena, three causes are given in the database. In the other two cases the depth of the reinforcement was the cause of the incident.

The completion date is unknown for three cases, the other two cases have a completion date of 1960 and were 57 and 53 years old when the incident occurred. These dates are within the applicable time period of 1950 – 1970 given in literature.

The structural components involved in the cause are in three of the five cases balconies and in two gallery floors. The four to one ratio also applies to the extent of damage, with four being structural damage and one being insufficient functionality.

At last, for the error type there is no pattern to discover. In two cases the type is unknown, two are given as other and one is a construction error.

**Cause 8: Corrosion steel support structure balconies, only two cases available**
For this cause it is again difficult to retrieve any funded conclusions as only two cases are available. It is noted that these cases consider a considerable number of balconies. In one case the considered buildings are, as expected apartments. In the other case there is stated it is housing unknown. In this case literature is followed as it is about balconies, the common building type for this cause is characterised as apartment.

There is one case where a time element is involved, namely a completion date of 1950 and 86 years old when the incident occurred. This later as the time period mentioned in literature, which is until 1945. As this source only considered balconies in Utrecht, there is chosen to apply a broader time period. This is also done as at this moment in time, there is little information available on the cause.

For the building component, the pattern is obviously balconies and the extent of damage fluctuates from (partial) collapse to material deterioration.

As this is a case of degradation and one case is clearly over the design life of 50 years, it is logical that both cases are marked as a user error. This error type is also considered in this study.

**Cause 9: Connection balconies, 5 causes available**
For this causes, there are three cases involving apartment buildings, one case involving a hybrid building and an unknown building type. There are three completion dates available, two in 2002 and one in 2000. The age of the buildings when the incidents occurred are two or three years, falling in the 0 – 5 age category. These cases thus happen rather early on in the use phase.

What is the problem to the connection that led to the incident? In one case the anchorage was missing and in another this was the case for the reinforcement. When the anchorage is present, there was still one case where the anchorage did not attach to the load bearing structure. Next to the anchorage, the suspension of the balcony was also miscalculated in one case. In the last case, the thin sheet balconies are slightly bending.

This variation in origin of the problem also comes back in the extent of the damage. In total, there is one case with no consequences, one case with insufficient functionality, two cases with structural damage and one case with (partial) collapse. In addition, no patterns can be discovered for the error type as it is marked as unknown in three cases. For the other two cases, there was one design and one construction error.

**Cause 10: Corrosion steel in swimming pools, 13 cases available**
The impact of a chloride environment in swimming pools on concrete is already covered within common cause two. However, this environment also has an impact on steel and in specific stainless steel. This cause also considers the mandatory investigation to stainless steel suspensions for ceilings within these building. This comes back in the database, where all cases consider the ceiling of swimming pools and most the suspension. The completion dates in the database vary between 1992 and 2000, resulting in age categories 0 – 5 and 5 – 25 for when the incident occurred.

The majority of the cases, eight in total, resulted in a (partial) collapse, followed by one case of structural damage and three cases with material deterioration. The case where structural damage occurred had more to do with an ill constructed ceiling suspension.

The error type for this cause was marked as other in nine cases. For the remaining cases, two were marked as unknown, one as a design error and the final case as a construction error. Thus, no pattern can be discovered for this aspect.

**Cause 11: Overloading roof due to water accumulation, 16 cases available**
The first pattern that is discovered for this cause is the fact that in 15 of the 16 cases, the roof was constructed with steel/metal. In the other case the material type was not known. This coincides with the statements by VROM which indicates that light plat steel roofs are at risk for this problem.

When looking at the building types, commercial buildings are dominant with seven cases. These are followed by hybrid building types with among others office and retail, both types considered in three cases. There are two cases which involved swimming pools. For the last case the building type was unknown just as any information on the time aspect. The other buildings are within a completion date of 1977 – 1992 and are within the age category 5 – 25.

The problem of water accumulation has three different origins in the database, namely:

- No/too small/insufficient/too high emergency drainages (7 cases).
- Too little slope in roof (4 cases).
- Stiffness roof (4 cases).

At last, there is one exception as the origin is the capacity of the sewage. All the cases resulted in a (partial) collapse of the building. The error type can be seen as design as it is mentioned in 11 of the 16 cases. For the rest of the cases there are three case unknown, one case other and one case as a combination.

**Cause 12: Overloading roof due to snow accumulation, 6 cases available**

The building types for roofs having problems with this cause are more varied as for the water accumulation. There are two commercial and two retail buildings mentioned. In addition, there are two building types marked as other (sport and logies). For the date and age not a lot can be said as this is unknown in most of the cases. The same accounts for the materials, with the exception of two roofs which are constructed with concrete.

The extent of damage does show the same pattern as water accumulation with five cases of (partial)collapse and one case of structural damage. In four of the cases there is mentioned that the roof collapsed under snow loading. In two cases there was specifically mentioned the snow blocked the drainages which caused snow and rain to pile up.

Three of the cases related to snow accumulation are specified to load and thus seen as a design error. In one case the user is at fault as the drainages where blocked. At last, there are two cases for which it is unknown. As the two cases are unknown, the collapse due to snow accumulation is mainly attributed to a design error. However, a distinction is made for the blocked drainages, as this is an user error.

**Cause 13: Problems with wall ties in façade, 13 cases available**

In the database the building types for this cause mainly have a residential function. There are two cases for other type of buildings and two cases for which it is unknown. For the residential functions, there are three cases of hybrid buildings, with the inclusion of office, retail, commercial, education and parking. Then there are also five cases which solely included apartments and three cases of single-family houses. In two of these last cases, the oldest completion dates, being 1930, were present. The corroded wall tie was then also detected as the buildings were 75 years old. This corrosion was mentioned in three more cases, two being apartment buildings and one hybrid building. Almost all of these buildings were over 50 years old, except for one case where the building was exactly 50 years old. Three of the cases were in IJmuiden and three in the Hague, all semi to close to the shore.

Besides the corroded wall ties, there are two mentions of too short wall ties, three mentions of too little wall ties, three cases of insufficient stiffness in the façade and two cases where the wall ties did not suffice or the connection was not okay. At last, there were two cases where the anchors were incorrectly fixated in the façade.

The number still adds up as in one case both the wall ties were insufficient and they were not fixed properly. In the cases mentioned above, there is more spread in the building types with three apartments, two hybrids with apartments, three other type of buildings and two cases for which it was unknown.

In case of the stiffness of the façade, there are two cases of a four-year-old building, this within the category 0 – 5. However, no real pattern can be discovered. In the other cases there is a significant spread from eight to 47 years old or even older buildings. The completion dates range between 1965 and 2010.

In total, the (partial) collapse is most present as it occurred in nine cases, with structural damage coming second with six occasions. There is one case which only resulted in insufficient functionality. This shows the extent raises between structural damage and (partial) collapse for most cases. Moreover, it is clear that most case shave a residential function.

In six cases the error type is marked as construction, in three as design, in two as user and for one as the other error type. At last, there were four cases where the error type is marked as unknown. The construction error is marked in cases of too short, incorrectly fixated, corroded or even no wall ties present. In case of the design error, in one case the wall ties were too short and in two the stiffness was the problem. The user error is mainly due to the lacking maintenance of the wall ties. In conclusion, the construction error is featured in most of the cases, but if the origin lies within bad maintenance, it should be marked as a user error.

**Cause 14: Façade panels letting go, 14 cases available**
For the façade panels letting go there are a few more specific causes which are listed in the database. In three cases the façade panels were not assembled properly, which could be due to the anchorage of the panels. There are two cases for which the glue of the panels was the main problem and one were the connection of the anchor or bolt was not correct. Then there are four cases where the load bearing capacity of the panels, due to the wind, is the problem. At last, there are three cases were the carrying system corroded which is marked as decay/degradation.

Looking at the building types, the category others is present with four cases and the offices are present in three cases. There are also three hybrid buildings which also include an office function. In addition, there are three apartment buildings plus commercial retail and educational buildings which are each featured once.

For the completion dates there can be seen that there are two cases which are significantly older, being 1963 and 1973. Both of these buildings were in their forties when the incident occurred. The other cases are closer together, being in the period 1999 – 2008. Except for the two older cases, almost all cases are within 0 – 5 years after completion.

When looking at the structural components, it is not only façade but also roof panels that must be considered. In twelve of the fourteen cases the cause resulted in a (partial) collapse. This is thus seen as a pattern for the extent of the damage. For the error type there are five design errors and six construction errors. In addition, there is one case of user error and two cases of unknown errors. Both the design as the construction error is thus listed in the table in subsection E.2.1 as a pattern.

**Cause 15: Glass fracture in façade and roof panels, 8 cases available**
The glass fracture is mainly present in office buildings (5 cases). In addition, there are also two hybrid buildings which have a combination of office, apartment and parking in one case and apartments with retail and parking in the other. At last, there is one case where a cinema, ranked as an other building type, had this problem.

Looking at the completion dates, all cases are within the period 1991 – 2007 and fractured within the first ten years after completion. Five of these cases even broke in the first two years after completion. The time period could have something to do with the appliance of hardened glass. In the database all cases are about façade panels and the extent of the damage in six of eight cases is (partial) collapse. In addition, there is one case for structural damage and one for insufficient functionality. So, the (partial) collapse is listed as the pattern for this cause. The pattern for error type is clear, as six of the eight cases are marked as construction. For the other two cases it is unknown.

**Cause 16: Dilatations, 10 cases available**
The problems with dilation could have multiple origins, as already stated in the cause, the dilatation could be filled, too small or even missing. Within the building types, two are featured more as the others as they both have three cases. These types are the office and apartment buildings. There are also two hybrid buildings in the database, where for both apartments were present.

In the completion date no real pattern can be discovered, except for the fact that after 2010 no problems with dilatations are listed. Most building, five out of ten cases, where within 5 – 25 years after completion when the incident occurred. There are no listings for buildings older as 50 years.

Looking at the structural components, the masonry façade wall is mostly present with 6 cases. There is also one mention of a façade panel. The extent of the damage varies between insufficient functionality in three cases to structural damage in four cases and (partial) collapse in two cases. In the error type there is a spread between the design with four hits and the construction which is mentioned five times. The other case is marked as an unknown error type. As both types are almost equally mentioned both are seen as a pattern. In case of construction, in four of the five cases its origin is the filling of dilatations.

**Cause 17: Corrosion connectors prefab concrete, 3 cases available**
The fact that only three cases are available makes the conclusions, regarding patterns within these cases, less reliable. For future studies, additional cases are required to retrieve more sound patterns. In all three cases, the spandrels are the structural component with the problem. However, an expert mentioned bolts were even more problematic than the reinforcement connection.

In two cases the apartment building type is featured, the other case is a hybrid buildings including apartments. There is only time information available for two cases for which one is completed in 1960 and one in 1970. The first case was 37 and the other 40 years old when the incident occurred. The extent of the damage varies from material deterioration to (partial) collapse. With the three cases available, there are two marked as unknown errors and one as construction. Thus, no pattern can be discovered.

**Cause 18: Settlement foundation, 9 cases available**

If looking solely at the database, the settlement mainly occured for buildings with a residential function as 3 single family houses and 3 other mentions of dwellings are given. There are two other type of buildings and one commercial buildings. The pattern could be residential, when only considering the database, but this cause can happen to any kind of building. There is also some variety in the completion date of the buildings affected by settlement, as some buildings are of the 19th century. What is important to note is that there are no cases available for buildings later as 2001.

This spread in completion date also comes back in the age of the building when the incident occurred. In some cases, problems arose within the first five years after completion and others when well over 50 years old. When looking at a more common element group for this cause, the foundation is mentioned most with six cases. Two of these cases are shallow foundations and one had a pile foundation. For the others it is unknown which foundation type was damaged. There are also two mentions of floors and one about the floor as well as the façade and the window. At last, the extent of the damage is mainly characterised by structural damage as this is featured in eight of nine cases. There is thus one deviating case as in this case the settlement resulted in (partial) collapse.

But what caused the settlements in the database? This could be to the soil type like peat or clay, as mentioned three times in the database. Then there are two cases where settlement occurred due to nearby construction. In one case a sewage pipe broke and in another the floor was not self-supporting, but poured on soil which settled over time, resulting in damage. Change in weight can also cause settlement as stated by one case where the timber floor was replaced by a concrete floor. This change in flooring caused settlement of the building. At last, there is one case where there is stated that the soil under the ground floor settled, resulting in damage.

There is no pattern within the error types of this cause, as there are three marked as other, three unknown, two construction and one design.

All hypothetical causes listed in the initial list are covered in the aforementioned text. The following cases came up during the validation process in appendix D. These causes could come from the database, which means cases are available for this study. However, the causes could also originate from the interviews with experts or other literature. In these cases, less information could be available in the database to draw any conclusions.

**Cause 19: incompetent renovation, 3 cases available**

These three causes are too little to retrieve any funded conclusions for the required information. Still an attempt is made in this paragraph. This lack of information is already seen in the building types as there are three different types listed.

Looking at the time aspect it is marked as unknown for most of the cases. What can be seen is that one structure is 379 years old and still collapsed due to an incompetent renovation. In another case the structure was 20 years old when it happened. In all three cases a wall was part of the renovation. In two cases a wall was removed which led to damage or collapse. In the other case the wall degraded due to the renovation. Next to a wall, in one case also a column was removed.

In two of the three cases the incompetent renovation led to structural damage and in one case to (partial) collapse. At last, for the error types two of the three cases are marked as a construction error. The other case is a design error, as a load carrying wall was incompetently replaced by a carrying beam and non-load bearing wooden wall. For this cause, there is too little information available. So, both the construction and design error are listed are listed in the details.

For causes 20 and 21 there is no information available in the database. In case of cause 21, this is logical as the problems with the MuWi floors in school have been detected in 2023, while the database goes up to 2018.

**Cause 21: Problems relating to corbels parking garage, 2 cases available**
In the database the incident for the Bos and Lommer Plaza in Amsterdam is listed for this cause. In the half-jointed connection, there was too little reinforcement available, while it was on the drawing. In addition, the loading was eccentric instead of centric. This generated a higher load on the element than calculated in design. The building in question is categorised as a hybrid, consisting of apartments, retail and parking. The half joint which failed was located in the parking garage of the building.

The experts also listed the parking garages as the main building type for this cause. In this case, the structure from 2004 was 2 years old when the incident occurred. This half joint was present at the column support of the beam, which coincides with the statements made by the experts. In case of the Bos and Lommer Plaza the incident led to a (partial) collapse. As the experts stated that first cracks occur in most situations, the range is set from structural damage to (partial) collapse.

The last cause, considering fall protection, is also not present in the database.

## E.2 Details for common causes

The results of the study performed in the section above, are combined with the information from the validation study in appendix D to retrieve the required details on the common causes. Next to these details, in this section the mandatory investigations are closer examined and more available investigations are referenced.

### E.2.1 Specifications sub-questions for structural failure incidents

The specifications are divided over two tables to provide a clear overview. As there is too little information available at this moment in time, in reality, these causes could also divert from the specifications listed in this subsection. In future studies these specifications must be studied to better reflect the real-life situation.

First the building typology, the age and the critical structural components are presented in table e.1. The defined building types from chapter 3 are used in this cause specification. The category hybrid buildings are also considered. if the building type in the table is part of this building, it must be accounted for.

For the age aspect, also the completion date could be presented as some of the causes are specific to buildings realised within certain time periods. It could also be possible that an age period is given, for instance the period 0- to 5-year-old.

If somewhat of a pattern is discovered in the database examination and no further information is available in appendix D to validate, this pattern is portrayed in a yellow marked cell. As there is only a limited number of cases available for each cause, these patterns alone could not provide a sound information. If no information is available for the cause specification, the cell is left blank.

Within table e.1 no references are given as it is a summary of the information presented in section E.1 and appendix D. When new information is obtained, this is first referenced in the text below and then given in the table. In some cases, some new information is obtained which is referenced in the text below and then stated in the table. In this text only the sections that require extra explanation are discussed.

Requiring more explanation is the time period posted for cause two. In case of chloride inclusion in the admixture of concrete, KPCV stated (see appendix D) that a time period of 1965 – 1983 is hazardous for Kwaaitaal and Manta floors. However, via the interviews with experts, it became clear that all prefab concrete in the period 1962 – 1980 could contain chlorides within in the admixture. For this study, a period of 1962 – 1983 is chosen to encompass both claims.

In addition, de-icing salts or certain cleaning products could also cause chloride damage to concrete and are mainly used on gallery and balcony floors. As stated earlier there is a mandatory investigation for monolithically connected cantilevering gallery and balcony floors. The applicable document for this investigation is the CUR 248, which is closer examined in subsection E.2.2. This document also provides a time period of 1950 – 1970 for these floors to be investigated (De Jonker et al., 2014). However, the use of de-icing salts and cleaning products could also affect floors not realised within this time frame.

To remain within the time period specification, for cause four there is also additional information regarding the timber piles. It turns out that the timber piles were used up to 1970 in the Netherlands (RVO, 2019).

There is also extra information for cause six, as a mandatory investigation must be conducted to this cause via (Wijte, 2019). In this source there is advised to mainly inspect non-residential buildings realised after 1999. More information on the mandatory investigation in the next subsection. There is a discrepancy between the TNO, stating that the cause is applicable up to 2017, and NTA 8790, stating it is applicable until 2019. As the NTA is the newest source available and a wider range is more conservative, the 2019 date is applied in this study.

The last mandatory investigation document for swimming pools, is only related to hanging constructions and fastening systems (NEN, 2015b). However, experts state all steel within this environment could be at risk of chloride-initiated corrosion. All the steel components are thus considered in cause 10.

For cause 11 a flowchart is made available by VROM for inspection (VROM Inspectie, 2003). In this source no dates are given, but the flowchart does states that lightweight plat roofs with steel construction are part of the danger. The flowchart for water accumulation could be of good use for the inspection to this cause. In the source the following building types are mentioned as vulnerable: Commercial, sports and swimming pools (VROM Inspectie, 2003). In the database offices and retail also come forward and are thus included.

The causes of snow and water accumulation are often considered at the same time which means a lot of factors are the same for causes 11 and 12. However, some experts also stated other type of roofs like inclined roofs which are connected to higher building parts can cause problems for snow accumulation. Drainage is also a critical component as the snow can cause blockages which makes it impossible for incoming rain or melt water to exit the roof. The connections are also an important structural component for this cause, see appendix D.

For cause thirteen there is also a risk-based assessment available via SBR. However, no specifications can be obtained via this source. The same applies for the use of glue in facades, being part of cause 14. There is a document available to check the glue (van Beek- van der Toorn et al., 2022), including some helpful boundaries for inspection, but no specifications for the tables.

In cause sixteen, considering the dilatations, the database shows that the outside façade wall mainly forms the problem. However, experts also state that other parts of the structure where significant thermal changes can occur are critical. An example of such a component is a load bearing concrete beam a in open parking garage. In addition, to the thermal changes, these dilatations are also exposed to the outside environment, resulting in degradation or filled dilatations.

Table E.1: Details building typology, age and structural components for common causes

| No. | Building typology | Age/Time period | Critical structural components |
|---|---|---|---|
| 1 | - | Most cases 0 – 5 years old<br>All within 50 years old | Façade panel<br>Beam - column support |
| 2 | Apartments<br>Swimming pools<br>Parking garages | Prefab concrete:<br>1962 – 1983<br>Balcony and gallery floor:<br>1950 - 1975 | Balcony and gallery floor<br>Kwaaitaal and Manta floor<br>Consoles and other prefab parts |
| 3 | Offices | 0 – 5 years old | Façade/roof panel |
| 4 | - | Up to 1970 | Timber foundation piles |
| 5 | - | 1970 - 1980 | Floors prestressed without bond |
| 6 | Non-residential | 2000 – 2019 | Plank floor |
| 7 | Apartments | 1950 – 1975 | External monolithically connected concrete balcony and gallery floors |
| 8 | Apartments | 1850 – 1950 | Steel consoles |
| 9 | Apartments | 2000 – 2005<br>0 – 5 years old | Balcony |
| 10 | Swimming pools | 1992 – 2000<br>0 – 5 and 5 – 25 years old | Hanging constructions and fastening systems.<br>All steel present |
| 11 | Commercial<br>Retail<br>Offices<br>Swimming pools<br>Other | 1977 – 1992<br>5 – 25 years old | Lightweight flat roofs (Steel/metal) and free span plates without beams. Emergency drainage, slope, strength and stiffness roof |
| 12 | Same as cause 11 | - | Same as cause 11 but can also be inclined roofs, |

| | | | |
|---|---|---|---|
| | | | drainage and connections structural parts |
| 13 | Most cases residential | Corrosion ≥ 50 years old<br>None later as 2010 | Outside masonry wall with wall ties |
| 14 | Most cases non-residential, mainly office and other<br>In 3 cases apartments | 1999 – 2008<br>0 – 5 years old | Façade panel<br>Roof panel |
| 15 | Offices (5/8)<br>Apartments (2/8) | 1991 – 2007<br>0 – 10 years old | Glass façade panel<br>Glass roof panel<br>(Hardened glass) |
| 16 | Apartments | Not after 2010 | Façade wall and other locations where structure exposed to significant thermal changes |
| 17 | Apartments | 25 – 30 years old | Spandrels<br>Also bolts |
| 18 | - | Until 2001 | Foundation |
| 19 | - | - | Load bearing walls, columns and recesses |
| 20 | - | - | - |
| 21 | Schools | 1951 – 1973 | MuWi Floor |
| 22 | Parking garages | - | Prefab beam-column connection via corbel<br>Half joint |
| 23 | Residential and non-residential | - | Fall protection<br>Railings<br>Balustrades |

Table E.2 provides the other part of the details, being the vital location, error type, extent of the damage and final remarks. Here the same statements as for the aforementioned table apply. In the vital location column, there is checked if there are any specific locations present within the building that are most critical for the applicable cause. If such a location is present the assessment can be performed in a more efficient and effective manner. The error type and extent of the damage categories mainly originate from the database and are thus mostly marked yellow. If additional information is required for the table, this is presented in the paragraphs below.

In cause three and four, the experts provided information on the vital location. The corners of the façade and the change in surroundings are both factors listed by these experts, along with the dropped ground water table, see appendix D.

For cause five and six too little information is available in the database. For these causes the information via literature and experts is used. Via these sources it became clear that when the prestress cables of the floors in cause five failed, it is still unlikely the floors collapses. So, the extent of the damage is set to structural damage. In one case this cause did result in (partial) collapse. Moisture entered during construction leading to corrosion of the cables. This entrance of moisture during construction is marked as a construction error.

However, if moisture enters during use, it is attributed to the user. That is why both error types are selected.

The problem relating to the seams of plank floors also has one case, which is attributed as a design error. This is also considered in the table as the faulty designed detail is the cause of these problems. For the extent of damage, a wide range is selected. In the case of the database, being the parking garage in Eindhoven, there was a collapse. However, multiple experts stated that there were also a number of buildings with no consequences, while this detail was present.

In cause seven cantilevering floors are discussed. The higher load on or the lower position of the reinforcement leads to cracks near the connection on the upside of the floor, as here the highest bending moment is present. That is why this location is given in the table. The critical location from cause eight comes from the experts which address the fact that near the façade, the steel consoles come into contact with most moisture. For the swimming pool there is a mandatory inspection document is available for ceiling structures. Experts state that this document provides good coverage for that aspect. What could be of interest is the basement, the facades, the dressing rooms and other steel constructions in these buildings.

As cause fifteen is about the fracture in glass panels, the locations where the thermal changes are the highest, are most important. However, this problem could also be about Nickel Sulphide inclusions, meaning that the other facades cannot be regarded as completely safe. The same accounts for cause 16 regarding the dilatations. In this cause not only the façade but also other dilatations within the structure must be considered. In addition, dilatations exposed to moisture/the outside environment are also important.

For the causes twenty and onward there is no information available in the database, the information in the cell is thus partly estimated. Firstly, for the change in use the vital location is where the change of use leads to higher loads on the structure. This cause is also specific to a design error as loads could be miscalculated. However, the user error is also applicable, as a higher load than prescribed could be applied on the structure. For this cause the extent of damage is set from no consequences to (partial) collapse.

With cause 21, considering the incorrect placement of MuWi floors in schools, the storey floor is most important. The error type is clear as the placement is a construction error. As pieces of these floors came down, but the floor itself did not collapse, the extent is set to structural damage.

The detailing of the reinforcement in the corbel (cause 22) could be both due to design, in case no correct detailing, or construction, if not placed correctly in the corbel. The extent of the damage of the wrong detailing is set to no consequences to (partial) collapse. As in literature nor by experts anything is stated on the location, this specification is not mentioned.

In the last cause no specifications regarding the location are available. Most critical is at great height and on the outside of the building, being more exposed to the outside environment. For the error type both construction as user are given as it could be not well connected or coming loose due to degradation. This cause could range from insufficient functionality to (partial) collapse.

Table E.2: Details vital location, error type, extent damage and other for common causes

| No. | Vital location | Error type | Extent damage | Other |
|---|---|---|---|---|
| 1 | - | Construction | S. d. – (P.) c. | - |
| 2 | Moisture and oxygen present.<br>Kwaaitaal and Manta mainly ground floor | Admixture: Construction<br>De-icing salts and cleaning products: User | M. d. – (P.) c.<br>Most S. d. | Concrete coverage reinforcement |
| 3 | Corners façade and roof more suction.<br>Change in surroundings | Design | (P.) c. | - |
| 4 | Dropped ground water table | User | S. d. | Can detect when see cracks in building |
| 5 | - | Construction<br>User | S. d. | Could use high water pressure to chip concrete to inspect cables |
| 6 | Primary load direction via seams floor and coupling reinforcement loaded in tension | Design | N. c. – (P.) c. | - |
| 7 | Upside floor near the façade wall | - | S. d. | - |
| 8 | Close/almost in façade | User | M. d. – (P.) c. | At location most exposed to moisture |
| 9 | - | - | N. c. – (P.) c. | - |
| 10 | Ceiling covered, more about basement, facades, slides, etc. | - | M. d. - (P.) c. | All steel in chloride environment swimming pool is risk |
| 11 | - | Design | (P.) c. | - |
| 12 | Where snow can pile up against higher building parts | Design<br>When blocked drainage: User | (P.) c. | - |
| 13 | Closer to shore more influence corrosion | Mainly construction<br>Bad maintenance: User | S. d. – (P.) c. | Not only corrosion also insufficient/too short/incorrect application ties |

| | | | | |
|---|---|---|---|---|
| 14 | Could also be corners roof and facade as here more suction wind | Construction/Design | (P.) c. | Glue<br>Anchors<br>Coating<br>Assembly<br>Moisture and corrosion |
| 15 | Façade with highest thermal fluctuation | Construction | (P.) c. | - |
| 16 | Highest thermal fluctuations, exposed to outside environment | Construction (mainly with filling)<br>Design | I. f. – (P.) C. | - |
| 17 | - | - | M. d. - (P.) c. | - |
| 18 | (Difference) soil type, nearby construction work, Leaking pipes under foundation | - | S. d. | Cracks structure/façade could be sign of foundation problems |
| 19 | - | Design<br>Construction | S. d. – (P.) c. | - |
| 20 | Where load increased | Design<br>User | N. c. – (P.) c. | - |
| 21 | Storey floors | Construction | S. d. | - |
| 22 | - | Design<br>Construction | N. c. – (P.) c. | - |
| 23 | Great height and exposed to outside environment | Construction<br>User | I. f. – (P.). c. | - |

### E.2.2 Reference applicable documents for causes

As can be seen in the subsection above and appendix D, for some of the causes there are already inspection documents available. To provide a complete overview, the documents that were found during the study to these causes, are listed in this subsection.

This is in particular important for the three mandatory investigations. The documents which can be used for these mandatory assessments are given below:

- CUR 248 (De Jonker et al., 2014), investigation to monolithically connected cantilevering balcony/gallery floors. Covers cause seven and partly cause two.
- Source (Wijte, 2019), for the investigation of plank floors with primary loading across the seams. This is the document for cause six.
- The NPR 9200 (NEN, 2015b), for metal hanging constructions and fastening systems in swimming pools. This document partly covers cause ten.

There is quickly highlighted in which circumstances, these mandatory investigations must be performed. Most of the information is already given in table e.1.

In the CUR 248, there is stated that mainly the monolithically connected exterior cantilevering floors for apartment buildings within 1950 – 1970 expose a risk, see figure e.1. For this cause both gallery as balcony floors must be checked.

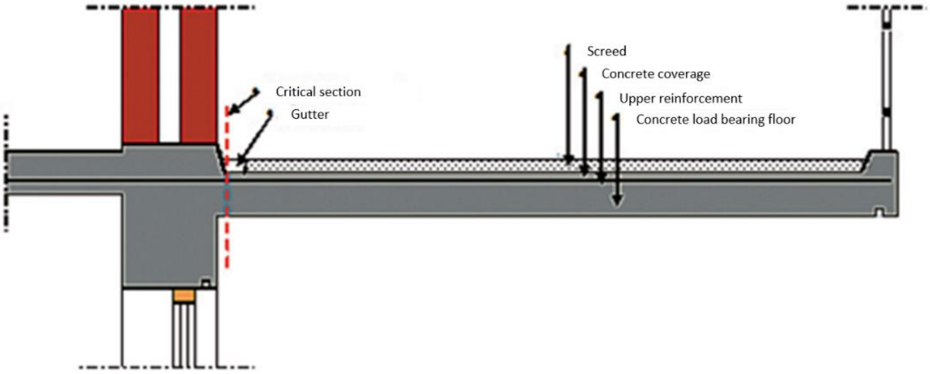


Figure E.1: Monolithically connected cantilevering floor (De Jonker et al., 2014)

For the problematic detail within plank floors for cause six, there is also an example given in figure e.2. By checking the drawings for this detail and use the information in table e.1, there can be decided if a mandatory investigation is required.

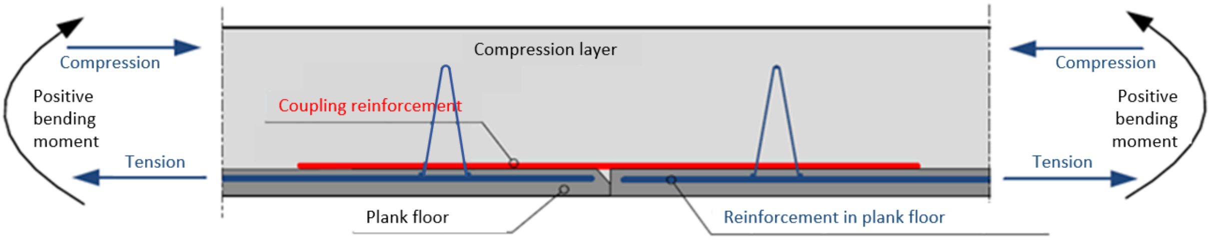


Figure E.2: Detail with problem for plank floors (Wijte, 2019)

In the interviews with experts, it became clear that the mandatory investigation to the ceiling structures of swimming pools has already been performed. However, as it is a mandatory investigation it must be investigated via the NPR 9200 if suspected to be present. This investigation is partly considered in cause 10 as it is about hanging constructions and fastening systems in swimming pools. The NPR states that an inspection provides indication of the following hazardous situations (NEN, 2015b):

- Collapse of materials which can possibly lead to (sustaining) injury.
- Non-resistant stainless-steel hanging construction which are loaded dynamically or in tension (in chloride environment).
- Heavily corroded unalloyed steel with significant volume increase/decrease due to corrosion.

If a swimming pool is to be inspected, the NPR should be reviewed to check if any of the risky situations are present. When these issues do not arise for the hanging constructions and fastening systems, the NPR helps in providing the conclusion all is clear.

Besides the mandatory investigation documents, for other causes there are also documents available that can aid in the assessment. These documents could, for instance, be used to determine how to further investigate the cause when detected and evaluate the risk. The documents are listed, along with the applicable cause, in table e.3. These are only the documents that came up during the studies to these causes. Future investigation must be performed to check if there are any other documents available.

