Second International Conference World of Construction Project Management 2007
Prof. H.A.J. de Ridder, Prof. J.W.F. Wamelink (Eds.)


# QUALITATIVE ANALYSIS OF CONSTRUCTION SAFETY CONSIDERATIONS OF BUILDING ABOVE ROADS

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## 1 Introduction

A shortage of land across the Netherlands and in most countries of Western Europe has led to the development of design and construction techniques that make intensive and multiple use of the limited space possible. In the last decade, the space available above transport infrastructure - such as roads and railway tracks - and existing buildings have been used at a growing rate in city centres (see figure 1). These multi-functional urban locations brings with it several safety risks when buildings are being constructed above infrastructure and existing buildings. Activities during construction stage of such projects form a hazard for people present on infrastructure beneath - called *third parties* - , such as drivers, passengers and other people present on the road beneath (Meijer & Visscher, 2001, Suddle, 2001). These problems are addressed in a detailed case study of multifunctional construction sites by Meijer and Visscher (2001), focussing particularly on process management aspects resulting in safety protocols in multi-functional urban locations, in which the problems with safety aspects in such surroundings were addressed for the first time in organisational terms. The safety protocols thus remain qualitatively based arguments. In order to support adequate safety protocols, it is vital to find a workable methodology for assessing the risks quantitatively of third parties due to falling elements in such conditions. However, a quantitative risk analysis can be conducted after the qualitative aspects of construction safety in such locations are analyzed. This paper will review the qualitative considerations on which considerations construction safety in multi-functional areas is dependent. Some qualitative aspects are shown in the empirical M.Sc. research of Suddle (2001), which was a part of the Ph.D. research project (Suddle, 2004), at Delft University of Technology, in which the methodology of risk assessment of third parties in such conditions during the construction stage was developed and the quantifications of risks due to falling elements were observed in detail (Suddle, 2001).

The structure of this paper is as follows: firstly a central model is constructed to analyse the considerations governing construction safety (*section 2*). This is examined in more detail in the following paragraphs. Thus the four main considerations of this model are examined in more detail in *section 2* up to and including *section 6*, namely: the external constraints, the regulations, the design and the completion of the works. Finally, some conclusions are drawn in *section 7*.

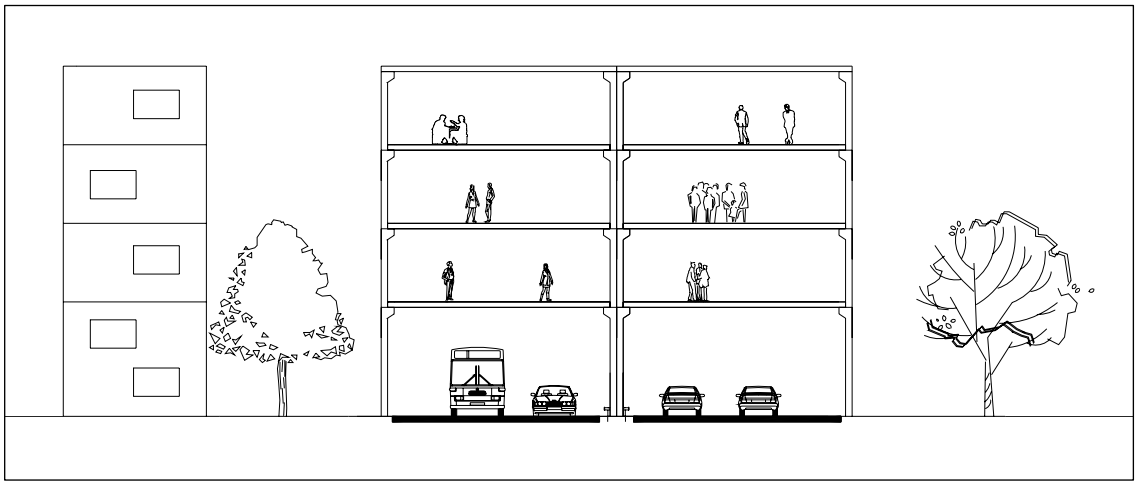

Figure 1: A schematic multi-functional area (Suddle, 2004).

