

ANALYSING SAFETY RISKS WHEN CONSTRUCTING OVER PUBLIC SPACES

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ABSTRACT: The safety issues at construction sites in the Netherlands have acquired a new dimension in recent years, largely because of a growing trend in the Randstad (western conurbation) to build on complex urban construction sites at dense and multi-functional locations. In The Hague several buildings have been built over the motorway "Utrechtse Baan", the main access route to the city. Traditionally, it was the municipal policy to close the road whenever heavy construction elements need to be erected. However, as there is no viable alternative route into the city, closing off the road and rerouting the traffic is not always an possible solution.; it leads to a barrage of protest. In this paper we present the findings of a study, which analysed this situation from various perspectives. These findings highlighted the crucial importance of placing safety on the agenda at the earliest possible stage in the project planning. National and local safety regulations also turned out to have a key role in this process. The level of risk involved in erecting heavy structural elements proved to be an unexplored area in the case of The Hague. The paper also uses the findings from the case study in The Hague to present the results of a quantitative analysis of the safety risks of construction operations above motorways.

Keywords – Construction sites, multi-functional urban locations, risk analyses, public safety.

1. INTRODUCTION

In most of the major cities in the Netherlands building projects are realised in which the use of urban space is intensified, leading to further integration of urban functions. These projects slot in neatly with the policy of the Dutch Ministry of Housing, Physical Planning, and the Environment (MVRM) to realize multi-functional urban locations in order to promote economic and social vitality in the cities. However, when these projects are being prepared, developed and implemented, complications sometimes arise, which are connected with safety guarantees on the one hand and minimum disruption to urban functions on the other. In the Municipality of The Hague major building projects are frequently realized above the main route to the city centre, the motorway Utrechtse Baan. During the construction stage, in which particular heavy structural elements were erected and assembled, this motorway was often closed to

traffic in order to avoid risks to third parties, people present at the infrastructure. But these motorway closures have met with a barrage of protests of the citizens. The Municipality of The Hague introduced constructional safety into the decision-making process for such projects at the earliest possible stage, in order to continue urban activities (such as traffic, everyday life, work and business). The reason hereof was that no extra costs, delays or illegal actions should occur.

These problems are addressed in a detailed case study of multifunctional construction sites by Meijer and Visscher (2001), consisting of the following points:

- an analysis of the legal means at the municipality's disposal for the management of safety during building projects;
- an evaluation of the development and building processes for several buildings;
- background profiles of safety issues and building techniques on the basis of literature searches and interviews with experts;
- an expert session where a protocol was discussed for managing the safety issues of such projects;
- a recommendatory report (based on the protocol) for the municipality on how to manage safety issues more effectively in the future.

An important lesson was learned from this project. The building operations that are carried out in the construction phase of such projects are a hazard for drivers, passengers and other people present on road beneath (Meijer & Visscher, 2001; Suddle, 2001A). However, there are no explicit legal norms for the safety of third parties during construction activities, especially not for such projects (Suddle, 2001B). Nor could we find a workable methodology for assessing the risks of third parties due to falling elements in such conditions. The quantifications of risks due to falling elements is observed in detail in the thesis of Suddle (2001A). For this to happen, an analysis of human and financial risks required a safety systems for the construction stage of such projects. It should be stressed that risks to human beings should be financially feasible and comply with the risk acceptance criteria at individual and social level (Vrouwenvelder *et al.*, 2001; Vrijling & Vrouwenvelder, 1997). These observations formed the departure points for a fundamental investigation of the safety issues surrounding multi-functional urban locations (Suddle, 2001A).

As may be clear from the above: the results presented in this paper are based on a case study into the problems of safety and traffic of the Utrechtse baan in The Hague, commissioned by the Municipality of the Hague (Meijer and Visscher, 2001) and the followed PhD thesis of Suddle (2004). The case study explored the various issues that play a role at construction sites at multifunctional urban locations. That project led to the conclusion that there was little known of the actual risks of falling elements. This formed the starting point for the thesis of Suddle.