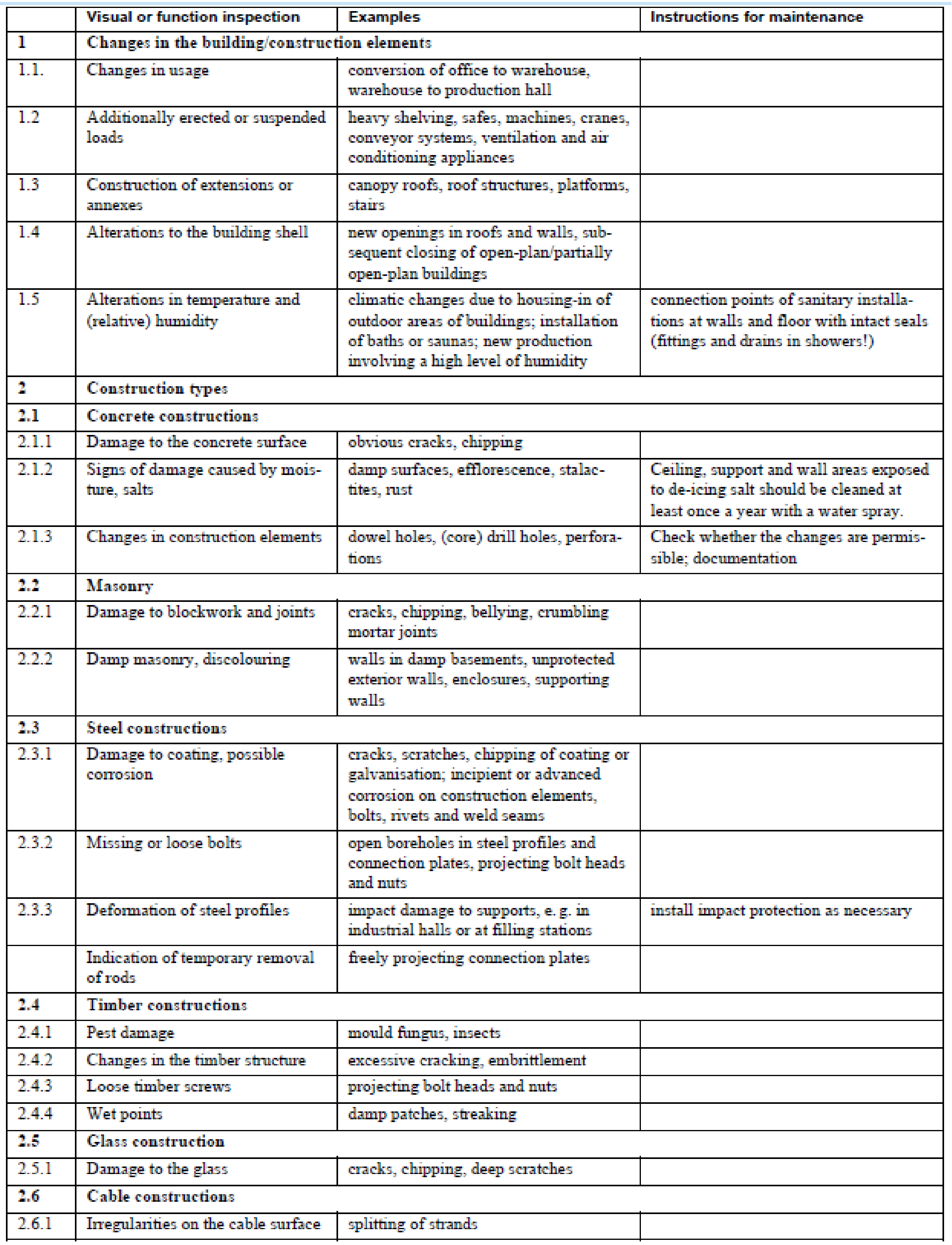
Table E.3: Applicable documents non-mandatory investigations for causes

| No. | (Non-mandatory) investigation document | Extra information |
|---|---|---|
| 2 | CUR 79 (van der Wegen & Wijte, 2016) | For Kwaaitaal and Manata floors |
| 4 | SBR/CUR/ F3O (F3O, 2016) | - |
| 5 | VROM guideline for investigating damage concrete structures before 1985 which are prestressed without bond (Adviesbureau ir. J.G. Hageman B.V., 2011) | - |
| 11 | VROM Guideline light plat roofs (VROM Inspectie, 2003) | Risk based assessment |
| 13 | SBR structural safety of outer leaf masonry façades (no reference available) | - |
| 14 | Plan for evaluating structural glued facades (van Beek- van der Toorn et al., 2022) | Only for glued façades |
| 18 | Assessment shallow foundations (Opstal et al., 2012) | Only for shallow foundations |

There must be noted the documents listed in this subsection are highly detailed and applicable to a single common cause. There are also more general documents for inspections available.

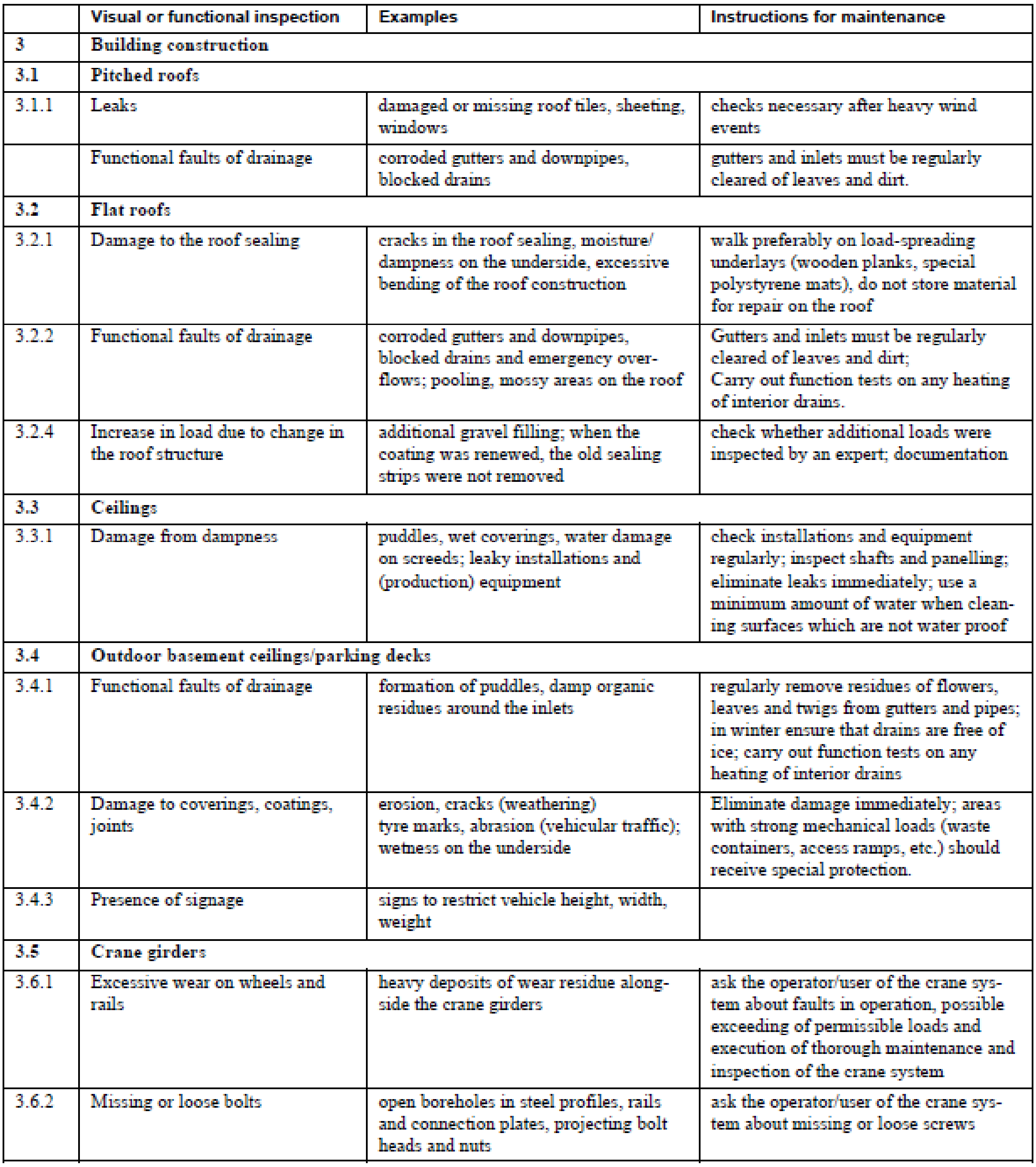
# F. Attention points VDI lists

There are two types of lists available as explained in section 4.2. First, the list for the building owner is given, which is followed by the inspection list for experts.



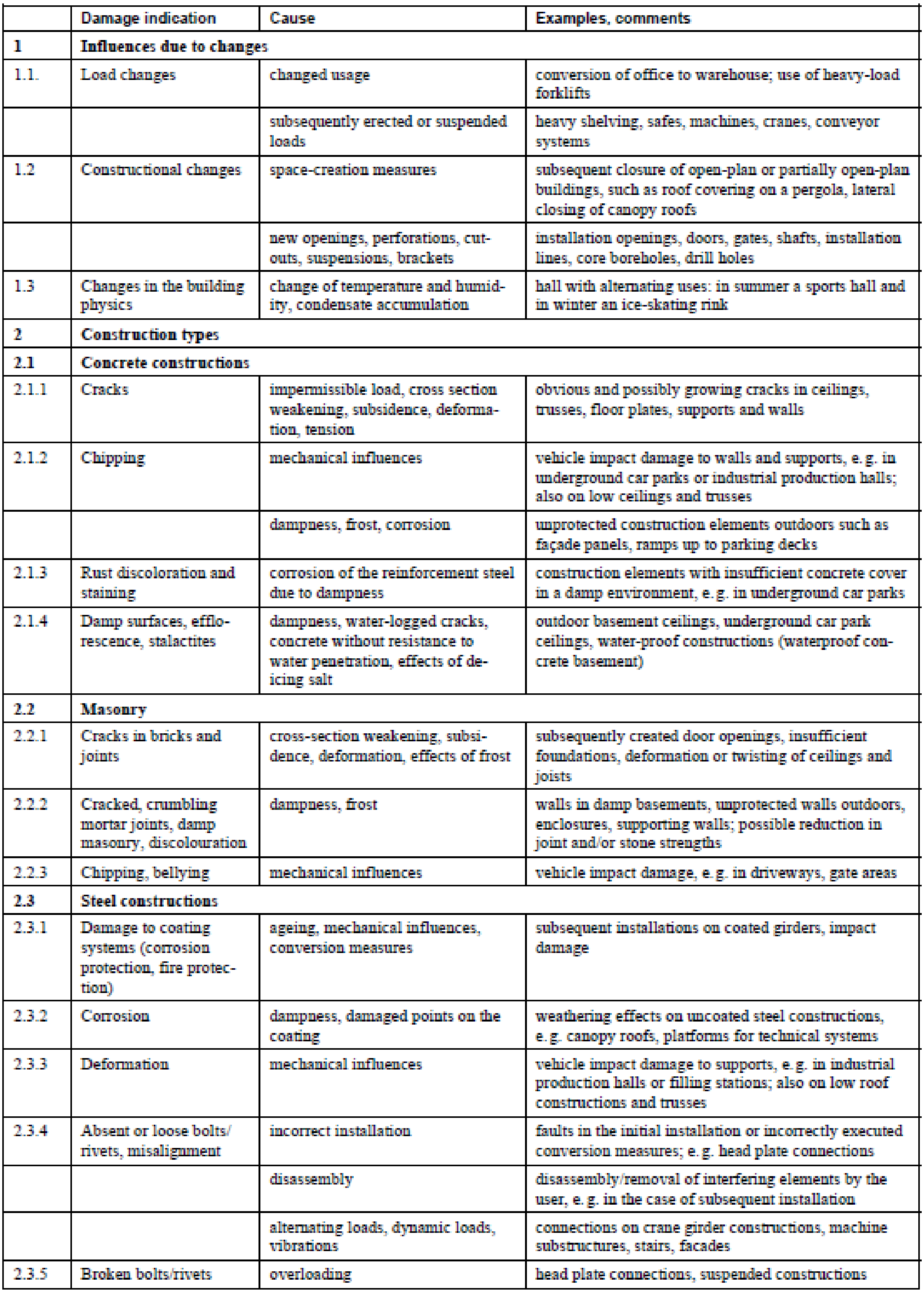
| | Visual or function inspection | Examples | Instructions for maintenance |
|---|---|---|---|
| **1** | **Changes in the building/construction elements** | | |
| 1.1. | Changes in usage | conversion of office to warehouse, warehouse to production hall | |
| 1.2 | Additionally erected or suspended loads | heavy shelving, safes, machines, cranes, conveyor systems, ventilation and air conditioning appliances | |
| 1.3 | Construction of extensions or annexes | canopy roofs, roof structures, platforms, stairs | |
| 1.4 | Alterations to the building shell | new openings in roofs and walls, subsequent closing of open-plan/partially open-plan buildings | |
| 1.5 | Alterations in temperature and (relative) humidity | climatic changes due to housing-in of outdoor areas of buildings; installation of baths or saunas; new production involving a high level of humidity | connection points of sanitary installations at walls and floor with intact seals (fittings and drains in showers!) |
| **2** | **Construction types** | | |
| **2.1** | **Concrete constructions** | | |
| 2.1.1 | Damage to the concrete surface | obvious cracks, chipping | |
| 2.1.2 | Signs of damage caused by moisture, salts | damp surfaces, efflorescence, stalactites, rust | Ceiling, support and wall areas exposed to de-icing salt should be cleaned at least once a year with a water spray. |
| 2.1.3 | Changes in construction elements | dowel holes, (core) drill holes, perforations | Check whether the changes are permissible; documentation |
| **2.2** | **Masonry** | | |
| 2.2.1 | Damage to blockwork and joints | cracks, chipping, bellying, crumbling mortar joints | |
| 2.2.2 | Damp masonry, discolouring | walls in damp basements, unprotected exterior walls, enclosures, supporting walls | |
| **2.3** | **Steel constructions** | | |
| 2.3.1 | Damage to coating, possible corrosion | cracks, scratches, chipping of coating or galvanisation; incipient or advanced corrosion on construction elements, bolts, rivets and weld seams | |
| 2.3.2 | Missing or loose bolts | open boreholes in steel profiles and connection plates, projecting bolt heads and nuts | |
| 2.3.3 | Deformation of steel profiles | impact damage to supports, e. g. in industrial halls or at filling stations | install impact protection as necessary |
| | Indication of temporary removal of rods | freely projecting connection plates | |
| **2.4** | **Timber constructions** | | |
| 2.4.1 | Pest damage | mould fungus, insects | |
| 2.4.2 | Changes in the timber structure | excessive cracking, embrittlement | |
| 2.4.3 | Loose timber screws | projecting bolt heads and nuts | |
| 2.4.4 | Wet points | damp patches, streaking | |
| **2.5** | **Glass construction** | | |
| 2.5.1 | Damage to the glass | cracks, chipping, deep scratches | |
| **2.6** | **Cable constructions** | | |
| 2.6.1 | Irregularities on the cable surface | splitting of strands | |

Figure F.1: List for viewing owner/representative (1/2) (VDI, 2010)



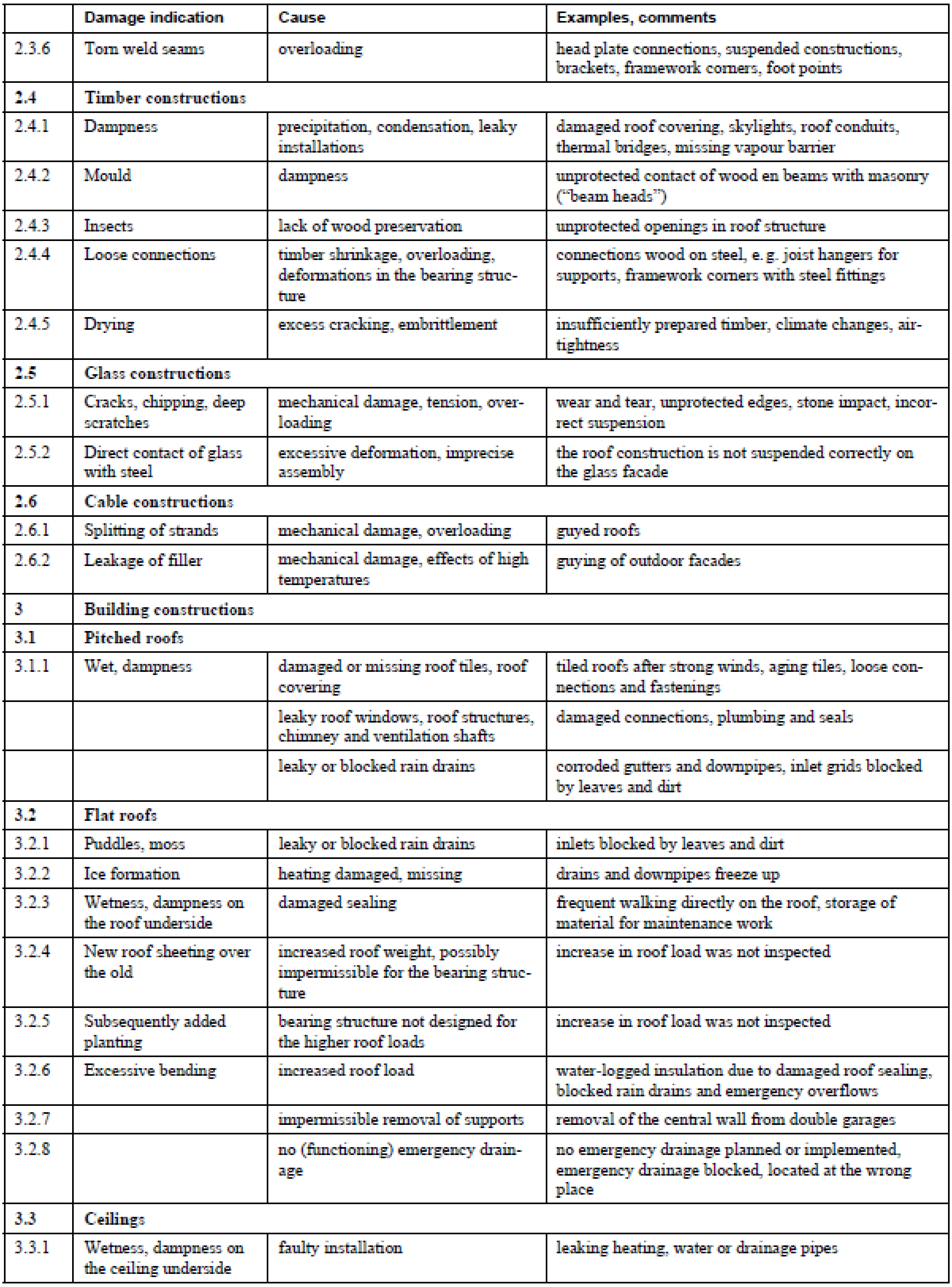
| | Visual or functional inspection | Examples | Instructions for maintenance |
|---|---|---|---|
| **3** | **Building construction** | | |
| **3.1** | **Pitched roofs** | | |
| 3.1.1 | Leaks | damaged or missing roof tiles, sheeting, windows | checks necessary after heavy wind events |
| | Functional faults of drainage | corroded gutters and downpipes, blocked drains | gutters and inlets must be regularly cleared of leaves and dirt. |
| **3.2** | **Flat roofs** | | |
| 3.2.1 | Damage to the roof sealing | cracks in the roof sealing, moisture/ dampness on the underside, excessive bending of the roof construction | walk preferably on load-spreading underlays (wooden planks, special polystyrene mats), do not store material for repair on the roof |
| 3.2.2 | Functional faults of drainage | corroded gutters and downpipes, blocked drains and emergency overflows; pooling, mossy areas on the roof | Gutters and inlets must be regularly cleared of leaves and dirt;<br>Carry out function tests on any heating of interior drains. |
| 3.2.4 | Increase in load due to change in the roof structure | additional gravel filling; when the coating was renewed, the old sealing strips were not removed | check whether additional loads were inspected by an expert; documentation |
| **3.3** | **Ceilings** | | |
| 3.3.1 | Damage from dampness | puddles, wet coverings, water damage on screeds; leaky installations and (production) equipment | check installations and equipment regularly; inspect shafts and panelling; eliminate leaks immediately; use a minimum amount of water when cleaning surfaces which are not water proof |
| **3.4** | **Outdoor basement ceilings/parking decks** | | |
| 3.4.1 | Functional faults of drainage | formation of puddles, damp organic residues around the inlets | regularly remove residues of flowers, leaves and twigs from gutters and pipes; in winter ensure that drains are free of ice; carry out function tests on any heating of interior drains |
| 3.4.2 | Damage to coverings, coatings, joints | erosion, cracks (weathering)<br>tyre marks, abrasion (vehicular traffic); wetness on the underside | Eliminate damage immediately; areas with strong mechanical loads (waste containers, access ramps, etc.) should receive special protection. |
| 3.4.3 | Presence of signage | signs to restrict vehicle height, width, weight | |
| **3.5** | **Crane girders** | | |
| 3.6.1 | Excessive wear on wheels and rails | heavy deposits of wear residue alongside the crane girders | ask the operator/user of the crane system about faults in operation, possible exceeding of permissible loads and execution of thorough maintenance and inspection of the crane system |
| 3.6.2 | Missing or loose bolts | open boreholes in steel profiles, rails and connection plates, projecting bolt heads and nuts | ask the operator/user of the crane system about missing or loose screws |

Figure F.2: List for viewing owner/representative (2/2) (VDI, 2010)



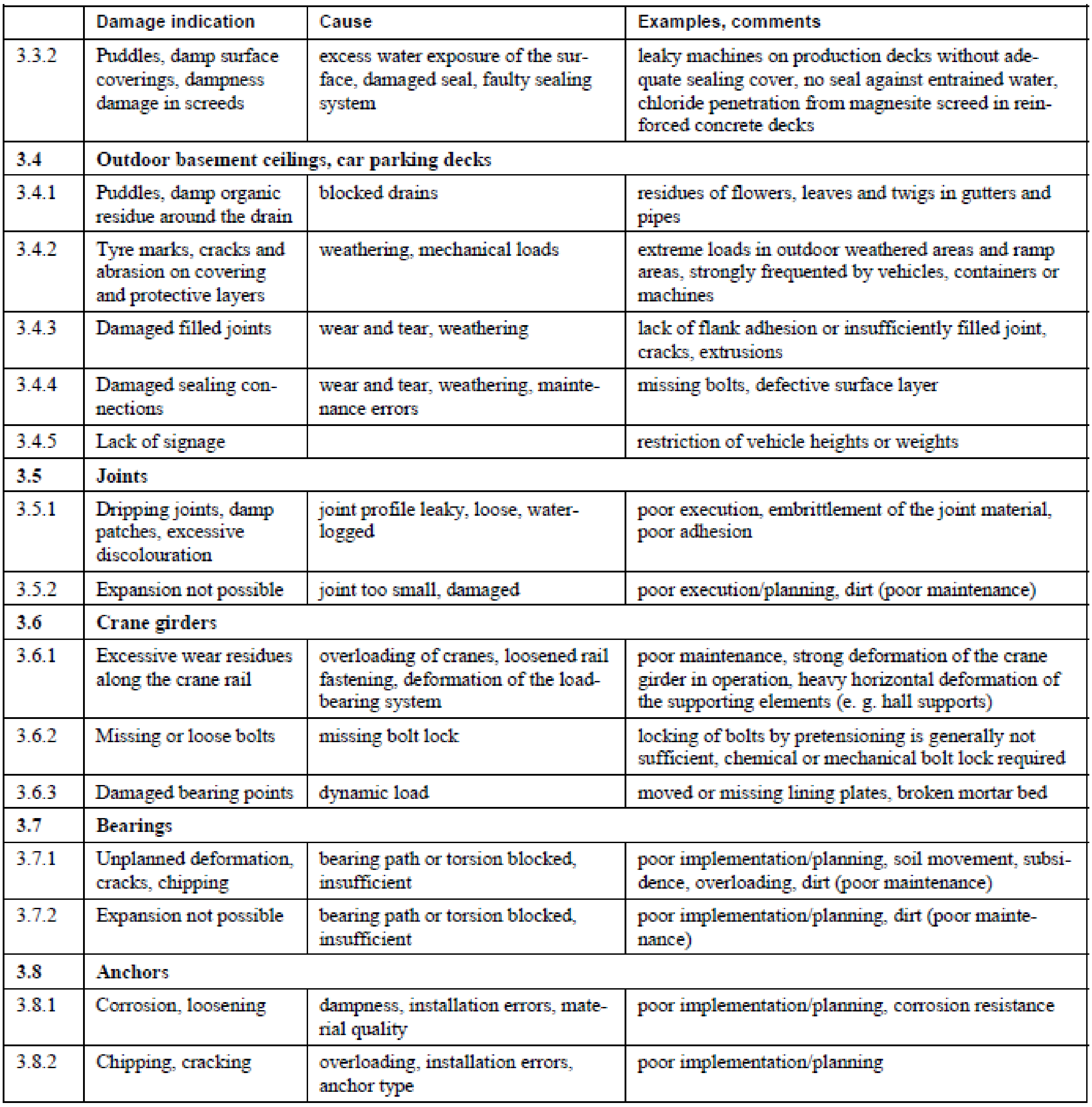
| | Damage indication | Cause | Examples, comments |
|---|---|---|---|
| **1** | **Influences due to changes** | | |
| 1.1. | Load changes | changed usage | conversion of office to warehouse; use of heavy-load forklifts |
| | | subsequently erected or suspended loads | heavy shelving, safes, machines, cranes, conveyor systems |
| 1.2 | Constructional changes | space-creation measures | subsequent closure of open-plan or partially open-plan buildings, such as roof covering on a pergola, lateral closing of canopy roofs |
| | | new openings, perforations, cutouts, suspensions, brackets | installation openings, doors, gates, shafts, installation lines, core boreholes, drill holes |
| 1.3 | Changes in the building physics | change of temperature and humidity, condensate accumulation | hall with alternating uses: in summer a sports hall and in winter an ice-skating rink |
| **2** | **Construction types** | | |
| **2.1** | **Concrete constructions** | | |
| 2.1.1 | Cracks | impermissible load, cross section weakening, subsidence, deformation, tension | obvious and possibly growing cracks in ceilings, trusses, floor plates, supports and walls |
| 2.1.2 | Chipping | mechanical influences | vehicle impact damage to walls and supports, e. g. in underground car parks or industrial production halls; also on low ceilings and trusses |
| | | dampness, frost, corrosion | unprotected construction elements outdoors such as façade panels, ramps up to parking decks |
| 2.1.3 | Rust discoloration and staining | corrosion of the reinforcement steel due to dampness | construction elements with insufficient concrete cover in a damp environment, e. g. in underground car parks |
| 2.1.4 | Damp surfaces, efflorescence, stalactites | dampness, water-logged cracks, concrete without resistance to water penetration, effects of de-icing salt | outdoor basement ceilings, underground car park ceilings, water-proof constructions (waterproof concrete basement) |
| **2.2** | **Masonry** | | |
| 2.2.1 | Cracks in bricks and joints | cross-section weakening, subsidence, deformation, effects of frost | subsequently created door openings, insufficient foundations, deformation or twisting of ceilings and joists |
| 2.2.2 | Cracked, crumbling mortar joints, damp masonry, discolouration | dampness, frost | walls in damp basements, unprotected walls outdoors, enclosures, supporting walls; possible reduction in joint and/or stone strengths |
| 2.2.3 | Chipping, bellying | mechanical influences | vehicle impact damage, e. g. in driveways, gate areas |
| **2.3** | **Steel constructions** | | |
| 2.3.1 | Damage to coating systems (corrosion protection, fire protection) | ageing, mechanical influences, conversion measures | subsequent installations on coated girders, impact damage |
| 2.3.2 | Corrosion | dampness, damaged points on the coating | weathering effects on uncoated steel constructions, e. g. canopy roofs, platforms for technical systems |
| 2.3.3 | Deformation | mechanical influences | vehicle impact damage to supports, e. g. in industrial production halls or filling stations; also on low roof constructions and trusses |
| 2.3.4 | Absent or loose bolts/ rivets, misalignment | incorrect installation | faults in the initial installation or incorrectly executed conversion measures; e. g. head plate connections |
| | | disassembly | disassembly/removal of interfering elements by the user, e. g. in the case of subsequent installation |
| | | alternating loads, dynamic loads, vibrations | connections on crane girder constructions, machine substructures, stairs, facades |
| 2.3.5 | Broken bolts/rivets | overloading | head plate connections, suspended constructions |

Figure F.3: Checklist inspection expert (1/3) (VDI, 2010)



| | Damage indication | Cause | Examples, comments |
|---|---|---|---|
| 2.3.6 | Torn weld seams | overloading | head plate connections, suspended constructions, brackets, framework corners, foot points |
| **2.4** | **Timber constructions** | | |
| 2.4.1 | Dampness | precipitation, condensation, leaky installations | damaged roof covering, skylights, roof conduits, thermal bridges, missing vapour barrier |
| 2.4.2 | Mould | dampness | unprotected contact of wood en beams with masonry ("beam heads") |
| 2.4.3 | Insects | lack of wood preservation | unprotected openings in roof structure |
| 2.4.4 | Loose connections | timber shrinkage, overloading, deformations in the bearing structure | connections wood on steel, e. g. joist hangers for supports, framework corners with steel fittings |
| 2.4.5 | Drying | excess cracking, embrittlement | insufficiently prepared timber, climate changes, air-tightness |
| **2.5** | **Glass constructions** | | |
| 2.5.1 | Cracks, chipping, deep scratches | mechanical damage, tension, overloading | wear and tear, unprotected edges, stone impact, incorrect suspension |
| 2.5.2 | Direct contact of glass with steel | excessive deformation, imprecise assembly | the roof construction is not suspended correctly on the glass facade |
| **2.6** | **Cable constructions** | | |
| 2.6.1 | Splitting of strands | mechanical damage, overloading | guyed roofs |
| 2.6.2 | Leakage of filler | mechanical damage, effects of high temperatures | guying of outdoor facades |
| **3** | **Building constructions** | | |
| **3.1** | **Pitched roofs** | | |
| 3.1.1 | Wet, dampness | damaged or missing roof tiles, roof covering | tiled roofs after strong winds, aging tiles, loose connections and fastenings |
| | | leaky roof windows, roof structures, chimney and ventilation shafts | damaged connections, plumbing and seals |
| | | leaky or blocked rain drains | corroded gutters and downpipes, inlet grids blocked by leaves and dirt |
| **3.2** | **Flat roofs** | | |
| 3.2.1 | Puddles, moss | leaky or blocked rain drains | inlets blocked by leaves and dirt |
| 3.2.2 | Ice formation | heating damaged, missing | drains and downpipes freeze up |
| 3.2.3 | Wetness, dampness on the roof underside | damaged sealing | frequent walking directly on the roof, storage of material for maintenance work |
| 3.2.4 | New roof sheeting over the old | increased roof weight, possibly impermissible for the bearing structure | increase in roof load was not inspected |
| 3.2.5 | Subsequently added planting | bearing structure not designed for the higher roof loads | increase in roof load was not inspected |
| 3.2.6 | Excessive bending | increased roof load | water-logged insulation due to damaged roof sealing, blocked rain drains and emergency overflows |
| 3.2.7 | | impermissible removal of supports | removal of the central wall from double garages |
| 3.2.8 | | no (functioning) emergency drainage | no emergency drainage planned or implemented, emergency drainage blocked, located at the wrong place |
| **3.3** | **Ceilings** | | |
| 3.3.1 | Wetness, dampness on the ceiling underside | faulty installation | leaking heating, water or drainage pipes |

Figure F.4: Checklist inspection expert (2/3) (VDI, 2010)



| | Damage indication | Cause | Examples, comments |
|---|---|---|---|
| 3.3.2 | Puddles, damp surface coverings, dampness damage in screeds | excess water exposure of the surface, damaged seal, faulty sealing system | leaky machines on production decks without adequate sealing cover, no seal against entrained water, chloride penetration from magnesite screed in reinforced concrete decks |
| **3.4** | **Outdoor basement ceilings, car parking decks** | | |
| 3.4.1 | Puddles, damp organic residue around the drain | blocked drains | residues of flowers, leaves and twigs in gutters and pipes |
| 3.4.2 | Tyre marks, cracks and abrasion on covering and protective layers | weathering, mechanical loads | extreme loads in outdoor weathered areas and ramp areas, strongly frequented by vehicles, containers or machines |
| 3.4.3 | Damaged filled joints | wear and tear, weathering | lack of flank adhesion or insufficiently filled joint, cracks, extrusions |
| 3.4.4 | Damaged sealing connections | wear and tear, weathering, maintenance errors | missing bolts, defective surface layer |
| 3.4.5 | Lack of signage | | restriction of vehicle heights or weights |
| **3.5** | **Joints** | | |
| 3.5.1 | Dripping joints, damp patches, excessive discolouration | joint profile leaky, loose, waterlogged | poor execution, embrittlement of the joint material, poor adhesion |
| 3.5.2 | Expansion not possible | joint too small, damaged | poor execution/planning, dirt (poor maintenance) |
| **3.6** | **Crane girders** | | |
| 3.6.1 | Excessive wear residues along the crane rail | overloading of cranes, loosened rail fastening, deformation of the load-bearing system | poor maintenance, strong deformation of the crane girder in operation, heavy horizontal deformation of the supporting elements (e. g. hall supports) |
| 3.6.2 | Missing or loose bolts | missing bolt lock | locking of bolts by pretensioning is generally not sufficient, chemical or mechanical bolt lock required |
| 3.6.3 | Damaged bearing points | dynamic load | moved or missing lining plates, broken mortar bed |
| **3.7** | **Bearings** | | |
| 3.7.1 | Unplanned deformation, cracks, chipping | bearing path or torsion blocked, insufficient | poor implementation/planning, soil movement, subsidence, overloading, dirt (poor maintenance) |
| 3.7.2 | Expansion not possible | bearing path or torsion blocked, insufficient | poor implementation/planning, dirt (poor maintenance) |
| **3.8** | **Anchors** | | |
| 3.8.1 | Corrosion, loosening | dampness, installation errors, material quality | poor implementation/planning, corrosion resistance |
| 3.8.2 | Chipping, cracking | overloading, installation errors, anchor type | poor implementation/planning |

Figure F.5: Checklist inspection expert (3/3) (VDI, 2010)

# G. Selection existing assessment methods

The information stated in this appendix supports the selection process of the explored sources in chapter 5. In section G.1 the delineation process for the considered sources is given. The final sources, which are considered in the exploration are posted in section 5.2. For the final selection, the sources are briefly described in section G.2.