## 2 Model approach to construction safety

To make an analysis of the considerations on which construction safety is dependent, it helps to approach the considerations in four levels (see figure 2). It should be noticed that *external constrains* / *conditions* and *regulations* determine the *design*, but also the design of the *completion of the works*. The design and completion of the works are in fact considerations that in turn need to be refined into subsidiary considerations. These considerations are controlled in different phases of the construction process. Other (f)actors are involved in each phase that control the considerations of "the design" and "the preparation of work". The so-called external constrains and regulations can hardly be controlled; these are in fact the preliminary details from which the project will then be fleshed out. The following sections will provide a more refined review of the above model.

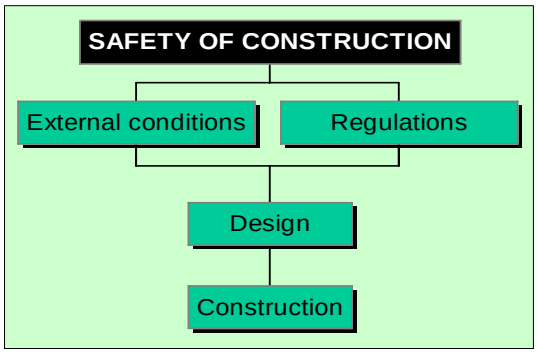


Figure 2: Primary level for construction safety.

## 3 External constrains

Firstly a distinction can be made between the location and the underlying situation. These are the main considerations on which safety is dependant. These considerations are also interrelated. After all, the situation may depend on the location where the building work is being completed and vice versa.

## 3.1 The location

The location means the place where the building work is being completed. There is a fundamental discrepancy between whether building work is being completed inside or outside a built-up area. Compare a dual carriageway with a residential area. There is a difference in how the construction process will be implemented. If something goes wrong during the completion of the works, the consequences (read: consequential losses) will be different in both cases. And therefore there is also a difference in safety for the construction process. But in turn the location in itself has completely different characteristics depending on whether it is inside or outside a built-up area. This consideration can also change as the process progresses.

## 3.2 The underlying situation

The underlying situation is also one of the considerations that are enormously important for safety during the construction process. A distinction can be made in relation to the underlying situation. The underlying situation means the situation above which the building work is being completed. Is it infrastructure? Is it a building? That is also the distinction that is made under the heading *underlying situation*. In this case the risk of failure and the consequences thereof vary, which means that this consideration depends on safety.

## 3.3 Type of the infrastructure and traffic type

If building work is completed above infrastructure, one type of multi-purpose area, then a distinction can be made between rail infrastructure and road infrastructure and probably also "navigable" infrastructure. More aspects on which safety is dependent are: number of lanes, length of vehicles, speed of traffic, intensity of traffic and density of traffic.

*Rail infrastructure*
Rail infrastructure can be subdivided into tram, metro and train. Building above rail infrastructure is very complicated. The risk of failure (probability of falling objects during the construction process) is probably more or less continuous compared with building above a highway, yet the consequential loss cannot be compared with building above a highway. After all, the damage upon closing a railway is economic, and is probably also socially different in nature compared with a road closure. This is also demonstrated by the fact that the structures and the functional layout of these are totally different.

*Road infrastructure*

Road infrastructure is typically a characteristic that is location-dependent. In the case of motorways and dual carriage-ways there is sometimes a 2 x 6-lane highway. In a residential area this is usually a small road, where it is sometimes difficult to drive through with a car. Of course the safety consideration whereby a large span has to be created is more significant than in the case of a small alley, if one were to build over that.

*Storage facility*
This type of infrastructure has been included in the series for the sake of completeness. A storage facility is understood to mean a space where goods are stored. During working hours there are significant movements of vehicles that drive in and out to store and/or remove goods. The expectation is that in the future, partly due to lack of space, it will be necessary to branch out into such insufficiently lucrative areas. Thus the door to the concept of multi-purpose urban areas is opened even wider. The safety consideration for such projects also largely depends on what is being stored. Thus for a storage facility for fireworks the safety consideration will (have to) be controlled extremely well.