In Section 2 we expatiate on the case study of The Hague on the basis of the protocol that was developed for the municipality. In Section 3 we explain the methodology of risk assessment and comparison of the safety measures and present the main findings of the specific study on the safety risks of these projects. The conclusions are set out in Section 4.

2. PROTOCOL FOR MANAGING CONSTRUCTIONAL SAFETY AND FUNCTIONAL DISRUPTION

The case studies and the interviews with representatives of the Municipality of The Hague, clients and contractors, and external experts formed the basis for a protocol that was specifically drawn up for safety-management in building projects at multi-functional locations (Meijer & Visscher, 2001). This protocol sets out the preconditions and the start scenario, the stage of the development and implementation process, and the responsibilities of the various parties. Later on, this protocol was used to manage the safety aspects of subsequent projects more effectively.

2.1 The Start Scenario

Considering the research we may conclude that, no heavy structural elements should be erected above roads when these are still in use. Not enough is known about the risks of large structural elements or about the extent to which certain reduced risks could be made acceptable by safety precautions. As there are no universal cut-and-dried criteria for 'acceptable' risks to third parties in construction operations, measures to limit the risks of hoisting and falling cannot be assessed for public acceptability. So, people have to resort to the 'zero' tolerance, i.e. the total elimination of risks. This means that before (high) building operations can go ahead, the possibilities for cordoning the site and, if relevant, for diverting the traffic will have to be explored. If a major traffic artery crosses the site and there is no prospect of a long-term diversion, the client will have to be persuaded to adopt a building method that involves the fewest closures.



Fig. 1. Construction of the Malie Tower in The Hague

2.2 Regulatory Framework

National and local regulations provide the Municipality of The Hague with a broad basis for setting conditions designed to guarantee maximum safety and minimum disruption for local residents and third parties, while demolition and construction projects are in progress. There is legislation at national level, (*Bouwprocesbesluit Arbeidsomstandighedenwet*) which addresses health and safety on site (Stichting Bouwresearch, 1996). A Health and Safety Plan is mandatory for projects above a certain size or which carry specific safety risks. This plan must ensure that site workers are adequately protected. The Municipal Building Decree (*Gemeentelijke Bouwverordening*) provides the municipality with an instrument, through which the safety of third parties during building projects can be monitored: the municipality may require the client to submit a construction or demolition safety plan which sets out beforehand how certain safety risks and issues will be avoided. Any road or lane closures and diversions that are considered necessary can then be organized via the roadworks licence (issued by the Police). Besides the regulatory framework, it is important to settle the question of accountability if – despite the safety precautions – in case of unforeseen circumstances. In many cases the contractor/building firm will be held liable for any accidents. However, under the Dutch Civil Code, the municipality may also be called to account, provided the situations in question constitute a direct threat to life.

2.3 Site Designation

The decision to build at a multi-functional urban location is often the result of an interchange between the municipality, which designates potential construction sites in a master plan, and the interest of a developer to build at a specific location, which is often fraught with constraints. The findings from the case studies of the Utrechtse Baan show that the municipality became increasingly aware of the fact that constructional safety needs to be placed on the agenda at the earliest possible stage during the development process of such a project. After all, the impact of a building project on the surroundings could play a direct role in the designation of sites.

When a master plan is being drawn up and sites are being designated a preliminary analysis of the safety risks could be performed straight away. This would cover, amongst others participants the potential for laying foundations and the scope for setting up site cordons and traffic diversions (if applicable). The potential for laying foundations can also have constructional repercussions. In order to ascertain the potential for the foundations a detailed inventory will need to be drawn up of the current functions of the location (pipelines, tunnels, foundations of adjacent buildings) and of any claims that can be expected in the future (e.g. for tunnels). Attention should be paid to an alternative building method when sites that may need to be cordoned off (if limited in size) are first identified. Preparations should also be drafted for the delivery and removal of materials.

2.4 Traffic Implications

If the site crosses a major traffic artery, it is important to pinpoint possible diversionary routes and to decide on an acceptable number and the time of closures. Attention should also be paid to the proposed timescale for the project and any prior claims for closures in connection with other building projects.

