The 3rd dimension of risk contours in multiple use of space

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Abstract

Buildings above roads and railways are examples of multiple use of space. Safety is one of the critical issues for such projects. Risk analyses can be undertaken to examine the required safety measures that are needed to realise these projects. When doing this risk analysis, the results have to be checked for risk acceptance criteria. One of these criteria is the individual risk. Traditionally, the criterion for acceptability of risks is a two-dimensional criterion and is depicted as contours on a - two-dimensional - map, but when doing risk analyses for multiple use of space a 3rd spatial dimension is introduced, namely the external safety and risks from the infrastructure towards the building above. Up until now there are no explicit norms or ideas about the individual risk contours in the 3rd dimension. This paper will propose an approach for the 3rd dimension for individual risk contours. According to this, engineers and designers can implement this knowledge for decision making when designing projects of multiple use of space.

1 Introduction

Lack of space leads to the design and construction of projects which make intensive and multiple use of the limited space. Buildings above 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. Therefore, safety is one of the critical issues in such projects for the construction phase as well as for the exploitation phase [Suddle, 2002A].

During the design phase of a project, risk analyses can be undertaken to examine the required safety measures that are needed to realise multiple use of space. When doing this risk analysis, the results have to be checked for risk acceptance criteria. If the results do not comply with these risk acceptance criteria, to be divided into criteria on an *individual* and on a *social* basis, extra measures can be taken to increase the level of safety. Besides, the assessment of management and risk is an activity that has a growing interest [Ale, 2002].

The criterion for acceptability of individual or localised risk is usually depicted as contours on a - two-dimensional - map [Ale et al., 1996]. However, when doing risk analysis for multiple use of land, the concept of multiple use of space where different functions are layered [Wilde, 2002], a 3rd spatial dimension is introduced.

Another instance where individual risk varies in the third dimension - i.e. in height - is in case of flood hazard. Generally, the individual risk can be given for persons behind a river dike in which is assumed that the houses are homogenous and consist two stories [Jonkman, 2001]. It has to be noted however that in some cases, especially people living in a high-rise building do not have the same individual risk. In this regard, it may be concluded that considering the limits for risk acceptance in multiple and intensive use of land the 3rd dimension is indispensable.

As dealing with the 3rd dimension safety system when doing risk analysis adds considerably to the complexity, this is not done in the traditional models for consequence analysis and frequency estimation. Therefor additional methods are needed for modelling the behaviour of risk in the 3rd dimension. Bayesian Networks can in this case be useful [Suddle, 2002B]. This paper will therefore propose such an approach for the 3rd dimension of individual risk contours for multiple use of space.

2 The three-dimensional approach of individual risk contours

2.1 Two-dimensional individual risk contours

Societal risk and individual risk of hazardous installations form boundaries for urban planning. Subsequently, these risks are adopted in urban planning around line infrastructure for transport of hazardous materials, which can also be considered to be hazardous installations. Traditionally, the city is planned far from hazardous installations and hazardous installations are planned far from the city. 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. Because new buildings were never planned above hazardous installations or transport infrastructure, a three dimensional approach of risk contours was not necessary. It is therefore common to display the risk contours in a two-dimensional map.

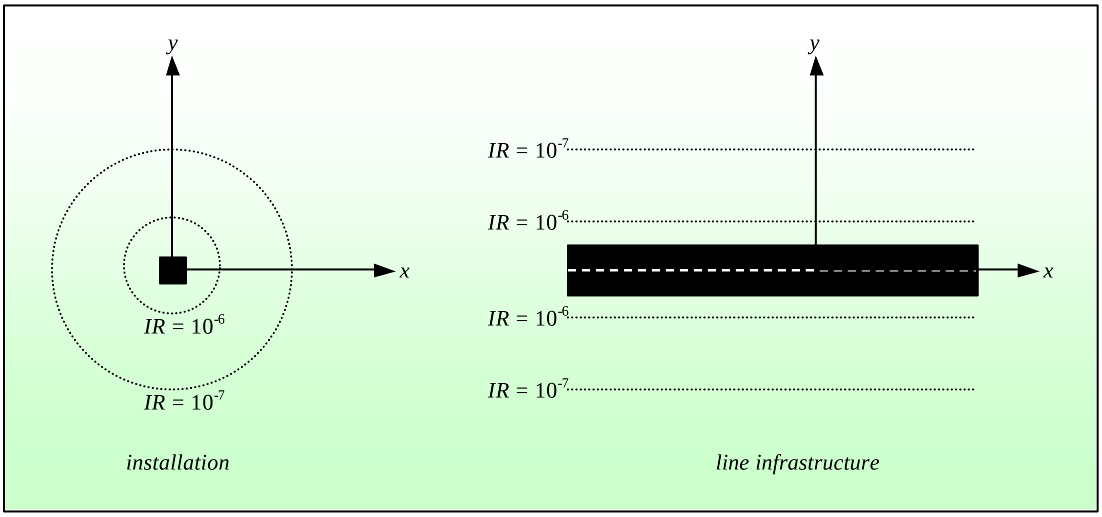

Figure 1: Two-dimensional individual risk contour for an installation and line infrastructure.