## G.1 Delineation available sources

Within the 24 sources considered for the NTA 8790 desk study, two sources are not considered at the start of this delineation. These are the 'ISO 2394' standard and the 'Richtlijn Eisen Inspectie en Kwaliteitsmeting Kunstwerken' by ProRail. The standard was not made available for this study and the document by ProRail could not be retrieved during the literature study to these sources. As sufficient other sources are available for the exploration, the remainder of the study is performed with only the available sources. In addition, the considered standard ISO 13822 is based on the ISO 2394, so some parts of this source are still considered.

In the desk study, the NEN 2767 standard is considered as two separate parts. For this exploration, this standard is considered as one source.

Next to the desk study, four additional sources, stated in section 5.2, are included in this delineation. There are thus 25 sources considered at the start of the delineation process, which is described in this section.

As a first step in this delineation, there is checked if there is any information available for the aspects stated in 5.2.1. In table g.1 there is given which aspects are considered by the 25 sources via green and yellow markers. In case the yellow marker is given, the information does not fully comply with the considered aspect. In subsection 0 the argumentation for among others the yellow markers is provided. Next to the aspects, the sources also contain other points which might be of added value for the development of the method. These other points are given in table g.2.

Table G.1: Different aspects available in sources

| | | Characteristics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Method** | **Institution** | **Reassessment method** | **Applicability** | **Stepwise/risk driven approach** | **Multiple risks** | **Info insp/dam/mat/ other** | **Example risks/evaluation** | **Critical dam patterns/ elements** | **Example reporting** | **Qualifications** |
| Protocol Beoordeling constructieve veiligheid Stadions betaald voetbal | ABT | ✓ | | ✓ | ✓ | ✓ | ✓ | | (✓) | ✓ |
| Guideline for Structural Assessment of Existing Buildings | ASCE | ✓ | ✓ | (✓) | ✓ | ✓ | | | ✓ | ✓ |
| Periodic Structural Inspection of Existing Buildings - Guidelines for Structural Engineers | Building and Construction Authority | (✓) | ✓ | (✓) | ✓ | ✓ | | (✓) | ✓ | ✓ |
| CUR aanbeveling 121, Bepaling ondergrens verwachte levensduur van bestaande gewapende betonconstructies | CUR | ✓ | | (✓) | | (✓) | | | ✓ | ✓ |
| CUR aanbeveling 124, Constructieve veiligheid bestaande bruggen en viaducten van decentrale overheden | CROW - CUR | ✓ | | ✓ | ✓ | ✓ | ✓ | | (✓) | |
| NEN-ISO 13822 | NEN - ISO | ✓ | ✓ | (✓) | ✓ | (✓) | | | ✓ | |
| NEN 8700 | NEN | | ✓ | | | ✓ | | | | |
| (Periodieke) inspecties van gebouwen | Kennisplatform Constructieve Veiligheid | | ✓ | | ✓ | | | ✓ | | |
| Guide for Conducting Risk Assessments | NIST | | | | ✓ | | ✓ | | ✓ | |
| Condition assessment as a tool for safe construction | New York Department of Buildings | | (✓) | | | ✓ | | (✓) | | (✓) |
| Verborgen gebreken? Lessen uit instorting van het dak van het AZ stadion | Onderzoeksraad voor veiligheid | | ✓ | | | ✓ | | (✓) | | |
| Structural Condition Assessments of existing Buildings and Designated Structures Guideline | Professional Engineers Ontario | ✓ | ✓ | (✓) | ✓ | | | | ✓ | ✓ |
| Richtlijn Beoordeling Kunstwerken | Rijkswaterstaat | | | | | ✓ | | | | |
| Guide to Safety at Sports Grounds | Sports Grounds Safety Authority | | (✓) | | ✓ | (✓) | | | | ✓ |
| Appraisal of Existing Structures | The Institution of structral engineers | ✓ | ✓ | ✓ | ✓ | ✓ | | (✓) | ✓ | ✓ |
| Standsicherheit von Bauwerken Regelmabige Uberprufung | VDI - GBG | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ |
| Handboek RVBBOEI inspecties | RVB | ✓ | ✓ | | ✓ | ✓ | ✓ | | (✓) | ✓ |
| NEN2767-1&2 Conditiemeting gebouwde omgeving | NEN | ✓ | ✓ | | ✓ | ✓ | ✓ | | | |
| Eenvoudige objectrisicoanalyse - werkomschrijving | Rijkswaterstaat | ✓ | | ✓ | ✓ | | ✓ | | ✓ | |
| Koninklijk besluit houdende de in voetbalstadions na te leven veiligheidsnormen, Artikel 4, 06-07-2013 | Federale overheidsdienst binnenlandse zaken België | | | (✓) | ✓ | | | | | ✓ |
| NTA8790 | NEN | ✓ | (✓) | ✓ | ✓ | ✓ | (✓) | ✓ | | ✓ |
| Study for a quantative risk assessment on accidental actions | Sarah Kleijn | | | (✓) | ✓ | | ✓ | | | |
| Analysekader vaste kunstwerken - Analysekader voor Viaducten, Vaste bruggen, Onderdoorgangen en Duikers | Rijkswaterstaat | ✓ | | | ✓ | | | | ✓ | |
| Inspectiekader RWS - Kader voor risicogestuurd inspecteren bij Rijkswaterstaat | Rijkswaterstaat | | | ✓ | ✓ | ✓ | | | | ✓ |
| Risicogestuurde methode | Nebest | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | |

Table G.2: Highlights content sources

| Method | Institution | Other comments per method |
|---|---|---|
| Protocol Beoordeling constructieve veiligheid Stadions betaald voetbal | ABT | Comparison standards (NEN8700 with NEN6702).<br>Desk study divided into multiple subjects |
| Guideline for Structural Assessment of Existing Buildings | ASCE | Also lists services, compensation, liability etc. |
| Periodic Structural Inspection of Existing Buildings - Guidelines for Structural Engineers | Building and Construction Authority | Clearly stated what to do with concealed parts of the structure during visual inspection.<br>Clear report format for visual inspection but not for full structural investigation |
| CUR aanbeveling 121, Bepaling ondergrens verwachte levensduur van bestaande gewapende betonconstructies | CUR | Only describes assessment and prediction rest of life for corrosion process within civil structures composed of reinforced concrete |
| CUR-aanbeveling 124, Constructieve veiligheid bestaande bruggen en viaducten van decentrale overheden | CROW - CUR | Risk analysis is on object level via traffic loads, consequence classes, technical aspects and damages/degradation.<br>Reporting only quickly stated in bullet points |
| NEN-ISO 13822 | NEN - ISO | Is based on ISO 2394.<br>Good reporting format, also stated what must be done for inspection and when performed |
| NEN 8700 | NEN | Referred by multiple methods as the standard on reassessment.<br>Developed method in thesis must comply with this standard.<br>In appendix E more information given regarding reassessment |
| (Periodieke) inspecties van gebouwen | KPCV | Triggers for assessment already given in desk study.<br>Critical damage patterns and structural elements could be of use in chapter 3.<br>Quickly stated how information inspection must be recorded |
| Guide for Conducting Risk Assessments | NIST | Only general risk assessment provides information |
| Condition assessment as a tool for safe construction | New York Department of Buildings | Reviews methods of structural condition assessment for existing buildings as they relate to issues during design and construction in dense building area.<br>Describes defect versus deterioration and provides definitions condition assessment.<br>ASCE11 also considered in review.<br>States qualifications but is from ASCE |
| Verborgen gebreken? Lessen uit instorting van het dak van het AZ-stadion | Onderzoeksraad voor veiligheid | Problem regarding buildings in use phase described, however referred to some methods.<br>Some incidents stated that occurred |
| Structural Condition Assessments of existing Buildings and Designated Structures Guideline | Professional Engineers Ontario | Reasons for assessment stated.<br>Duty to report and condition assessment given |

| | | |
|---|---|---|
| Richtlijn Beoordeling Kunstwerken | Rijkswaterstaat | Guideline assessment structural safety of existing civil structures for renovation, use and disapproval |
| Guide to Safety at Sports Grounds | Sports Grounds Safety Authority | Used older version for check.<br>Appraisal of existing structures mentioned as good method for reassessment |
| Appraisal of Existing Structures | The Institution of structural engineers | Extensive report |
| Standsicherheit von Bauwerken Regelmabige Uberprufung | VDI - GBG | First, the building is classified, this classification determines the actions |
| Handboek RVBBOEI-inspecties | RVB | Extensive information regarding maintenance.<br>In accordance with NEN2767.<br>For some sections stated what to report etc. but no clear format |
| NEN2767-1&2 Conditiemeting gebouwde omgeving | NEN | List for condition assessment provided |
| Eenvoudige objectrisicoanalyse - werkomschrijving | Rijkswaterstaat | Template which can be used to perform ORA.<br>ORA can be divided into simple, detailed and advanced analysis dependent on type of object |
| Koninklijk besluit houdende de in voetbalstadions na te leven veiligheidsnormen, Artikel 4, 06-07-2013 | Federale overheidsdienst binnenlandse zaken België | Different type of inspections ordered, namely visual and detailed inspection |
| NTA 8790 | NEN | Still under development, so the results could change.<br>Not evaluated by desk study |
| Study for a quantitative risk assessment on accidental actions | Sarah Kleijn | Assessment of accidental actions.<br>At end of method loop which lets go back if new hazards might arise or assumptions made did not uphold |
| Analysekader vaste kunstwerken - Analysekader voor Viaducten, Vaste bruggen, Onderdoorgangen en Duikers | Rijkswaterstaat | Performance requirements stated.<br>Definitions of failure given and standardised table for risks.<br>There is stepwise approach for actions to take after risks identified, but no stepwise approach in risk assessment |
| Inspectiekader RWS - Kader voor risico gestuurd inspecteren bij Rijkswaterstaat | Rijkswaterstaat | Document has purpose to provide information on the three inspection levels.<br>Clearly stated why risk-based inspections required.<br>Per inspection type mentioned what must come forward plus what tasks are performed by what party |
| Risicogestuurde methode | Nebest | Other way of quantifying risks as other methods |

### G.1.1 Motivation yellow markers table g.1

Per aspect there is briefly explained why yellow markers are given. In the first column there is only one yellow marker for the guideline by the Building and Construction Authority. This assessment is divided into two parts, the visual inspection and the full structural investigation. The yellow marker is implemented as the document mainly elaborates on the visual inspection part and does not provide any details for the structural investigation.

In case of the applicability of the source for CC2 buildings, the first two yellow markers are given as only a part of CC2 buildings is considered. The presentation by the New York Department of Buildings focusses on existing building in relation to design and construction in dense building areas (Eschenasy, n.d.). In the other case the source is specifically for sport facilities. The third and final yellow marker is given to NTA 8790. The NTA is applicable for all existing buildings, however the focus lies on significant public buildings within CC3.

For the stepwise/risk-based approach, yellow markers are mainly applied in case the assessment only consists of two steps. There is a distinction in steps for assessment, but it is kept to a minimum. In most of these cases, the first step consists of a preliminary assessment and, if required, the detailed assessment must be performed.

The thesis by Sarah Kleijn is an exception as in this risk assessment the entire object is considered. However, the yellow marker is given as in the end of the assessment there is a feedback loop available. In this loop there is checked whether the assumptions made at the start of the assessment still uphold and if new hazards arose. So, this method does not provide a stepped approach of assessment, but there is a loop available.

In the following three columns, aspects relating to provided additional information or examples by the source, are covered. Yellow markers are applied for these aspects in case there is some information available, but no complete overview is given. If, for instance, some points regarding reporting are stated, a yellow marker is applied as in other methods complete formats are available. The same applied for the critical damage patterns/elements, in some sources there is some information given regarding this aspect, but no complete overview.

At last, the aspect, considering the qualifications, is given. For this aspect there is only one yellow marker, which is given to the presentation by the New York Department of Buildings. This marker is given as there are qualification present, but these originate form the ASCE source.

### G.1.2 Delineation considered sources

The number of sources must be decreased to allow for a detailed exploration of the available information. However, a variance in sources must be maintained to retrieve a good overview on all the information available. The different aspects, given in table g.1, help in the delineation, while also considering this variety in formation.

The first step in this delineation is to exclude all sources which do not provide a reassessment method. These are the required sources for the exploration, as parts of these methods could be used for the development of the assessment process. This delineation step is portrayed in the table below.

Table G.3: Reassessment methods available

| Method | Institution | Characteristics<br>Ressessment method | Applicability | Stepwise/risk driven approach | Multiple risks | Info insp/dam/mat/ other | Example risks/evaluation | Critical dam patterns/ elements | Example reporting | Qualifications |
|---|---|---|---|---|---|---|---|---|---|---|
| Protocol Beoordeling constructieve veiligheid Stadions betaald voetbal | ABT | ✓ |  | ✓ | ✓ | ✓ | ✓ |  | ✔ | ✓ |
| Guideline for Structural Assessment of Existing Buildings | ASCE | ✓ | ✓ | ✔ | ✓ | ✓ |  |  | ✓ | ✓ |
| Periodic Structural Inspection of Existing Buildings - Guidelines for Structural Engineers | Building and Construction Authority | ✔ | ✓ | ✔ | ✓ | ✓ |  | ✔ | ✓ | ✓ |
| CUR aanbeveling 121, Bepaling ondergrens verwachte levensduur van bestaande gewapende betonconstructies | CUR | ✓ |  | ✔ |  | ✔ |  |  | ✓ | ✓ |
| CUR aanbeveling 124, Constructieve veiligheid bestaande bruggen en viaducten van decentrale overheden | CROW - CUR | ✓ |  | ✓ | ✓ | ✓ | ✓ |  | ✔ |  |
| NEN-ISO 13822 | NEN - ISO | ✓ | ✓ | ✔ | ✓ | ✔ |  |  | ✓ |  |
| Structural Condition Assessments of existing Buildings and Designated Structures Guideline | Professional Engineers Ontario | ✓ | ✓ | ✔ | ✓ |  |  |  | ✓ | ✓ |
| Appraisal of Existing Structures | The Institution of structral engineers | ✓ | ✓ | ✓ | ✓ | ✓ |  | ✔ | ✓ | ✓ |
| Standsicherheit von Bauwerken Regelmabige Uberprufung | VDI - GBG | ✓ | ✓ | ✓ | ✓ | ✓ |  |  | ✓ | ✓ |
| Handboek RVBBOEI inspecties | RVB | ✓ | ✓ |  | ✓ | ✓ | ✓ |  | ✔ | ✓ |
| NEN2767-1&2 Conditiemeting gebouwde omgeving | NEN | ✓ | ✓ |  | ✓ | ✓ | ✓ |  |  |  |
| Eenvoudige objectrisicoanalyse - werkomschrijving | Rijkswaterstaat | ✓ |  | ✓ | ✓ |  | ✓ |  | ✓ |  |
| NTA8790 | NEN | ✓ | ✔ | ✓ | ✓ | ✓ | ✔ | ✓ |  | ✓ |
| Analysekader vaste kunstwerken - Analysekader voor Viaducten, Vaste bruggen, Onderdoorgangen en Duikers | Rijkswaterstaat | ✓ |  |  | ✓ |  |  |  | ✓ |  |
| Risicogestuurde methode | Nebest | ✓ | ✓ | ✓ | ✓ |  | ✓ |  | ✓ |  |

In table g.2 there can be seen that one reassessment method does not consider multiple risks, only the corrosion within civil structures composed of reinforced concrete (Boutz et al., 2018). In addition, this source only has three aspects which are marked green. These aspects are also considered in other sources. In conclusion, the CUR 121 is not further considered in the exploration.

There is another source where only three aspects are marked green, the ‘Analysekader vaste kunstwerken’ by Rijkswaterstaat. Again, these aspects are available in other sources, thereby excluding the source for further consideration.

In the aforementioned table there can also be seen that the method by Rijksvastgoedbedrijf (RVB) and NEN 2767 show great resemblance. The RVB uses the NEN 2767 for the quantification of the condition, but also provides quantifications and some information on reporting. However, these last-mentioned aspects are already available. As the NEN 2767 forms the origin of the assessment and is easier to explore, this method is selected over the RVBBOEI inspections.

With the seclusion of the aforementioned sources, this leaves twelve assessment methods for the exploration. As stated earlier, the methods must present a wide range of different aspects. When considering this range in the green markers, the reassessment method by the Professional Engineers of Ontario does not contribute as much to the different aspects available. In addition, the method presents a two stepped assessment for the stepwise/risk driven approach. These two stepped assessments are also available in other methods which present more variety for the exploration. This method is thus also discarded.

Two methods which also show resemblance are the method by ABT and NTA 8790. As no information is available on the NTA, while the ABT was already included in the desk study, NTA 8790 is considered in the exploration and the ABT method is excluded.

In the following table, there is summarised why sources are excluded in the study.

Table G.4: Motivation sources not considered in exploration

| Source | Reason not considered |
|---|---|
| ABT | Method shows resemblance to NTA8790. There are however a few aspects that are still considered. |
| CUR 121 | Only considers the corrosion of reinforced concrete in civil structures. Other aspects like the example reporting and qualifications are also covered by other assessment methods. |
| NEN8700 | Not a reassessment method. |
| KPCV | Not an assessment method. However, some information is applicable and used in this document. |
| NIST | Risk assessment for cybercrime. Other than that general risk assessment, which is already covered by other sources. |
| New York Department of Buildings | Not an assessment method, presentation specific for design and construction in a dense building area. |
| Dutch Safety Board | Not a reassessment method, information used in another part thesis. |
| Professional Engineers of Ontario | Two stepped assessment method which is already covered by other sources. |
| Rijkswaterstaat, Richtlijn Beoordeling Kunstwerken | Not a reassessment method. |
| Sport Grounds Safety Authority | Not a reassessment method. |
| RVB | Method based on NEN 2767.<br>Other aspects like qualifications and descriptions report are also provided by other sources. |
| Federale Overheidsdienst Binnenlandse Zaken België | Not a reassessment method. |
| Master thesis Sarah Kleijn | Not a reassessment method. |
| Rijkswaterstaat, Analysekader vaste kunstwerken | Only considers three aspects, which are covered by other sources. |
| Rijkswaterstaat, Inspectiekader RWS | Not a reassessment method. |

With the exclusion of the aforementioned sources, the delineation is completed. There is a final selection of ten assessment methods for the exploration. In the table below, the range of aspects for this final delineation is given. There can be seen that all the aspects are represented over these ten assessment methods. In addition, there can be seen that a variety in aspects is available. There are for instance two methods which focus on civil structures.

Table G.5: Final selection considered sources

| | | Characteristics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Method** | **Institution** | **Ressessment method** | **Applicability** | **Stepwise/risk driven approach** | **Multiple risks** | **Info insp/dam/mat/ other** | **Example risks/evaluation** | **Critical dam patterns/ elements** | **Example reporting** | **Qualifications** |
| Guideline for Structural Assessment of Existing Buildings | ASCE | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ |
| Periodic Structural Inspection of Existing Buildings - Guidelines for Structural Engineers | Building and Construction Authority | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ |
| CUR aanbeveling 124, Constructieve veiligheid bestaande bruggen en viaducten van decentrale overheden | CROW - CUR | ✓ | | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| NEN-ISO 13822 | NEN - ISO | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | |
| Appraisal of Existing Structures | The Institution of structral engineers | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ |
| Standsicherheit von Bauwerken Regelmabige Uberprufung | VDI - GBG | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ |
| NEN2767-1&2 Conditiemeting gebouwde omgeving | NEN | ✓ | ✓ | | ✓ | ✓ | ✓ | | | |
| Eenvoudige objectrisicoanalyse - werkomschrijving | Rijkswaterstaat | ✓ | | ✓ | ✓ | | ✓ | | ✓ | |
| NTA8790 | NEN | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Risicogestuurde methode | Nebest | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | |

## G.2 Descriptions selected methods

In this section the selected assessment methods are briefly described as additional information is required for the exploration. The information that is required: the approach of the assessment, the way risks are identified and compiled, possible actions to mitigate risks and any manuals/tools helping the assessment. In case any information for the first desk study subjects listed in figure 5.1 is incomplete, this information is also given in this section. As the NTA 8790 and the risk-based assessment method by Nebest are not evaluated in the desk study, for these cases all information must be retrieved.

### G.2.1 Guideline for Structural Assessment of Existing Buildings (ASCE, 2000)

The American Society of Civil Engineers provides a methodology for assessment of the structural condition of existing buildings constructed with (combinations of) concrete, metals, masonry and wood within this standard (ASCE, 2000). The standard provides an assessment procedure which is based on engineering judgement in combination with investigation and testing methods. In addition, a reporting format is provided.

**General approach**

The standard recommends a multilevel approach due to the costs of an extensive structural assessment. Essentially, the approach comprises a preliminary assessment and, if required, the detailed assessment must be performed. However, the detailed assessment can also be performed immediately if seen fit. In case a significant quantity of buildings is considered, this number can be reduced via given criteria to minimise unnecessary detailed investigations (ASCE, 2000).

The flowchart where all the steps of the assessment are described is given in figure g.1. In the first assessment step, the available data must be examined before the site inspection. This data can then be confirmed via this inspection.

A preliminary assessment is performed to check the structural adequacy and the need for a detailed assessment. The collected intel is used to perform the following points (ASCE, 2000):

- Estimation building capacity with earlier specified criteria (including code compliance).
- Assessment of property damage.
- Identification of structural deficiencies in the building (minimum life span, public safety and standards).

In the preliminary analysis only the critical members and connections are analysed.

In the detailed assessment the following points are performed (ASCE, 2000):

- To determine if the performance criteria are satisfied, else rehabilitation is required.
- To identify deficiencies and, in case of rehabilitation, provide alternatives.

This assessment is similar to the preliminary assessment, except for the greater detail and higher accuracy, which increase the reliability of the recommendations made. As such, the detailed assessment considers the entire structural system.

It is important to note that non-structural components which may contribute to structural resistance, must be considered in the assessment.

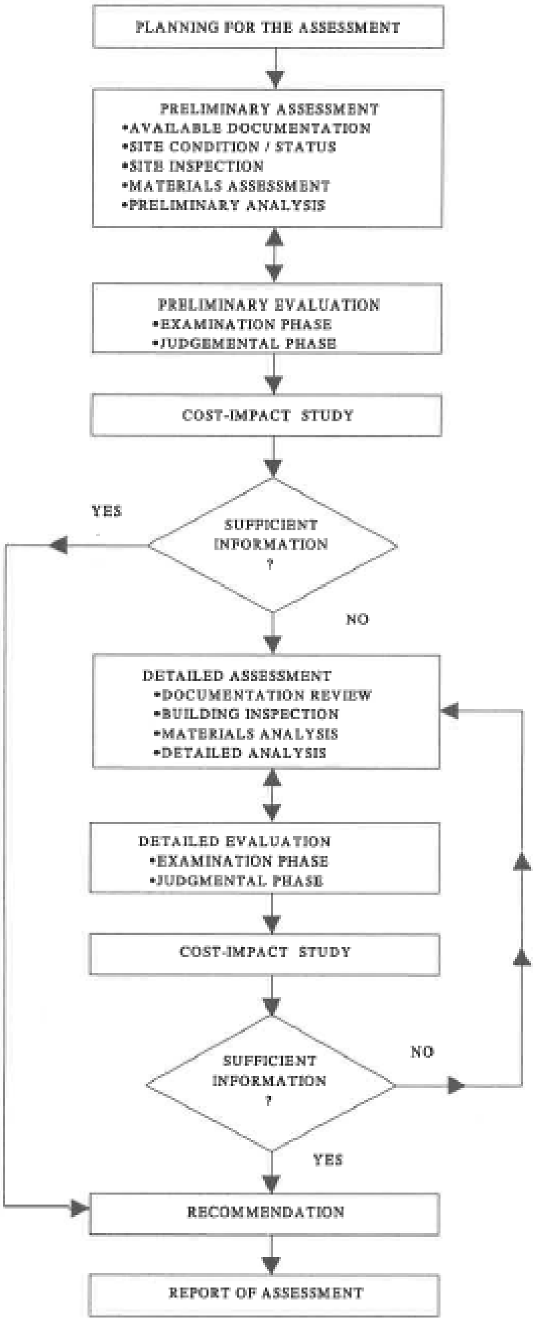


Figure G.1: Workflow ASCE Standard (ASCE, 2000)

**Risks compiled/identified/assessed**

Both the preliminary as the detailed assessment are evaluated using predefined performance criteria. If the structural conditions are marginal during preliminary assessment, further analysis in the detailed assessment may be required. However, if significant deficiencies come forward during the preliminary analysis, immediate recommendations can be given.

A cost-benefit analysis may help in deciding whether a detailed assessment is necessary or not. This cost -benefit analysis provides a rough estimate for the preliminary analysis. If the analysis shows rehabilitation is feasible, the more detailed assessment can be performed. If not, alternate uses or a rest of use plan may be determined.

In the detailed assessment, the building is deemed adequate, in case the performance criteria are met and there are no deficiencies. If this is not the case more sophisticated analysis could be performed. If this still does not provide the desired outcomes, a realistic recommendation for disposition must be formulated.

In conclusion, the risks are considered in a more abstract, qualitative way via engineering judgement.

**Actions**

If not conform criteria in the detailed assessment, alternate concepts for correction of eventual deficiencies or upgrading of building must be identified and described. Not given what kind of actions could be taken. There are two cost benefit analyses performed in the method where more insight is gained into the risks.

**Manuals/tools helping assessment**

In case of detailed assessment, there is stated where data could be retrieved. Material properties and possible deterioration mechanisms are also listed for concrete, metals, masonry and wood. There is also described what for inspections and test can be performed, also listing the expected level of experience for the action. With these actions, there is also given what kind of issues can be resolved.

As aforementioned, there is a report format available within this method. The chapter headers are given along with a description of its required content.

**Other**

All personnel involved in the assessment must have the correct technical qualifications along with practical experience, education and required professional judgement for the individual technical tasks (ASCE, 2000). There is also stated that an inspection team should at least include one structural engineer, with experience in structural evaluation, and personnel familiar with the building. The final results of the assessment, including the conclusions, must be interpreted by a professional engineer who is qualified in the correct discipline.

Next to user qualifications, also demands are given for equipment to be used during assessment. The equipment must be appropriate to perform the various tests and inspections stated in this method (ASCE, 2000). This means that the equipment must be working and if calibrated, the calibration reports must be available.

### G.2.2 Periodic Structural Inspection of Existing Buildings (BCA, 2022)

These guidelines for periodic structural inspection of existing buildings are presented by the Building and Construction Authority (BCA). The guidelines were introduced along with the Singapore Building Control Act in 1989. This inspection is applicable to all buildings in exception of detached, semi-detached, terraced or linked houses (only residential) and temporary buildings.

**General approach**

The method encompasses two stages:

1. Visual inspection
2. Full structural investigation

Before inspection, the engineer must obtain and study a set of building layout plans from the BCA. One of the reasons to study these plans is to identify special and critical structures. The following points must be included in the study (BCA, 2022):

- The condition of the building.
- The loading on the structure of the building.
- Any unauthorised works.

In case it is not possible to visually inspect the full building, engineering judgement must be used. When this is the case, minimum requirements on the inspection coverage are provided. For these requirements a difference is made between residential, non-residential and mixed-use buildings. If the requirements are not able to be fulfilled, again professional judgement must be applied. In the method more information regarding important factors and criteria for complex buildings are given.

In the event there are no signs of defects, deformation or deterioration, the visual inspection is sufficient. Else, there must be decided upon which action to implement, for instance, repair works or a full structural investigation. When the latter is chosen and the deficiencies are of local nature, the investigation may first be applied to only that area (BCA, 2022). The scope of the full investigation is given in the document.

**Risks compiled/identified/assessed**

So, when there are defects, deformation or deterioration, professional judgement must be performed to select follow up actions. The risks are thus identified in a qualitative matter. However, there is some help provided by stating the severity of the problems (BCA, 2022):

- Defects of no structural significance.
- Defects requiring remedial action and/or monitoring.
- Suspected defects of structural significance needing full structural investigation/immediate action.

**Actions**

There is stated that for all detected defects, the engineer must provide recommendation on the appropriate remedial actions and/or procedures. There are some of the possible actions given, for instance, need for removal of unauthorised works.

**Manuals/tools helping assessment**

As can be seen in the desk study, a report format with headers and description of the content and a checklist is provided. Here there is stated how the information could be retrieved and what must be reported. Among others, in this format there is stated how defects/deformations/deterioration can be detected via visual inspection.

**Other**

The frequency for which the inspection must be performed and the qualifications for the engineer conducting the assessment, are stated in the desk study (Kuijer et al., 2022). In addition, the engineer must have a practising certificate under the Professional Engineers Act 1991, which authorises him/her for civil engineering work (BCA, 2022). The engineer must provide enough diligence and take active interest in the assessment. It is thus not acceptable to delegate the entire inspection work to another person which is not a registered professional engineer.

The report must be signed by the structural engineer who was appointed for the inspection.

### G.2.3 CUR 124 (CROW-CUR, 2019)

This method helps local governments to validate the structural safety of existing bridges and viaducts. The prioritisation for an acreage of objects as well as the structural safety of an individual object are considered. A good prioritisation focusses on the most urgent (risky) structures for assessment (CROW-CUR, 2019). Therefore, the method provides a risk-based assessment.

**General approach**

In this approach, first a prioritisation for an acreage of structures is performed. Then the assessment procedure is highlighted for individual structures. To perform this risk-based prioritisation, an object risk analysis (ORA) is used. This analysis leads to a quantified risk score of the object. The higher the score, the more important it becomes to perform a reassessment. A high-risk score often comes from lack of information.

As the retrieval of information is a time extensive process, this information must be collected in an iterative way (CROW-CUR, 2019). This iterative process along with the entire flow of the prioritisation and assessment can be seen in the flowchart, which is captured in figure g.2. There can be seen it entails a risk-based process with multiple choices, which either lead to finalisation or a more detailed step.

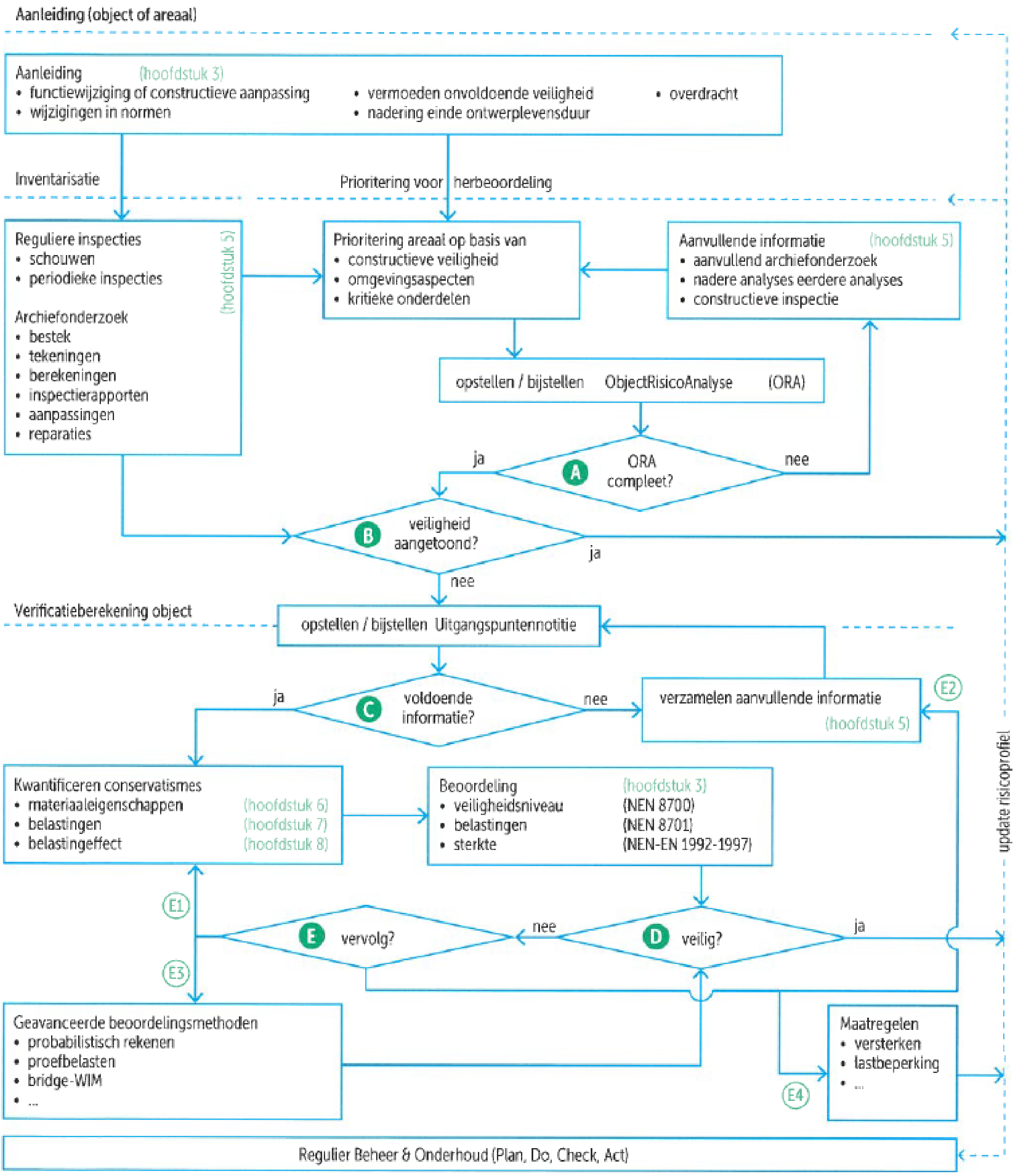


Figure G.2: Flowchart for assessment CROW CUR 124 (CROW-CUR, 2019)

**Risks compiled/identified/assessed**

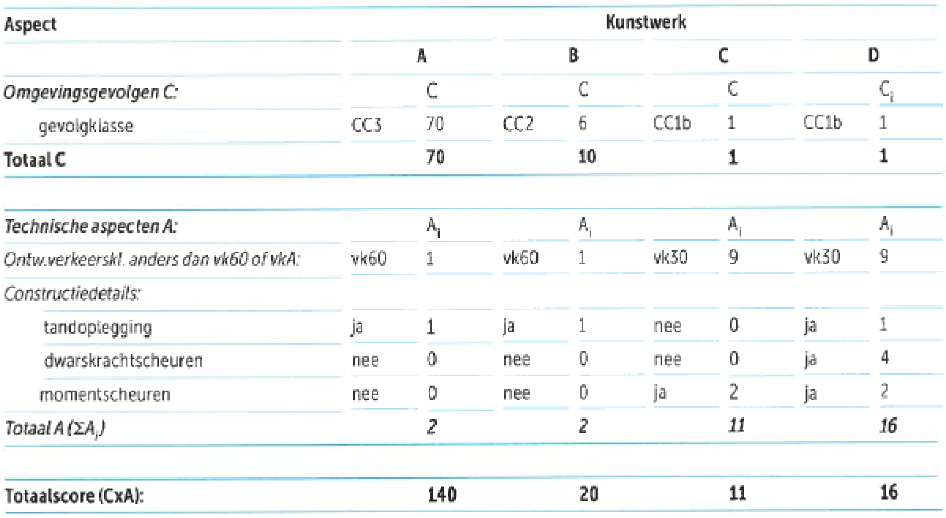
The method describes how the ORA for the prioritisation of objects must be performed. This risk is determined by multiplying the chance (letter A) times the consequences (letter C). For the chance the following points are considered when present: Technical aspects, loads, load bearing capacity, defects and degradation (CROW-CUR, 2019). The quantification of A for the traffic loads, bending cracks and shear cracks are given in the document. For other aspects there is stated how the A can be determined. Then there also are the consequences marked with the letter C. These consequences are related to the consequences classes, the exact numbers are also given in the source. This leads to the following equation (CROW-CUR, 2019): $R_{Object} = C \sum A_j$

In the tables below, an example of the ORA is given.

