Safety of construction in intensive use of space

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Abstract

Lack of space leads to the design and construction of projects which make intensive and optimal use of the limited space. Buildings above roads, railways and buildings themselves are examples of intensive use of space projects. The construction processes of those buildings are in general extremely complicated. Safety is one of the critical issues. At the Department of Building Engineering & Structural Engineering of the Delft University of Technology, a research has recently been completed [1] about the safety for people present in the neighbourhood of these projects (such as users of infrastructure where above buildings are being built). This paper will give an overview of this research work.

1 Introduction

The combination of growing welfare and the awareness of spatial quality leads to a rising need of space. Intensifying of available space, by means of multiple land use, is an option to satisfy and fulfil this need. In The Netherlands several multiple and intensive use of space projects have already been realised. Examples of such projects are buildings situated over the motorway the "Utrechtse Baan" in The Hague. An important lesson from these projects is learned; while realising such complicated projects, controlling the safety issue is characteristic in the construction phase. In the last decade the focus is on controlling the safety in every complicated project. Association with the safety aspect is significant to ensure the safety for people present in the neighbourhood of these projects (such as users of infrastructure where above buildings are being built), especially in the construction phase.

In reported research project, carried out as a graduate study about safety aspects of the building process in case of intensive land use at the Department of Building Engineering of the Faculty of Civil Engineering and Geosciences at the Delft University of Technology, the safety is analysed for such people, called *third parties* in this study.

Figure 1: Buildings realised above a motorway ”The Utrechtse Baan” in The Hague, The Netherlands.

The major question in this research is: which aspects influence the safety of third parties in the construction phase and how can we ensure the safety of third parties in compliance with economic considerations. Moreover, the level of risk acceptance criteria, to be divided into criteria on an individual and on a social basis, may not be exceeded. To answer this question we have to analyse what safety means?

2 Safety

Safety is complementary with the level of risk. The common definition of risk (associated with a hazard) is a combination of the probability that hazard will occur and the (usually negative) consequences of that hazard [2,3]. The consequences can be expressed in material damage or in loss of human life.

The risk has to be checked for risk acceptance criteria. In more detail, the acceptance limits for a given disaster originate from three different angles [4]:

1. a comparison with other risks related to individual safety
2. societal aversion to big disasters, especially when many casualties are involved
3. economic considerations

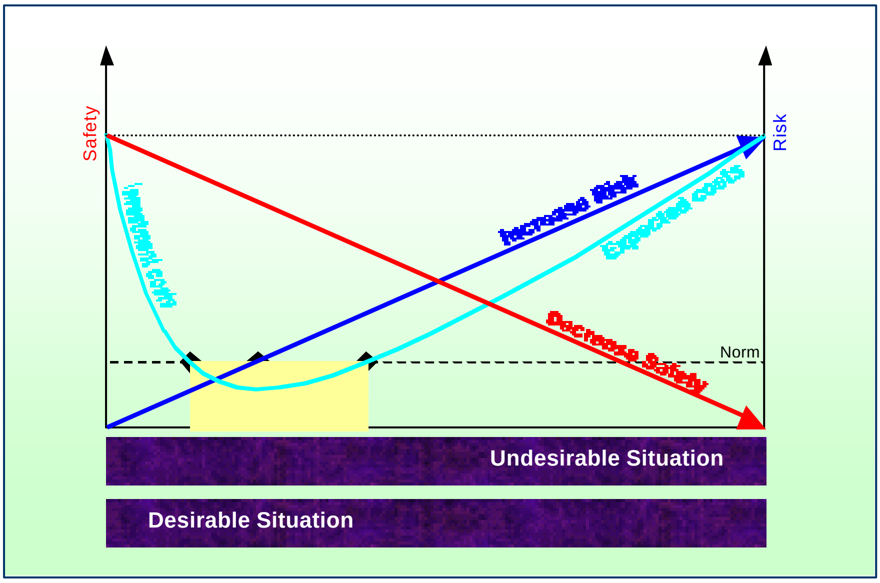


Figure 2: Model safety vs risk [1,5]

On the basis of law there are no explicit norms for the safety of third parties. Case studies of projects built over the motorway the Utrechtse Baan showed that specifying the safety requirements at an early stage decreases later problems with safety. It is essential to have clarity among those who are responsible for taking safety measures. Moreover it is necessary to have an adequate and effective organisation at the construction site. This can restrict potential danger during construction.

3 Safety aspects

To determine the safety and the risks for third parties in intensive land use projects, a classification has been made for aspects, which influence the safety of third parties in the construction phase. This classification consists of four main aspects (see figure 3).

Firstly, the *regulations* are a tool for the process during the project: the regulations control the safety during the construction phase. The regulations are also a basis for structure calculations, etc. The law is a part of this main aspect.