2.5 Information to the Client

If a client or developer shows interest in a site, he should be informed of the implications of a development project. This information provides the developer with a clear picture of the space and the scope for design freedom offered by the site. By this the developer is aware of the design information and limits. For example, the spatial placements of the foundations and their restrictions can be presented, and the closure of the road may be observed. If the number of road closures needs to be limited, the developer can be informed immediately that he will have to deploy specific building methods and bear any extra costs that these may

involve. Agreements can also be reached with the developer on the fines he may incur if unforeseen circumstances result in a deeper impact on the public road than was initially anticipated.

2.6 Design

The developer commissions a design. At a preliminary meeting or during the licensing procedure the municipality decides whether the plan meets the criteria for site safety and nuisance control. The traditional process of definitive design – licence application – licence approval – contracting-out – development (construction, materialization, details, building method), in which the contractor plays no part until the licence application is approved, has very little to offer such projects. To arrive at a solution in which the building activities cause minimum disruption, it is essential to create an interaction between design – construction principle – materialization and building method. Therefore, the best solution is to involve the contractor at an early stage.

2.7 Construction Principles and Building Methods

It is the contractor's job to select a building method to realize the architectural and structural plans. The construction method and the layout of the site are determined by the spatial design, the construction principle, the materialization and the characteristics of the building site. The contractor will probably opt for a method which can realize the project as cheaply and as quickly as possible. His choice will be shaped by his own knowledge and experience.

The Municipal Building Control Authority should be abreast of the technical options for realizing building projects which seriously affect the underlying traffic routes. If it is familiar with the possible solutions, it can make well-argued, realistic demands on the developers. A specific analysis of the potential extra costs of alternative construction principles might tip the scales when the disadvantages of closing of a main traffic artery are being weighed against the effects on the building costs. Essentially, the developer should find a solution that is acceptable to the municipality at his own expense. However, the municipality is not in the position to set cast-iron conditions for the building methods. Developers must be apprised immediately of the costs (fines) they will incur if they deviate from the planned claim on public space (i.e. the number of road/lane closures).

The case studies on The Hague showed that the effects of specific construction principles and building methods chosen at an early stage on the surroundings did not become entirely clear until the building process was far advanced.

If potentially high levels of disruption are involved, the conditions for the size and layout of the site and the construction principle, materialization and building method need to be formulated at an early stage. These conditions should take the form of performance targets, so that the builder has sufficient scope to tackle the project as he sees fit.

These conditions might include: the ultimate dimensions of the cordoned building site; the delivery routes for building materials and equipment (including any restrictions); permanent safety-net constructions to catch relative small fragments of material and pieces of equipment; the maximum number of road closures that is permitted for building the platform and performing any later hoisting operations.

2.8 Implementation plan and safety plan

If the design principles are approved, an implementation plan and an accompanying safety plan need to be drafted. The municipality has set specific requirements for the safety plan, over and above the statutory requirements of the Working Conditions Act (*Arbeidsomstandigheden Wet*).

2.9 Roadworks licence

The potentially necessary closures, which are indicated in the safety plan, are discussed at the meeting for the roadworks licence. First, an assessment is performed on the basis of the criteria submitted by the municipality. Again, the implementation of this project needs to be cleared against any other projects. An indication will have to be provided of any areas of flexibility in the implementation plan.

2.10 Steering and supervision

Despite careful preparation and specific criteria, unforeseen circumstances can crop up at any time. There is no such thing as a universally applicable blueprint in the building sector. Unforeseen circumstances might arise through the characteristics of the location, the experience, wishes and potential of the participating parties, the choice of design and building method, convergence with other projects in the vicinity, or even the weather conditions during the scheduled implementation period. In short, no matter how good the timetable, improvisation will usually be needed at some time during the project. This was borne out by experience in the case studies.

2.11 Evaluation

Afterwards, the projects should be subjected to systematic and extensive evaluation. Which principles were applied? What information was given to the developer? How did the cooperation work out between the municipal departments? What unforeseen circumstances arose and which emergency steps had to be taken? The results of the evaluations should then be used to further refine the departure points for future projects.