Table G.6: Example ORA CRU 124 (1/2) (CROW-CUR, 2019)

| **brug** | **gevolgklasse** | **verkeersklasse bij ontwerp** | **tandoplegging** | **waargenomen scheuren** |
|---|---|---|---|---|
| A | CC3 | klasse 60 | ja | geen |
| B | CC2 | klasse 60 | ja | geen |
| C | CC1b | klasse 30 | nee | geen |
| D | CC1b | klasse 30 | ja | moment en buiging |

Table G.7: Example ORA CRU 124 (2/2) (CROW-CUR, 2019)



| **Aspect** | **Kunstwerk** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **A** | | **B** | | **C** | | **D** | |
| *Omgevingsgevolgen C:* | | C | | C | | C | | $C_i$ |
| gevolgklasse | CC3 | 70 | CC2 | 6 | CC1b | 1 | CC1b | 1 |
| **Totaal C** | | **70** | | **10** | | **1** | | **1** |
| *Technische aspecten A:* | | $A_i$ | | $A_i$ | | $A_i$ | | $A_i$ |
| *Ontw.verkeerskl. anders dan vk60 of vkA:* | vk60 | 1 | vk60 | 1 | vk30 | 9 | vk30 | 9 |
| *Constructiedetails:* | | | | | | | | |
| tandoplegging | ja | 1 | ja | 1 | nee | 0 | ja | 1 |
| dwarskrachtscheuren | nee | 0 | nee | 0 | nee | 0 | ja | 4 |
| momentscheuren | nee | 0 | nee | 0 | ja | 2 | ja | 2 |
| *Totaal A ($\Sigma A_i$)* | | *2* | | *2* | | *11* | | *16* |
| **Totaalscore (CxA):** | | **140** | | **20** | | **11** | | **16** |

In the examples there can be seen that object A in this case has the highest score and should thus be prioritised for assessment. There is no level given where the risks are deemed to suffice, as it entails a qualitative equation (CROW-CUR, 2019).

If decided to perform an assessment for an object, it is a quantitative assessment based on legislation. If at point D in the flowchart there is decided more steps are required, the steps marked with an E become applicable. The choice for E1 – E4 could be made via a cost benefit analysis.

**Actions**

In the steps marked with an E, examples of actions and measures are given. Apart from these examples, no additional information regarding the subject is available within the method.

**Manuals/tools helping assessment**

In conclusion of the ORA and as starting point for the assessment, a memorandum must be composed. The aspects required in this memorandum is given in bullet points.

In the document there is given how the required information for assessment could be retrieved, what information is required and more, including inspection points. Material properties are also given for concrete, reinforcement, prestressing steel, steel, masonry, timber and the subsurface. Again, there is given how different material properties be obtained. The method provides more information regarding loads, calculations, models, different kinds of defects and how these could be inspected including required results. At last, information on material testing/inspection is given.

**Other**

In the document, information is given regarding the assessment of an object for the standards (among others NEN 8700). Here three levels for assessment, namely, new, renovation and rejection level, are stated. The prognosis on the remaining lifetime of the object is based on these levels. In addition, there is explained that resistance must be higher as applied loads and information regarding consequence classes. Also the legislation and philosophy of existing documents is given.

### G.2.4 NEN – ISO 13822 (NEN-ISO, 2010)

This is an international standard describing general requirements and procedures for the assessment of existing structures (NEN-ISO, 2010). These procedures and requirements are based on structural reliability principles and consequences of failure, where ISO 2394 forms the basis of this method. There is also stated under which circumstances this standard can be applied, which are given in the desk study. All kinds of structures including groups of structures are considered with this method.

**General approach**

Frist the objective for the structural performance of the assessment must be determined in alignment with the client and, if necessary, the authorities. Here there are three levels (NEN-ISO, 2010): Safety performance, continued function performance and special performance requirements from client. There is suggested to perform a site visit before the procedure of the method. The entire approach is given in figure g.3.

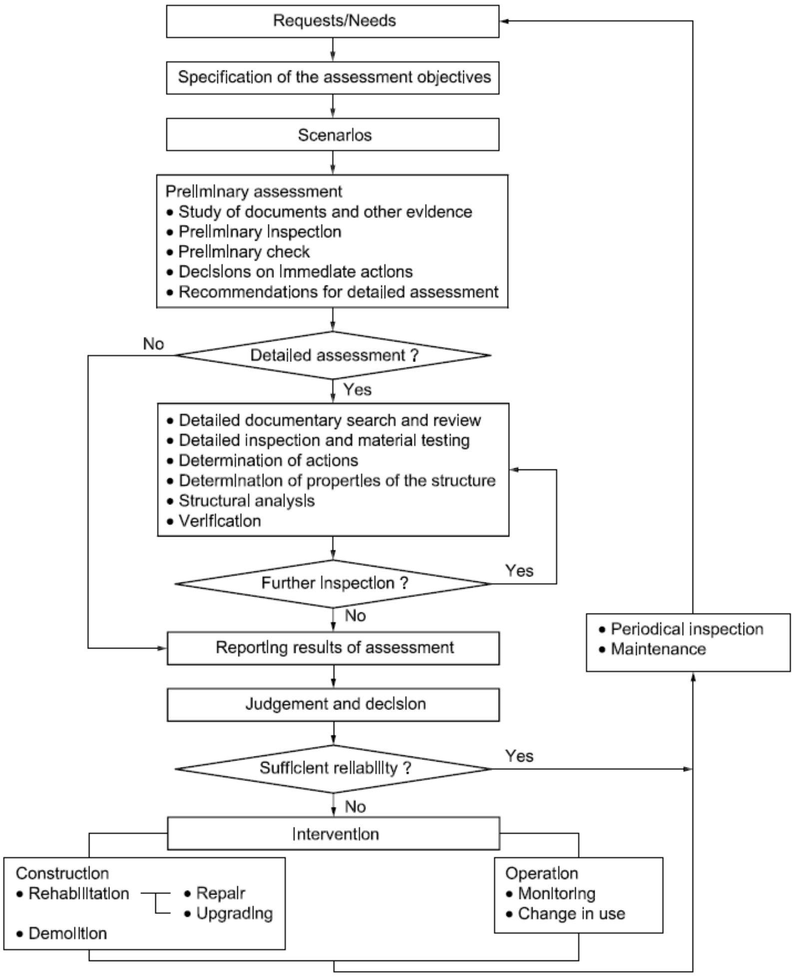


Figure G.3: Flowchart process ISO 13822 (NEN-ISO, 2010)

In the flowchart mentioned above, there is a header labelled scenario. In each scenario a predominant process or action and, when appropriate, accompanying processes or actions are mentioned (NEN-ISO, 2010). These scenarios are related to a change in structural conditions or actions and must be specified in the safety plan to identify potential critical situations. This identification of scenarios forms the basis for the assessment and if required provides interventions to ensure structural safety and serviceability.

The preliminary inspection, within the preliminary assessment, consists of a visual observation using simple tools, to identify possible damages of the structure and identify the structural system (NEN-ISO, 2010).

When it is uncertain what the surrounding actions and the effects/properties of the actions are, a detailed assessment should be recommended.

More information on the other steps is available in the standard.

**Risks compiled/identified/assessed**
There is no clear structure given to quantify risks, decisions are made using engineering judgement. When applicable, calculations are made to verify if the assessment is within the criteria of the reliability level.

The verification step in the detailed assessment is given to ensure this target reliability level, which represents the required level of structural performance (NEN-ISO, 2010). A reliability assessment is performed with limit states. The results must undergo a plausibility check as for instance, the results of the analysis along with the real condition must be explained (NEN-ISO, 2010). The target reliability level is composed of criteria, which are defined in proven and accepted design codes. In the method there is further elaborated on this reliability level.

**Actions**
A possible conclusion of the preliminary assessment could be that immediate actions are required. In this case there must be a potentially dangerous conditions which must be solved. If uncertain, the critical deficiencies should be assessed and actions taken if required.

For the detailed assessment there is stated that appropriate actions should be taken in case, the assessment shows the structural safety and/or serviceability are inadequate. The results must be used to provide recommendations on structural interventions regarding repair, rehabilitation or upgrading of the structure (NEN-ISO, 2010). By implementing these recommendations, the object can fulfil its intended remaining service life.

In the end several interventions might be possible, for instance, repair, rehabilitation, monitoring, maintenance critical components, upgrading and demolition (NEN-ISO, 2010). If interventions are required, these must be recommended in the report.

**Manuals/tools helping assessment**
The documents available must be corrected and updated to include previous changes to the structure. In addition, the method provides more demands and helpful information regarding the data used in the assessment, just as for the structural analysis. For the detailed assessment there is even stated what documents must be reviewed.

In addition, more information, along with an example, are given on inspection, evaluation and results of inspections. For these inspections and possible actions, testing for stating and dynamic properties of structures and assessment of time-dependent reliability are included. Even a format to write a test plan are available.

At last, there is report format given that provides headers and specifications of its content along with demands regarding reporting.

**Other**

As some structures also prove themselves over the years, assessment on the basis of satisfactory past performance is also considered. Reasons are provided regarding the safety and serviceability part to not perform the assessment.

There is also information available on the design of upgrading structures and heritage structures.

### G.2.5 Appraisal of Existing Structures (ISTRUCTE, 2010)

This method is applicable for the structural reassessment of buildings. However, other type of structures can also be implemented. This source has already been thoroughly examined in the first desk study (Kuijer et al., 2022). As a result, this study already provides good points on the principles of the method, the reasons for reassessment and what is required for assessment. In general, the method asks the following questions to the individual performing the reassessment (ISTRUCTE, 2010):

- Is the structure adequately safe now and in the future?
- Can the object be used for its intended purpose now and in the future?

There are also questions to be asked during the assessment, these are stated in the first desk study. What is important to note is that the method states that engineering judgement is always leading, the one performing the assessment has most insight into the true conditions of the object (ISTRUCTE, 2010).

**General approach**

The first step in the assessment is compiling a brief to guide the work of the engineer. There must be agreed upon the contents of the brief by both the engineer and the client. The description on the required content of this brief can be found in the report (ISTRUCTE, 2010).

Then, before the assessment can take place, information must be obtained via sources like a desk study and site inspections. In the method, there is stated that much time can be saved when documented information is retrieved before any physical investigation is performed, apart from a visual inspection (ISTRUCTE, 2010). The site inspection includes a visual part, measurements to dimensions and checks to structural arrangements, materials plus the condition of the structure. There is stated that in many cases a visual inspection with a desk study suffices. Despite this fact, reasons for performing additional tests are also provided.

Next is the assessment, where the paths and stages have an iterative process. The assessment consists of the following stages (ISTRUCTE, 2010):

1. Preliminary broad assessment to suitability intended use plus physical condition, robustness and strength. Simple calculations are performed when necessary.
2. Detailed assessment including numerical checks on stability and integrity, the strength of each member is checked numerically. Conventional limit state calculations are applied
3. More in-depth analysis. Based on best knowledge that can practically be retrieved

When the first or second step provide enough investigation, the assessment can be concluded. Only if, for instance, step one does not provide enough clarity the second step must be performed. In the document describing the method, extensive flowcharts on the approach of the method are provided. As an example, the flowchart of the initial assessment stage is given in the figure below.

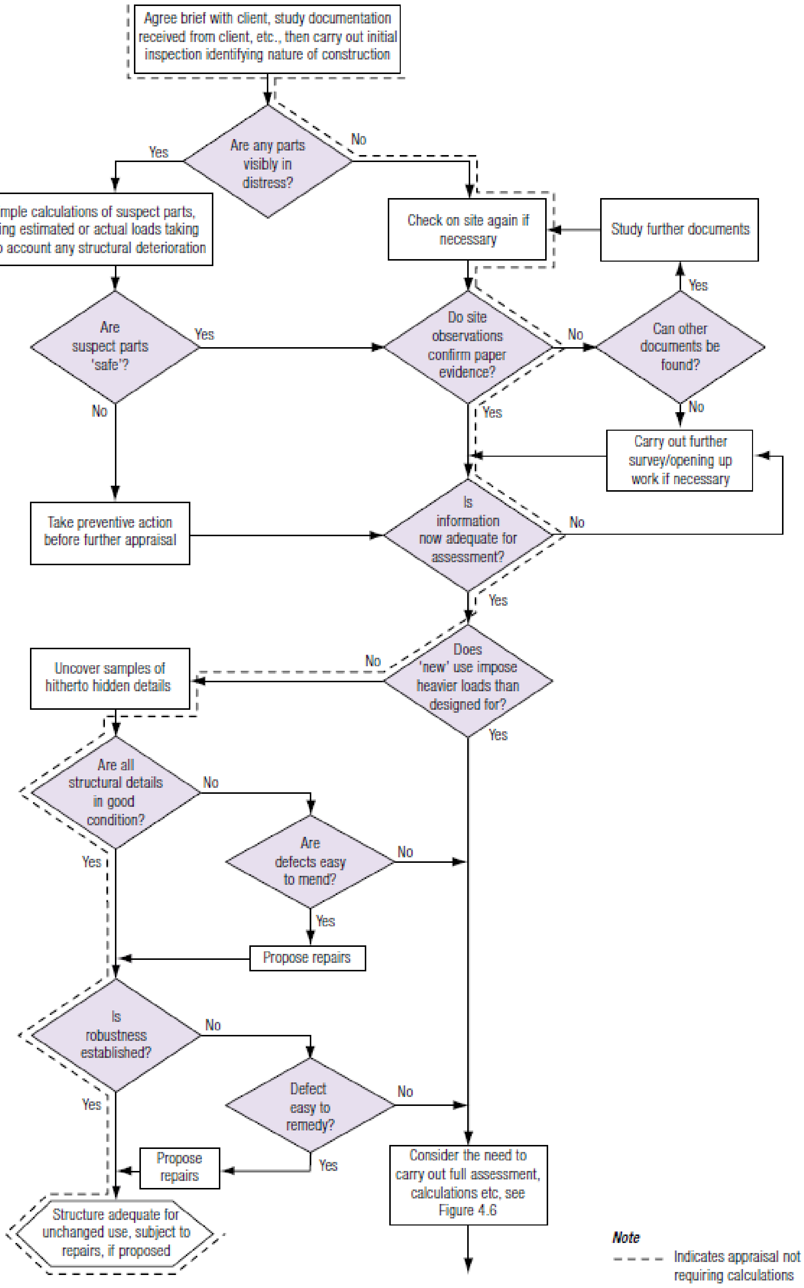


Figure G.4: flowchart for the initial stage (ISTRUCTE, 2010)

An important factor is the potential hazard to which local failure may lead to more widespread damage/collapse (ISTRUCTE, 2010). Most risk is involved in situations where failure of small mass can lead directly to loss of support for a large mass of material. It is unlikely visual feedback is useful in these cases, a significant level of confidence in the assessment is required.

**Risks compiled/identified/assessed**

The risks are being qualitatively assessed via engineering judgement in combination with calculations. For example, there is advised to balance calculations and judgement based on experience in the initial stage (ISTRUCTE, 2010). There is also stated that many buildings do not comply with the code requirements. This does not mean these structures are unsafe, engineering judgement is required in these situations.

There is also information given regarding the acceptable level of risk. There is attempted to link this level to a law or standard, as the level of safety is generally considered a governmental matter (ISTRUCTE, 2010). In addition, cost benefit analysis is also included to determine whether risks should be eliminated or not. Unless the costs are significantly disproportionate to the risk, there is a duty to eliminate these foreseeable risks.

**Actions**

Information provided on future performance via exploration results.

**Manuals/tools helping assessment**

There is a detailed description available for what content should be stated in the report including a format with chapters, which are again further described. Next to the reporting, influencing factors are also available. Here information is given on the assessment of structures along with safety factors and calculations requiring extra consideration.

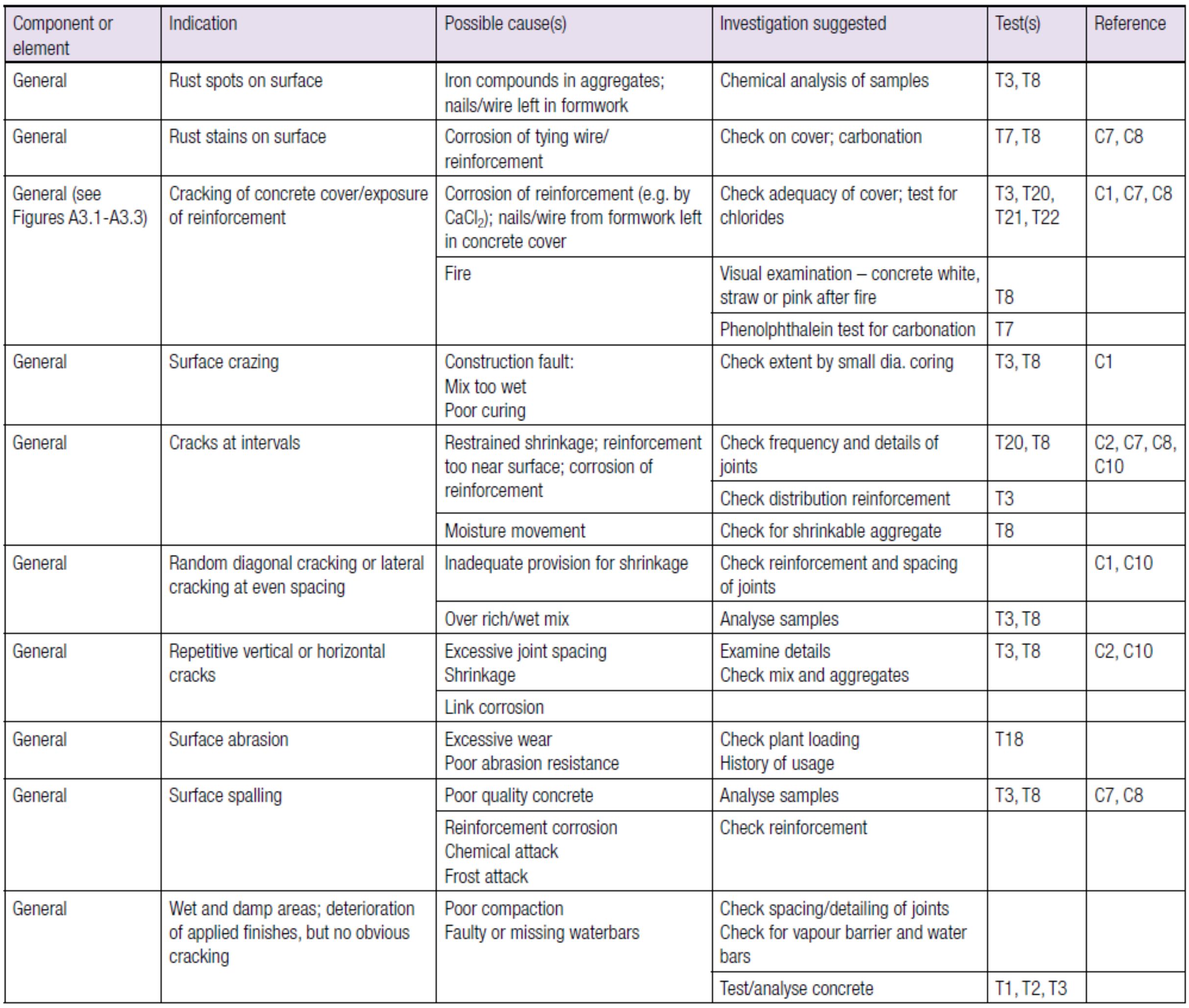
Another important aspect of the method is the description of testing and monitoring. The reasons for testing, how tests should be performed and information on a variety of testing methods (including accompanying tools required) are all discussed. A distinction is made within the tests based on the applicable material.

Subsequently, the materials itself are also closer examined, considering the use properties and deterioration of masonry, timber, metals (including alloys), concrete, steel-concrete composites, polymeric materials, fibre-reinforced polymer composites, advanced composite materials, polymers plus adhesives, protective materials, glass and fabric.

All the gained knowledge on testing methods and the materials is used to develop table with types of defects. In these tables, there is given what kind of tests could be performed to mitigate the applicable defect. These tables are only available for the following materials: concrete, masonry, structural steel (including cast iron and wrought iron) and timber. In table g.8, an example of such a table is given for the concrete material. There can be seen the tests are described using codes, which are specified in the chapter describing these tests.

In conclusion, health and safety considerations, for conducting safe inspections, are also given.

Table G.8: Example on tables with defects (ISTRUCTE, 2010)



| Component or element | Indication | Possible cause(s) | Investigation suggested | Test(s) | Reference |
|---|---|---|---|---|---|
| General | Rust spots on surface | Iron compounds in aggregates; nails/wire left in formwork | Chemical analysis of samples | T3, T8 | |
| General | Rust stains on surface | Corrosion of tying wire/ reinforcement | Check on cover; carbonation | T7, T8 | C7, C8 |
| General (see Figures A3.1-A3.3) | Cracking of concrete cover/exposure of reinforcement | Corrosion of reinforcement (e.g. by $CaCl_2$); nails/wire from formwork left in concrete cover | Check adequacy of cover; test for chlorides | T3, T20, T21, T22 | C1, C7, C8 |
| | | Fire | Visual examination – concrete white, straw or pink after fire | T8 | |
| | | | Phenolphthalein test for carbonation | T7 | |
| General | Surface crazing | Construction fault:<br>Mix too wet<br>Poor curing | Check extent by small dia. coring | T3, T8 | C1 |
| General | Cracks at intervals | Restrained shrinkage; reinforcement too near surface; corrosion of reinforcement | Check frequency and details of joints | T20, T8 | C2, C7, C8, C10 |
| | | | Check distribution reinforcement | T3 | |
| | | Moisture movement | Check for shrinkable aggregate | T8 | |
| General | Random diagonal cracking or lateral cracking at even spacing | Inadequate provision for shrinkage | Check reinforcement and spacing of joints | | C1, C10 |
| | | Over rich/wet mix | Analyse samples | T3, T8 | |
| General | Repetitive vertical or horizontal cracks | Excessive joint spacing<br>Shrinkage | Examine details<br>Check mix and aggregates | T3, T8 | C2, C10 |
| | | Link corrosion | | | |
| General | Surface abrasion | Excessive wear<br>Poor abrasion resistance | Check plant loading<br>History of usage | T18 | |
| General | Surface spalling | Poor quality concrete | Analyse samples | T3, T8 | C7, C8 |
| | | Reinforcement corrosion<br>Chemical attack<br>Frost attack | Check reinforcement | | |
| General | Wet and damp areas; deterioration of applied finishes, but no obvious cracking | Poor compaction<br>Faulty or missing waterbars | Check spacing/detailing of joints<br>Check for vapour barrier and water bars | | |
| | | | Test/analyse concrete | T1, T2, T3 | |

**Other**

In the method no complete overview of qualifications is given. However, for inspections and other site work extensive information is available, including some relevant aspects on qualifications. There is stated that inspections should not be performed by inexperienced people working on their own. Even an experienced engineer visiting the building alone should report back at certain intervals. The engineer should be trained to be aware of likely hazards and be familiar with safety equipment plus safe systems (ISTRUCTE, 2010). In addition, basic first aid knowledge may be desirable. For some sites, specialist training may be necessary. This must not only be verified with the client, but also independently investigated.

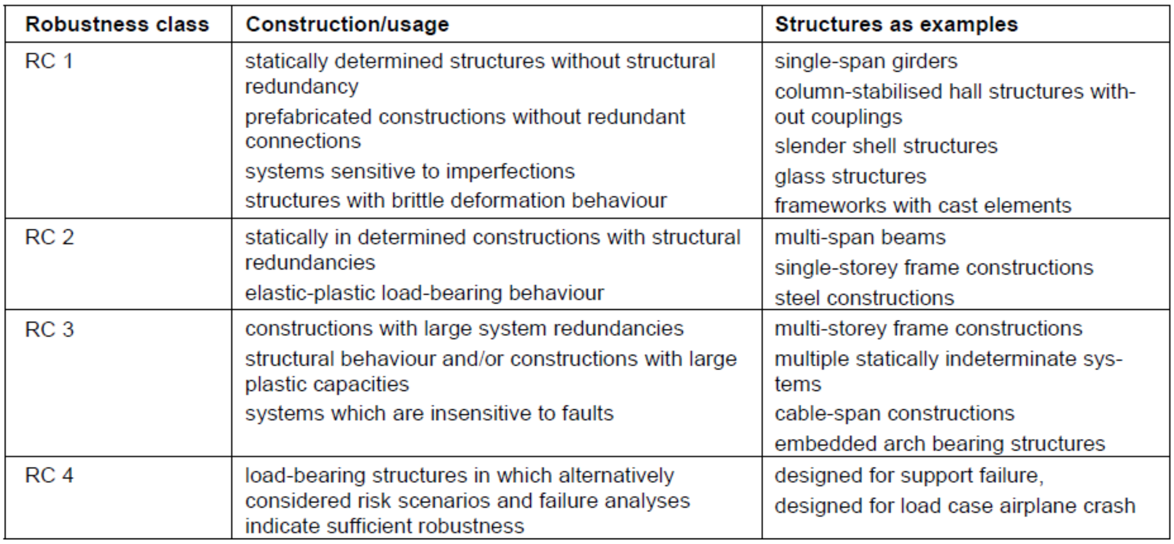
### G.2.6 VDI 6200 Structural safety of buildings, regular inspections (VDI, 2010)

This guideline is developed in strict accordance with requirements and recommendations of standard VDI 1000 (VDI, 2010). The guideline is developed after building collapses throughout Europe, at the start of 2006, called for regulations, regarding structural safety. This guideline contains assessment - and evaluation criteria plus practical instructions for periodic inspections to structural safety (VDI, 2010). In addition, recommendations concerning maintenance of buildings are provided.

**General approach**

In the first step the object is classified to determine the depth of the assessment. Both the consequence as the robustness is considered in this classification. The robustness classification used in the method is given in table g.9. As the consequence classes are already examined in this document, these are not further explained in this section.

Table G.9: Robustness classification by VDI (VDI, 2010)



| Robustness class | Construction/usage | Structures as examples |
|---|---|---|
| RC 1 | statically determined structures without structural redundancy<br>prefabricated constructions without redundant connections<br>systems sensitive to imperfections<br>structures with brittle deformation behaviour | single-span girders<br>column-stabilised hall structures without couplings<br>slender shell structures<br>glass structures<br>frameworks with cast elements |
| RC 2 | statically in determined constructions with structural redundancies<br>elastic-plastic load-bearing behaviour | multi-span beams<br>single-storey frame constructions<br>steel constructions |
| RC 3 | constructions with large system redundancies<br>structural behaviour and/or constructions with large plastic capacities<br>systems which are insensitive to faults | multi-storey frame constructions<br>multiple statically indeterminate systems<br>cable-span constructions<br>embedded arch bearing structures |
| RC 4 | load-bearing structures in which alternatively considered risk scenarios and failure analyses indicate sufficient robustness | designed for support failure,<br>designed for load case airplane crash |

For new materials and/or new production methods used, the building must be classified as Robustness class one (VDI, 2010). There must be checked if the correct robustness class is applied. This check must be performed during the first inspection for existing buildings and for new buildings by the check engineer.

Documents required for assessment must be reviewed/drawn up at the moment of first inspection (VDI, 2010). Then during first inspection, points of possible fatigue, extant of changes in usage and more points given in the document must be checked. In this first inspection, the inspection intervals and classification are determined along with the selection of document to be stated in the logbook (VDI, 2010).

For the assessment the following stages are considered (VDI, 2010):

- Surveillance by owner/authorised representative
- Inspection by expert, is a visual inspection (without technical equipment)
- Thorough inspection by special expert, all main load bearing elements (including ones difficult to reach) are inspected up close. If defects come forward, these must be assessed on the aspect of structural safety

The frequencies of these stages depend on the consequence classes. In some cases, the classification results in the fact that certain stages do not have to be considered at all. In reality, the intervals depend on a wide range of individual building characteristics. There is also advised to perform an unscheduled inspection following extraordinary events.

In the first stage there is stated that all influences, which have an impact on structural safety, must be considered.

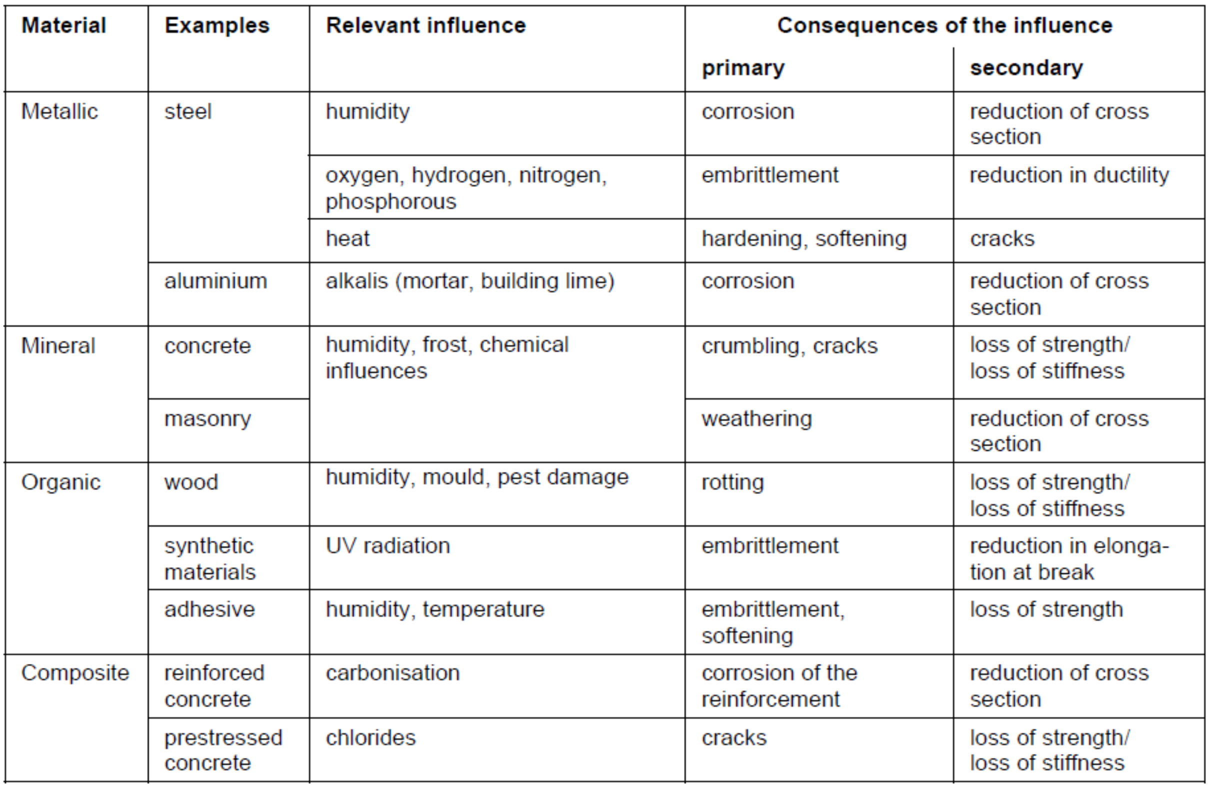
In case the structural safety is seen as insufficient, additional information is given for renovation planning and required measures.

