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Contributing human and organizational factors for the failure of balconies in Maastricht

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Abstract

In 2003 five balconies of an apartment building in Maastricht, the Netherlands, collapsed, resulting in two fatalities. The building was just completed.

Forensic investigations showed that detailing of the reinforcement in the precast concrete slabs of the balconies was questionable. Several design changes hampered clear force flow through the structural elements. Inappropriate design fixes were made after discovery of some cracks that could not avoid failure of a lower concrete ridge, resulting in a progressive collapse of the 5 balconies.

Profound investigation of this case showed various human and organizational factors, that might have contributed to the failure. A complex process, with several design changes and many involved parties increased the probability of failure. Furthermore, insufficient communication, inadequate checking and inadequate follow up to warnings were present.

This paper will give insight in technical causes of the failure and of contributing human and organizational factors. These underlying factors will be systematically studied, by using a theoretical framework.

Keywords: forensic structural engineering, structural failure, human and organizational factors

1 Introduction

In 2003 a residential building called Patio Sevilla was delivered. In the evening of April 24 2003, five balconies of this apartment building collapsed, resulting in two fatalities. Several major investigations were started by insurance companies, police and criminal court.

To focus on learning points related to structural safety, it is worthwhile to investigate failure cases with a framework of set parameters.

Terwel set up a framework with possibly influencing factors for structural safety [1,2]. The framework is based on critical success factors derived from management literature and factors from safety science. In chapter 3 the framework will be explained.

This paper will first reveal technical causes of the failure, and subsequently analyse to what extent human and organizational factors in the building process (as listed in the theoretical framework) might have played a role in the failure case of the collapse of the balconies of Patio Sevilla in Maastricht. The focus is on the involved parties in the primary building process, like engineers and contractors.

The analysis of the technical, human and organizational factors of this case is based on: judgement of court [3-5], report expert witness [6], various other investigation reports [7,8], newspaper articles [9,10] and a book chapter on this incident [11].

2 Structure and technical cause of failure

The balcony structure was made out of prefabricated concrete. On two positions per balcony a hinged, thermally isolated connection between balcony slab and floor was designed. To provide a stable structure a steel column 100*100 was added as third support (see figure 1 for a top view of the standard balconies).

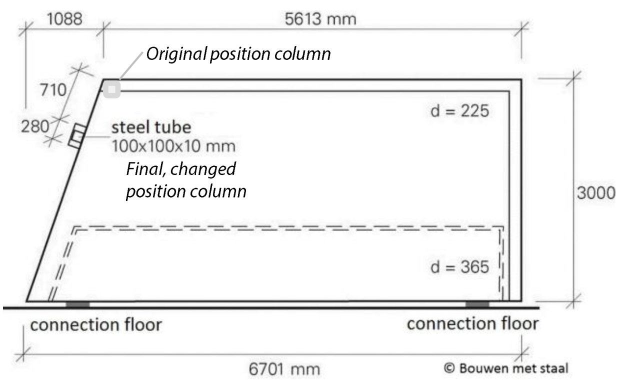

Figure 1: Top view of standard balcony with original and final position of column (adapted from [11,12] with permission). Mind that balcony slab level 1-5 is thicker than slab on ground level (figure 2).

During construction cracks were observed in the balcony of the ground floor. It appeared that this balcony was reduced in thickness, and that the position of the column was not aligned with the supporting wall, after a change in design. These changes were not incorporated in the design. Therefore, the ridge on the ground floor underneath the column was not supported by the foundation wall. This inadequacy was fixed by applying a steel support underneath the concrete ridge (see figure 2). The height difference between the top of the steel support and slab was filled with masonry. In this way, it was assumed that the essential column 100*100 was adequately supported.

