Physical Safety aspects in Metropolitan Habitats above Infrastructure

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Summary

Buildings above roads and railways are examples of multiple use of space. Safety is one of the critical issues for such projects. Moreover, at some places in The Netherlands, hazardous materials are transported on the infrastructure. This paper will give an overview of physical safety measures for people in metropolitan habitats above infrastructure projects, which can be compared with and considered as multiple use of space projects. In this paper, safety measures are presented for the building above infrastructure, when considering main scenarios on infrastructure. The accidents on infrastructure can be grouped into four dominant classes; traffic accidents (mechanical load on the structure of the building), fires, leaks of toxic substances, and explosions. Finally, the possibilities of transport of hazardous materials and the urban development will be discussed.

Key words: safety; multiple use of space; safety measures; transport of hazardous materials.

1. Introduction

Lack of space leads to the design and construction of projects which make intensive and multiple use of the limited space. Buildings / Metropolitan Habitats above infrastructure, such as roads and railways, are examples of such projects. Usually, a large number of people and several multiple risk dimensions are involved. Due to the complexity and interrelationships, a small accident, like a fire in the building or the infrastructure, can easily lead to a big disaster. Moreover, several places are characterised by exceeding the acceptability and tolerability criterion of safety, due to transport of hazardous materials [1]. Remarkably, these areas where transport routes of hazardous materials take place are exactly the areas for which the Fifth National Policy Document on Spatial Planning of The Netherlands desires intensification, combination and transformation. Furthermore, the transport of hazardous materials has continually increased over many years. Therefore, safety is one of the critical issues in such projects for the construction phase as well as for the exploitation phase [2]. This paper will give an overview of possibilities of how to deal with the increasing demand of space and the increasing transport of hazardous materials.

2. Physical Safety in Multiple Use of Space

2.1 The assessment and optimisation of Physical Safety in Multiple Use of Space

Probabilistic risk analyses can be undertaken to assess the safety level and to examine the required safety measures that are needed to realise these projects. When doing this risk analysis, the results have to be checked against the risk acceptance criteria. If the results do not comply with these risk acceptance criteria, extra measures can be taken to reach a certain level of safety. However, these measures have to be economically viable. The risk analysis should look at the construction stage and when the building is in use, for four different situations (figure 1) [2]:

- [1] External safety and risks from the building in relation to the infrastructure beneath (e.g. falling elements and fire);
- [2] External safety and risks from the infrastructure towards the building (e.g. release of toxic gasses, fire, explosions and accidents);
- [3] Internal safety and risks from the constructions enclosing the infrastructure (e.g. explosions, fire, explosions and accidents);
- [4] External safety and risks from the infrastructure towards the vicinity (e.g. release of toxic gasses, fire, explosions and accidents);

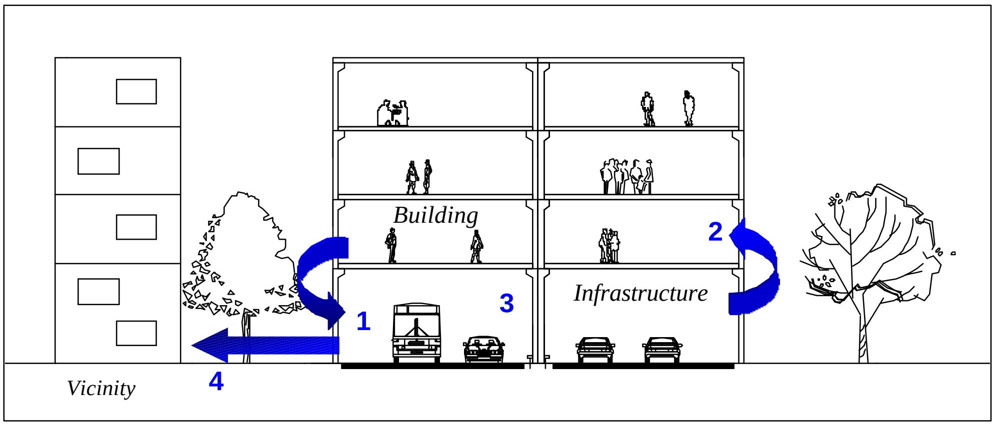

Figure 1: The four risk interactions in multiple use of space projects.