**Risks compiled/identified/assessed**
Object is classified via consequences and robustness, further actions depend on engineering judgement.

**Actions**
If the safety proves to be insufficient in the restoration planning step, there is stated that measures must be taken. In case the safety is sufficient but a negative prognosis is given, safety management with an early warning system can be implemented (VDI, 2010).

**Manuals/tools helping assessment**
There is also information for the main materials used in structures. The most common changes for building materials due to environmental influences are given in the table below. There is also given how the changes in building materials can be detected including inspections/tests.

Table G.10: information building materials by VDI (VDI, 2010)



| Material | Examples | Relevant influence | Consequences of the influence | |
|---|---|---|---|---|
| | | | primary | secondary |
| Metallic | steel | humidity | corrosion | reduction of cross section |
| | | oxygen, hydrogen, nitrogen, phosphorous | embrittlement | reduction in ductility |
| | | heat | hardening, softening | cracks |
| | aluminium | alkalis (mortar, building lime) | corrosion | reduction of cross section |
| Mineral | concrete | humidity, frost, chemical influences | crumbling, cracks | loss of strength/ loss of stiffness |
| | masonry | | weathering | reduction of cross section |
| Organic | wood | humidity, mould, pest damage | rotting | loss of strength/ loss of stiffness |
| | synthetic materials | UV radiation | embrittlement | reduction in elongation at break |
| | adhesive | humidity, temperature | embrittlement, softening | loss of strength |
| Composite | reinforced concrete | carbonisation | corrosion of the reinforcement | reduction of cross section |
| | prestressed concrete | chlorides | cracks | loss of strength/ loss of stiffness |

A logbook must be updated to provide a compact overview of the building, the basic data of structural analysis and permit documentation (VDI, 2010). The layout and content of this logbook are captured in a format, which is given in the source.

For the first two stages mentioned, there are specifications/checklists with minimum requirements available. Here information is given regarding defects on certain construction parts. There is also a concise layout available for the documentation of the assessment.

**Other**
If extraordinary events occurred, there is recommended to carry out an unscheduled inspection. It is also recommended to perform the second stage inspection for conversions, changes of usage and technical modernisations in case no technical inspections have been performed (VDI, 2010).

For the document review, the standards and material qualities at the time of erection must be considered.

In case there cannot be guaranteed that only very small subsoil deformations can occur, there is recommended measurement points are examined. In the construction phase or first inspection the exact geodetic height can be measured at these points, thereby tracking the settlement behaviour (VDI, 2010)

For the different stages of assessment there are also different levels of qualifications required. These classifications are already specified in the desk study (Kuijer et al., 2022). There is however one extra demand for experts. Within the minimum five years of experience, at least three must be within the compilation of structural analysis. Moreover, for the minimum of 10 years' experience for the special expert, at least five years in compilation of structural safety verifications and one year in technical site supervision are required (VDI, 2010). These special experts are usually civil engineers with the earlier mentioned qualifications or check engineers and employees of check authorities in the field of structural safety.

Despite the fact that in the first stage of assessment no experts are required, there is clearly explained under which circumstances these experts should be contacted. Any non-destructive test methods and interpretation of results must be performed by an expert.

There is also a section on planning and execution for regular inspection and maintenance in the use phase. There is ,among others, mentioned that points in the load bearing structure must be open and accessible to inspection, but also projected against the environment.

### G.2.7 NEN 2767 (NEN, 2019a) (NEN, 2008)

The NEN 2767 standard consists of two parts, the NEN 2767-1 and the NEN 2767-2. The NEN 2767-1 encompasses an objective/unambiguous condition assessment for all objects within the built environment. The NEN 2767-2 provides an overview of the objects assessed in this method. Via this standard, the technical state of an object is determined by assessing the deficiencies spotted during inspection. Not only the aspect of structural safety is considered, the aspects electro, climate and transport are also taken into account.

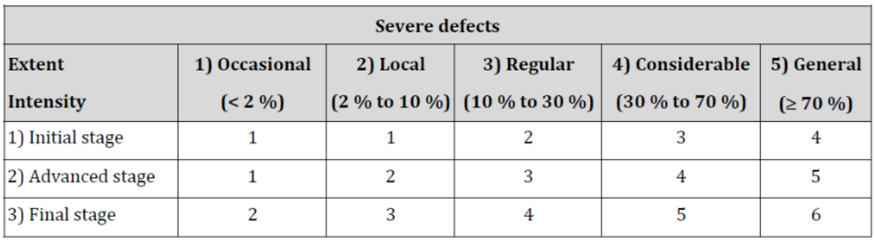
**General approach**
The method considers the following levels: Object, element and building installation/component. Via an inspection based on sensory observations (mostly visual), with if required tools, the information is retrieved for the condition assessment. To help with the inspection, lists of possible faults have been given. These faults have been categorised in multiple aforementioned technical disciplines. More information on these lists of faults is given under the manuals/tools header. After the inspection, the condition assessment can be performed. There are multiple steps to be taken in this assessment, as explained in the next paragraph.

### Risks compiled/identified/assessed

For the condition assessment, the deficiencies are being quantified. A six-point scale is used where one resembles an excellent condition and six a very bad condition.

The following three parameters are used to retrieve this score: severity, extent and intensity. The severity and intensity are both subdivided into three levels, severity from minor to severe defect and intensity from initial to advanced stage. The extent parameter is subdivided into five levels, using percentages to show the extent in relation to the building/installation component. This leads to matrices where the condition of the building/installation components determined. An example of such a matrix for severe defects is given in table g.11. For the other defect levels the standards must be consulted.

Table G.11: Example for composing condition scores for severe defects (NEN, 2019a)



| Severe defects | | | | | |
|---|---|---|---|---|---|
| Extent<br>Intensity | 1) Occasional<br>(< 2 %) | 2) Local<br>(2 % to 10 %) | 3) Regular<br>(10 % to 30 %) | 4) Considerable<br>(30 % to 70 %) | 5) General<br>(≥ 70 %) |
| 1) Initial stage | 1 | 1 | 2 | 3 | 4 |
| 2) Advanced stage | 1 | 2 | 3 | 4 | 5 |
| 3) Final stage | 2 | 3 | 4 | 5 | 6 |

The condition assessment is also able to consider multiple defects that apply to one building/installation component.

The total condition score for an assembly of components is retrieved by applying correction factors. The method provides an example to indicate how this must be done.

In addition, the method provides a way of assessing its condition in case no defects or wear can be observed. In that case, as a last resort the aging curve could be used. This aspect is only applicable for components where aging is objectively measurable over its lifetime.

### Actions

This method only provides a condition assessment. However, the effects of not solving a deficiency can be quantified, thereby providing insight into the urgency of the deficiency. In the standard multiple aspects from the RAMSHEEP list are mentioned. There is also stated that the entire RAMSHEEP list could be used. Again, in the standard multiple examples are provided. More information on the RAMSHEEP phenomenon is given in the next subsection.

### Manuals/tools helping assessment

The aforementioned lists of faults are given in NEN 2767-2. These lists are categorised by the four disciplines: building, electro, transportation and mechanical engineering. The elements considered in each discipline are stated and provided with a NL-SFB code. Per element there is stated what deficiencies can occur and what the severity of this deficiencies are, thereby providing immediate input for the condition assessment. Just as the elements, a code is applied for the deficiencies.

In case the list cannot be used, as the information is not available in appendix A of NEN 2767-1, there is described what must be done. In this standard there is also stated what kind of tools can be used for the inspections. These tools differ per discipline.

### G.2.8 ORA Rijkswaterstat (Rijkswaterstaat, 2016)

This analysis consists of three levels: Simple, detailed and advanced. The simple level consists of a FMECA (Failure Modes, Effects and Criticality Analysis) analysis, where the risks are semi-quantified (Rijkswaterstaat, 2016). For the detailed and advanced analysis RCM (Reliability Centred Maintenance) calculations and fault tree analyses are performed. In this source only the simple analysis is provided.

**General approach**

Despite the fact that only the simple analysis is considered, there is explained when what analysis must be applied. Via a flowchart and a table, where multiple factors like the intensity of use are taken into consideration, there is determined what extent of risk analysis is required for what civil structure.

This (simple) object risk analysis could be used for the six-year assessment conducted by Rijkswaterstaat. The phases considered in the analysis, with description of activity and final products, are stated below (Rijkswaterstaat, 2016):

1. Desk study, the available information on the object is collected, the study is performed and initial risks are determined. This phase concludes with an initial object - function analysis and the initial step of the FMECA analysis.
2. In the second phase the object is inspected. The true condition, damages and irregularities found during inspection are processed. This leads to an adapted object - function analysis and the second step of the FMECA analysis.
3. The final phase is risk control. In this step measures are proposed to mitigate the risks, also approximating the impact these measures have on the risks. In this phase the FMECA analysis is concluded (All steps included).

These phases are further subdivided in steps, which are further discussed in the analysis (Rijkswaterstaat, 2016).

**Risks compiled/identified/assessed**

The FMECA analysis considers the risks in a semi-quantitative way. The chance that an event occurs and the consequences are compared in a risk matrix. The quantified chances are split into chances subject to aging and chances constant over time. Below the chances are given (the t stands for moment next failure expected).

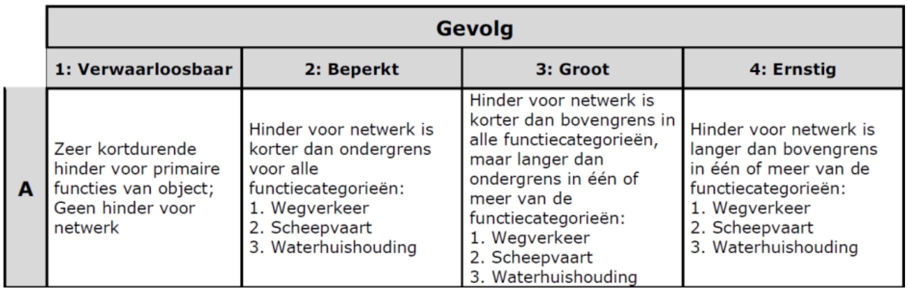
For chances influenced by aging (Rijkswaterstaat, 2016):

1. Negligible (20 years < t)
2. Small (6 years < t ≤ 20 years)
3. Mediocre (2 years < t ≤ 6 years)
4. Considerable (½ year < t ≤ 2 years)
5. Certain (t ≤ ½ year)

For the chances constant over time the same categories are used. The only difference is the fac the t now stands for the average frequency that these chances are expected to occur.

For the consequences a four-level scale is implemented with the following categories (Rijkswaterstaat, 2016): Negligible, limited, considerable and severe. To provide more assistance on the consequence quantification a table with the aspects from AMSHEEP (Availability, Maintainability, Safety, Security, Health, Environment Economics and Politics) is given in the method. The R of reliability, which is normally in front, is already considered in the chance of occurrence. In the table for each of these aspects the possible consequences are given. The maximum score for one of these categories is used as the consequence. In table g.12 an example is given for the availability.

Table G.12:Example interpretation consequences for the Availability (Rijkswaterstaat, 2016)

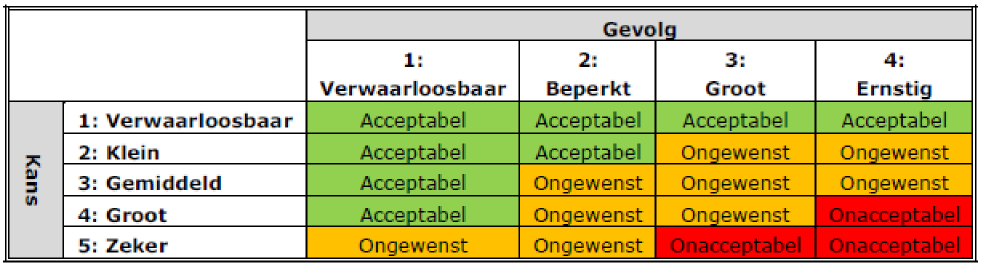


| | **Gevolg** | | | |
|---|---|---|---|---|
| | **1: Verwaarloosbaar** | **2: Beperkt** | **3: Groot** | **4: Ernstig** |
| **A** | Zeer kortdurende hinder voor primaire functies van object;<br>Geen hinder voor netwerk | Hinder voor netwerk is korter dan ondergrens voor alle functiecategorieën:<br>1. Wegverkeer<br>2. Scheepvaart<br>3. Waterhuishouding | Hinder voor netwerk is korter dan bovengrens in alle functiecategorieën, maar langer dan ondergrens in één of meer van de functiecategorieën:<br>1. Wegverkeer<br>2. Scheepvaart<br>3. Waterhuishouding | Hinder voor netwerk is langer dan bovengrens in één of meer van de functiecategorieën:<br>1. Wegverkeer<br>2. Scheepvaart<br>3. Waterhuishouding |

The risk is obtained by multiplying the chance with the consequence. An example of a risk matrix is given in table g.13. As it is a semi-quantitative assessment, the following risk categories are defined:

- Unacceptable (score 15 – 20)
- Undesirable (5 – 12)
- Acceptable (1 – 4)

Table G.13: Risk matrix (Rijkswaterstaat, 2016)



| | | **Gevolg** | | | |
|---|---|---|---|---|---|
| | | **1: Verwaarloosbaar** | **2: Beperkt** | **3: Groot** | **4: Ernstig** |
| **Kans** | **1: Verwaarloosbaar** | Acceptabel | Acceptabel | Acceptabel | Acceptabel |
| | **2: Klein** | Acceptabel | Acceptabel | Ongewenst | Ongewenst |
| | **3: Gemiddeld** | Acceptabel | Ongewenst | Ongewenst | Ongewenst |
| | **4: Groot** | Acceptabel | Ongewenst | Ongewenst | Onacceptabel |
| | **5: Zeker** | Ongewenst | Ongewenst | Onacceptabel | Onacceptabel |

**Actions**

From the undesirable risk level measures need to be implemented. In case there can be proven that measures are not necessary/infeasible for undesirable risks, this is also accepted. If risk prove to be unacceptable, a measure must be implemented. An example of such a measure, is the adaptation or providing variable maintenance measures over the regular maintenance scheme.

In the FMECA analysis the effectivity of the measures is examined via the approximation of the residual risk when the measure would be implemented. The risk can be reduced by implementing measures for the chance or consequence aspect. In this process of selecting the correct measures to mitigate the risks, the costs of the measures are also taken into account.

**Manuals/tools helping assessment**

As aforementioned there is clearly stated what type of analysis must be conducted for the object, with the help of flowcharts and tables. This clear manner of information sharing also comes back in the description on the different steps to be conducted in the analysis. Each step is well explained and clear examples are given to help the reader in its understanding.

To perform the FMECA analysis an excel format is made available. Besides the fact that the format can be used for the analysis, the format also provides an example.

A quality assessment must be performed after the ORA is conducted to see if the right decisions have been made. For this assessment questions are stated and a tab is reserved in the excel format. With these questions, again, clear support is given to perform the assessment.

**Multi-person principle**

The quality assessment must be performed by someone who did not execute the ORA. The person who performed the ORA has the chance to give comments on the findings of the quality assessment. The individual performing the quality assessment then decides whether the ORS is appropriate or not.

**Frequency**

There is stated that this analysis could be used as a six-year conservation advice for Rijkswaterstaat.

### G.2.9 NTA 8790 (NEN, 2023)

This NTA is developed to create a uniform way of working, help in formulating projects for clients and function as assessment guideline for assessors (NEN, 2023). The document provides a method for periodic assessment to the structural safety of existing buildings and is mandatory for a group of buildings. However, the method can also be used for buildings which are not within this mandatory group. The method is risk based, with its focus on elements for which collapse results in the most significant risks towards safety of persons (NEN, 2023). This means not all parts of the building are considered and when insufficient information is available, additional investigations must be performed.

**General approach**

In the method a difference is made between the initial and periodic assessment. The attention points and frequency of the periodic part follow from the performed desk study, performed in preparation of this method. In figure g.5 the process of the entire assessment is detailed. For detailed information on each step, the document itself should be accessed.

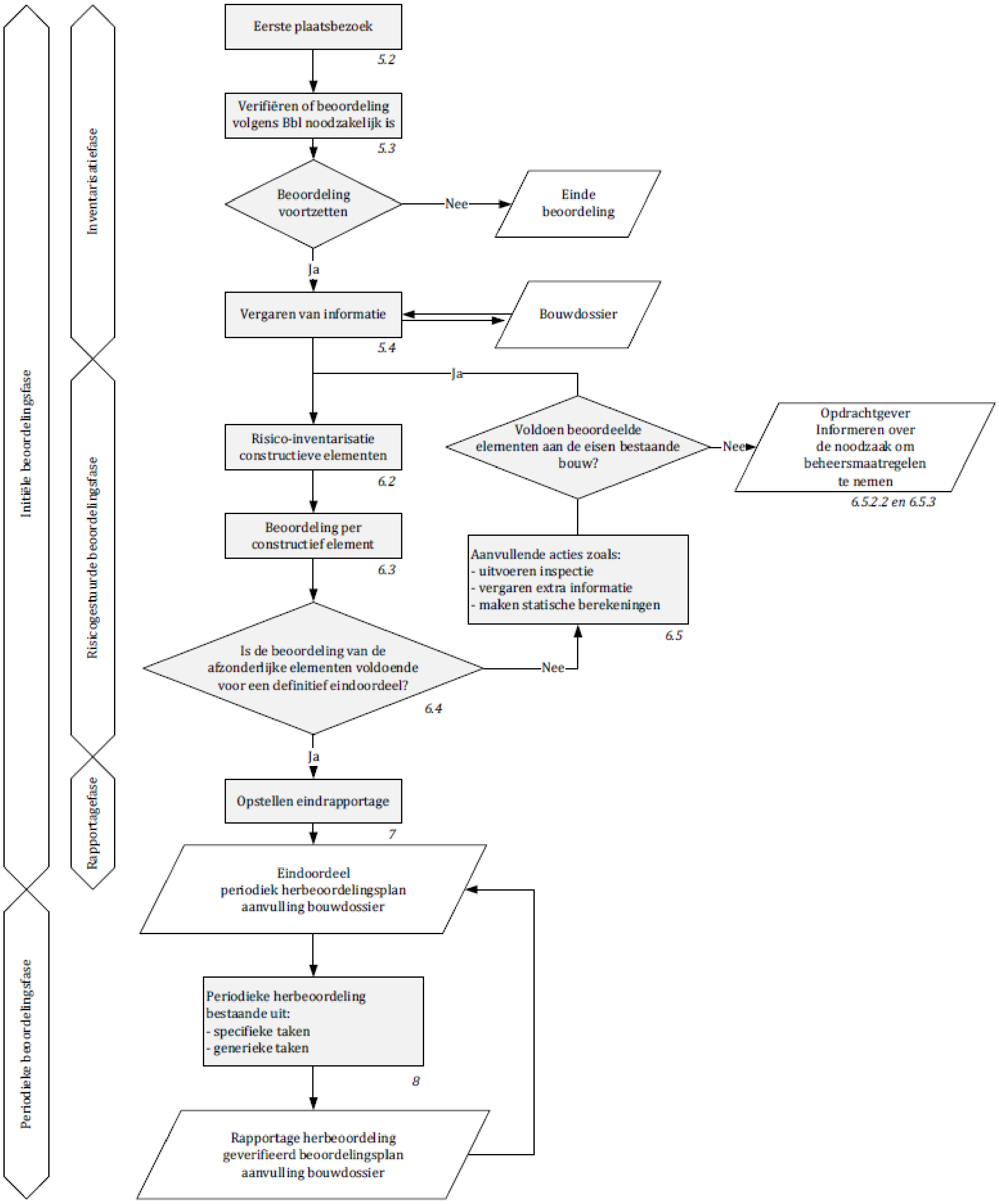


Figure G.5: Flowchart NTA 8790 (NEN, 2023)

Although the NTA is for all buildings, there is a step where there is checked if the object must be mandatorily assessed. These are buildings with a gathering, educational, sport, or other use function for persons which (de Jonge, 2023):

- Are used by at least 5000 persons.
- And/or have a space destined for at least 500 persons.

Besides these demands, the building must be realised after 1st of January 1950 or have adaptations made to the structure/change in use after this date (de Jonge, 2023). If the user area is not separated by external separation structures it must be mandatorily assessed.

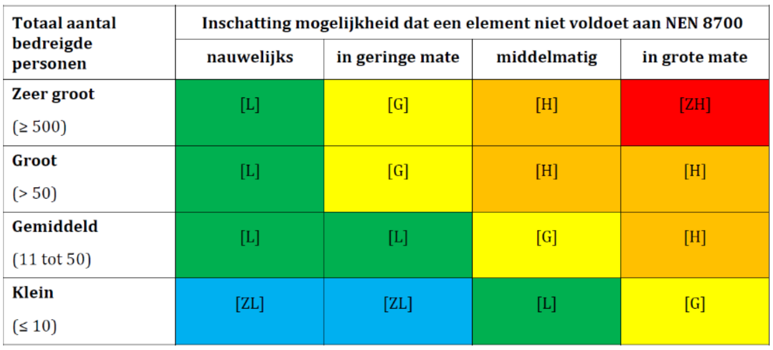
The assessment can be stopped in case no mandatory investigation is required. When assessment is conducted, information must be collected. There must be made sure that all the documents used for this collection are assessed on sufficient insight, structural set up and properties of relevant structural elements (NEN, 2023). In case not enough information is available, this process of information collection must be performed again. It is important to note that the first sight visit is before the information retrieval via documents.

All risks detected in the assessment phase and possible risks that could progress over time, have to be named in the final report of the initial assessment. These risks can then be considered within the periodic assessment. This assessment is also conducted to check if any changes were applied that affect the initially considered risks. The findings during the periodic assessments must be reported in the building archive.

**Risks compiled/identified/assessed**

Risk are determined via the chance an element is not up to standards and the potential danger for persons if the element collapses. For danger of collapse there is looked at direct danger, only considering the specific element, and indirect danger via possible mechanisms of progressive collapse. For all scenarios there is estimated how many people are endangered by this element in regular use. This leads to the following risk matrix for all elements considered.

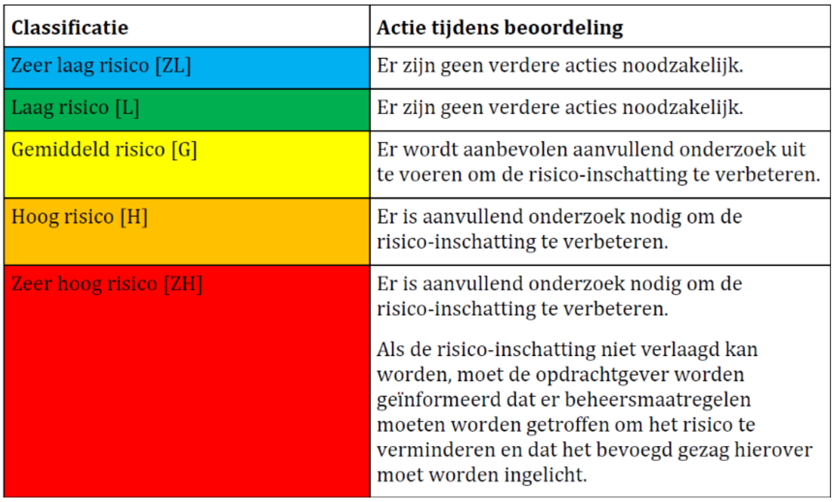
Table G.14: Risk matrix NTA 8790 (NEN, 2023)



| **Totaal aantal bedreigde personen** | **Inschatting mogelijkheid dat een element niet voldoet aan NEN 8700** | | | |
|---|---|---|---|---|
| | **nauwelijks** | **in geringe mate** | **middelmatig** | **in grote mate** |
| **Zeer groot**<br>(≥ 500) | [L] | [G] | [H] | [ZH] |
| **Groot**<br>(> 50) | [L] | [G] | [H] | [H] |
| **Gemiddeld**<br>(11 tot 50) | [L] | [L] | [G] | [H] |
| **Klein**<br>(≤ 10) | [ZL] | [ZL] | [L] | [G] |

The colours given in the table, resemble a risk scale which is given in table g.15. This scale also explains what additional actions should be taken per risk level.

Table G.15: Classification risks NTA 8790 (NEN, 2023)



| **Classificatie** | **Actie tijdens beoordeling** |
|---|---|
| Zeer laag risico [ZL] | Er zijn geen verdere acties noodzakelijk. |
| Laag risico [L] | Er zijn geen verdere acties noodzakelijk. |
| Gemiddeld risico [G] | Er wordt aanbevolen aanvullend onderzoek uit te voeren om de risico-inschatting te verbeteren. |
| Hoog risico [H] | Er is aanvullend onderzoek nodig om de risico-inschatting te verbeteren. |
| Zeer hoog risico [ZH] | Er is aanvullend onderzoek nodig om de risico-inschatting te verbeteren.<br>Als de risico-inschatting niet verlaagd kan worden, moet de opdrachtgever worden geïnformeerd dat er beheersmaatregelen moeten worden getroffen om het risico te verminderen en dat het bevoegd gezag hierover moet worden ingelicht. |

There is checked if sufficient level of detail is available to provide a funded conclusion on the structural safety of an existing building and if the object complies with the rules (NEN, 2023). If one of the following two statements is true, this is the case:

- Classification below acceptable level and cannot be higher estimated.
- Plausible that more information does not lower the risk classification.

If not applicable, additional actions need to be performed. More on these actions in the next paragraph.

**Actions**

As given in table g.15, there is already given for what risks what actions must be performed. The following possibilities for actions are given and further specified (NEN, 2023): Inspections, calculations and (material) investigations. There is advised to compare the possible additional actions to the impact of taking measures. There must be worked from coarse to fine in selecting the possible actions.

The periodic assessment is based on the risk classification, the frequency of the tasks is given in … Despite these frequencies, once in ten years a general task must be performed to check if the assessment plan is still valid, see figure g.6.

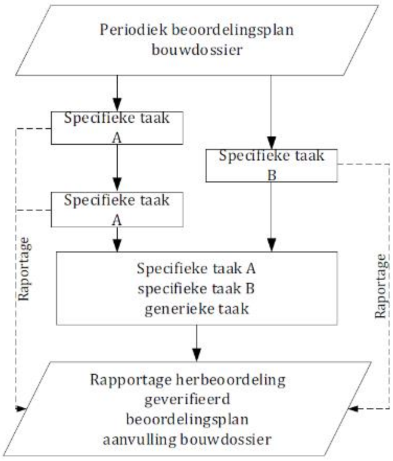
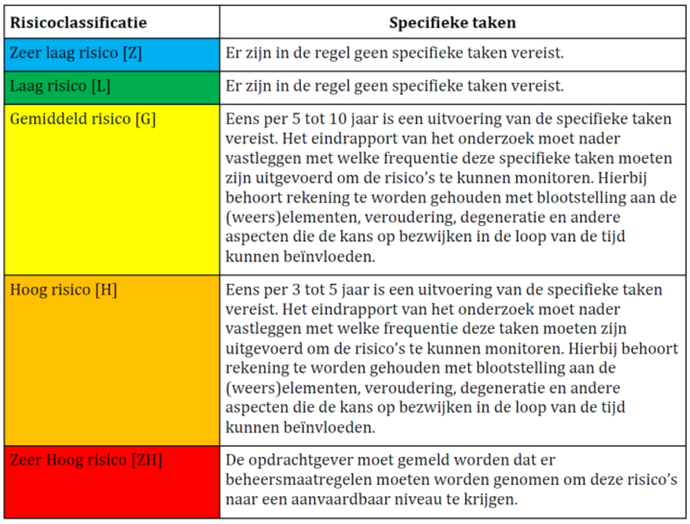


Figure G.6: Periodic assessment scheme (NEN, 2023)

Table G.16: Specific tasks periodic assessment (NEN, 2023)



| Risicoclassificatie | Specifieke taken |
|---|---|
| Zeer laag risico [Z] | Er zijn in de regel geen specifieke taken vereist. |
| Laag risico [L] | Er zijn in de regel geen specifieke taken vereist. |
| Gemiddeld risico [G] | Eens per 5 tot 10 jaar is een uitvoering van de specifieke taken vereist. Het eindrapport van het onderzoek moet nader vastleggen met welke frequentie deze specifieke taken moeten zijn uitgevoerd om de risico's te kunnen monitoren. Hierbij behoort rekening te worden gehouden met blootstelling aan de (weers)elementen, veroudering, degeneratie en andere aspecten die de kans op bezwijken in de loop van de tijd kunnen beïnvloeden. |
| Hoog risico [H] | Eens per 3 tot 5 jaar is een uitvoering van de specifieke taken vereist. Het eindrapport van het onderzoek moet nader vastleggen met welke frequentie deze taken moeten zijn uitgevoerd om de risico's te kunnen monitoren. Hierbij behoort rekening te worden gehouden met blootstelling aan de (weers)elementen, veroudering, degeneratie en andere aspecten die de kans op bezwijken in de loop van de tijd kunnen beïnvloeden. |
| Zeer Hoog risico [ZH] | De opdrachtgever moet gemeld worden dat er beheersmaatregelen moeten worden genomen om deze risico's naar een aanvaardbaar niveau te krijgen. |

**Manuals/tools helping assessment**
In each step details given on what to be studied or inspected. Information sources, relevant pieces of information, description of study and important points for inspections are provided. Also stated what must be included in inspection plans and report inspection.

There is no report format available, but there are two points which must be included in the report for the initial assessment: extension building archive with applicable material and inspection plan for periodic assessment.

In the appendices of the source, more background information is provided. In these appendices there is an inventerisation to vulnerable structures and structural elements, which is used in the validation process for common causes of failures, see appendix D. There is also an estimation to the extent of damages provided. At last, the change in spatial rules is considered for the periodic assessment of a building.

**Other**
The independence of the assessor is made specific in the letter from the minister. The company performing the assessment cannot be involved in the asset (management), use and design/renovation of the building (de Jonge, 2023).

In addition, qualifications are provided for both the organisation as the personnel conducting the assessment. There is among others stated that within the team, one individual has the final responsibility. This individual must have a specific title and must have visited the site of the object. The qualifications of the personnel are given in years of experience.

### G.2.10 Risicogestuurde methode

Nebest also has developed a more risk-based approach to retrieve insight into the true structural condition of the building. The risk Inventerisation consists of a desk study in combination with a quick scan at location. More on the approach below.

**General approach**
In total the assessment consists of the three following phases:

- Assessment based on desk study.
- Assessment based on inspection on location (quick scan).
- Assessment of control measures.

First a decomposition of the building is performed using the NL-SFB codes.

At the end of each phase the risks are determined for the assessment.

Following the desk study and the site inspection, via the control measures actions can be undertaken to reduce the risks. These actions could entail more evasive inspections/tests or additional actions and more.

**Risks compiled/identified/assessed**
The risks in this approach are considered in a quantitative way based on the Fine and Kinney method. The risks are retrieved by using the following three aspects:

$$Risk = chance \times detection \times consequence$$

The risk output is divided into five different categories via the following colour codes:

- Green
- Yellow
- Orange
- Red

**Actions**
For each risk, several control measures are given to mitigate the risk. There is a prioritisation available for risks on two levels, the A and B category. An A risk is seen as a significant risk which falls in the red category, which means the (structural) safety is not guaranteed. For this category risks, there is advised to take urgent control measures. Nebest states its best to take these control measures within one year after the assessment. The B risks are undesirable as they fall within the orange category. There is advised to consider some prioritisation in implementing the control measures and apply these within five years after assessment.

The control measures target either one or multiple aspects of the risk quantification: chance, detection and consequence.

**Manuals/tools helping assessment**
There is an excel format available within Nebest that can be used to perform the assessment.

**Other**
No other aspects/information

# H. Analysis existing assessment methods

The evaluation of the selected assessment methods, outlined in subsection 5.2.2, is performed in this appendix. The results of the evaluation for each criterion are presented and discussed. In general, a score of one is assigned when no information on that particular aspect is provided in the source. If there is another reason for assigning the score of one, it is explicitly discussed. For this evaluation, use is made of the brief description on the methods provided in section G.2. In each section of this appendix, one of the three criteria is discussed.

Next to the evaluation of the available methods, the developed assessment process is also evaluated via the same criteria. The process is scored in the same overview as the available methods to be able to compare its content and validate the fact that it is indeed an improvement. The validation is given in a separate header in each section.At last, other important aspects beyond these criteria, that should be considered in the development, are considered in section H.4.

## H.1 Trustworthy

The table below presents the scores for the aspects related to the criterion of trustworthiness. Following the table, the scores and their significance are briefly discussed, highlighting the most important information. This discussion provides valuable insight into the trustworthiness of the methods evaluated and their relative strengths and weaknesses in this regard. By considering these scores and their implications, a better understanding of the methods under consideration is obtained. Next, these methods are compared to the developed assessment process.