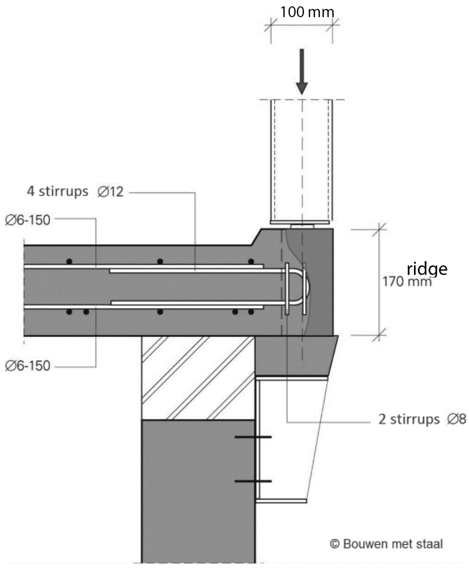

Figure 2: Detail of solution with steel support ground floor (adapted from [11,12] with permission)

Technical cause of failure

Various parts of the structure were subject to the forensic investigations. Experts agreed that detailing of the reinforcement of the ridge at ground floor was inadequate and not according to the codes. Furthermore, the bolted connection of the steel support on the foundation wall was not properly constructed and the connection between the steel support and the concrete ridge was suboptimal.

Finally, it was concluded by experts and court that that the combination of a bending moment and a concentrated force on the small ridge resulted in failure of the ridge on ground floor level. This resulted in a progressive collapse of the other balconies as the columns lacked support [3].

It should be noted that not all experts agreed on the technical cause of failure.

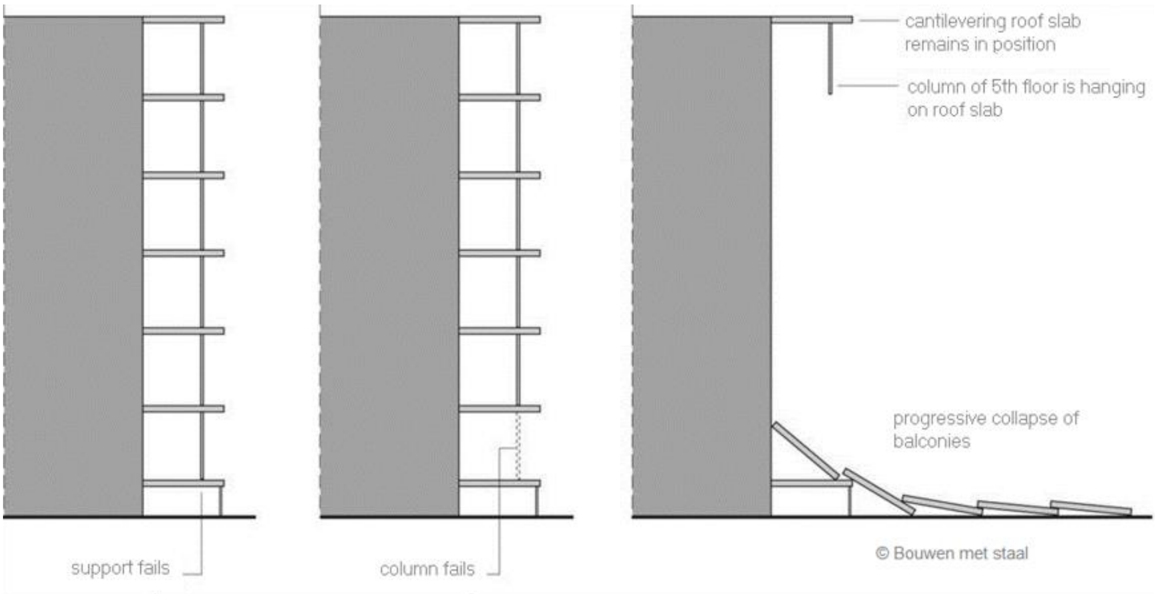

Figure 3: Side view of building: initial failure leading to progressive collapse (adapted from [11], with permission)

The company of the engineer of record had to pay a fine of €22.500. For the Netherlands this is a remarkable decision, because fatal structural incidents are rare, and therefore it rarely happens that an engineer of record is convicted. The court motivated this fine by stating that the main engineer didn't fulfil his checking and coordinating task adequately. The criminal cases against the main contractor and the detailed engineer of the balconies resulted in an acquittal, although their contribution to the failure was acknowledged.