In order to determine the effect of safety measures on both human and economical risks, one should integrate and verify these measures by this risk analysis. In general, these measures are drawn up to reach a certain level of safety. These measures, which are normally part of the safety chain, can be integrated in the architectural and functional design of the building (if possible), while normal safety measures are only a cost-raising factor. From a decision point of view, it is a necessary strategy to balance costs and benefits of such measures and their contribution to physical safety. Besides, when a risk analysis is performed, it is important to realise that decision making about risks is very complex and not only technical aspects but also economical, environmental, comfort related, political, psychological and societal acceptance play all an important role, as discussed by [3].

2.2 Physical Safety in the Construction Stage

In order to asses the physical safety in the construction stage, one should focus on people present on infrastructure beneath - called *third parties* - , such as drivers and passengers. It appeared from the FMEA (Failure Mode and Effect Analysis), presented in the thesis of [4] that the safety of third parties during construction largely depends on *falling elements*. The falling objects can be bolts, screws, part of concrete (structures), parts of a scaffold, building parts, hammers, beams, façade elements or even construction workers. Hence, these falling elements may cause casualties among people present at the infrastructure and in some cases economical risks as well.

2.3 Physical Safety in the Exploitation Stage

It appeared from the FMEA that the risk for people, either in the building above the infrastructure or at the infrastructure or in the vicinity during the exploitation stage largely depends on the hazards taking place on *the infrastructure* or the hazards taking place in *the building*. The hazards taking place on the infrastructure can be grouped into four dominant classes; *collisions* with the building structure, *fires*, *leaks of toxic substances*, and *explosions* (consecutively decreasing in probability and increasing in consequences). In contrast, the hazards in the building are mainly *fire*, *explosions* and in some cases (with a very low probability of occurrence) *falling objects*. These accidents can also be the starting points of others. A fire for instance can cause an explosion and vice versa. The release of toxic gasses hardly initiates other events.

3. Safety Measures

3.1 Introduction

In general, safety measures are implemented to reach a certain level of safety. These measures will reduce either the probability and / or the consequences of an incident in the building on top of the infrastructure, in the vicinity or in the covered infrastructure itself. From a risk management point of view, it is desired that the implemented measures should be cost effective. Moreover, it is beneficial from an economical viewpoint to integrate these measures during the design stage [5].

3.2 Safety measures in the construction stage

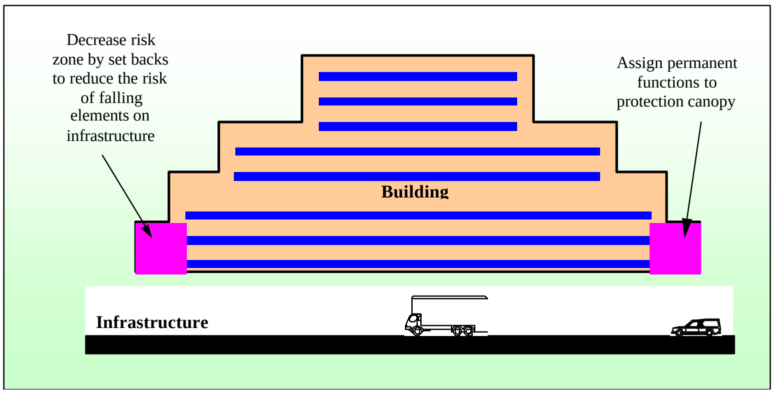

Figure 2: Set backs in the form of the building.

The safety measures for the construction stage can be divided into two main groups; *structural / functional* measures (such as applying different types of protection canopies to prevent that falling elements reaches the third parties) and *logistic measures* (such as closing off the road and rerouting the traffic). The advantage of logistic measures is that these are quite cost-effective. Structural safety measures can be integrated in the architectural, functional and structural design of the building on top of the infrastructure. The disadvantage of temporary safety measures is that these are a cost-rising factor in projects. In contrast, if permanent safety measures are implemented, synergetic effects can be achieved; the safety for third parties can be guaranteed and the designer can bring out a multifunctional design, by which extra costs for removing the safety measure can be saved.