Table H.1: Exploration scores criterium trustworthy

| **Method** | **Institution** | **Multi-person** | **Qualifications** | **Structure approach** |
|---|---|---|---|---|
| Guideline for Structural Assessment of Existing Buildings | ASCE | 1 | 3 | 3 |
| Periodic Structural Inspection of Existing Buildings – Guidelines for Structural Engineers | BCA | 1 | 2 | 2 |
| CUR-aanbeveling 124 | CROW - CUR | 1 | 1 | 2 |
| NEN-ISO 13822 | NEN - ISO | 1 | 1 | 2 |
| Appraisal of Existing Structures | The institution of Structural Engineers | 1 | 1 | 3 |
| Standsicherheit von Bauwerken Regelmaβige Uberprufung | VDI – GBG | 1 | 3 | 2 |
| NEN 2767 | NEN | 1 | 1 | 2 |

| | | | | |
|---|---|---|---|---|
| Eenvoudige objectanalyse – werkomschrijving | Rijkswaterstaat | 3 | 1 | 3 |
| NTA 8790 | NEN | 2 | 3 | 2 |
| Risicogestuurde inspectie | Nebest | 2 | 1 | 1 |
| **Developed assessment process** | | 3 | 3 | 2 |

### H.1.1 Exploration existing assessment method

Upon examining the multi-person principle, it is clear that nearly all methods are assigned a value of one, indicating that no mention is made of another individual checking the assessment process.

The Rijkswaterstaat method is assigned a three, as it specifies that a quality assessment must be conducted following the application of the method. This quality assessment verifies whether the appropriate decisions were made during the execution to yield correct results (Rijkswaterstaat, 2016). An individual who did not conduct the assessment of the object must perform this quality assessment, utilising a set of predetermined questions in combination with noticeable aspects of the performed assessment. The individual who did perform the assessment to the object must provide reaction to the one reviewing, after which the quality assessment can be finalised.

The Nebest method is assigned a two as it requires the final report to be reviewed by another individual. Once both parties are satisfied with the report, it is submitted to a third individual for release. In case of the NTA there is clearly mentioned the assessment is performed in a team with one individual having the final responsibility, but nothing is given on checking the assessment by another person. This is the reason the method is given a score of two.

Four methods address the next aspect, all of which state that qualified engineers must conduct the assessment and/or inspections. In some instances, the required certifications for the engineers are explicitly listed. The Building and Construction Authority (BCA) inspection method specifies these qualifications and mandates that the engineer must personally conduct the inspection, meaning that they must visit the building and cannot delegate the task to anther individual (BCA, 2022).

This method is assigned a score of two, as the other two methods provide additional information on this aspect. The ASCE method not only specifies the qualifications of the engineer but also addresses the equipment, requiring it to be in working order and, if applicable, accompanied by calibration reports (ASCE, 2000). The method also indicates the level of user expertise (low, moderate or high) required for each test listed in the tables.

The VDI method specifies different qualifications for different tasks and includes an experience requirement in terms of years for each task.

At last, NTA 8790 also uses years of experience for the assessment team and a difference in qualifications for regular to more severe actions. There are also requirements stated for the organisation performing the assessment, for instance the independency of the organisation in relation to the object. The individual with the final responsibility must have visited the site in real life.

In comparison to the previous two aspects, the final aspect in this criterion receives significantly higher scores. This is due to the fact that all methods have various positive attributes, such as report formats, explanation on the approach and/or tools/manuals to aid in the assessment. The distinction between a score of two and three in this aspect is determined by the quantity of, and value of the information provided. The identified information for the considered aspects is listed below.

Nearly all methods provide some information regarding reporting, even including formats. The CUR method only provides bullet points of information just as the NTA, while the VDI method offers slightly more detail in the form of a chapter arrangement. However, some methods provide more information regarding reporting. The BCA periodic inspection method includes a report format for visual inspection only, while the Nebest and Rijkswaterstaat (ORA) methods provide an excel format with examples for conducting assessments. This can serve as a valuable tool for ensuring a more reliable assessment. Three methods provide a header format with description of what must be included in each section, all of which can directly be incorporated into the new method under development. Additionally, the NEN-ISO 13822 mentions that the future performance of the building must be discussed prior to conducting the assessment (NEN-ISO, 2010). The appraisal of existing structures also requires a brief to be written in consultation with the client. The NEN 2767 does not provide a report format.

The structure of the approach itself varies among the methods. Some methods, such as those by ASCE and NEN-ISO, provide an approach that is at such an abstract level that many details remain unclear. These methods do include a flowchart and description of the steps, but little additional detail is provided on how to execute the step and when to proceed to the next step. In contrast, the Appraisal of Existing structures and CUR 124 methods include detailed flowcharts, that clearly indicate when to take the next step. The comprehensive description of the assessment process, complete with clear examples and tables, provided by the ORA of Rijkswaterstaat and the NEN 2767 is also particularly helpful. THE NTA 8790 also provides a clear way of assessment via a flowchart and explanation for each step with some good points. The Nebest inspection method is currently assigned a one, as it lacks clear guidance in steering the assessment and remains somewhat subjective. This is partly due to the fact that the method is still under development.

Although the structure of the ASCE assessment is somewhat abstract, the method provides extensive tools and manuals on other aspects. Notably, the document includes tables that provide detailed information on tests, including their purpose, advantages, limitations and required user expertise (ASCE, 2000). Additional tables specify which evaluation (test) must be performed for which condition. The method also provides information on the most used materials and various types of damages and defects. This is also true for the Appraisal of Existing structures, which includes information on each component, such as indications, possible causes, suggested investigations and references to tests. These tests are described in detail, along with other information on materials.

The CUR method provides a table of the most important aspects of materials and specifies the required information for each object type and type of material. However, this is more straightforward for infrastructural objects than for buildings as these can vary significantly.

The method also includes information on calculation models, even an iterative approach is taken in the description of these models.

The VDI addresses changes in building characteristics that can occur due to environmental influences and provides checklists for the first two inspection types, specifying what should be inspected and hot to address any issues or comments. The BCA method also provides guidance on how to proceed when a visual inspection cannot cover an entire area. This is a valuable consideration as parts of a structure within a building are often inaccessible for visual inspections.

The NEN 2767 includes a list of deficiencies with codes assigned to building parts and potential defects. Scores for the condition assessment are already provided for these deficiencies. If a deficiency is not listed, it must be assessed by the individual conducting the assessment. Despite the well explained steps and the lists, the condition assessment is given a two as no information is given regarding material properties and more.

Another potentially useful tool is the risk assessment performed in the ORA by Rijkswaterstaat. To quantify the consequences, the RAMSHEEP table is used as an aid. A description of this tool is given in subsection G.2.8 of appendix G.

Finally, there is the tools available by the NTA. In the NTA there is given how the extent of the damage could be estimated which is a good feature. There also is a list with vulnerable structures/structural elements which also gives a more uniform approach plus guidance to a good result. The reason the NTA is given a two as there is nothing on material properties, tests/investigations and not a lot of information regarding reporting.

### H.1.2 Developed assessment process

For the first aspect, the multi-person principle, the developed process is given a score of three. This score is applied as the process provides a slightly adapted version of the quality assessment given by the Rijkswaterstaat ORA. Another individual must perform this check and questions are provided to guide the assessor. As the quality assessment is given a score of three and the assessment is only slightly adapted, this score is also given to the developed process.

The VDI 6200 standard and the NTA 8790 were used for the description on the qualification of this method, which are described in section 6.4. In the method there is also a difference in qualifications for different actions and it is based on years of experience. Moreover, the person responsible for the assessment must have visited the site in real life, just as in the NTA. As the qualifications are in detail described, the developed assessment process is also given a three for this aspect.

In the last aspect, the structure of the approach, first the available report formats were discussed. In the developed method a first draft for a report format is available. The report format in the NEN – ISO 13822 standard was the main inspiration for this aspect. In addition, an excel format is made to perform the different parts of the risk analysis which must be performed within the new method. However, this excel format must be further improved and automated before it can be used for regular assessments. Both the report format and the excel format are first draft which must be further developed in future studies to this assessment method.

In addition, there is an extensive description on the different steps to be performed available. Even the outcomes of the different analyses' steps are given to provide more clearance. Moreover, a clear explanation on how the risk assessment is provided along with help in the quantification of the likelihood, consequences (AMS€P) and detection filter. The ORA of Rijkswaterstaat is the method where most of the information for this structured approach is obtained. On top of that, this thesis also provides help in identification of defects with the study to common causes for structural failure incidents in the Netherlands.

However, there are for this aspect also some points of improvement that are available within the other methods. Some further detail levels guiding the assessor in its process, like present in the ASCE method or the Appraisal of Existing Structures, are only referenced. More elaboration could be provided for these levels in future studies. Due to this room for improvement, this last aspect is given a score of two.

The assessment process is thus given a maximum score on two of the three aspects available within the trustworthiness criterium. This score is obtained, as the content of the existing method scoring the highest on the applicable aspect is incorporated in the developed assessment process. In some cases, the content is slightly adapted to fit the purpose of this assessment process. For in particular the last aspect, there is still room for improvement in future studies.

## H.2 Effectivity

For the effectivity criterium, the scores are applied below.

Table H.2: Exploration criterium effectiveness existing methods

| **Method** | **Institution** | **Structure risk assessment** | **Critical factors** | **Identification risks** |
|---|---|---|---|---|
| Guideline for Structural Assessment of Existing Buildings | ASCE | 1 | 1 | 1 |
| Periodic Structural Inspection of Existing Buildings – Guidelines for Structural Engineers | BCA | 1 | 2 | 3 |
| CUR-aanbeveling 124 | CROW - CUR | 2 | 1 | 3 |
| NEN-ISO 13822 | NEN - ISO | 1 | 1 | 1 |
| Appraisal of Existing Structures | The institution of Structural Engineers | 2 | 2 | 2 |
| Standsicherheit von Bauwerken Regelmaβige Uberprufung | VDI – GBG | 2 | 1 | 2 |
| NEN 2767 | NEN | 1 | 1 | 1 |
| Eenvoudige objectanalyse – werkomschrijving | Rijkswaterstaat | 3 | 1 | 2 |
| NTA 8790 | NEN | 2 | 3 | 2 |
| Risicogestuurde inspectie | Nebest | 3 | 1 | 2 |
| **Developed assessment process** | | 3 | 3 | 2 |

### H.2.1 Exploration existing assessment methods

Examining the structure of the risk assessment, reveals that the VDI 6200, begins by classifying the structure according to its consequence and robustness classes. This classification determines the timing and nature of the inspections to be performed, ensuring that objects with higher risks receive more attention, thereby by increasing its effectivity.

In practice, it is often necessary to assess a group of objects rather than a single object. In such cases, the CUR 124 method can be useful. This method conducts an object risk analysis prior to the actual assessment to determine which object is in most need of assessment. Risks are classified according to chances (traffic class and certain deficiencies) and consequences (consequence classes) (CROW-CUR, 2019), ensuring that only the most urgent buildings are considered. Once an object has been prioritised in the CUR method, a full structural assessment with checks is performed. However, prioritisation is generally easier for civil structures than for buildings, as the latter tend to be more unique, therefore applying a score of two.

The NTA also has a score of two for its risk assessment. There is clearly explained how the risks should be determined, via the number of persons at risk, providing a clear quantification for the consequence. However, this shows only persons are considered within the consequences. In the consequence classification there can be seen other important consequences, for instance the economic aspects, are also considered as these could be severe. Still, a two is given for this method as there is a form of semi-quantification of risks available and appropriate actions are given to be performed. The frequency of the periodic assessment is also based on the severity of the risk.

The Appraisal of Existing Structures method is assigned a value of two, although engineering judgement is used for each decision making it is sometimes unclear whether it is acceptable or not. The steps in the flowchart are detailed with yes or no answers, which makes it clear whether a step is completed or not.

The ASCE and NEN-ISO methods are assigned a value of one because, as previously mentioned, their risk assessments are described at an abstract level, with no clear explanation on how risks are considered or discarded. What can help is the suggestion for cost-benefit analysis after the preliminary and the detailed assessment for the ASCE method. The BCA method also receives a value of one. Its visual inspection categorises deficiencies on a three-level scale, ranging from insignificant to requiring action, monitoring or even structural investigation. However, apart from this scale, there is no clear structure to approach risks for the visual inspection and certainly not in the full structural investigation. For this investigation, no structure at all is provided.

The NEN 2767 is also assigned a value of one. Risks are assessed according to their extent, intensity and severity. However, the method does not effectively identify risks. Sometimes a defect on a small area can have significant consequences, while the extent factor results in a reasonably good condition score. The risks are thus not effectively identified. One positive aspect of the method is that the score helps in showing when the defect is acceptable or not.

Finally, two methods are assigned a value of three. These methods, the ORA by Rijkswaterstaat and the Nebest inspection method, both employ quantitative risk assessments and provide clear criteria for determining when risks are acceptable. The ORA method uses a chance times consequence approach, while the Nebest method includes the detection. This factor provides a prioritisation of risks for elements that are not detectable. Both methods perform a risk assessment after each stage, from the desk study, visual inspection to the proposed control measures, providing insight in the risks at each stage. The Nebest method also specifies that risks classified in the most urgent category must be addressed within one year, while those in the next most urgent category are recommended to be addressed within five years.

Regarding the critical factors, almost all methods lack significant strengths in this aspect. Only two methods, the Appraisal of Existing Structures and the one by BCA, are assigned a value of two. The BCA method mentions certain reinforced concrete structures and other factors as being important. The Appraisal of Existing Structures mentions that the locations where small amounts of energy can cause high-energy collapses must be marked as dangerous. There are also some other points provided for consideration. The NTA 8790 is the only method provided with the score of a three as an entire appendix is based on vulnerable structures and structural parts. This list helps with the focus of the assessor.

Being more abstract, the NEN-ISO 13822 and ASCE methods do not provide any means of limiting the number of risks identified and considered, thereby receiving a score of one on the identification of risks. In contrast, in the Nebest and Rijkswaterstaat methods, where risk assessments are performed at multiple stages, the most significantly risks are immediately identified. This provides some limitation on the considered risks for the next stages. However, as at the start all risks are considered, the score is given a two.

The appraisal of Existing Structures, VDI and the NEN 2767 methods include lists of deficiencies and solutions which could limit the number of risks considered. However, there is a danger that risks not included in these lists may be overlooked. The NEN 2767 is even given a one as in principle almost all possible deficiencies are stated in these lists. The NTA is given a two as the list with vulnerable points provide some focus to limit the number of risks. There is also worked from coarse to fine, with only the most important risks considered further down the line.

The BCA method has been assigned a value of three because its checklist limits the number of risks to a certain amount. The CUR method also receives a value of three due to its ORA for the prioritisation, which lists only the most important risks. If other risks need to be considered, they must be manually quantified. Here the same danger as mentioned in the paragraph above is applicable.

### H.2.2 Validation developed assessment process

Just as the Risk analysis by Rijkswaterstaat and Nebest, this process is assigned with the maximum score for the structure of the risk assessment. In the process there is a clear quantitative risk assessment available which is performed with the help of clear criteria. Next to the risk, which is composed of likelihood times consequence, a detection filter is applied. This filter helps in the categorisation of outcomes, checking if the risks are detectable and detected. This categorisation is the most significant different in comparison to the two aforementioned methods.

After each stage a risk analysis must be performed, just as in Rijkswaterstaat and Nebest method, to retrieve insight in the risks at each stage. This allows the assessor to act on these detected risks in the next stage of the assessment. For each outcome category, a different follow-up action must be taken, thereby providing the most effective action for the considered risk. A visual inspection, for instance, is not effective for a non-visual detectable hazard. At last, there is also made clear what to do for the different risk levels, thereby providing a clear structure in approaching the risks.

In this study the common causes for structural failure incidents in the Netherlands are examined, see chapter 4. As this list of common causes is included in the assessment process, critical factors for assessment are available. As these common causes are also validated by experts and literature, a score of three is given for this aspect.

In the last aspect of effectivity, there is checked if the number of risks is controlled. The assessment process is assigned a two, for the same reason this score is applied to the Rijkswaterstaat and Nebest methods. After each stage the risks are assessed, thereby providing more focus as the most significant risks are further considered. This provides some limitation on the considered risks in the next stages. However, at the start all the risks are considered in this method. These risks are of course steered by the critical factors discussed above, but no prioritisation of elements like the CUR 124 or a checklist of things to consider like the BCA method are given to limit the risks beforehand. In future studies more investigation could be performed to check if the number of risks could be controlled beforehand without leaving out the danger of leaving out the most significant risks.

So, the assessment process has the highest scores for the first two aspects. For the last aspects the process could be improved in future studies.

## H.3 Efficiency

The last criterion concerns efficiency and is discussed in this section.

Table H.3: Exploration criterium efficiency

| Method | Institution | Qualifications | Coarse to fine | Time | Tools |
|---|---|---|---|---|---|
| Guideline for Structural Assessment of Existing Buildings | ASCE | 2 | 2 | 2 | 3 |
| Periodic Structural Inspection of Existing Buildings – Guidelines for Structural Engineers | BCA | 1 | 1 | 2 | 2 |
| CUR-aanbeveling 124 | CROW - CUR | 1 | 3 | 3 | 3 |
| NEN-ISO 13822 | NEN - ISO | 1 | 2 | 2 | 1 |
| Appraisal of Existing Structures | The institution of Structural Engineers | 1 | 3 | 2 | 3 |
| Standsicherheit von Bauwerken | VDI – GBG | 3 | 2 | 3 | 2 |

| | | | | | |
|---|---|---|---|---|---|
| Regelmaβige Uberprufung | | | | | |
| NEN 2767 | NEN | 1 | 1 | 3 | 3 |
| Eenvoudige objectanalyse – werkomschrijving | Rijkswaterstaat | 1 | 2 | 2 | 2 |
| NTA 8790 | NEN | 2 | 3 | 2 | 2 |
| Risicogestuurde inspectie | Nebest | 1 | 3 | 3 | 2 |
| **Developed assessment process** | | 3 | 3 | 2 | 2 |

### H.3.1 Exploration existing assessment methods

For this aspect, which concerns the insurance that personal with the right qualifications are assigned to the right work (thereby avoiding the use of over-qualified personnel), many methods provide little information. Only three methods receive a score higher than one, as they do provide information on different levels of qualifications. As previously mentioned, the ASCE methods has tables for tests where a three-level scale is used for the required expertise level, therefore retrieving a score of two. The NTA is also given a two as a difference in qualifications is made for regular and more detailed actions to mitigate the risk.

The VDI method receives a score of three for this aspect, as it specifies three different qualifications for its three-level inspection levels in the format. The first level of inspections is conducted by the owner or an authorised representative, then there is the inspection by an expert and at last a thorough examination is performed by a special expert (VDI, 2010). For as well the expert as the special expert the minimum required years of experience in the working field are stated. These years also form the main difference between the two qualification levels.

In terms of working from coarse to fine, two methods employ a two-step approach, progressing from a preliminary to a detailed assessment if necessary. These methods are the NEN-ISO 13822 and the ASCE method. In the ASCE method, only critical members are assessed in the preliminary assessment, while the detailed assessment considers the entire structure. An iterative loop is used to gather information during the detailed assessment, if insufficient information is obtained, the process returns to the start of the detailed assessment. This loop is also present in the NEN-ISO 13822 method. As these methods provide a two-step coarse to fine approach, they are assigned a value of two.

The BCA method also employs a two-step approach, progressing form a visual inspection to a full structural investigation. However, this method receives a value of one because little attention is given to the full structural investigation and the visual inspection considers the entire object at once. The NEN 2767 method also receives a value of one because it does not employ a coarse to fine approach, it only includes a visual inspection to the entire object. This means any missed details may not be detected later.

The VDI method employs three levels of assessment, ranging from coarse to fine. These levels are determined, which not only indicates whether and what must be done, but also the frequency at which the inspection must be performed. The ORA by Rijkswaterstaat also determines in advance which of three analyses must be undertaken. A flowchart and multiple tables for civil structures are used to determine whether a simple, detailed or advanced analysis is required. These methods are assigned a value of two.

Four methods receive a value of three for this aspect: The Appraisal of Existing Structures, CUR 124, the NTA and the Nebest inspection method. The Appraisal of Existing Structures employs a three staged approach from coarse to fine, with multiple points at which the assessment can be halted if sufficient risks have been identified/reduced. The CUR method uses a risk analysis as its coarse step to prioritise objects for assessment. Both the risk analysis and full assessment include an iterative information process, as shown in figure g.2. The method even suggests a cost-benefit analysis to determine whether further detailed steps or control measures are appropriate. In the NTA there is also worked from coarse to fine as stated in the study itself. Here, the risks are assessed at a coarse level the first time. Every time the assessment is seen as not sufficient, more detailed actions must be performed, At last, the Nebest method includes a desk study and a quick scan as its initial coarse steps. Based on these steps, it is determined which control measures must be implemented. More detailed steps are only taken if they can help reduce the most urgent risks.

Before considering the time aspect of efficiency, the tools that can aid efficiency are examined. While the tools for the trustworthiness criterion are primarily intended to confirm the ‘ring of trustworthiness’, this section focuses on tools that can reduce the time and effort required for assessment. The NEN-ISO 13822 method is assigned a value of one, because it provides little information or tools to improve efficiency. The same accounts for the NTA 8790.

Many methods, including the ones by Rijkswaterstaat (ORA) and Nebest, receive a value of two. These methods provide an excel format with examples to aid efficiency. The ORA also includes a detailed description of all steps and the RAMSHEEP tool for quantifying consequences. The NEN 2767 method also receives a value of two, because it provides a list of deficiencies with codes that can be used in the assessment. The VDI method includes tables of minimum requirements and a format for signage for the first two inspection levels, which can be particularly helpful when the owner or authorised representative is conducting the inspection. The BCA method also receives a value of two because its checklists and coverage percentages for visual inspections aid in efficiency, although the reporting format provides little assistance for the full structural investigation.

Three methods receive a value of three: the CUR, Appraisal of Existing Structures and the ASCE method. The CUR method provides tables specifying the information required for each object and material type, as well as guidance on how to obtain information if it is not included in documents. There must be noted that this is easier for infrastructure objects as these are more uniform than buildings. The most important material properties are summarised in tables and the explanation on the models is also helpful.

The Appraisal of Existing Structures method includes tables detailing defects and appropriate actions. The method specifies for which defects, which tests should be performed. It also provides information on the advantages and limitations for each test, as well as its purpose, required user expertise and principal operation (ASCE, 2000). The Appraisal of Existing Structures also provides information on tests to help determine which test is appropriate for which defect. At last, it should be noted that all report formats discussed in section H.1 can also improve the efficiency of the method and should therefore be considered valuable.

The aforementioned aspects of working from coarse to fine and using tools to speed up the assessment process provide some indication of time required for the assessment. These points are considered in combination with other relevant factors present within each method. First, the methods that receive a value of three for this aspect are examined. The CUR method is assigned a value of three because its object risk analysis narrows down an entire group of objects. Once it is narrowed down, the assessment is conducted using an iterative approach for information gathering. However, it does include a structural investigation for the entire object. The Nebest risk-based inspection method is optimised for time efficiency by only performing a desk study and a quick scan, followed by only paying attention to the control measures for the non-acceptable risks. The VDI 6200 also receives a value of three, primarily because the frequency of its different levels is optimised based on the classification of the structure. The NEN 2767 method is also assigned a value of three because it only consists of a visual inspection, which can be performed quickly.

Considering the NTA, the first site visit in combination with a desk study could already be sufficient. Else, the loop is entered and every time more detailed information must be obtained. However, there are little tools available and there also must be checked if the building is within the mandatory investigation. Then for the periodic assessment the differently categorised risks, must be checked at different moments in time. In addition, every ten years a more general actions must be performed. By performing the checks for the risks at different moments in time, can result in an inefficient assessment scheme. Therefore, the NTA is given a score of two.

The BCA method only includes a visual inspection if no structural investigation is required, but if the visual inspection is insufficient, the full structural investigation can be time consuming. The frequency at which the method is performed is different for residential and non-residential buildings. This two-way factor for assessment also applies to the ASCE and NEN-ISO 13822 methods.

The Appraisal of Existing Structures method receives a value of two, despite its three-stage approach with multiple points at which the assessment can be halted. This is due to the extensive description of the method, which includes a significant amount of information that must be considered. Additionally, the brief that must be composed beforehand also takes time. Finally, the ORA by Rijkswaterstaat is assigned a value of two. It shares many similarities with the Nebest method but requires more steps to perform.

### H.3.2 Validation developed assessment process

The qualification aspect is also given a three as the same distinction in qualifications is performed as the VDI 6200. By keeping the qualifications specific for different actions of work, the method becomes more efficient.

In the assessment process, first a more abstract level of assessment is performed. Only when necessary, more specific assessment actions become applicable. The coarse to fine working of the method is given in a more implicit manner in figure 6.1. There is chosen to not provide a line to distinct the more abstract and more detailed levels of the assessment. In practice, there are circumstances where the more detailed steps can already be performed within the abstract level. If it, for example, becomes clear (in ORA1) that there is a non-visual detectable hazard in the form of wall ties, ORA step three can immediately be performed. If this step results in easy to perform actions, these actions could immediately be executed during the more abstract visual inspection step. The method thus facilitates a coarse to fine process, which allows combining steps. This efficient way of working results in a score of three for the coarse to fine aspect.

The time aspect is optimised in the process, as only steps need to be performed if truly necessary. This comes back in the outcome categories, where only the steps required for that outcome must be performed. However, for each risk a consequence score must be determined for the AMS€P categories. These different categories result in more work, even despite the fact that only the critical categories relating to structural safety are considered. It can thus be performed in less time as the method by Rijkswaterstaat as this method considers the full AMSSHE€P categories. However, it probably takes more time than the methods scoring a three. In conclusion, the method is scored a two as the process is optimised but the consequence categories cost time.

At last, the tools which can aid in efficiency are considered for the developed process. The help in quantification of the risks, just like the Rijkswaterstaat method, aids in efficiency. However, the excel format needs to be further improved in future studies. In addition, there are other methods which have more tools available, like tables coupling defects to possible tests, to help in the efficiency of the method. These methods are referenced in section 6.5 and could be included in future studies. That is the reason the method receives a two on this aspect.

In conclusion, the assessment process does provide the best score on the first two aspects. Considering the time aspect, this method is more extensive and takes up more time, even though the process is optimised. The last aspect is also scored as there is still room for improvement. In the CUR 124 more aspects are given the higher score. This method thus shows to have more potential for the efficiency aspect but is only available for the infrastructural sector. In addition, there are some other methods that also have the same score configurations as with the development, with variation for the different aspects.

## H.4 Other

During the selection process of existing methods to explore, it was noted that some documents, although not considered, contained important points relevant to this thesis. This subsection briefly outlines these points.

The Assessment method developed for stadiums by ABT begins with a site inspection, followed by a desk study. This desk study is divided into three parts: surroundings, material properties and structural plus technical assembly of the stadium (ABT, 2020). The surrounding section primarily investigates whether the wind load assumed in the design is accurate.

Additionally, it is suggested that a reference project could be used during the desk study to identify potential risks and enable a more focused assessment. Before the desk study there is stated where what information can be found.

Through the site inspection a subsequent desk study, risks are evaluated in a risk-based manner. This approach involves initially assessing entire building sections and applying greater detail only to those deemed high-risk. A four-level scale is used, ranging from acceptable to attention, critical and unacceptable (ABT, 2020). If necessary, appropriate measures are suggested. This risk assessment can be considered as the initial evaluation and is called the zero assessment.

This zero assessment determines the scope of both the yearly condition assessment and the multi-year assessment. The yearly inspection serves to identify any deviations from the initial evaluation (ABT, 2020). These inspections do not necessarily need to be conducted by experts, but it is recommended to select personnel with some experience in building assessment or management. In contrast, the multi-year assessment involves a more thorough evaluation of the structure’s true condition, based on the initial evaluation and subsequent findings (ABT, 2020). This inspection and assessment are conducted by an expert, often from a bureau with extensive knowledge of structural safety, particularly in regard to stadiums. Overall, it is recommended that the method be caried out by an expert specialising in the structural safety of stadiums or similar structures. However, the selection of the appropriate party is ultimately up to the owner, with independence being advised. Some prior knowledge of the stadium in question may also be beneficial during the assessment.

The KPCV source, although not considered, provides valuable information on the reasons for conducting assessments and the tools available for these inspections. These reasons are given below to provide more insight (KPCV, 2021):

- Design- and execution errors.
- Aging
- Signals
- Known structures inheriting risk.
- Change in use.
- Change in surroundings.
- Changes in load bearing structure.

Regarding the first point, in the source it is recommended that the structure undergoes a visual inspection to identify any potential errors (KPCV, 2021). For aging, an inspection every 5 to 10 years is advised. If any signals are detected, this should trigger an investigation into the building’s structural safety. This also applies to the structures known to inherent risks. For the last three points, it is necessary to assess the impact on the load bearing structure if they are applicable (KPCV, 2021).

Additional information on notable points during inspection provided by the source, are listed and used in the validation of common causes for structural failure incidents in subsection D.5.1 of appendix D. The NEN-ISO 13822 also outlines reasons for conducting assessments, which are mentioned in the first desk study described in section 5.1.

The conclusions of this desk study are also incorporated into the results of this exploration to the existing assessment methods. This means that the findings on the desk study, including information on frequencies, qualifications and other aspects for the various methods considered in this study, are considered.  All the results of this evaluation are presented in section 5.3.

# I. First stage assessment process

In the first stage of the assessment process, users must consider a wealth of detailed information. The main report concisely outlines the steps involved. This appendix provides the more detailed information, with each section corresponding to a step in the first stage of the assessment process.

## I.1 Preparation phase

This step requires more detailed information of two elements: the questions to be posed to the client and the sources for obtaining documents for the desk study. First the questions to align the assessment with the client are given.

**Alignment client**

Below questions are posted which should be considered for the alignment with the client.

- What are the expectations of this assessment?
- What is the maintenance history of the building?
- Have there been any changes in use or are any anticipated in the future?
- Have there been any concerns raised by users of the building or other individuals?
- Are there any damages or previously repaired damages?
- Are there any other important points to consider?
- What are the future plans for the building?
    - Continuity in use for more than 10 years.
    - Renovation or other measures within 5 – 10 years.
    - Renovation or other measures (such as demolition) within less than 5 years.
- Are there any other special requirements important for the assessment?

**Desk study information retrieval**

Potential sources for documents to investigate during the desk study include (ABT, 2020):

- Municipality (archives and licences)
- Architects
- Engineering firms
- Leading and other contractors

Relevant documents for the desk study could include (NEN, 2023):

- Licenses
- Drawings
- Structural calculations
- Specifications
- Geotechnical reports
- Execution documents
- Inspection reports
- Damage reports
- Maintenance reports
- Reports by owner or users
- Pictures

It is important to remember that the desk study should initially be performed at an abstract level. Nevertheless, it is beneficial to gather most of the documents listed above, as more detailed documents can be accessed immediately if required.

## I.2 Desk study

Within the desk study, more guidance is available for the study to the structural assembly of the building. The points to consider in this assessment step are given below.

**Structural assembly**

The ABT method provides useful points to guide this part of the study. However, as it was developed for assessing stadiums, it is quite extensive. Therefore, some points are either not considered or slightly adapted. The aspects to be considered for the structural assembly include (ABT, 2020):

- Analysis of the (global) set up of the main load bearing structure, stability and foundation.
- Analysis of the correct translation from main engineer's design into execution-ready documents.
- Impact adaptations/extensions on the original design.
- Impact of increased loads on the object, such as the application of solar panels.
- Impact of damages and (if performed) repairs on the original design.

There are also some more specific points, that should only be considered at this stage if deemed necessary at this stage (ABT, 2020):

- Assessment of (design) loads, load combinations and other principles for relevant rules/standards.
- Analysis of structural detailing of concrete and/or steel structures and/or other materials.
- Analysis of detailing in structural details.
- Analysis of floor partitions.

These lists are not exhaustive. Additional points may need to be considered if applicable.

For checking the structural assembly, there are also questions available in NTA 8790. These questions aid in gaining a thorough understanding before proceeding to the next part of the study (NEN, 2023):

- What building parts/elements compose the system?
- How are vertical loads transported though the system to the foundation?
- How are horizontal loads transported through the system to the foundation?
- How does the building resist extraordinary loads?

## I.3 Visual inspection

The final stage requiring additional information is the visual inspection step of the assessment. This step necessitates the use of specific tools to ensure a comprehensive inspection and to gain all necessary results. The tools required for visual inspection are detailed below.

**Tools for visual inspection**

The tools, along with some additional devices that could be included in the inspection are as follows (NEN, 2008):

- Digital distance meter
- Measuring tape
- Water level measurement
- Compass
- Flashlight
- Binoculars
- Mirror
- Crack width measurement loop/card
- Glass width meter
- Pocketknife/awl/screwdriver
- Hammer
- Device for detailed photos
- Ladder (Possibly foldable)
- Endoscope
- Notebook with pencil or pen/iPad
- Gloves
- Safety helmet

In addition to these tools, some other devices could be applicable for this inspection. While these devices are often associated with additional actions rather than a more abstract visual inspection, they could be used during the visual inspection to enhance on-site assessment efficiency. The following devices could be used (NEN, 2008):

- Concrete coverage meter
- Schmidt hammer
- Phenolphthalein test fluid for carbonatation depth
- Cordless drill
- Joint hardness tester
- Paint layer thickness gauge
- Humidity meter
- Karsten tube set
- Slope meter

# J. Report format

As detailed in subsection 6.2.6, this appendix provides help for the reporting phase of the initial assessment. This first attempt to a report format is an adapted version of the one given in NEN-ISO 13822 (NEN-ISO, 2010). The different parts of the report given below are highlighted via headers with short descriptions on its content. Next to the initial assessment, also report formats for the different periodic actions are given.