3. RISK ANALYSIS

Given the case study described in section 2.0, the following subsection presents the methodology of risk assessment for third parties due to falling elements in multifunctional urban locations.

3.1 Qualitative Risk Analysis

In order to compare the relation between the human and financial risks with safety measures, such as closing off the road or to implement a protection canopy, a quantitative risk analysis is required. This relation in multifunctional urban locations has been analyzed in a specific research project (Suddle, 2001A) that was initialized on basis of the conclusions of the case study in The Hague. First, a qualitative risk analysis for the safety of third parties has been performed by FMEA-techniques (Failure Mode and Effect Analysis). This technique represents a complete view of hazards and consequences. In this study this technique is applied for the construction of a building over a motorway. Normally a FMEA consists of effects of failure like cost increase, time loss, loss of quality, environmental damage and loss of human life. Considering the aim of this study, risk regarding cost increase and loss of human life were taken into account. It appeared from the FMEA that safety of third parties during construction largely depends on falling elements. The falling objects may consist of bolts, screws, part of concrete (structures), parts of a scaffold, building parts, hammers, beams, or even construction workers.

3.2 Quantitative Risk Analysis

Hence, these falling elements may cause casualties among people present at the infrastructure and in some cases economical risks as well as. This observation was analyzed in more detail by a quantitative risk analysis using Bayesian Networks for a case (Suddle, 2001A). This case consists of a building of 10 stories that is built above a 2 by 2 lane motorway. The span and the linear direction of the building are respectively 20 meters and 50 meters. Two risks, loss of human life and economic loss, were

considered in these networks. In this regard, possible quantifiable parameters should be transformed into conditional probabilities, which were determined from both the classification aspects for safety of third parties during construction and the FMEA. These quantifiable aspects are the following:

- a) the position where the element falls (inside or outside the building);
- b) the situation below the building;
- c) (design) errors;
- d) the weight of the falling element;
- e) the actions of elements in relation with installation of elements;
- f) the collapse of the main structure of the building caused by falling elements;
- g) the probability of elements falling;
- h) the height from which the element is falling;
- i) fatalities and economic risk.

These aspects were taken into account in the quantitative risk analysis using Bayesian Networks. The probabilities of these aspects were determined by mathematical analysis, historical data, expert opinion or by engineering judgment. Same order magnitudes following from occurrence frequencies of hazardous events combined with different probabilities are used to determine the failure probability. The quantification of these probabilities can be found in the PhD thesis of Suddle (2004).

3.3 Results of Risk Analysis

The risk results are presented in table 1. Table 1 shows that the individual risk in building above roadways is lower than for building above railway tracks, and the $E(N_d)$ for building above roads is almost in the same order of magnitude (1.0) as building above railway tracks. Constructing a building above existing buildings is done with less risk.

Table 1. The individual risk of third parties and loss of human life of building above roads, railways and existing buildings (results adapted from thesis; Suddle (2001A)).

Building above:	Roadway	Railway	Existing Buildings
Individual risk IR	$3.0 \cdot 10^{-6}$	$1.8 \cdot 10^{-5}$	$3.0 \cdot 10^{-7}$
Expected loss of human life $E(N_d)$	1.65	1.33	$8.01 \cdot 10^{-4}$
Expected injuries	5.46	1.72	$8.10 \cdot 10^{-6}$

3.4 Sensitivity analyses

In order to formulate safety measures and to determine their effects, a sensitivity analysis is performed. The sensitivity analysis provides both transparency of relevant scenarios and uncertainties of the results of a risk analysis. The dominant aspects are: (1) the number of actions per project; (2) the position where the element falls; (3) the situation below the building; (4) the weight of the falling element. Furthermore, the risk zones of the building, the façades spanning the road, form an important nexus for the safety of third parties present on the infrastructure. Surprisingly, factors, such as (design) errors, and collapsing of the main structure of the building caused by falling elements turn out to be hardly of any influence on the overall risk. Another main influence parameter for the risk is the height of the building. The higher the building, the higher the risk of third parties due to falling elements. It also means that the higher the building, the more safety measures have to be taken. In contrast, the covering length of the building hardly influences the individual risk of the third parties during construction stage.