3.3 Safety measures in the exploitation stage

When considering the exploitation stage in multiple use of space projects, safety measures can be implemented to (the boundaries of) areas, such as the building on top of the infrastructure, the infrastructure itself and the vicinity. Safety measures in the exploitation stage can be distinguished into three main categories: (1) functional safety measures; (2) structural safety measures and (3) human related safety measures. The scale level of functional measures is mostly related to the urban development or the configuration of space. The scale level of structural and human related measures interacts with the building or infrastructure level.

3.3.1 Examples of functional safety measures

A very traditional measure for multiple use of space projects is to implement a functional measure from a logistic point of view, in which one separates the transport of hazardous materials from the normal traffic. In addition, one may decide to prevent realising buildings on top of infrastructure on which the transport of such materials takes place. One may also set up a new chemical installation next to the place where the hazardous material is processed, if possible.

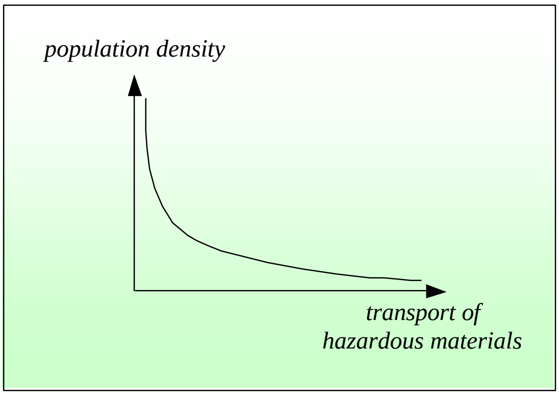

Figure 3: Reverse relation between the population density and the number of transported dangerous goods

Another proactive / functional measure could be the realisation of functions with a low density of population on top of and along the infrastructure, such as a park or parking garages, through which the number of people exposed to the risk of the transported goods can be minimised. In essence, due to safety considerations and an acceptable level for group risk, there is a reverse relation between the population density and the number of transported dangerous goods in a specific area. The higher the number of transported hazardous materials, the lower the population that density can be allowed. Given the fact that transport of hazardous materials is allowed in such areas, the building and infrastructure parameters can be influenced by their configuration. This will result in the variation of the (individual) risk and the group risk for the building on top of the infrastructure and for the vicinity. The main influencing (functional) building and infrastructure parameters are the width and height of the covered infrastructure, possibly combined with the length of covered infrastructure and the height level of the infrastructure. These influencing parameters form a main part of the functional measures. By implementing functional measures, effective results can be achieved.

3.3.2 Examples of structural safety measures

Structural measures can be implemented on (boundaries of) the building above the infrastructure or the infrastructure itself. For instance, buildings on top of the infrastructure or structure thereof can be designed column free on footprint of the infrastructure, as illustrated in figure 4. This is of course no general design solution and mostly the result of architectural considerations. By this, the probability of a collision of a vehicle with the main structure of the building will decrease.