Furthermore, *external conditions* are a main part for the safety of third parties. Typically, the external conditions, imposed by the environment, are a part of the aspects that can hardly be influenced. Another main aspect for the safety of third parties is the *design*.

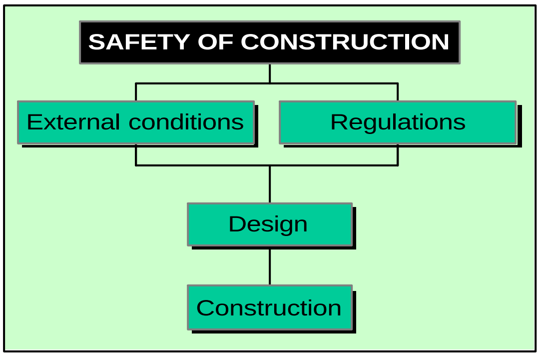


Figure 3: Classification for the safety for third parties in construction phase [1,5]

This aspect can be subdivided in dimensions of the building, architecture, structure, function of the building and the technology; these subaspects can be influenced and controlled in the project design phase.

Finally, the main aspect *construction* can be mentioned as a part for the safety of third parties. The subaspects of the design phase are difficult to changes in the construction phase. However, we have to realise that mistakes made in the design phase will always return in the construction phase. The construction (phase) is characterised by the many different parties that are involved, organisation between these parties, regulations and preventive measures, to deal with the safety of third parties during the construction.

4 Risk analysis

In this research the relation between the main safety aspects of construction in intensive use of space and their risk has been analysed. Therefore, risk analyses have been made for cases.

Firstly, 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 consequences like cost increase, time loss, loss of quality, environmental damage and loss of human life. Considering the aim of this study, cost increase and loss of human life are taken into account.

It appeared from [1] that the safety for third parties in the construction phase was mainly determined by the event of falling elements (structural and non-structural). The falling objects could be bolts, screws, part of concrete, parts of a scaffold, building parts, hammers, beams, or even construction workers. These falling elements form a hazard to the safety of third parties in terms of loss of their lives as well as in economical way.

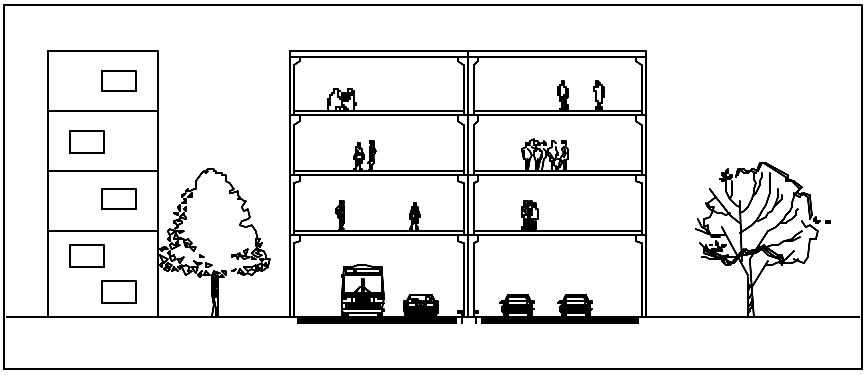


Figure 4: Case 2x2 lane motorway.

This observation is analysed in more detail by a quantitative risk analysis with Bayesian Networks for a case [1]. This case consists of a building of 10 stories that is built above a 2x2 lane motorway. The span and the linear direction of the building are respectively 20 meters and 50 meters. A Bayesian Network is a graphical tool that represents the relations between the events and aspects. Subsequently, these relations can be quantified in probabilities. Two consequences, loss of human life and economic loss, were considered in these networks.

The possible quantifiable aspects, following from the classification for the safety for third parties in construction (figure 3) and the FMEA, are:
- the situation below the building
- (design) errors
- the position where the element falls (inside or outside the building)
- the collapse of the main structure caused by falling elements
- the weight of the falling element
- the height from which the element is falling
- the probability of falling of elements

These aspects are taken into account in Bayesian Networks. Each aspect is represented as a *node* in these networks (see figure 5). Each node is divided in categories. The relations between the nodes are connected and expressed in conditional probabilities between the (categories of these) nodes. These probabilities are determined by historical data or by engineering judgement.