*Type of traffic*
The next thing that needs to be determined is the traffic that moves within the underlying infrastructure. The type of traffic can be subdivided into general traffic or the traffic used to transport hazardous substances. The consequential loss is different for both, depending on the situation. Thus it can be viewed as being a safety consideration.

*Stratification of infrastructure*
In order to make a distinction between safety during the construction process, it is important to examine the *stratification of infrastructure*. Safety during the construction process for one layer of infrastructure is different than when building above two layers of traffic flow. Compare building above Zoetermeer station with building above Blaak station. In the case of Blaak station there are two intersecting traffic flows (metro and train). This means that when building buildings above several traffic flows, more and more stringent safety precautions must be applied than when building above one layer of infrastructure.

*Elevation of infrastructure*
After examining the stratification of the infrastructure, it is important to analyse the level at which the infrastructure is located. An analysis must also be made of the layer on which the building work will be completed. This consideration will be explained in the following section. It is also relevant here that construction safety changes depending on the location of the layer of infrastructure. Infrastructure that is located at a very great depth in relation to ground level has a limited impact on safety considerations whilst building, compared to infrastructure that is located at +2 in relation to ground level. The type (coated or uncoated) of the underlying infrastructure is also important for safety.

S*tructure*

The structure is also a consideration upon which safety depends. A distinction is made between the existing structure and one that is added in order to catch falling objects during construction. The structure can be divided into three forms: tube, U-profile section and slabs. Building a building above a tube is safer for road users than when building above infrastructure that is located on a slab. What it comes down to is that the consideration of (existing and the form of the existing) structure is also a consideration that relates to safety during a construction process.

*Additional structure*
Additional structure is understood to mean the presence of a structure that is not part of the structure of the infrastructure, for instance a cover that can be used as an overhead protective structure. Of course there will be a difference in terms of safety when such an additional structure is in place.

### 3.4 The Building

When building a building above an existing building the safety consideration is completely different than when building above infrastructure (Visscher et. al, 2006). When building above a building the underground routes for the rail and road infrastructure can be accessed. However, some other significance should be attached to this. In the case of buildings it is important to first look at the existing building. The following considerations for the existing building must be subjected to an accurate assessment: dimensions of the building, number of storeys, elevation, existing structure, over which construction work will be carried out and the number of people located in that building. These considerations also fall under the main consideration *External constraints* and are similar to the considerations relating to infrastructure. A flow of people can be viewed as being a group of elements that move at a particular speed, intensity, density and direction. The safety of these people demands the highest priority during the implementation phase, because if a falling object did hit one of these people (third-parties), then the personal injury will be greater than the economic damage. This is what we want to avoid. This means that when building buildings above buildings the safety consideration has a more direct relationship with people than when building buildings above infrastructure.

## 4. Regulations

The most important regulations are evident from the literature, see e.g. Meijer en Visscher (2001). At national level the *Working Conditions Legislation* is relevant (Construction Process Decree on Working Conditions). In the first instance, this focuses on safety on the construction site. The *municipal building regulations* represent the basis for controlling the safety of third-parties as a result of the implementation of the construction projects. Pursuant to these regulations, a construction or demolition safety plan may be required from the client. Furthermore closures of the public highway and diversions are governed by means of the

public works permit. The *construction safety handbook* is used as a guideline for municipal good practice governing construction safety. In order to control the potentially detrimental effects on the direct surrounding area during the completion of large construction projects, the municipal *Excavated Building Site Memo* is also important.

## 5. The Disign

The design is typically a main consideration that can be managed throughout the entire process. This means that controlling the consideration of safety needs to be determined during the design phase. The design is primarily to be controlled based on the following five subsidiary considerations: architecture, geometry, function, structure and technology.

### 5.1 Regulations

When a start is made on a design, in principle the regulations come under consideration. The regulations represent an engineer's first resource. Dutch regulations are included in the TGB and the NEN standards. Regulations represent the basic tools for a designer. This means that they cannot be managed and so we will not examine them. Nevertheless, they serve as a basis for controlling the consideration of safety. Moreover, the legal frameworks apply that are set out in section 4.