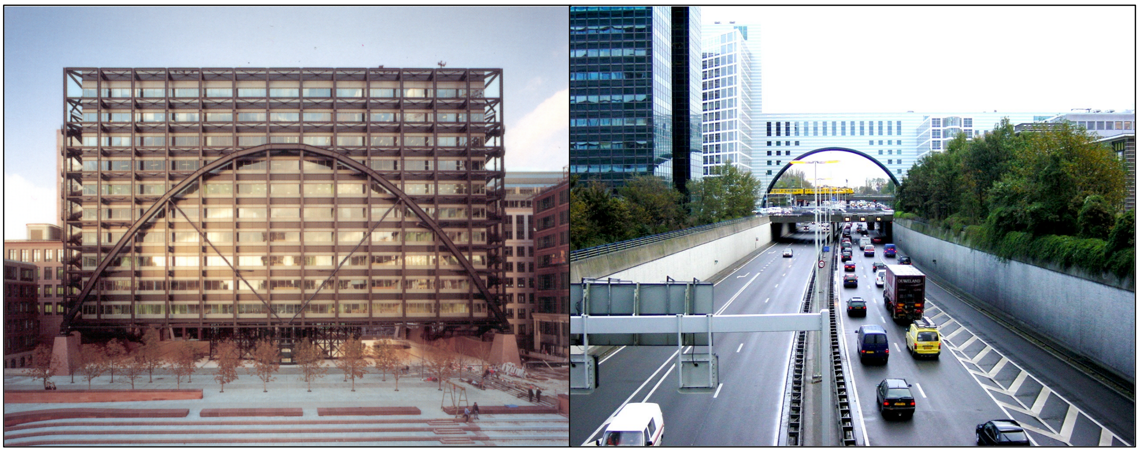

Figure 4: Examples of structural measures in buildings; Exchange House in London, UK (left) and the Haagse Poort in The Hague, The Netherlands.

Examples of safety measures against fires could be a fire-resisting layer, an additional concrete layer or longitudinal ventilation see [5]. Sprinkler systems both in buildings and in the infrastructure beneath could also be effective, in case of fire occurrence. However, it can be stated that there is little scientific data and experience with sprinklers in tunnels or covered infrastructure. The survey of [5] presented that safety measures against fires, release of toxic gasses and collisions with the main structure of the building above can easily be realised, while measures against explosions are both structurally and financially impossible to realise in practice. One should seriously consider that transported materials causing an explosion, such as LPG or ammonia, do not harmonise with urban development near or on top of such transport route. So, one should concentrate on logistic measure, through which the explosion scenario is excluded. In this regard, it is persuasively proposed to separate the hazardous material causing an explosion from urban activities and visa versa, especially in The Netherlands. Furthermore, measures against toxic gasses are possible, but less cost effective than measures against fire. Therefore, separation of the transport of toxic gasses through urban development is optional as well. By this, urban development can be ”easily” accomplished.

3.3.3 Examples of human related safety measures

The origin of safety measures aiming on evacuation of human beings are mostly based upon the escape opportunities of people in an emergency situation and the availability and accessibility of emergency response, such as the fire brigade and ambulances. In essence, these measures are mostly measures of the repression class of the safety chain and should be implemented in both buildings on the top of the infrastructure and towards the infrastructure itself.

4. Discussion: multiple use of space and / or transport of hazardous materials

As mentioned before, in the future, both the shortage of land and the possible increase of transport of hazardous materials may come into conflict. Both aspects are stimulated by the government / community, since these aspects are of great economic value. General opinion is that the transport of hazardous materials forms an obstacle for urban development. That is not 100 % correct, because risks of some materials can be reduced by countermeasures. However, materials such as toxic and / or flammable gasses cause extremely large consequences (fatalities) and taking measures against these two types is not cost-effective and even impossible to realise. Therefore, the risks should not be underestimated when urban development and transport of hazardous materials are combined without countermeasures. If the urban developments and transport of hazardous materials are considered from a helicopter view, a question arises whether it is necessary to realise urban development projects on locations where transport of hazardous materials takes place, since the transport of hazardous materials does not harmonise with urban development. Line infrastructure for transport of hazardous materials is, however, mostly in use for transport of people as well and is therefore often passing through densely populated urban areas. Some transport routes in The Netherlands were planned to function as major transport routes of hazardous materials [6]. Still, there are urban developing plans close to transport routes of hazardous materials, which is contradicting with each other and should therefore be considered carefully. The other side of the medal is that the transport of hazardous materials should be dissuaded from urban areas, if possible. Transport of hazardous material causing large fatalities, such as toxic gasses and / or flammable gasses, should be banned from urban areas. Many international examples support this statement. Yet, measures against the scenarios caused by toxic liquids and flammable liquids, can be taken. So, if there is really no option to separate the transport of both toxic liquids and flammable liquids from urban activities, these materials could be transported, since the consequences can be controlled with cost-effective countermeasures.