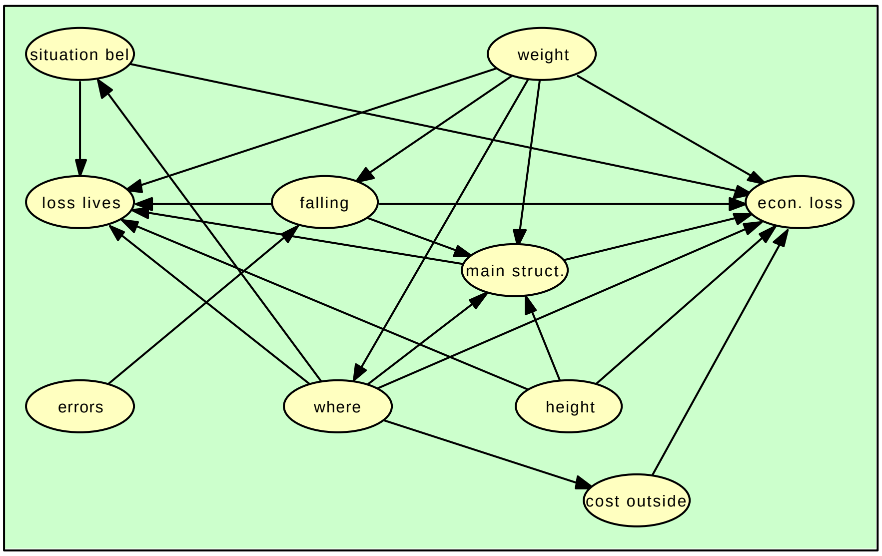


Figure 5: Bayesian Network for building over roads.

To determine the risks for third parties in the construction phase by building over railways, such network is made for a case of building over a railway. In this network a new node is added, which represents the situation at platform. Finally, the risks for third parties are also determined by making these networks for building over an existing building.

5 Results of the risk analysis

The results of the risk analyses according to [1] followed by the Bayesian Networks are the following:

Table 1: Results of the risk analysis.

Building over	Roadway	Rail track	Building	
Expected loss of human life	1,65	1,33	$8{,}01 \cdot 10^{-4}$	social
Expected injuries	5,46	1,72	$8{,}10 \cdot 10^{-6}$	social
Expected costs	€ 945.000	€ 1.035.750	€ 17.700	economical

The results show that building over road infrastructure is the unsafe way to build, followed by building over rail infrastructure. Building over existing buildings is with less risk. From financial point of view, building over rail infrastructure is not significantly different from building over road infrastructure. Again, building over existing buildings is with less risk.

When considering the acceptance limits for risk acceptance, to be divided into criteria on an individual and on a social basis [2,3,4], the results for building over rail and road infrastructure are slightly exceeded. Therefore, safety measures are analysed and optimised for building over road infrastructure.

6 Optimisation safety level for building above roadways

The safety measures are formulated and their effect on risks optimised. Firstly, a sensitivity analysis is performed to determine which aspects of the Bayesian Network are dominant. The dominant aspects are:

- the number of actions per project
- the position where the element falls
- situation below the building
- the weight of the falling element.

Furthermore, the risk zones of the building, the façades that are crossing the road, are an important nexus for the safety of third parties. Surprisingly, factors that turned out to be hardly of any influence are (design) errors and collapsing of the main structure caused by falling elements.

In consideration of the sensitivity analysis, safety measures are formulated for the optimisation. These can be divided into two groups:

- structural measures (measure 1,2,3,6,7 of table 1) such as applying different types of a support floor to prevent that falling elements reaches the third parties.
- logistic measures (measure 4,5 of table 1).

Per measure the total costs, consisting of investments and their economical risk, and the expected loss of human life $E(N_d)$ are determined by Bayesian Networks. The several measures, as named in table 1, are implemented in these Bayesian Networks. This is done by adding a node (e.g. a support floor) or to changing the conditional probabilities between these nodes.

Logically, changes exert influence on the economic risk as well as risk for loss of human life. The result and the effect of these changes is represented in table 1.

When applying the safety measure 5 - close off the road and reroute the traffic - or measure 4 - construction in night - the expected number of loss of human lives can be reduced to zero. Controversially, the total costs to realise this measure are very high. However, these costs are reduced low when pumped concrete is implemented for the floors. Additionally, human risk in terms of number of loss of human lives can also be reduced compared to the initial situation (case study, measure 0), where no concrete support floor is applied for interrupting falling elements and hollow core slab floor is implemented.

The reason for reduction of the risk is due to decreasing the number of actions. Nevertheless, in comparison with initial situation, the change in the human risk is not a substantial progression.

The advantage of applying a support floor under the building is that risk caused by small elements is eliminated. Besides, the psychological (shock) effect of third parties is taken away.

We can assume that the optimisation is also estimated for building over rail tracks, because the risk of building over roads is in the same order as building over rail tracks.