## J.1 report format assessment

**Title and subsequent page**

On the title page the title, client, date and author should be stated. If applicable, the assessment party should be stated along with the address(es). In addition, the names of the people who performed the assessment and the representatives of the client involved with the project should be mentioned. To validate the multi-person principle, the author, the person to perform the quality assessment (see subsection 6.2.7) and the third individual, who also checked the content of the report, provide their autograph.

**Summary**

This is kept the same as NEN-ISO 13822: In one or two pages in clear language the problem, significant features of the investigations performed and the conclusions with recommendations must be summarised. In this summary also important exclusions or reservations must be included. Within the conclusions and recommendations, it is particular important to mention what measures and periodic actions are advised. In case these actions are advised, the important points and required frequency (see section 6.3) for these actions must be stated.

**Table of contents**

The following chapters should be included:

1. Scope assessment
2. Description structure and ORA step one
3. Visual inspection and ORA step two
4. Investigation
5. Analysis
6. Verification and discussion
7. Review of intervention options
8. Conclusions
9. Recommendations

   Annexes

**1. Scope assessment**

In this section both the reasons for the assessment and the scope of the work are specified. Here the results of the alignment with the client, as explained in subsection 6.2.1,must be given. In this chapter the procedure of the assessment, as explained throughout section 6.2, must shortly be described along with all activities which were performed. The safety plan, discussed in subsection 6.2.5, is the final subject for this header.

### 2. Description of the structure and ORA step one

The following items should be addressed (NEN-ISO, 2010): Name, address and description structural system with some of the most important drawings. The history of the building from original construction to present should be given (to what extent possible). The results of the desk study, via the distinction structural assembly and material properties, must thus be applied in this chapter.

In the report format made available by the BCA method for visual inspection, there are also some points which need to be taken into consideration (BCA, 2022): Number of storeys in each building block, description usage building, import load conditions and the soil conditions along with the foundation system.

The robustness classification, along with the table describing this classification (table g.9), must be presented in this chapter.

In addition, the most important results of ORA step one must be discussed, given in their result categories as defined in figure 6.3. There must be stated what is done to limit the hazards which are not visually detectable and also not identified.

### 3. Visual inspection and ORA step 2

The one performing the assessment must write the report and also perform the visual inspection. Frist, there must be stated what coverage was obtained during inspection. If there were any other limitations beyond the control of the assessor, this must also be made clear. Next to the coverage, the most noticeable points should be quickly discussed along with some pictures.

In addition, the second step in the ORA must be reported in the same fashion as the first step. The most significant risks must be reported, along with a description on what is done to make sure no significant undetected risks rise to the occasion.

In the end of this chapter, there must be stated whether the initial phase of the assessment was sufficient or the loop must be entered.

### 4. Investigation

In this chapter, the documents that are made available and used for the entire assessment must be listed along with the source. The same accounts for any inspections and investigations that have been performed when seen as required after step two. These actions must all be well documented with clear conclusions.

Again, any limitations to these inspections and investigations must be stated. If samples were taken for inspection these must also be well documented as well as the location, date and circumstances under which these samples were taken. If the samples had to be tested, the laboratory should be mentioned along with copies of the results in the annex of the report.

### 5. Analysis

If any calculations had to be performed, the results along with the criteria and the extent of the calculations must be listed here. The details to the summarisation in this chapter, should be given in the annex.

### 6. Verification and discussion

With possible actions being taken to reduce the risks, the verified risk procedure must be stated in this chapter. If no additional actions need to be taken, the final risks may be addressed one more time to provide a clear overview on the condition of the building.

The risks and findings must also be discussed in this chapter. As example, for the most important risks, the applied scores could be discussed.

### 7. Review of intervention options

The possible options for measures to be taken should be reviewed. It may be an option to provide estimated costs for the measures. The measures that are urgent should already have been communicated with the client. In this case, a short summary of the measures, along with the final advice, must be given.

If measures had to be applied there must also be stated what for an impact this had on the risks (Provide new scores).

### 8. Conclusions

As stated in the NEN-ISO 13822, firm and reasoned judgements should be reached after the careful assessment of the information obtained (NEN-ISO, 2010). However, it is important the conclusions are brief and that the accuracy and limitations of the assessment are mentioned. It must be based on the previous sections in the report. The limitations of the method itself must also be considered in the conclusions.

### 9. Recommendations

The following items should be presented in this section (NEN-ISO, 2010):

- Course of action for the client (must be logical follow-up from the conclusions)
- The remaining prognosed service life of the building could be stated along with updated maintenance points.
- A cost indication of the advised measures could be given.

### Annexes

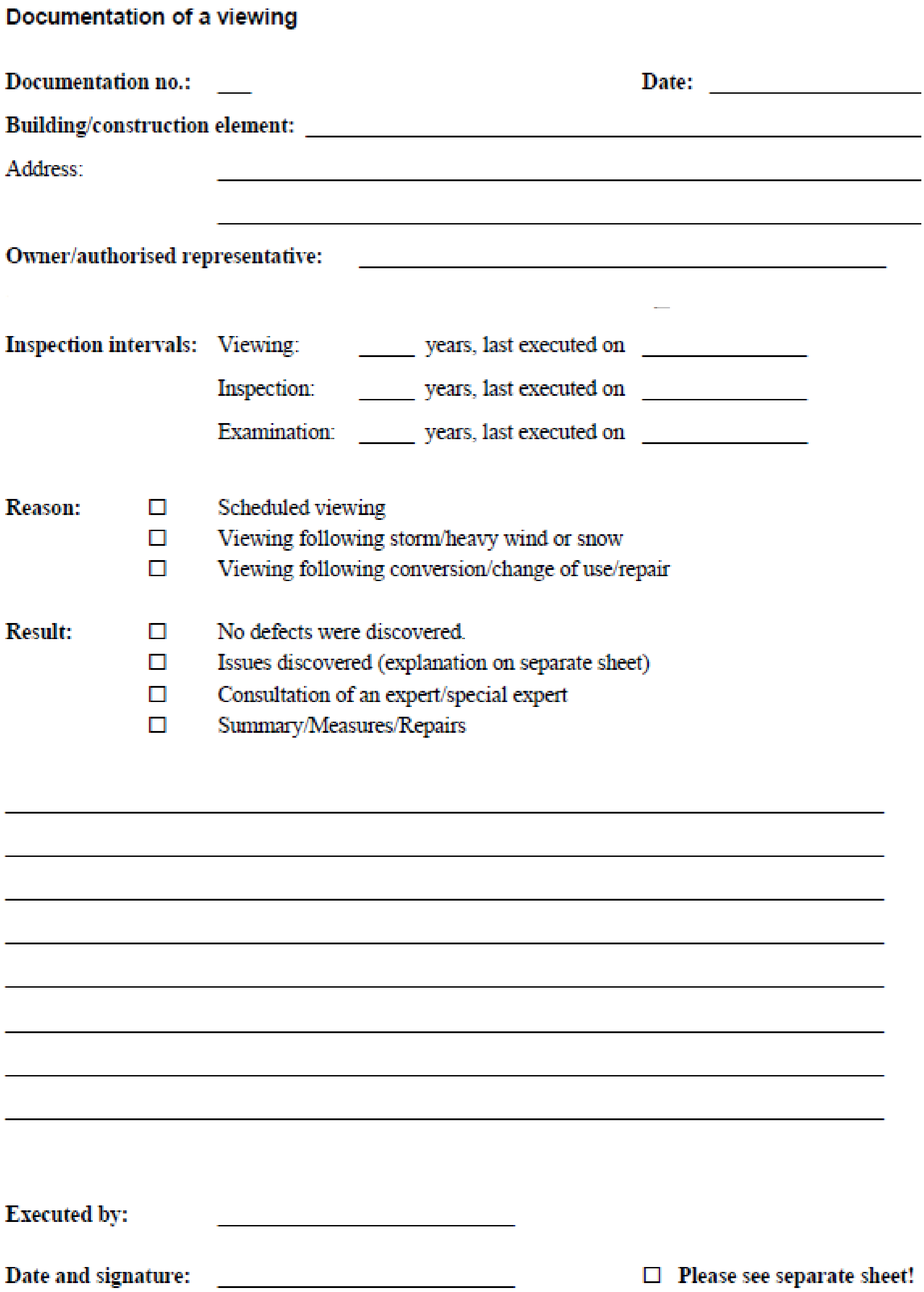
Here the following items should be listed (NEN-ISO, 2010): drawings, photographs, laboratory reports, calculations etc. Besides these items, also the quality assessment performed by the second individual to provide its signature on the opening pages, must be included in the annexes.

## J.2 report formats for periodic actions

there are three levels of periodic assessment that can be performed. Below for the three different assessment types, the formats are given. As given in subsection 6.2.8, the first two levels are only applied to check if the structural safety, validated in the initial assessment, is still applicable. As so, no extensive report is required to check the structure. The attention points from chapter 4, are again important for these two levels. In the subsection below, the notation formats for the two inspection levels are given.

### J.2.1 Formats for first two periodic assessment levels

To both notation formats given by the VDI method, the consequence class line is removed as this method is only applicable to CC2 structures. First, there is the notation format for the visual inspection by the owner/representative of the owner, which is given in figure j.1.



**Documentation of a viewing**

**Documentation no.:** ___ **Date:** ____________

**Building/construction element:** ____________

Address: ____________

____________

**Owner/authorised representative:** ____________

**Inspection intervals:** Viewing: _____ years, last executed on ____________

Inspection: _____ years, last executed on ____________

Examination: _____ years, last executed on ____________

**Reason:**
- ☐ Scheduled viewing
- ☐ Viewing following storm/heavy wind or snow
- ☐ Viewing following conversion/change of use/repair

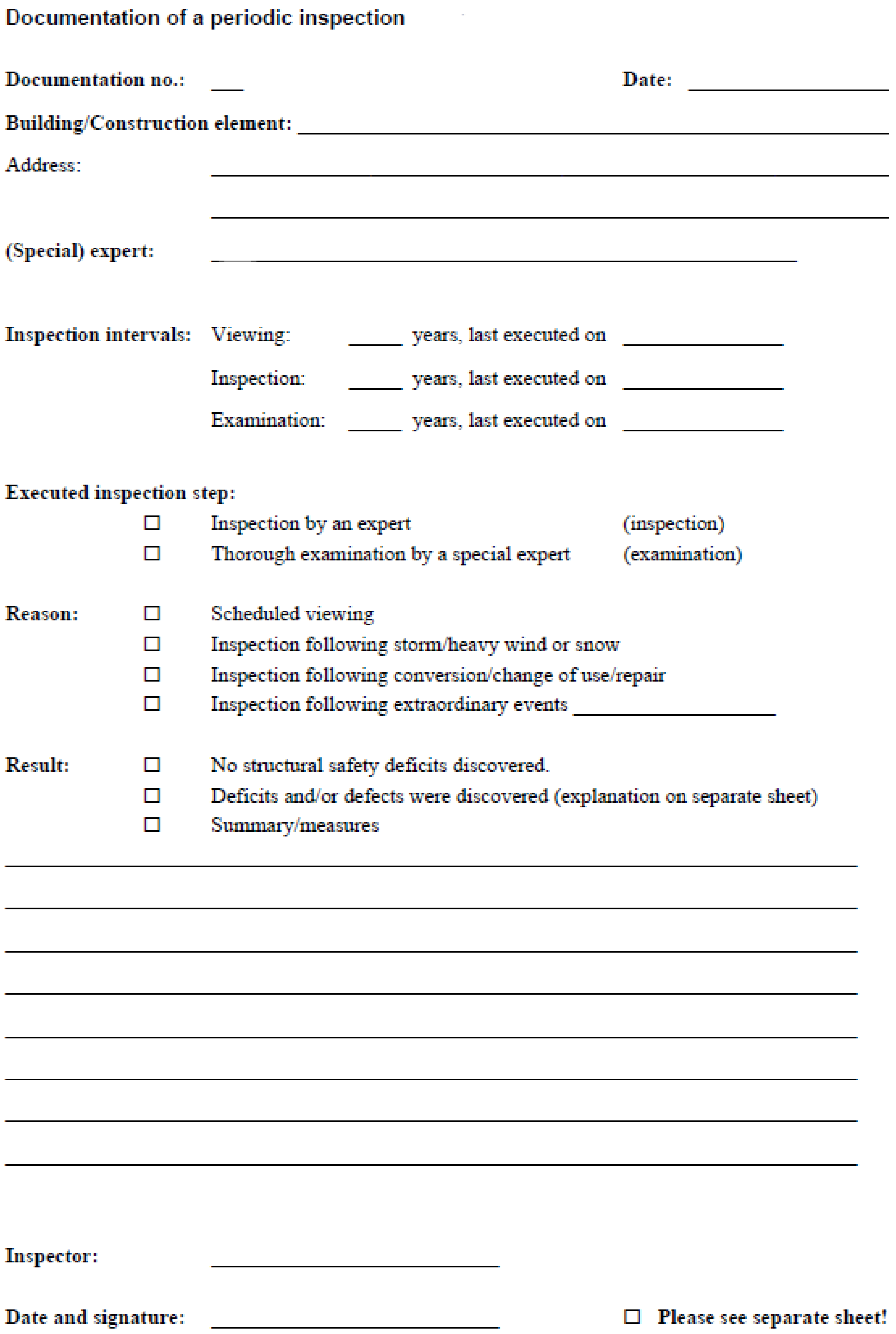
**Result:**
- ☐ No defects were discovered.
- ☐ Issues discovered (explanation on separate sheet)
- ☐ Consultation of an expert/special expert
- ☐ Summary/Measures/Repairs

**Executed by:** ____________

**Date and signature:** ____________ ☐ **Please see separate sheet!**

Figure J.1: Notation format for periodic inspection owner/representative (VDI, 2010)

Next, there is the notation format for a visual inspection by an expert, see figure j.2. Again, the consequence class line is removed as this is not applicable for this method. There can be seen that the notation can also be used for the periodic assessment by a special expert. This format can be used, but for this highest level a report is required for which the format is given in subsection J.2.2.



Documentation of a periodic inspection

**Documentation no.:** ___ **Date:** ________________

**Building/Construction element:** ______________________________________________

Address: ______________________________________________

______________________________________________

**(Special) expert:** ______________________________________________

**Inspection intervals:** Viewing: _____ years, last executed on _____________

Inspection: _____ years, last executed on _____________

Examination: _____ years, last executed on _____________

**Executed inspection step:**

☐ Inspection by an expert (inspection)

☐ Thorough examination by a special expert (examination)

**Reason:**

☐ Scheduled viewing

☐ Inspection following storm/heavy wind or snow

☐ Inspection following conversion/change of use/repair

☐ Inspection following extraordinary events ________________

**Result:**

☐ No structural safety deficits discovered.

☐ Deficits and/or defects were discovered (explanation on separate sheet)

☐ Summary/measures

**Inspector:** ______________________

**Date and signature:** ______________________ ☐ **Please see separate sheet!**

Figure J.2: Notation format periodic inspection expert (VDI, 2010)

For both of the levels, a small version of the quality assessment, must be performed. This smaller version must be posted via another notation and signed by both the one performing the inspector as the reviewer. The quality assessment must be proportionate to the amount of work performed for the particular level of the quality assessment.

### J.2.2 Periodic structural assessment format

For this periodic level, a report format like given in section J.1, is expected. This format is slightly adapted in this subsection to fit the periodic structural assessment. Only if adaptations need to be applied in comparison to the aforementioned report format, these are given.

#### 1. Scope assessment

Only if changes are applied to the scope, these must be adapted. In addition, the safety plan and the activities which were performed for assessment must also be presented.

#### 2. Description of the structure and ORA step one

This chapter only needs to be given in case adaptations to the structure have been performed since the initial assessment. If one of the information points, given in the original format is changed, this must also be reported. In addition, if measures for the initial assessment have been taken that changed the structure, this must be reported.

ORA step one only needs to be performed if any changes to the desk study were required. Else, this aspect does not have to be considered. If changes did influence the old first step of the ORA, these adaptations must be applied and discussed in the chapter. More significant risks could be lower or smaller risks could have gained in importance.

#### 3. Visual inspection and ORA step two

A visual inspection needs to be performed, but in the back of the mind the results of the initial assessment must be considered along with the results of the desk study and ORA step one. Besides that, there must be checked if new problems came under attention during the inspection. Again, limitations beyond the control of the assessor(s) should be made clear. As for the coverage, if anything is changed to the original statement this should be mentioned.

With this inspection step two of the ORA must be updated where applicable. It could be that after these steps the periodic assessment is seen as sufficient if all risks are considered to be acceptable. This must then be concluded.

#### 4. Investigation

Only if other documents are used or documents are updated, it should be stated in this chapter. Else the chapter must only be applied if the risks from ORA step two are not seen as acceptable. In that case additional actions, with inspections and investigations, must be reported here. For the content there is referred to the aforementioned report format for the initial assessment.

#### 5. Analysis

Only if applicable and then the same as the initial report format

#### 6. Verification and discussion

Next to the original description, the results must be compared to the results of the initial assessment.

#### 7. Review of intervention points

Same as original, thus only if applicable.

### 8. Conclusions

Next to the original statements, if there are differences between the initial and the current assessment, these should be emphasised.

### 9. Recommendations

Is kept the same as in the initial report format.

### Annexes

Same as initial assessment report format

# K. (R)AMSSHE€P scores for consequences

In this appendix, a tool is offered for the quantification of the consequences explained in section 6.3. For each letter considered within AMSSHE€P a brief adapted description is given below (Rijkswaterstaat, 2017):

- (A) Availability: Here the availability of the building for the sure is considered. For instance, not being able to use a balcony as this is too dangerous.
- (M) Maintenance: Expressed as the degree or feasibility of functional maintenance after a structural failure mechanism or damage has occurred (Rijkswaterstaat, 2017). For instance, maintenance where special equipment is required.
- (S) Safety: The safety of the user, people in the surrounding and, if applicable, personnel for maintenance or other functions are covered with this letter. The aspect of injuries or even casualties is encapsulated by this category.
- (S) Security: Rijkswaterstaat states that this is the extent to which an object can be protected against conscious unwelcome/unsafe human action(s). An example for this aspect is vandalism or even terrorism.
- (H) Health: This letter considers the wellbeing for all persons mentioned in the safety aspect above. A problem in this category could be the use of toxic substances.
- (E) Environment: The consequences for flora and fauna for the structural failure/damage. Also, vibrations due to a collapse are considered in this category.
- (€) Economics: These are the financial consequences for structural failures. The maintenance costs, claims, fines and social impact are included (Rijkswaterstaat, 2017).
- (P) Politics: Rijkswaterstaat uses the effect the consequence has on the reputation of the managing party or the ones responsible for the consequence. If for instance an object does not comply with the standards this can lead to a negative impact on the reputation of the managing party (Rijkswaterstaat, 2017).

For these letters the scores are specified in table k.1. If possible, the table is kept the same as in the ORA method by Rijkswaterstaat (Rijkswaterstaat, 2016). Only the availability and the first column, describing the extra score which is added, are adapted to fit the developed assessment method which is for buildings.

For each risk/failure mechanism, a score must be given for all the aspects (letter) in the table. Per risk/failure mechanism the highest consequence score among all of the aspects must be selected (Rijkswaterstaat, 2016). This score is the final consequence score which is used in the risk assessment.

Table K.1: AMSHE(E)P for quantification consequences (Rijkswaterstaat, 2016)

| | **1: None** | **2: Negligible** | **3: Limited** | **4: Significant** | **5: Severe** |
|---|---|---|---|---|---|
| A | Entire building is available for the user | Users have small hinderance in use building | Users are slightly obstructed in use building | Users are significantly obstructed in use building | Users cannot access the building |
| M | No maintenance required | Local maintenance, can be easily executed | Maintenance with extra effort (Need special equipment or wait for parts for example) | Maintenance with significant effort (Wait for license or specially fabricated parts for instance) | Maintenance does not outweigh economic service life, other measures required |
| S | No injuries for any person | Failure leads to direct/indirect non-sustaining injuries without omission from activities for one or multiple persons | Failure leads to direct/indirect non-sustaining injuries which require medical assistance/hospitalisation for one or multiple persons | Failure leads to direct/indirect sustaining injuries for one person | Failure leads to direct/indirect sustaining injuries for multiple persons or fatal injuries for one person |
| S | No undesirable human actions | Undesirable human actions which possibly have minor consequences like graffiti | Undesirable human actions which possibly have minor consequences like access to unimportant spaces | Undesirable human actions which possibly have significant consequences, like access to important spaces | Undesirable human actions which possibly have severe consequences, like access to vital spaces |
| H | No effects on wellbeing | Over time Negative effects to wellbeing for one or more persons | Over time, temporary negative effects to human health for one or more persons | Over time, sustaining negative effects to human health for one person | Over time, sustaining negative effects to human health for multiple persons or fatal effects to human health for one or more persons |
| E | No consequence for flora and fauna | Negligible consequences for flora and fauna | Limited consequences to flora and fauna, no measures required as solves itself | Significant consequences to flora and fauna, measures required to prevent worse | Severe long-term consequences to flora and fauna, measures required to prevent worse |
| € | Consequence costs < €100 | Consequence costs between €100 and €10,000 | Consequence costs between €10,000 and €100,000 | Consequence costs between €100,000 and €500,000 | Consequence costs > €500,000 |
| P | No political consequences | Complaints | Local damage to reputation | Regional damage to reputation | Nationwide damage to reputation |

As explained in section 8.2, not all letters are that important to this method. In order to keep the method efficient in use, the categories Security, Health and Environment are not further considered. In addition, the safety category is restructures to provide distinction in one or multiple casualties as a consequence of failure. The final table to help in the risk quantification is given below.

Table K.2: AMS€P for quantification consequences (Rijkswaterstaat, 2016)

| | **1: None** | **2: Negligible** | **3: Limited** | **4: Significant** | **5: Severe** |
|---|---|---|---|---|---|
| A | Entire building is available for the user | Users have small hinderance in use building | Users are slightly obstructed in use building | Users are significantly obstructed in use building | Users cannot access the building |
| M | No maintenance required | Local maintenance, can be easily executed | Maintenance with extra effort (Need special equipment or wait for parts for example) | Maintenance with significant effort (Wait for license or specially fabricated parts for instance) | Maintenance does not outweigh economic service life, other measures required |
| S | No injuries for any person | Failure leads to direct/indirect non-sustaining injuries without omission from activities for one or multiple persons | Failure leads to direct/indirect non-sustaining injuries which require medical assistance/hospitalisation for one or multiple persons | Failure leads to direct/indirect sustaining injuries or fatal injuries for one person | Failure leads to direct/indirect sustaining injuries or fatal injuries for multiple persons |
| € | Consequence costs < €100 | Consequence costs between €100 and €10,000 | Consequence costs between €10,000 and €100,000 | Consequence costs between €100,000 and €500,000 | Consequence costs > €500,000 |
| P | No political consequences | Complaints | Local damage to reputation | Regional damage to reputation | Nationwide damage to reputation |

# L. Additional information for assessment

There is additional information available that could be implemented to improve the assessment performed with the method. The additional information sources applicable to this method are delineated in table l.1. These sources, along with their corresponding methods and references, ensure accessibility of the information.

Table L.1: Further information which could be accessed for assessment

| Method | Institution | Additional information | Source |
|---|---|---|---|
| Guideline for Structural Assessment of Existing Buildings | ASCE | • Information regarding materials and damage patterns given.<br>• Tables for tests with a.o. purpose, principle, user expertise, advantages and limitations.<br>• Tables coupling defect/property to evaluation method (tests). | (ASCE, 2000) |
| CUR 124 | CROW - CUR | • Tables provided with main material properties.<br>• Per type of object with material stated what information required.<br>• More information like iterative approach in calculation models given. | (CROW-CUR, 2019) |
| Appraisal of Existing Structures | The Institution of Structural Engineers | • Tables given with indications possible causes, suggested investigations and references applicable tests.<br>• Tests and materials extensively described.<br>• Brief must be written before assessment. | (ISTRUCTE, 2010) |
| NTA 8790 | NEN | • Help in estimation of extent damage. | (NEN, 2023) |

The available sources given in the table above could be incorporated in the method in future studies.

# M.Case study building A

This appendix provides a summary of the case study used for the validation in chapter 8, specifically focussing on Building A as described in section 7.2. The steps outlined in the validation are presented here. However, as this is a hypothetical assessment, no additional actions are undertaken and no measures are prescribed to the client. The steps are executed solely for the purpose of validating the assessment process.

Each step is briefly described based on the guidelines provided in section 6.2.Concise information from each step, along with the corresponding analysis, is included in this appendix. To ensure confidentiality, all information has been anonymised to prevent identification of the actual building.

## M.1 Preparation phase

The initial step involves obtaining an overview of the building using online resources such as Google Maps. The findings from this overview are incorporated into the building description provided in section 7.2. However, to maintain anonymity in this thesis no images of the building are included. The focus of this study is on validating the assessment method, rather than reassessing the building itself.

### M.1.1 Alignment with client

For this validation also a meeting with the asset manager of the building was conducted. There is explained to this individual how the validation is performed. Next, the questions posted in subsection 6.2.1 are asked, providing the following answers:

- **Expectation assessment**: To avoid any surprises and provide a better approximation of the level of safety to structure the maintenance planning. In addition, the NEN 2767 has is limitations, resulting in the fact that structural risks are underexposed.

- **Maintenance history:** Building realised in period 1968 – 1970, using a semi-prefab concrete structure with prefab masonry elements for the facades. A relatively low level of maintenance is required for this structure. Regular maintenance and renovations have been conducted.

- **Renovation/adaptation history**: Early 2000s the inside of the dwellings were renovated. Mid 2000s, the external parts of the building were renovated. In this renovation, the ground floor was segmented. Moreover, an underpass was crated for improved access on both sides of the building.

- **Change in use:** In one part building, the storage spaces on the ground floor were adapted to commercial units. In addition, communal area was created on this floor. In general, the apartments have remained largely unchanged.

- **Signals users:** Troubles with moisture in cavity of outside facades in the past, due to type of stone and moisture coming from the apartments. Over the winter, some of the stones obtained frost damage. Present day, the facades are coated and have more ventilation. Nebest has inspected the doves connecting the prefab masonry parts in the early 2010s.

Moreover, problems with concrete falling down from element providing transition from one façade to another in similar complex a few years ago. At last, also problems with pipes being corroded.

- **Damages:** Some of the damages have already been listed above. The window frames in the bedrooms have been changed from timber to plastic but have been deteriorating due to bad quality.

- **Other points:** problems with installations, which are not considered as assessment about structural safety.

- **Plans future:** In recent future renovation project will be conducted providing severe maintenance and improving sustainability of the apartments. This maintenance takes place despite little signals it was necessary.

The asset manager agreed the documents delivered to Nebest, could be used for this assessment process. There must be emphasised that a significant number of drawings and documents were not available. A significant part of the structure could not be studied due to this lacking documentation.

## M.2 Desk study

Most documents are available for the foundation of the building, including pile deflections. For the rest of the building only more general structural and installation drawings are available. As there was also a condition assessment of the building available, this is also taken into account in the desk study.

### M.2.1 Material properties

For the concrete piles, the length, detailing and maximum allowable loads are all given within drawings. In addition, on the drawings of the foundation strips more information regarding the used in situ concrete for the entire project is available. Within this information is the minimum concrete coverage for the reinforcement that should be obtained for different building parts. The properties of the reinforcement are also given.

Furthermore, there is known that the galleries, balconies and consoles consist of prefab concrete. The facades consist of prefab masonry panels connected with doves to the structure. More information on the materials of other building components is given in the risk analysis steps.

### M.2.2 Structural assembly

In this subsection the questions posted in subsection 6.2.2 are answered:

- **Global set up:** Concrete load bearing structure. Walls provide the stability for horizontal (wind) loads and also transport the vertical loads, coming from the floors to the concrete foundation beams. These beams distribute the loads evenly over the piles which transport the loads to the soil layers beneath.
  The galleries are supported by consoles which are again connected to the load bearing walls which transport the loads to the foundation. The balconies are supported by the walls itself.

- **Design to execution ready documents:** No information on preliminary documents or calculations, only part of execution ready documents available. For the pile deviations, the majority is less than 10 mm if there is a difference at all. In a few cases, one pile has been replaced by two piles. The highest deviations detected are 25 and 32 mm, which are all in the direction of the beam. As after all those years there are no signs of failure that indicate problems with the foundation and the fact the deflection was well considered at the time, indicates that there is no problem with the pile deviations.

  As aforementioned, there are no other subjects to examine for this aspect.

- **Impact adaptations/extensions:** As given in preparation phase, the ground floor is adapted at multiple areas to create both commercial as communal activities. In addition, an underpass was made at ground floor level. However, no records of these adaptations have been found in the desk study.

- **Impact increased loads**: Commercial activities might have increased loads, but nothing detected in desk study.

- **Impact damages and repairs:** Damaged concrete part in sections between facades, previous moisture problems façade (fixed by applying coating and ventilation) and process of corroding pipes which even continues after applying coating. It is important to note that the steel doves in the façade were still in good condition in 2011.

The set of questions by the NTA is also answered:

- **System parts:** Floors, walls, galleries, consoles, balconies, foundation beams and piles.
- **Vertical load transport:** Floors transport loads to walls which transport the loads to foundation beams. These beams divide the loads over the piles, which transfer the loads to the ground.
- **Horizontal load transport:** Horizontal load is transferred through facades to floors or directly to the walls. From here on the same load path as the vertical load bearing system is followed.
- **Extraordinary loads:** No calculations available to check if these loads are considered.

### M.2.3 Robustness classification

The robustness class of the building is determined using table g.9. As there was little information available it was difficult to perform this robustness classification. RC 3 is selected as it entails a concrete wall system, which is insensitive to faults and spans multi-storeys. This does not mean all structural components are considered to be robust. For instance, the gallery floors supported by consoles, if one of the consoles fail two gallery plates will also fail.

### M.2.4 Component division

In the excel performing the analysis, the building is dividing into the different building components listed in table 6.1. In this decomposition the attention points and common causes for structural failure incidents are also considered. Via this decomposition the first risks can be quantified in the first step of the risk analysis.