It is better, however, to separate the transport and the urban development activities entirely. The problem in The Netherlands is that alternative routes for rerouting that transport are sometimes difficult to find, due to lack of space and large significance of spatial quality. Nevertheless, one may realise alternative logistic transport systems, such as rerouting the transport on ships, where almost no (densely) populated areas are established near the rivers and large quantities of hazardous materials can be transported. Moreover, most of these chemical installations are situated near harbours or rivers. In this way, rerouting the transport through not densely populated areas becomes perhaps the most effective measure to tackle the safety problem in The Netherlands. The major advantage of the separation of transport of hazardous materials and urban development is that the risks for users of the buildings along the infrastructure decrease. Note that one should stand by the agreement that these transport routes will not be used in the future to establish new projects of urban development, otherwise the same problems may occur in the future after all. Hence, multiple use of space projects can easily be realised and the transport of hazardous materials can be increased.

5. Conclusions

This paper shows that safety for both the construction and exploitation stages is one of the prime considerations in multiple use of space projects. Although the construction time of multiple use of space projects is quite short in comparison with the life time of a project, the safety during construction of multiple use of space projects should not be underestimated. It appeared that the falling elements form a major hazard for third parties during construction (users of the infrastructure). Measures against such hazard can easily be taken from a structural point of view - such as applying a protection canopy, - or logistic point of view - such as rerouting the traffic when heavy elements are erected above the infrastructure. If it is decided to take structural measures, one should keep in mind to integrate them in the functional design of the building for the exploitation stage, through which the costs of removing that measure can synergistically be saved.

If we focus on the exploitation stage of such projects, collisions, fires, explosions and leaks of toxic substances are the main hazards occurring on the infrastructure (consecutively decreasing in probability and increasing in consequences). In order to guarantee a certain safety level during exploitation, safety measures are necessary. Functional and structural safety measures against fires and collisions against the main structure of the building along or on top of the infrastructure, can easily be realised and are besides cost-effective, while measures against explosions / peak overpressure are both structurally and financially impossible to realise in practice. Measures in buildings against the release of toxic gasses can be realised, but are not cost-effective. If it is possible to separate the transport of hazardous materials from the urban planning activities, than the logistic measures are cost-effective in comparison with structural measures in buildings, through which multiple use of space projects can easily be realised and the transport of hazardous materials can be increased.

References

[1] RIVM, *Yearly environmental report 1998*, 1998.

[2] SUDDLE S.I., Drie dimensionale veiligheidsbenadering bij drie dimensionaal ruimtegebruik, *PAO Cursus Bouwen boven wegen en sporen syllabus; Bouwen boven wegen en sporen*, 28 november 2002, pp. 1 - 10.

[3] SUDDLE S.I. & WAARTS P.H., The Safety of Risk or the Risk of Safety?, *Safety and Reliability 2003*, Proceedings of ESREL 2003, European Safety and Reliability Conference 2003, 15 - 18 June 2003, Maastricht, The Netherlands, Bedford & van Gelder (eds) © 2003 Swets & Zeitlinger, Lisse, The Netherlands, ISBN 90 5809 551 7, Volume 2, pp. 1511 - 1518.

[4] SUDDLE S.I., *Veiligheid van bouwen bij Meervoudig Ruimtegebruik*, M.Sc. Thesis, TU-Delft, april 2001, 298 pp.

[5] SUDDLE S.I., ALE B.J.M., WAARTS P.H., WEERHEIJM J., A quantitative introduction of physical safety measures for realising buildings above roads and railway tracks, *Proceedings of Congress 25th ESReDA SEMINAR 2003 on Life Time Management of Structures*, Paris, France, November 17 - 18, 2003, 12 pp.

[6] ALE B.J.M., *Achtergrondstudie; Risico's en veilgheid, Een historische schets*, Faculteit TBM, TU Delft, juni, 2003, 70 pp.