3 Theoretical framework

3.1 General explanation

A full explanation of the framework is provided in[2]; the definitions in this paper were explained in [13].

The theoretical framework, used to classify various underlying factors, makes a distinction in three levels, see figure 4.

On macro level possible underlying external factors are listed. These factors are related to the situation in which a project exists and they are usually hard to influence by any of the project participants.

On meso level project factors, company factors and project characteristics are distinguished. Project factors are related to the collaboration of several parties within a project. Company factors take into account that every company brings his own features, like organization, culture, working conditions and habits in a project. Project characteristics are related to type and complexity of the project and the phase of a project.

On micro level possible underlying human factors are mentioned.

This paper will focus on meso (organizational) and micro level (human) factors. Furthermore, project characteristics are analyzed (not included in figure 4).

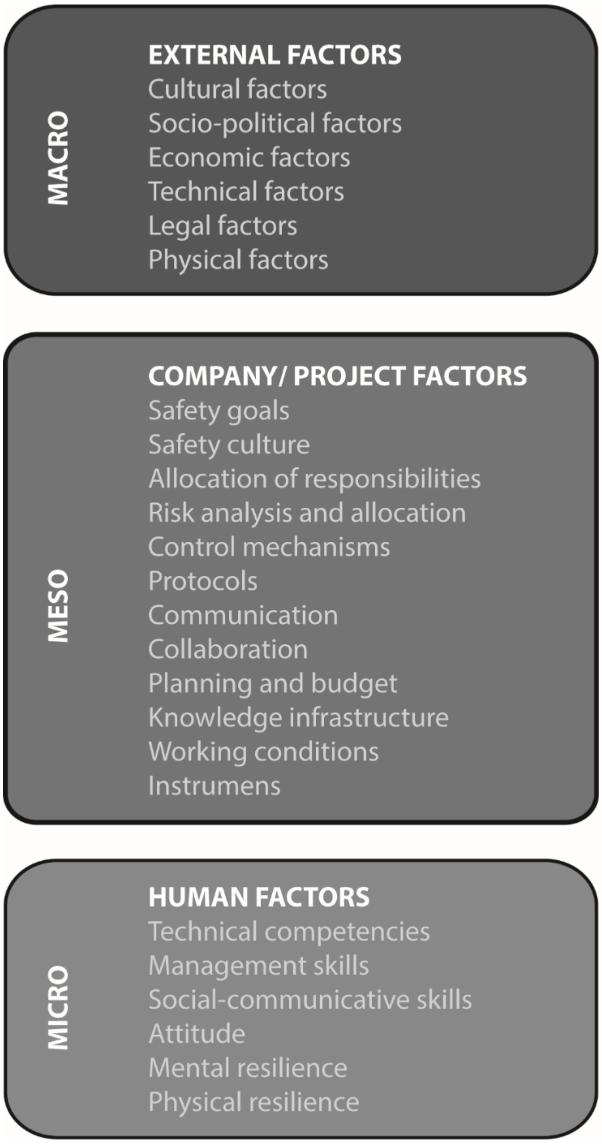

Figure 4: Theoretical framework (project characteristics not depicted, adapted from [2])

4 Analysis of human and organizational factors in the Maastricht case

4.1 Project characteristics

The majority of structural engineers will not regard this project as complex in nature. However, because of several design changes the *complexity of the structural solution* for the balcony support increased during the project.

First, the column was repositioned towards the boundaries of the slab, to be able to integrate the column with the finishing structure (aesthetical reason [11]). Figure 1 clarifies the original position and the final, changed position of the column. To be able to support the balcony a ridge on the side of the balcony slab is required (see also figure 1). Second, during preliminary design the engineer designed two moment resisting connections, between floor of apartment and balcony. During technical design phase, this was changed by a supplier into two hinged connections [6].