### M.2.5 ORA step 1

This step is performed in excel. The results are given below.

| Building information | | | Step 1: Assessment considering desk study | | | Score | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Building part | Element | Findings study | Cause failure | Possible failure mechanisms | time interval t | Likelihood | Help consequence score | | | | | | | | Consequenc | Risk score | Detection | Hazard category | Explanatory note |
| | | | | | | | | A | M | S | S | H | E | € | P | | | | | |
| **16** | **Retaining walls, foundation** | | | | | | | | | | | | | | | | | | | |
| 16.12 | Foundations, footings and strips, foundation strips | In situ reinforced concrete strips | 1970: Realisation date;<br>Information materials present;<br>Reinforcement drawings available for some locations;<br>Drawings imply coverage between 25 and 30 mm | - Degradation<br>- Design error<br>- Execution error | Insufficient load bearing capacity;<br>Concrete damage;<br>Corrosion reinforcement; | 6 - 20 | 2 | 3 | 3 | 2 | 1 | 1 | 1 | 3 | 2 | 3 | 6 | 3 | Non- visual | Failure would be gradual process;<br>Sructure proven itself, but exposed to outdoor environment;<br>Prescribed coverage for wet and dry environment is 30 mm and 25 mm for semi-moist environment; |
| **17** | **Pile foundations** | | | | | | | | | | | | | | | | | | | |
| 17.21 | Pile foundations, displacement, bearing piles | Reinforced concrete piles | 1970: Realisation date;<br>Information materials present;<br>Drawings reinforcement, allowable load on piles and pile deflections given | - Degradation<br>- Design error<br>- Execution error | Insuffiicent load bearing capacity;<br>Settlement;<br>Concrete damage;<br>Groundwater fluctuation;<br>Negative soil friction; | 6 - 20 | 2 | 1 | 4 | 1 | 1 | 1 | 1 | 3 | 1 | 4 | 8 | 4 | Non - visual | If failure, forces could probably be diverted to other piles via foundation beams;<br>Structure proven itself, but exposed to outdoor environment |
| **21** | **External walls** | | | | | | | | | | | | | | | | | | | |
| 21.21 | External walls, load bearing, massive walls | Concrete elements at corners facade | 1970: Realisation date;<br>Concrete came loose in similar complex resulting in corrosion reinforcement;<br>Detected cracks in this complex | - Degradation<br>- Design error<br>- Execution error | Concrete damage;<br>Corrosion reinforcement;<br>Insufficient load bearing capacity; | 0.5 - 2 | 4 | 1 | 2 | 3 | 1 | 1 | 1 | 2 | 2 | 3 | 12 | 1 | Visual | First signs damages visible in this complex;<br>In similar complex damage progressed;<br>Check extent problem in step 2 |
| 21.22 | External walls, load bearing, cavity walls | Prefab masonry panels connected via doves | 1970: Realisation date;<br>Non structural cracks, condition score = 2;<br>Inspection to doves at start 2010s;<br>Sufficent doves and in good state, only some surface damages of prefab elements;<br>Advice to evaluate anchorage via standard with constuctor | - Degradation | Corrosion doves;<br>Damages bricks; | 6 - 20 | 2 | 1 | 3 | 5 | 2 | 3 | 1 | 3 | 3 | 5 | 10 | 3 | Non-visual | All was fine in 2010s, building was approximately 40 years old;<br>Currently building approximately 50 years old;<br>this date also mentioned in comon cause;<br>As examined small change something wrong, but has been more than 10 years back |

| Building information | | | Step 1: Assessment considering desk study | | | Score | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Building part | Element | Findings study | Cause failure | Possible failure mechanisms | time interval | Likelihood | Help consequence score | | | | | | | | Consequenc | Risk score | Detection | Hazard category | Explanatory note |
| | | | | | | t | | A | M | S | S | H | E | € | P | | | | | |
| **23** | **Floors, galleries** | | | | | | | | | | | | | | | | | | | |
| 23.21 | Floors, load bearing, Suspended floor | Prefab concrete floor elements | 1970: Realisation date;<br>Condition score inside floors without finishing is 1;<br>Besides desciption 10 mm coverage no information | - Degradation<br>- Design error<br>- Execution error | Insufficient load bearing capacity;<br>Damages concrete;<br>Corrosion reinforcement; | > 20 | 1 | 4 | 3 | 5 | 1 | 1 | 1 | 4 | 4 | 5 | 5 | 3 | Non -visual | Could have progressive collapse;<br>First expect signals;<br>Inside enviroment and structure proven itself;<br>described coverage within limits |
| 23.22 | Floors, load bearing, balconies | Prefab concrete plates supported by walls | 1970: Realisation date;<br>Condition score balconies is 1;<br>No information available for balconies, except fact that they are supported by walls; | - Degradation<br>- Design error<br>- Execution error | Insufficient load bearing capacity;<br>Corrosion reinforcement, in specific chloride damage<br>Damages concrete | 2 - 6 | 3 | 3 | 3 | 5 | 1 | 1 | 1 | 3 | 4 | 5 | 15 | 3 | Non -visual | In common causes, could have chloride elevation + outdoor conditions to trigger degradation mechanism;<br>Structure proven itself but exposed to outdoor environment |
| 23.23 | Floors, load bearing, a | Prefab concrete plates supported by consoles | 1970: Realisation date<br>Condition score galleries is 1;<br>No information available galleries, except fact supported by consoles | - Degradation<br>- Design error<br>- Execution error | Insufficient load bearing capacity;<br>Corrosion reinforcement, in specific chloride damage;<br>Damages concrete | 2 - 6 | 3 | 4 | 3 | 5 | 1 | 1 | 1 | 3 | 4 | 5 | 15 | 3 | Non -visual | In common causes, could have chloride elevation + outdoor conditions to trigger mechanism;<br>Structure proven itself but exposed to outdoor environment |
| **24** | **Stairs, ramps** | | | | | | | | | | | | | | | | | | | |
| 24.11 | Stairs, ramps, straightflight stairs | Concrete stairs inside | 1970: Realisation date<br>Concrete stairs given in one drawing, no further information;<br>Condition score = 1 | - Degradation<br>- Design error<br>- Execution error | Insufficient load bearing capacity;<br>Damages concrete;<br>Corrosion reinforcement | > 20 | 1 | 3 | 3 | 5 | 1 | 1 | 1 | 3 | 4 | 5 | 5 | 2 | Visual | Inside, not exposed outdoor environment;<br>First signals could be visual detectable;<br>Structure proven itself |
| 24.15 | Stairs, ramps, stairs, terras | Concrete terrases inside | 1970: realisation date<br>Concrete stairs given in one drawing, no further information;<br>Condition score = 1 | - Degradation<br>- Design error<br>- Execution error | Insufficient load bearing capacity;<br>Damages concrete;<br>Corrosion reinforcement | > 20 | 1 | 3 | 3 | 5 | 1 | 1 | 1 | 3 | 4 | 5 | 5 | 2 | Visual | Inside not exposed to outdoor environment;<br>Structure proven itself;<br>First sginals could be visual detectable |
| 24.11 | Stairs, ramps, straightflight stairs | Steel | 1970: Realisation date<br>Condtion score = 1<br>No further information | - Degradation<br>- Design error<br>- Execution error | Insufficient load bearing capacity;<br>Corrosion steel;<br>Corrosion connections | 6 - 20 | 2 | 2 | 2 | 3 | 1 | 1 | 1 | 2 | 3 | 3 | 6 | 1 | Visual | Outdoor environment, could be subsequent to degradation;<br>If fail could fall on gallery plate, which likely holds the load of the stairs |
| **27** | **Roofs** | | | | | | | | | | | | | | | | | | | |
| 27.21 | Roofs, load bearing, flat roofs | Concrete roof | 1970: resalisation date;<br>No further information;<br>No condition score | - Degradation<br>- Design error<br>- Execution error | Insufficient load bearing capacity<br>Degradation roof | 6 - 20 | 2 | 4 | 3 | 5 | 1 | 1 | 1 | 2 | 4 | 5 | 10 | 1 | Viusal for drainage aspect | No information available but structure provene over years;<br>Except for drainange, structure under finishing |

| Building information | | | Step 1: Assessment considering desk study | | | Score | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Building part | Element | Findings study | Cause failure | Possible failure mechanisms | time interval t | Likelihood | Help consequence score | | | | | | | | Consequenc | Risk score | Detection | Hazard category | Explanatory note |
| | | | | | | | | A | M | S | S | H | E | € | P | | | | | |
| **28** | **Building frames, other primary elements** | | | | | | | | | | | | | | | | | | | |
| 28.20 | Building frames, walls and floors, general (collection level) | Concrete walls apartments | 1970: realisation date;<br>No further information available | - Degradation<br>- Design error<br>- Execution error | Insufficient load bearing capacity;<br>Corrosion reinforcement;<br>Concrete damage | > 20 | 1 | 5 | 4 | 5 | 4 | 1 | 2 | 5 | 5 | 5 | 5 | 3 | Non - visual | Failure wall or frame can lead to progresive collapse part structure;<br>Structure proven itself over the years;<br>Structure inside not exposed to outdoor environment |
| 28.21 | Building frames; walls and floors, walls and floor frames | Concrete lift tube on roof | 1970: Realisation date;<br>No further information available | - Degradation<br>- Design error<br>- Execution error | Insufficient load bearing capacity;<br>Corrosion reinforcement;<br>Concrete damage | > 20 | 1 | 3 | 2 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 1 | Visual | No further information in this phase of the study |
| 28.21 | Building frames; walls and floors, walls and floor frames | Concrete walls supporting balconies | 1970: Realisation date;<br>No further information available | - Degradation<br>- Design error<br>- Execution error | Insufficient load bearing capacity;<br>Corrosion reinforcement;<br>Concrete damage | > 20 | 1 | 5 | 4 | 5 | 4 | 1 | 2 | 5 | 5 | 5 | 5 | 2 | Visual | Failure wall could lead to further collapse;<br>Structure proven itself over the years;<br>Outdoor environment, is subject to degradation |
| 28.20 | Building frames, walls and floors, general (collection level) | Concrete structure commercial buildings | For one complex ground floor is changed from garages to commercial activities;<br>No documents available | - Design error<br>- Execution error | Incompetent renovation/adaptation | > 20 | 1 | 4 | 3 | 5 | 4 | 1 | 2 | 4 | 5 | 5 | 5 | 2 | Visual | No information available;<br>Structure proven itself while possible common cause present;<br>Inside, not subject to outdoor environment |
| 28.11 | Building frames; columns and beam frames, colums and beam frames | Concrete column in boiler room building | Not detected in desk study | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 28.21 | Building frames, walls and floors, wall and floor frames | Prefab concrete edge beam roof | 1970: Realisation date;<br>No information available;<br>Condition score = 1 | - Degradation<br>- Design error<br>- Execution error | Insufficient load bearing capacity;<br>Corrosion reinforcement, in specific chloride damage;<br>Concrete damage | 2 - 6 | 3 | 2 | 3 | 3 | 1 | 1 | 1 | 3 | 3 | 3 | 9 | 1 | Visual, except chloride content | Good condition score and structure proven itself, but exposed to outdoor environment;<br>Possible danger chloride content |
| 28.21 | Building frames, walls and floors, walls and floor frames | Prefab concrete consoles | 1970: Realisation date;<br>Condition score = 1;<br>No information available | - Degradation<br>- Design error<br>- Execution error | Insufficient load bearing capacity;<br>Corrosion reinforcement, in specific chloride damage;<br>Concrete damage;<br>Insufficient anchorage | 2 - 6 | 3 | 4 | 4 | 5 | 1 | 1 | 1 | 2 | 5 | 5 | 15 | 1 | Visual, except chloride content | Good condition score;<br>Could be subject to degradation;<br>Could have chlorides in admixture |

| Building information | | | Step 1: Assessment considering desk study | | | Score | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Building part | Element | Findings study | Cause failure | Possible failure mechanisms | time interval t | Likelihood | Help consequence score A | M | S | S | H | E | € | P | Consequenc | Risk score | Detection | Hazard category | Explanatory note |
| **31** | **External wall openings** | | | | | | | | | | | | | | | | | | | |
| 31.1 | External openings, not filled | Underpass created in existing structure | Underpass created after structure was already in use, not in original plans;<br>No further information available | - Design error<br>- Execution error | Incompetent renovation/ adaptation | >20 | 1 | 4 | 4 | 5 | 3 | 1 | 1 | 5 | 5 | 5 | 5 | 1 | Visual | Structure proven itself over the years;<br>Would signal before collapse |
| **33** | **Secondary elements to floors** | | | | | | | | | | | | | | | | | | | |
| 33.0 | Floor openings, gener | Among others for elektra | There are some drawings of openings listed but none are available | - Design error<br>- Execution error | insufficient load bearing capacity surrounding floor area | >20 | 1 | 4 | 4 | 5 | 4 | 3 | 1 | 4 | 4 | 5 | 5 | 3 | Non-visual | Structure proven itself over years;<br>Inside little degradation;<br>recesses not visible |
| **34** | **Secondary elements to stairs** | | | | | | | | | | | | | | | | | | | |
| 34.12 | Stair balustrades, handrails; balustrades, outer balustrades | Metal fencing filled with glass for balconies | No information in desk study;<br>Condition score = 1 | - Degradation<br>- Execution error | Corrded connections or elements;<br>Not connected or insufficiently assembled | 6 - 20 | 2 | 2 | 2 | 5 | 1 | 1 | 1 | 2 | 2 | 5 | 10 | 1 | Visual | Structure proven itself;<br>Good condition score, but outdoor thus degradation posssible |
| 34.12 | Stair balustrades, handrails; balustrades, outer balustrades | Timber fencing with safety galss connected via steel connections for galleries | No information in desk study;<br>Condition score = 1 | - Degradation<br>- Execution error | Corrded connections or elements;<br>Not connected or insufficiently assembled | 6 - 20 | 2 | 2 | 2 | 5 | 1 | 1 | 1 | 2 | 2 | 5 | 10 | 1 | Visual | Structure proven itself;<br>Good condition score, but outdoor thus degradation posssible |
| 34.12 | Stair balustrades, handrails; balustrades, outer balustrades | Metal fencing Galleries | No information in desk study;<br>Condition score = 1 | - Degradation<br>- Execution error | Corroded connections or elements;<br>Not connected or insufficiently assembled | 6 - 20 | 2 | 2 | 2 | 5 | 1 | 1 | 1 | 2 | 2 | 5 | 10 | 1 | Visual | Structure proven itself;<br>Good condition score, but outdoor thus degradation posssible |
| 34.21 | Stair balustrades, handrails; handrails, inner handrails | Metal fencing Stairs inside | No information in desk study;<br>Condition score = 1 | - Degradation<br>- Execution error | Corroded connections or elements;<br>Not connected or insufficiently assembled | >20 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | Visual | Structure proven itself;<br>Good condition score and inside |
| 34.12 | Stair balustrades, handrails; balustrades, outer balustrades | Metal supports Stairs outside | No information in desk study;<br>Condition score = 1 | - Degradation<br>- Execution error | Corroded connections or elements;<br>Not connected or insufficiently assembled | 6 - 20 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 4 | 1 | Visual | Structure proven itself;<br>Good condition score, but outdoor thus degradation posssible |
| **47** | **Roof finishes** | | | | | | | | | | | | | | | | | | | |
| 47.11 | Roof finishes; finishes, flat roof finishes | Bitumeuous roof cladding | No information desk study;<br>condition score = 1 | - Degradation<br>- Execution | Insufficient fixation against wind;<br>Degradation connections | 6 - 20 | 2 | 1 | 2 | 4 | 1 | 1 | 1 | 2 | 3 | 4 | 8 | 1 | Visual | Structure proven itself<br>Good condition score, but outdoor so vulnerable to degradation |

All documents which were available have been considered as well as the alignment with the client. In addition, the structure has already proven itself over the years. However, there was little documentation available. If this would not have been a fictive assessment, further effort must be made to retrieve more documentation. For instance, by consulting the archive within the municipality.

For this fictive assessment, the remaining hazards which are non-visual detectable and not detected, are accepted. The assessment can thus be progressed with the visual inspection.

## M.3 Visual inspection and ORA step 2

The hazards from ORA step one that have been marked as visual detectable, along with new points coming forward, are inspected. Both types of hazards considered during the visual inspection, are evaluated in the second step of the ORA. This analysis is given below.

| Building information | | | Step 2: Visual inspection | | Score | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Building part | Element | Attention points after fase 1 | Findings inspection | time interval | Likelihood | Help consequence score | | | | | | | | Consequenc | Risk score | Detection | Explanatory note |
| | | | | | t | | A | M | S | S | H | E | € | P | | | | |
| **21** | **External walls** | | | | | | | | | | | | | | | | | |
| 21.21 | External walls, load bearing, massive walls | Concrete elements at corners facade | Cracks and concrete damage in general;<br>Signs corrosion reinforcement | Cracks indeed detected in complex, which can lead to concrete parts coming loose | 0.5 - 2 | 4 | 1 | 2 | 3 | 1 | 1 | 1 | 2 | 2 | 3 | 12 | 1 | As same failure can happen as in similar complex, the risk is undesriable and additional actions need to be performed |
| **24** | **Stairs, ramps** | | | | | | | | | | | | | | | | | |
| 24.11 | Stairs, ramps, straightflight stairs | Concrete stairs inside | Cracks and concrete damage in general;<br>Deformations | Stairs look to be in good shape, in some places small pieces of concrete chipped off | > 20 | 1 | 3 | 3 | 5 | 1 | 1 | 1 | 3 | 4 | 5 | 5 | 2 | Acceptable risk, no follow up actions to be taken |
| 24.15 | Stairs, ramps, stairs, terras | Concrete terrases inside | Cracks and concrete damage in general;<br>Deformations | Terraces look to be in good shape | > 20 | 1 | 3 | 3 | 5 | 1 | 1 | 1 | 3 | 4 | 5 | 5 | 2 | Acceptable risk, no follow up actions to be taken |
| 24.11 | Stairs, ramps, straightflight stairs | Steel | Corrosion;<br>Connections;<br>Deformation | Stair elements look to be in good shape. However, most of the connections seemed to be corroded which could result in failure of the outdoor stairs. | 2 - 6 | 3 | 2 | 2 | 3 | 1 | 1 | 1 | 2 | 3 | 3 | 9 | 1 | Undersirable risk, risk must be solved in next steps |
| **27** | **Roofs** | | | | | | | | | | | | | | | | | |
| 27.21 | Roofs, load bearing, flat roofs | Concrete roof | Material;<br>Drainage;<br>Loads on roof | Not able to inspect inside dwellings;<br>No emergency drainages, but low edge with max 20 mm in height;<br>drainage cleaned every year | 6 - 20 | 2 | 4 | 3 | 5 | 1 | 1 | 1 | 2 | 4 | 5 | 10 | 3 | Concrete structure likely to be okay, but not able to inspect;<br>Closer detail to drainages could be obtained |

| Building information | | | Step 2: Visual inspection | | Score | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Building part | Element | Attention points after fase 1 | Findings inspection | time interval t | Likelihood | Help consequence score A | M | S | S | H | E | € | P | Consequenc | Risk score | Detection | Explanatory note |
| **28** | **Building frames, other primary elements** | | | | | | | | | | | | | | | | | |
| 28.20 | Building frames, walls and floors, general (collection level) | Concrete walls apartments | Non-visual | Some pipes corroded, exporting fluids which might cause degradation into the load bearing structure | 6 - 20 | 2 | 5 | 4 | 5 | 4 | 1 | 2 | 5 | 5 | 5 | 10 | 3 | Due to leakages, parts inside load bearing structure could be exposed to moisture and other harmful substances |
| 28.21 | Building frames; walls and floors, walls and floor frames | Concrete lift tube on roof | Check for cracks and state concrete | Saw some significant cracks and fibres visible for finishes | 6 - 20 | 2 | 3 | 2 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 6 | 1 | Structure proven itself, but not clear how cracks came there and if they progressed |
| 28.21 | Building frames; walls and floors, walls and floor frames | Concrete walls supporting balconies | Check for cracks and state concrete | Detected cracking of part wall where balconies are supported; If fail the balconies would experience additional stress and might partly fail | 0.5 - 2 | 4 | 3 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 12 | 1 | Crack in concrete is undesirable as it is right under support balconies |
| 28.20 | Building frames, walls and floors, general (collection level) | Concrete structure commercial buildings | Check inside shops if detectable | Where possible no adaptations were made as<br>only small openings were made for entrance | > 20 | 1 | 4 | 3 | 5 | 4 | 1 | 2 | 4 | 5 | 5 | 5 | 3 | Risk deemed to be acceptable, but detection score gone up as structure behind finishes |
| 28.11 | Building frames; columns and beam frames, colums and beam frames | Concrete column in boiler room building | - | One beam and column support wall of above apartments;<br>Cracks in finishing beams with firbes coming loose;<br>Cracks concrete column;<br>Cracks in concrete outer wall, probably due to thermal load | 6 - 20 | 2 | 5 | 4 | 5 | 4 | 1 | 1 | 5 | 5 | 5 | 10 | 2 | Sturcutr ewoould likely signal before collapse;<br>Failure leads to progressive collapse;<br>Detected cracks which might be problematic |
| 28.21 | Building frames, walls and floors, wall and floor frames | Prefab concrete edge beam roof | Cracks and concrete damages in general;<br>Deformation;<br>Signs corrosion reinforcement;<br>Chlorides not visible | Did not see any damages | 2 - 6 | 3 | 2 | 3 | 3 | 1 | 1 | 1 | 3 | 3 | 3 | 9 | 3 | All looks good but possible chloride problem is not visible |
| 28.21 | Building frames, walls and floors, walls and floor frames | Prefab concrete consoles | Cracks and concrete damages in general;<br>Deformation galleries;<br>Signs corrosion reinforcement | Consoles look to be in good state, However one console has concrete damage with corroded bolts inside. Is supporting the roof | 2 - 6 | 3 | 4 | 4 | 5 | 1 | 1 | 1 | 2 | 5 | 5 | 15 | 1 | Chloride content could not be seen and the part of concrete which is loose must be closer examined |

| Building information | | | Step 2: Visual inspection | | Score | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Building part | Element | Attention points after fase 1 | Findings inspection | time interval t | Likelihood | Help consequence score A | M | S | S | H | E | € | P | Consequenc | Risk score | Detection | Explanatory note |
| **31** | **External wall openings** | | | | | | | | | | | | | | | | | |
| 31.1 | External openings, not filled | Underpass created in existing structure | Deformations;<br>Cracks | No deformations detected.<br>Did detect one crack in the masonry which probably formed during execution;<br>crack did not continue in the concrete structure, As masonry most vulenerable to defromation probably first cracked;<br>Rest looks good and that the crack did not progress over time | >20 | 1 | 4 | 4 | 5 | 3 | 1 | 1 | 5 | 5 | 5 | 5 | 1 | Risk is seen as acceptable, no further actions required |
| **34** | **Secondary elements to stairs** | | | | | | | | | | | | | | | | | |
| 34.12 | Stair balustrades, handrails; balustrades, outer balustrades | Metal fencing filled with glass for balconies | Connections;<br>Corrosion;<br>Quality glass | Could not enter balconies but all looks to be okay | 6 - 20 | 2 | 2 | 2 | 5 | 1 | 1 | 1 | 2 | 2 | 5 | 10 | 1 | In future could inspect the fencing to see if all-in good state |
| 34.12 | Stair balustrades, handrails; balustrades, outer balustrades | Timber fencing with safety galss connected via steel connections for galleries | Connections;<br>Corrosion; | Bolts connecting panels to underside gallery floor corroded;<br>Side connections corroded on many places;<br>Tmber frames decayed and cracks in glass show stress | 0.5 - 2 | 4 | 2 | 2 | 5 | 1 | 1 | 1 | 2 | 2 | 5 | 20 | 1 | Due to severe degradation this fencing has a higher chance of collapse as thought |
| 34.12 | Stair balustrades, handrails; balustrades, outer balustrades | Metal fencing Galleries | Connections;<br>Corrosion | Good quality, all looks good | >20 | 1 | 2 | 2 | 5 | 1 | 1 | 1 | 2 | 2 | 5 | 5 | 1 | Looks all good,has been replaced |
| 34.21 | Stair balustrades, handrails; handrails, inner handrails | Metal fencing Stairs inside | Connections;<br>Corrosion | Good quality, sometimes paint chipped off | >20 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | Inside sometimes no paint but all looks good |
| 34.12 | Stair balustrades, handrails; balustrades, outer balustrades | Metal supports Stairs outside | Connections;<br>Corrosion | Good qualtiy, except for the connections those are degraded and form a risk | 0.5 - 2 | 4 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 8 | 1 | Need additional actions but already covered in steel stairs component |
| **47** | **Roof finishes** | | | | | | | | | | | | | | | | | |
| 47.11 | Roof finishes; finishes, flat roof finishes | Bitumeuous roof cladding | Connections;<br>Degradation;<br>Ballast material | Grind used to ballast roof all looks solid. However, btiumeous roof not has more as 20 years | 6 - 20 | 2 | 1 | 2 | 4 | 1 | 1 | 1 | 2 | 3 | 4 | 8 | 1 | This bitemeous cannot go more than 20 years |

Following the second step of the ORA, there must again be evaluated whether the non-detected hazards are accepted. As all the information is collected in the steps, in this case these hazards are seen as acceptable and the assessment is continued.

At this point there must be checked if the assessment is seen as sufficient. As there are multiple risks which are marked as undesirable or unacceptable the assessment is not seen as sufficient at this point in time. For these risks, the additional actions or measures must be selected to mitigate the risk. This selection is made in the following section. This forms the last step in the validation process.

## M.4 Selection additional actions/measures and ORA step 3

The selection of actions or measures with the impact on the risks is given in the tables below.

| Building information | | | Step 3: Possible actions | Score | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Building part | Element | Proposal possible actions | time interval t | Likelihood | Help consequence score A | M | S | S | H | E | € | P | Consequenc | Risk score | Detection | Explanatory note |
| **16** | **Retaining walls, foundation** | | | | | | | | | | | | | | | | |
| 16.12 | Foundations, footings and strips, foundation strips | In situ reinforced concrete strips | Closer examination foundation beams via access points to underside foundation | >20 | 1 | 3 | 3 | 2 | 1 | 1 | 1 | 3 | 2 | 3 | 3 | 1 | Via investigation foundation the condition can be assessed, if sufficient, the chance score can be lowered to one |
| | | | Provide regular monitoring thereby seeing first signs of failure | 6 - 20 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 4 | 3 | This reduces the consequences as it is noticed before any severe failure could take place |
| **17** | **Pile foundations** | | | | | | | | | | | | | | | | |
| 17.21 | Pile foundations, displacement, bearing piles | Reinforced concrete piles | Closer examination pile foundations via access points to see pile heads and see if any settelements. | >20 | 1 | 1 | 4 | 1 | 1 | 1 | 1 | 3 | 1 | 4 | 4 | 4 | As cannot see entire pile, never entirely sure but by looking at top piles and indiciations if any settleements occured, the risk can be mitigated |
| | | | Provide regular monitoring thereby seeing first signs of failure | 6- 20 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 3 | 1 | 3 | 6 | 4 | Even with monitoring, nothing is done on the consequence side. It has little impact on the risk |
| | | | More detailed investigations piles | >20 | 1 | 1 | 4 | 1 | 1 | 1 | 1 | 3 | 1 | 4 | 4 | 4 | Via more detailed investigation further insight is retrieved into the condition of the piles |
| **21** | **External walls** | | | | | | | | | | | | | | | | |
| 21.21 | External walls, load bearing, massive walls | Concrete elements at corners facade | Provide repairs element, just as the similar complex | >20 | 1 | 1 | 2 | 3 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 1 | By providing repair measure the high chance can be solved |
| | | | Closer investigation to the failure mechanism | 2 - 6 | 3 | 1 | 2 | 3 | 1 | 1 | 1 | 2 | 2 | 3 | 9 | 1 | With closer investigation, a better approximation on the chance of failure can be given. However, not expected element will have more than six years |
| 21.22 | External walls, load bearing, cavity walls | Prefab masonry panels connected via doves | Assess facade and doves to check the condtion of the structure | >20 | 1 | 1 | 3 | 5 | 2 | 3 | 1 | 3 | 3 | 5 | 5 | 1 | By checking the condition of the facades, the chance can be better approximated |
| | | | Close off all areas under the facades making them not accessible | 6- 20 | 2 | 4 | 3 | 1 | 2 | 3 | 1 | 3 | 3 | 4 | 8 | 3 | Reduces consequences for safety aspect. However, the accessibility of this measure increases to four thereby making the risk still undesirable |

| Building information | | | Step 3: Possible actions | Score | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Building part | Element | Proposal possible actions | time interval t | Likelihood | Help consequence score A | M | S | S | H | E | € | P | Consequenc | Risk score | Detection | Explanatory note |
| **23** | **Floors, galleries** | | | | | | | | | | | | | | | | |
| 23.22 | Floors, load bearing, balconies | Prefab concrete plates supported by walls | Investigation to concrete material, in specific chlorides, plus notification residents to not use de-icing salts or chlorides to clean balconies | >20 | 1 | 3 | 3 | 5 | 1 | 1 | 1 | 3 | 4 | 5 | 5 | 1 | Via this investigation the risk can be reduced to an acceptable level |
| | | | Disallow residents to access blaconies or walk in area close proximity | 2-6 | 3 | 3 | 3 | 1 | 3 | 2 | 1 | 3 | 3 | 3 | 9 | 3 | This way the safety aspect is decreased but the access, health and security aspect are increased. The risk is reduced but not enough to make the risks acceptable |
| 23.23 | Floors, load bearing, a | Prefab concrete plates supported by consoles | Investigation to concrete material, in specific chlorides, plus notification residents to not use de-icing salts or chlorides to clean balconies | >20 | 1 | 4 | 3 | 5 | 1 | 1 | 1 | 3 | 4 | 5 | 5 | 1 | Via this investigation the risk can be reduced to an acceptable level |
| | | | Temporary support galliers | 2-6 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 9 | 3 | Lower safety consequence but other aspects are increased, therefore the risk is still undesirable |
| **24** | **Stairs, ramps** | | | | | | | | | | | | | | | | |
| 24.11 | Stairs, ramps, straightflight stairs | Steel | Replace corroded connection parts for new outdoor weather resistant parts | >20 | 3 | 2 | 2 | 3 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 1 | Increasing the chance for connections |
| | | | Closer material investigation connections to check degradation scale and estimate lifetime | 6-20 | 2 | 2 | 2 | 3 | 1 | 1 | 1 | 2 | 3 | 3 | 6 | 1 | Better approximation on time interval and thus chance failure. However, not expected connections can function for more than 20 years |
| | | | Further prevent access to stairs, along with area stair can fall on | 2 -6 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 6 | 1 | Slight impact, safety aspect is reduced, but risk score is still a two |
| | | | Temporary support stairs | 2 - 6 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 3 | 3 | 9 | 1 | No impact risks as safety aspect is decreased but politcs aspect stays the same |
| **27** | **Roofs** | | | | | | | | | | | | | | | | |
| 27.21 | Roofs, load bearing, flat roofs | Concrete roof | Inspection inside dwellings | 6-20 | 2 | 4 | 3 | 5 | 1 | 1 | 1 | 2 | 4 | 5 | 10 | 3 | As the structure is probably behind architectural finishing this action would not lead to further improvement risk |
| | | | Closer investigation by removing some of the finishes | >20 | 1 | 4 | 3 | 5 | 1 | 1 | 1 | 2 | 4 | 5 | 5 | 1 | Uncertainty structure can be solved via this action |

| Building information | | | Step 3: Possible actions | Score | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Building part | Element | Proposal possible actions | time interval<br>t | Likelihood | Help consequence score<br>A | M | S | S | H | E | € | P | Consequenc | Risk score | Detection | Explanatory note |
| **28** | **Building frames, other primary elements** | | | | | | | | | | | | | | | | |
| 28.20 | Building frames, walls and floors, general (collection level) | Concrete walls apartments | Replacement corroded pipes | >20 | 1 | 5 | 4 | 5 | 4 | 1 | 2 | 5 | 5 | 5 | 5 | 3 | Some moisture stains near exposed part pipes, if remove no more leakages |
| | | | Further investigation to scale of penetration moisture/substances in structure | >20 | 1 | 5 | 4 | 5 | 4 | 1 | 2 | 5 | 5 | 5 | 5 | 1 | By further investiagtion there can be checked if there is indeed a danger of this moisture penetration to the structure |
| 28.21 | Building frames; walls and floors, walls and floor frames | Concrete lift tube on roof | Closer investigation to origin crack and severity | >20 | 1 | 3 | 2 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 1 | If outcome is that crack no problem sturctural safety and degradation, the chance can be decreased |
| | | | Temporary support walls structures lift shaft | 6-20 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 4 | 1 | Would reduce the consequences |
| | | | Replace by new lift housing | | 1 | 3 | 2 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 1 | Would reduce the chance of failure |
| 28.21 | Building frames; walls and floors, walls and floor frames | Concrete walls supporting balconies | Closer investigation to origin crack and how severe it is, suspision due to thermal load | >20 | 1 | 3 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 1 | If outcome is that crack no problem for sturctural safety and degradation the chance can be decreased |
| | | | Apply temporary support balcony | 0.5-2 | 4 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 8 | 1 | Consequences are decreased but still undesirable aspect |
| | | | Repair crack wall | 2 - 6 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 9 | 1 | Chance decreased but if do not know cause, phenomen can occur again within a few years |
| 28.11 | Building frames; columns and beam frames, colums and beam frames | Concrete column | Closer investigation to origin crack and the severity | >20 | 1 | 5 | 4 | 5 | 4 | 1 | 1 | 5 | 5 | 5 | 5 | 1 | Chance more accurately estimated via investigation |
| | | | Temporary support boiler room | 6-20 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 3 | 1 | 3 | 6 | 2 | Lots of consequences solved except for the maintanance aspect which still is about the column and beam |
| 28.21 | Building frames, walls and floors, wall and floor frames | Prefab concrete edge beam roof | Investigation to concrete material, in specific chlorides, plus notification residents to not use de-icing salts or chlorides to clean balconies | >20 | 1 | 2 | 3 | 3 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 1 | Chance is decreased as true condition clear |
| 28.21 | Building frames, walls and floors, walls and floor frames | Prefab concrete consoles | Investigation to concrete material, in specific chlorides, plus notification residents to not use de-icing salts or chlorides to clean balconies | >20 | 1 | 4 | 4 | 5 | 1 | 1 | 1 | 2 | 5 | 5 | 5 | 1 | By investigating the chloride problem, if not present structure in good state |
| | | | Temporary support consoles | 2 - 6 | 3 | 3 | 4 | 1 | 3 | 1 | 1 | 3 | 4 | 5 | 12 | 3 | Consequence for safety aspect reduced. However, other aspects scoring a four are still present making the risk undesirable |

| Building information | | | Step 3: Possible actions | Score | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Building part | Element | Proposal possible actions | time interval t | Likelihood | Help consequence score A | M | S | S | H | E | € | P | Consequenc | Risk score | Detection | Explanatory note |
| **34** | **Secondary elements to stairs** | | | | | | | | | | | | | | | | |
| 34.12 | Stair balustrades, handrails; balustrades, outer balustrades | Metal fencing filled with glass for balconies | Visually inpsect fencing on the balconies | >20 | 1 | 2 | 2 | 5 | 1 | 1 | 1 | 2 | 2 | 5 | 5 | 1 | Via this action the true state of the fencing can be closer examined, thereby checking if it can hold for more than 20 years |
| 34.12 | Stair balustrades, handrails; balustrades, outer balustrades | Timber fencing with safety galss connected via steel connections for galleries | Closer investigation to the fencing to examine the true state | 2 - 6 | 3 | 2 | 2 | 5 | 1 | 1 | 1 | 2 | 2 | 5 | 15 | 1 | Not expected that with closer approximation years of failure, the balustrade will live past six years |
| | | | Replace for new fencing | >20 | 1 | 2 | 2 | 5 | 1 | 1 | 1 | 2 | 2 | 5 | 5 | 1 | By replacing with new fencing the chance is decreased |
| | | | Close of acces near these fences also on the ground | 2 - 6 | 3 | 4 | 2 | 1 | 3 | 2 | 1 | 2 | 2 | 4 | 12 | 1 | Safety aspect consequence decreased but significant impact on accessibility building |
| **47** | **Roof finishes** | | | | | | | | | | | | | | | | |
| 47.11 | Roof finishes; finishes, flat roof finishes | Bitumeuous roof cladding | Replace bitemeous cladding | >20 | 1 | 1 | 2 | 4 | 1 | 1 | 1 | 2 | 3 | 4 | 4 | 1 | By replacing bitemous material the time interval for failure is increased |
| | | | With additional actions not expected adaptation chance | | | | | | | | | | | | | | |