### 5.2 The architecture

The architecture of a building is the appearance designed by the architect, who is already involved at the preliminary stage of the project. The architecture, greatly dependent on the dimensions and the function of the building, is determined at the design phase of the overall project. In some cases the form of the building is already determined before the design is completed. In this context architecture is understood to mean the particular form of the building. The form of the building is an important consideration upon which safety depends.

### 5.3 Geometry of the building

The geometry of a building is understood to mean the shape of a building. This is highly dependent on the architecture of the chosen building. These are basic characteristics of a building that will take shape during the preliminary phase of design. The geometric characteristics of a building can be broken down into: the selected grid plan, the dimensions of the building and the lowest building point in relation to the underlying infrastructure/building.

*The selected grid plan*
The selected grid plan is highly location-dependent. If the building is being built above a cycle track, then the span is just a few metres and it does not matter where the columns are to

be installed. If the building is being built above a railway track, then it is critical to modify the grid plan according to the areas that are free. In the case of the latter the span will be larger.

*The dimensions of the building*
These three values are illustrated in the figure below.
The dimensions of the building also fall under the heading geometry. The dimensions of the building can be broken down into: Width of the span *(W)*, the length of the arch *(L)* and the height of the top of the building above ground level *(H)*. The consideration of safety whilst building is always different if these three values are varied. For a high-rise building a falling object will hit the ground harder than in the case of a low building. That means that the consequential loss will be greater. This in turn has an effect on risk and therefore also on safety.

*The lowest building point in relation to the underlying infrastructure/building*
The lowest building point in relation to the underlying infrastructure/building is also an important consideration on which construction safety depends. Indeed by adding the height of the lowest storey designated by *ΔH*, an additional drop height is created, thereby also increasing the impact of any falling object. Figure 3 provides a clear picture of this.

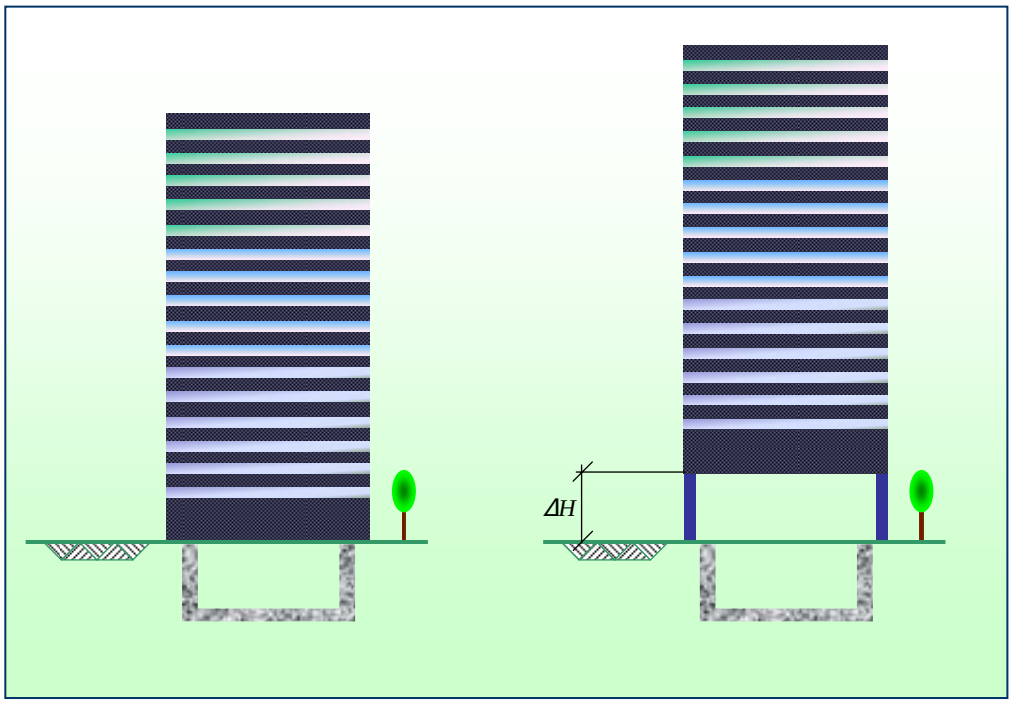

Figure 3: The lowest layer is also a variable for construction safety in multi-functional areas (Suddle, 2001).