These changes resulted in a solution with less robustness, that was more vulnerable to failure.

Complexity of the process can be regarded as medium complex. First, the various design changes had an important impact on miscommunication and not fitting of parts.

Another aspect of *complexity of the process* is the number of parties involved.

For the design and construction of the balconies many parties were involved. The client decided to arrange a Design and Construct team, with various parties [3]. An international renown architect was responsible for the main design; he was supported by a Dutch architect [7].

For the structural design an engineer of record was responsible. A main contractor hired subcontractors for the balconies (with separate parties for reinforcement and thermally isolated connections) and the columns. This fragmentation enabled miscommunication in the process.

Related to the *phase of the project*, it can be stated that the root of problems was in the transition of phases. First, according to [6] it was not clear when the technical design phase was finished, resulting in a not fully coordinated set of drawings for architect and structural engineer. Second, the transition between detailed engineering and construction stage seemed to have played a role. During detailed engineering, it appeared that the work of various parties involved was not properly coordinated. During construction phase first warnings popped up (cracking, notification of probably not functioning ridge by contractor) but these warnings were not always adequately followed up.

4.2 Organizational factors

Safety goals and safety culture seem not to have been very well developed. When information was not available, sometimes assumptions were made, without adequate checking the other project partners. A positive exemption is the situation where the contractor warned the structural engineer after discovering cracks, by indicating that he had the feeling that the structure of the ridges was insufficient [3].

Unclear *allocation of responsibilities* was often mentioned in the report by the expert witness [6]. In the contract between engineer and client a standard allocation of responsibilities was listed. However, this didn't comply with the allocation of responsibilities in the technical specifications, and the applied allocation in the project was also different. Therefore, it was not fully clear who was responsible for design changes. Many parties were responsible for parts of the balcony structure, but no-one showed overall responsibility. It was for instance reported in the newspaper that the structural engineer would have stated that he was only responsible for the main load bearing structure (which was the building) and everything else was outside his scope [9]. However, in the legal procedure [4] the structural engineer was regarded as engineer of record, with the responsibility to determine the starting points for the balcony structure and to perform general checking of the main points of the structure and its detailing (as was written in the technical specifications).

Several subtasks were not adequately addressed. According to the technical specifications, the contractor was responsible for the engineering of the columns, but the structural engineer determined the size of these columns. The contractor designed footplates for these columns, which were not adequate. No calculations of these footplates could be found, and no proof of sharing the info of these footplates with the structural engineer was present in the files [6].

The studied files gave no proof of proper *risk management*. A risk analysis was not made for this project.

Insufficient *checking* was mentioned in this case several times as contributor to the failure. The client did not arrange adequate supervision [6]. The structural engineer did not properly check the integrity of all elements in the structure. He paid adequate attention to the thermally isolated connections, but not to the column-balcony connection [6]. Following the warning signal of cracks in the ridge, no proper analysis of the stresses in these ridges was performed, thus missing the chance to avoid the failure [3].

Related to *protocols*, it was observed that not all paperwork was correct. The contract with the contractor was only signed sometime after start of construction. A signed contract between structural engineer and client couldn't be found [6]. However, it is questionable if these issues would have avoided the failure.

Insufficient *communication and collaboration* seem to be at the root of this failure. First, the results of design changes were poorly communicated. During construction, drawings were used where the changed thickness of the balcony slab at ground floor was not implemented. For the steel support as fix for misalignment, the structural engineer used outdated information. This was corrected by the contractor, without communicating this with the structural engineer [3,6].

Furthermore, the structural engineer seems not to have shared information with the contractor regarding loads on steel columns and balcony slabs [6]. Therefore, the detailed engineer of the balcony slabs is insufficiently aware of the loads that would act on the ridges. The detailed engineer of the thermally isolated connections, makes his own calculation of loads (instead of using the loads by the structural engineer) and changes the support from moment resisting into hinged [6].

Moreover, the contractor fails to provide the structural engineer with detailed calculations and drawings regarding the connection of the columns with the balcony [6].