3.5 An Analysis of the Cost-Effectiveness of Safety Measures

A spectrum of safety measures are formulated and optimised for the construction stage in the case of realising buildings above roads. These measures can be divided into two main groups; *structural / functional* measures (such as applying different types of a protection canopy to prevent falling elements ever reaching the third parties), and *logistic measures* (such as closing off the road and rerouting the traffic). Total costs $C_{tot,i}$, consisting of investments C_0 , and their economical risk C_i (direct and indirect), combined with the expected loss of human lives $E(N_d)$, are determined per measure. The formulated measures, as named in table 2, are implemented in and verified by the quantitative risk

analysis. Logically, changes exert influence on the economical risk as well as the risk for loss of human lives. The result and the effect of the formulated safety measures are represented in table 2.

3.6 Decision making on safety measures

Considering the safety measures of table 2, the decision maker, has to consider the dilemma: "which measure has to be given preference?", the one of minimum investments, C_0 , the one that minimises the economical risk, C_i , or the one that decreases the loss of human lives $E(N_d)$. This results in the situation that the decision for a measure is not always based on minimising economical grounds, but that human risk should be taken into account as well. So, several options to implement measures can be considered.

If we focus for instance on safety measure 5 of table 2 - closing off the road and rerouting the traffic - or measure 4 - construction during the night - the expected number of loss of human lives $E(N_d)$, can be reduced to almost zero, this because a very small number of people are exposed to the effects of falling elements (small numbers of participants N_{pi}). Controversially, the total costs C_{tot} of such measures are relative high, because the investments in this measure are high as well.

Table 2. Safety measures; their investments and their risks ($\alpha = 0$).

Safety Measures	Investments C_0	Economical risk C_i	Total Costs C_{tot}	$E(N_d)$
0: Initial situation	-	€ 970,000	€ 970,000	1.65
1: Heavy concrete floor under building	€ 330,000	€ 770,000	€ 1,100,000	0.69
2: Heavy concrete floor in risk zone	€ 110,000	€ 770,000	€ 880,000	0.72
3: Light plate in risk zone	€ 79,000	€ 850,000	€ 923,000	0.77
4: Construction during the night	€ 1,800,000	€ 950,000	€ 2,750,000	0.01
5: Close off the road and reroute traffic	€ 4,100,000	€ 950,000	€ 5,050,000	0
6: Pump concrete	€ 100,000	€ 890,000	€ 990,000	1.63
7: COMBI 2&6	€ 210,000	€ 700,000	€ 910,000	0.67

However, these costs can be reduced in case of pumping concrete to floors of the building (measure 6), through which the number of actions of lifting, moving and elevating (structural) elements can be minimised.

Applying measure 6 means that the human risk in terms of number of loss of human lives $E(N_d)$ can also be reduced in comparison to the initial situation (case study, measure 0). In the initial situation, it is assumed that no support floor or a protection canopy is applied for interrupting falling elements and a hollow core slab floor is implemented as floor system for the building. Unfortunately, in comparison with the initial situation, the change in the human risk is not a substantial progression, the value for $E(N_d)$ was 1.65 and becomes 1.63. The main advantage of applying a protection canopy or a support floor under the building is that the risk predominantly caused by small (non-structural) elements, is eliminated. Besides, a protection canopy may also prevent a psychological (shock) effect of motorists.

4. CONCLUSIONS

The case study about the safety at the construction sites at the motorway Utrechtse Baan made clear that there was very little knowledge about the risks and the most cost effective measures. The evaluation of some construction projects, interviews with experts and an expert discussion meeting resulted in a protocol. This protocol contains many relevant constraints and decision moments to minimize and control safety risks and hinder for the users of the multi functional urban area. The erection of heavy structural elements occurred to be an important risk factor. Closing of the road seemed to be the only possible measure. The more detailed study afterwards into the actual risks and the cost effectiveness of available measures increased the insight in the problem. We now may conclude that closing off the road does not always provide most the cost-effective solution.

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