## 5.4 Function of the building

The function of a building is also a consideration on which construction safety depends. If a football stadium is being built above infrastructure, then the requirements of noise pollution and safety are different than when building a skyscraper above this infrastructure. When building a factory these requirements will be different again. For the surrounding area too the consequences are different for different types of projects. This is connected with the function of the new building to be built. The following distinction can be made: residential function, work function and recreation.

## 5.5 The structure of the building

A very important manageable factor is the structural composition of the building. In terms of structural elements a distinction can be made between the following considerations: main bearing structure of the building, the stability system, fitting out and finishing work, materials used, floor construction and the foundation. These considerations are completely in the hands of designers/engineers. When selecting one of the considerations the overall concept changes, which means that the probability of errors in terms of the selection of these considerations increases. The choice of the above considerations has implications on construction safety.

*Bearing structure and the stability system of the building*
Before a building is designed, a number of alternatives will be generated. These concern the main supporting structure and the stability system. If an external stability is selected for the building, then construction elements will be visible on the facade (Malietoren). If stability is derived from the internal structure, there will be no construction elements in the external facade. This means that installing such elements can determine the probability of such elements falling. It can be concluded from this that the stability system of the building is a variable for safety during construction. Partly depending on the stability system this kind of rationale can be constructed for the main supporting structure.

*Materials used*
The materials selected for the construction elements of the building represent an important parameter for construction safety. It has already been demonstrated that the consequence depends on the impact, and this in turn will depend on the mass and the speed of the falling object. This means that lightweight and heavy materials are expected to cause little and much damage, respectively. Compare concrete elements with steel elements. Concrete elements are more solid than steel elements for absorbing compressive forces. As a result heavy elements will cause more damage than lightweight elements. The choice of materials is completely manageable.

*Fitting out and finishing work*
The choice of the fitting out and finishing work is also a consideration on which construction safety depends. There is a substantial difference between laying bricks and installing prefabricated panels for finishing work; the probability of a masonry brick falling is expected to be greater than when installing panels, which possibly span four storeys at once. Now, not

only the probability of something falling is different: the consequence is also different for each choice.

*Floor construction*
The floor construction is also part of the building. Fitting the floor construction is also a construction safety consideration. There is a significant difference between using a steel slab concrete floor, in which the concrete is pumped up from below, and using concrete hollow-core slabs, that need to be hoisted up. As a result, the (fitting of the) floor construction affects both the probability and the impact of something falling. It can be concluded from this that this consideration affects safety during construction.

*Foundation*
It is evident from the literature study that the choice of foundation has important logistical implications for the completion of the works. The Equinox building has its foundations on the Utrechtse Baan. Consequently, construction safety is different than for other buildings that have separate foundations. But it is also important what the nature of the foundations is: if piles are driven alongside the existing infrastructure this can result in damaging effects on the surrounding area, whereas drilling piles into the ground normally causes hardly any disturbance.

### 5.6 Technology

Technology is the preparatory work for the completed design. This includes determining the methods in order to complete the physical design. In relation to this main consideration on which construction safety depends, a distinction can be made between six secondary considerations, namely: preparation (preparatory work), implementation methods, calculation, detailed breakdown, preparation (getting work sites ready for construction) and dimensioning. Some of the above secondary considerations, however, would not normally be found under the heading *technology,* such as calculation. Nevertheless, they are categorised under this, because the probability of human errors is greatest when defining the calculation for the structure, the completion of the works and the preparatory work. In other words, the greatest probability of error is in relation to the above secondary considerations. Some uncertainty concerning the concept of safety has already been introduced. The secondary considerations cannot be separated from one another. The methods, either calculation methods or implementation methods, determine how to build or what to build with, which means that this is all related to the concept of construction safety.

## 6 The completion of the works

It is evident from the previous paragraphs that the considerations on which safety depend can be mainly controlled during the design phase of a project. Nevertheless things do need to be ironed out in terms of considerations that surface during the implementation phase of the project. This section will examine these considerations. The considerations for the

completion of the works relating to the concept of safety are subdivided into five subsidiary considerations, namely: regulations, interested parties, organisation, management considerations and preventive measures.