Finally, the contractor several times informed the structural engineer about cracks in the balconies of various appartments. However, there were also cracks in the ridge of the collapsed balconies, but these were not communicated with the structural engineer. The contractor decided, without communicating with the engineer, to apply similar measures as with the other ridges [6].

It is not clear if *planning and budget* were too tight. During the legal case financial problems of the structural engineer were reported [4]. It is not clear if these were a result of the incident. Time pressure was reported when a fix needed to be designed for the ridges that were not supported. When the problems were discovered by the contractor, the same day the structural engineer designed a solution and a few hours later the contractor had adjusted this solution and ordered the materials [6], II 3.9).

It is not to be expected that a more advanced *knowledge infrastructure* within a company, or in between the companies would have improved the result, as knowledge infrastructure is related to general knowledge of solutions, structural behavior etc. One indication of a failing knowledge infrastructure is that when the person from the contractor, that had initially warned for the cracks and the ridge structure, needed to be replaced (because of illness [10]), the new person not directly applied the same measures as the initial person had done. However, this would not have avoided the failure.

Furthermore, it appeared that within Dutch building industry there was no general agreement regarding the real behavior of the ridges and the strategy for second load paths with balcony structures. So, knowledge infrastructure on national level could still be improved [6].

There is no indication that *working conditions* played a role in this case.

If this project was elaborated in a 3D BIM environment (more advanced *instruments*), not fitting of parts would have been detected earlier. However, at the time of this project this was not common practice. Furthermore, as the structural engineer paid limited attention to the connections, it is questionable that he would have used more advanced 3D calculation software for the situation with the ridge, if this would have been available.

4.3 Human factors

The overall support system can be regarded as too vulnerable. It would have been more logical if the columns would have transferred their loads directly to the foundation, than that they first had to transfer the loads through a small ridge [6]. Apart from this, it could have been expected that a structural engineer would make a design with adequate detailing according to the codes [6]. These two issues might indicate a lack of technical skills by the engineer of record or the detailed engineer. However, if a skilled person doesn't take time to check the situation, technical skills might have been present but were not used. Furthermore, it was indicated that both engineer of record and detailed engineer worked with incomplete information. So, a lack of technical skills was indicated but not proven.

Although lack of communication and collaboration is mentioned on organizational level, based on the available information it is hard to conclude if individuals lacked *management* or *social communicative skills* or that they didn't use available skills. Furthermore, it is not clear if a lack of *mental resilience* played a role.

The case doesn't provide proof that a lack of physical resilience did add to the failure.

4.4 Essential human and organizational factors

Now, it will be analyzed what human and organizational factors were essential. Essential factors are that factors that if they would have been improved, the specific problem would not have occurred.

An incomplete allocation of responsibilities is regarded as the first essential factor. Although an initial allocation of responsibilities was present in the contract phase, during the actual design and building the allocation was not properly followed. Especially, the role of coordinating engineer who coordinated the various engineers involved was lacking.

A lack of checking is regarded as the second essential factor. If checking, especially by the engineer of record, would have been more comprehensive, also checking of connecting parts and disciplines, than it is believed that the failure would not have occurred.

Insufficient communication is regarded as the third essential factor, as this resulted in making choices based on incorrect information.

Other factors may have contributed. However, it can be doubted if these factors would have been on a higher level that the failure would not have happened.

5. Conclusion & Discussion

The technical cause of the progressive collapse of various balconies in 2003 in the Netherlands, can be attributed to inadequate detailing of a ridge of a prefabricate concrete slab at ground level. Essential human and organizational contributing factors where a lack of allocation of responsibilities, insufficient checking and communication.

As this analysis is based on available information from the legal case, and additional sources, there will be involved parties who have another opinion about the contributing technical, human and organizational factors. For instance, some parties suggested that construction errors were made, that triggered the failure.

However, without trying to analyze these kind of failure cases, it is hard to actually learn from failures. This case was a wake-up call for Dutch building industry, where various initiatives started to improve structural safety.

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