Table 1: Safety measures; their investments and their risks

Measures	Invest-ments	Economic risk	Total Costs	$E(N_d)$
0: Begin situation	-	€ 972.430	€ 972.430	1,65
1: Heavy concrete floor building	€ 329.860	€ 767.097	€ 1.096.957	0,69
2: Heavy concrete floor in risk zone	€ 111.450	€ 772.504	€ 883.954	0,72
3: Light plate in risk zone	€ 78.450	€ 846.242	€ 924.692	0,77
4: Construction in night	€ 1.750.000	€ 952.524	€ 2.702.524	0,01
5: Close off the road and reroute traffic	€ 4.093.750	€ 951.159	€ 5.044.909	0
6: pump concrete	€ 100.000	€ 892.741	€ 992.741	1,63
7: COMBI 2&6	€ 211.450	€ 695.431	€ 906.881	0,67

7 Decision making

Considering the safety measures, the decision maker, mostly the municipality, finds himself in a dilemma: to which measure has to be given preference, the one that minimises the economic risk or the one that decreases the loss of human lives.

Eventually, the decision comes down to that beyond minimising the normal definition of risk - probability multiplied by negative consequences - also the controversial psychological definition of risk - a lack of supposed control - is applied. This results in the situation that the decision for a measure is not always based on minimising economic backgrounds, but also the risk for humans is taken into account, the third parties in this case.

8 Practical Recommendations

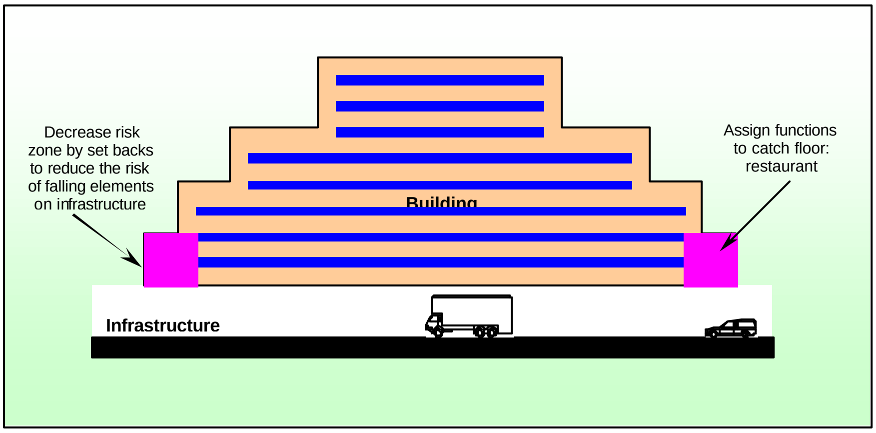
The combination of the formulated safety measures (see section 6) and the hesitation of decision makers (see section 7) can contribute to an instrument - existing recommendations - that can be applied in projects of multiple land use. In this research two types of recommendations are done:

- recommendations for the municipalities
- recommendations for the design engineers

Case studies of projects built over the Utrechtse Baan showed that municipalities formulated such extreme demands at the construction site that these were difficult to realise for the contractor. But there has to be a balance between those extreme and not realizable demands. Therefore, municipalities are advised to handle with the concept of risk acceptance instead of risk exclusion.

The recommendation to the designer - the architect or the structural engineer - is to integrate the formulated safety measures (see section 6) in the design of the building. This results in a synergetic effect. On the one hand the safety for third parties is guaranteed, on the other hand the designer can bring out a multifunctional design. He can achieve this goal by designing the periphery of the building or designing the shape of the building in such a way that the safety for third parties in the construction phase is safer. When façade and other structural elements are transported to a floor, the erecting of these elements can be done from inside the building. Because, when the transport and erecting of these elements is done from outside the building, the elements can fall outside the building. This can endanger the safety of third parties.

Figure 6: Improvement of the safety for third parties can be realised by set backs in the form of the building.



Using "set backs" in the form of the building can also be a potential contribution to the safety of third parties (see figure 6). The height of the risk zones can be decreased by applying these set backs. Several support floors can intercept falling elements from higher floors. By this, the elements are not intercepted in an early stage, but also the impulse of the falling element is strongly reduced. Configuration with the form of the building can be used in architectural impression of the building.

The formulated safety measures (see section 6) can also be integrated in the functional design of the building. If we consider the safety measure ”applying a support floor”, a function like a restaurant or a parking garage (like the Malie Tower see figure 1) can be integrated in the lower floors of the builing.

9 Future Research

This research presented the approach for the safety of third parties during the construction phase. Obviously, there are other types of safety conceivable, like the safety in the exploitation phase or the external safety and risks from the infrastructure towards the building (e.g. explosions and accidents).

At the Faculty of Civil Engineering and Geosciences of Delft University of Technology, a research programme in this field has been set up in order to fill the lack of knowledge of the possibilities and problems of multiple land use above infrastructure from a safety engineering point of view. The research is being done in close cooperation with Corsmit Consulting Engineers in Rijswijk and the Netherlands Organization for Applied Scientific Research in Delft (TNO) under the supervision of Prof. Jan Vamberský and Prof. Ton Vrouwenvelder.

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