## 6.1 Regulations

The regulations which have been examined above in section 4 apply during the implementation phase. This means that all parties that are involved in the project (must) work in accordance with these regulations. The regulations, that are organisational in nature, are Working Conditions Legislation (Construction Process Decree on Working Conditions), municipal building regulations, construction safety handbook and excavated building site memo. The Uniform Administrative Conditions (UAC) are also relevant during this phase. The Uniform Administrative Conditions provide an insight into the legal relationship between the client and the contractor.

## 6.2 Interested parties

The interested parties can influence the consideration of safety significantly, since each interested party has its own impact on the overall project. There are a number of parties in the implementation phase that have a direct say on the consideration of safety. These can be divided into internal and external interested parties. It cannot be said exactly whether they increase or reduce safety, as this is situation-dependent. The *internal interested parties* are usually those that are actively involved in the construction process. The list of participants is as follows: client, contractor(s), sub-contractor(s), site supervisor(s) and suppliers. The *external interested parties* are usually those that are on the sidelines of the project. They do not have any direct impact on the completion of the construction process. They can evaluate the process - and even stop some things - from the perspective of on the one hand third-parties, and on the other hand interested parties and stakeholders. The list of participants is as follows: the local council, Working Conditions Service, the inspectorate, local residents, third-parties.

## 6.3 Organisation

The organisational structure adopted for the work is also a variable for the consideration of safety during the completion of the works. One can imagine that the work is carried out by two contractors, each with its own specialisation. The one finds implementation method A much better, the other finds implementation method B much better. This results in a difference of opinion. Secondly, an implementation method involving large risks may be opted for. This means that there is sufficient say about controlling safety by the organisation within which the work is being completed. Classifying organisational structure may also include the degree of participation and say in the overall project. One participating party perhaps has more of a grip on the process than another party. As a result, it will probably make incorrect decisions about safety.

## 6.4 Management considerations

The management considerations can be divided into errors and other management considerations. Within this context, management considerations are described as errors that are prevented during the implementation phase. Now it is not the case that the errors that are made during the design phase no longer occur during the implementation phase. More importantly still: the errors during the design phase are not going to impose their (detrimental) effects until during the implementation phase. The implementation phase involves many actors that at least differ from one another in terms of their nature. Take, for example, a contractor; it has numerous in-house people, varying from bricklayers to project managers and from steel benders to building supervisors. However, all of these people have one consideration in common: *they all make errors* (completion errors, wrong technology, intentional or unintentional errors). The other management considerations are considerations that can be very well prevented and/or controlled during and before the implementation phase. The following distinction can be made: construction site logistics, methods of implementation, deployment of materials, accidents and time related.

## 6.5 Preventive measures

Preventive measures are the safety measures that a participating party can take, in order to guarantee the safety of third-parties. Thus the local council can notify local residents about the fact that a project is in progress. A better (mandatory) measure is that the local council shuts off the road where the project is in progress.

# 7. Conclusions

This paper endeavoured to paint a picture of the considerations on which construction safety depend in relation to construction work in multi-purpose areas. This model is based on the most important chronological classification of the project on the one hand, and on the other hand the classification is based on the manageability of the consideration of safety. In most multi-functional projects safety is dependent of the following considerations: the regulations, the external constraints, the design and the completion of the works. These considerations appear to influence safety during construction. However, the more progress that is made in the project, the less of a grip one has on the consideration of safety during construction. The regulations are a manual; these serve amongst other things to control the consideration of safety during construction. But they also serve as a foundation for the structural calculations, etc. during the design stage. The external constraints typically articulate a consideration that cannot or can rarely be changed. These conditions are imposed by the environment. During the design virtually all considerations are manageable, such as the dimensions of the building, its architecture, its structure, function and technology. When it comes to the implementation

phase of the project, the considerations that have been designated during the design phase are difficult to change. The errors that are made during the design phase come to light during the implementation phase. As a result the consideration of safety is compromised. It should be noted that a quantitative risk analysis can be made on the base of these analysed qualitative aspects of construction safety parameters in multi-functional areas.

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