The individual risk is dependent on the geographic position and is displayed in the form of iso-risk contours on a geographic map. The individual risk is thus not characteristic for any person, but only for the location for which it is calculated. Thus, the individual risk contour maps give information on the risk of a location, regardless whether people are present at that location or not [Bottelberghs, 2000; Ale, 2002]. The risk contours for a hazardous installation and a transport route are shown in figure 1.

2.2 Three-dimensional individual risk contours

Nowadays, due to lack of space in combination with awareness of spatial quality, one is forced to look for new concepts of urban planning in which the space is used more intensive. The possibilities to use the land more than once by building over line infrastructure are studied and applied. Accordingly, an approach and a creation for the third dimension are rather inevitable. When considering the three-dimensional individual risk contours for installations, one may assume that the form of such contours, in open-air, may be a half an ellipsoid, as presented in figure 2. These risk contours are related to the intensity of combustion caused by a flame [Drysdale, 1999]. A similar but transposed figure for line infrastructure is also drawn.

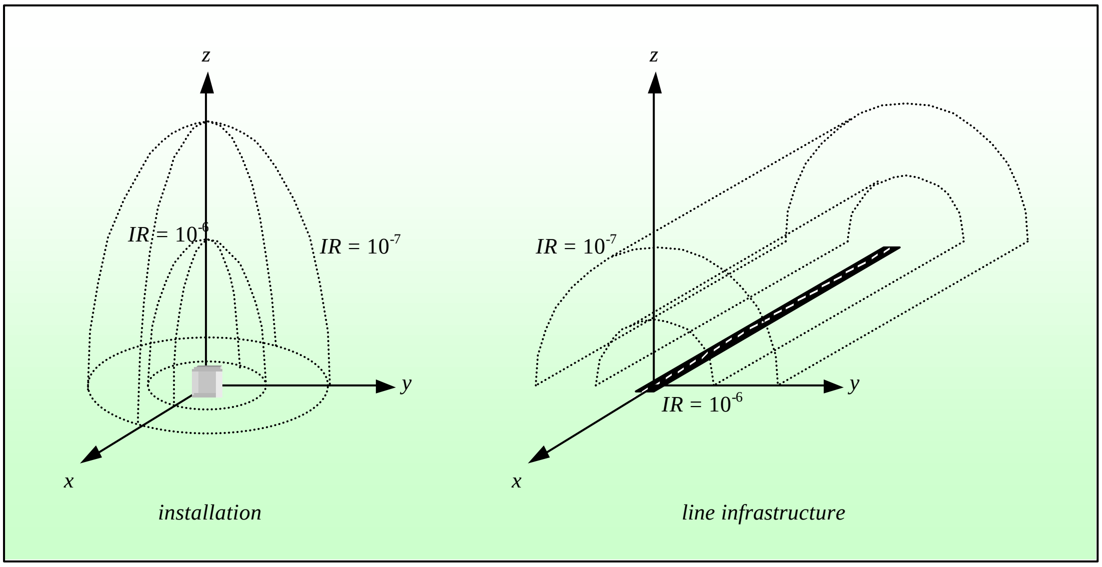

Figure 2: Three-dimensional individual risk contours for an installation and line infrastructure.

Although the contours are depicted as closed in all dimensions, it should be noted that it is possible that the contours do not close in the vertical, resulting in vertical cylinders rather than ellipsoids. Such may be the case if a building is realised above the hazardous installation and if the risk is posed by the scenario's involving the potential collapse of structures in which people are present.

The general equation of an ellipsoid whose centre is the origin and whose axes correspond the x, y and z-axis is:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1 \qquad (1)$$

In the same way, one may outline the three-dimensional risk contour approach for line infrastructure, which is a half a cylinder. The general equation of a cylinder is:

$$\frac{y^2}{b^2} + \frac{z^2}{c^2} = 1 \tag{2}$$

The height of the risk contour depends on the (quantity of) hazardous materials produced in the installation or transported at the infrastructure for both examples. In most cases the height (z) of the individual risk contour is bigger than its width (x,y). However as indicated the integrity of the structure may have a large effect on the shape of these contours. A tool to calculate the effect of a scenario is CFD (Computational Fluid Dynamics). CDF calculations are often used to calculate the effects of fires and explosions in and around complex structures such as oilrigs and tunnels. In essence, the calculations involve the numerical solution of the coupled differential equation describing the laws of conservation of mass, impulse and energy. The output of the CFD calculations is three-dimensional descriptions of effects, which can be translated into probability of death or other damage where necessary.

3 Buildings above infrastructure

3.1 Basic conditions

The realisation of buildings above infrastructure can influence the shape and the surface of the cross section of the individual risk contour. In order to analyse the height of risk contour in multiple use of space, the individual risk can be analysed in a risk analysis by using Bayesian Networks. The individual risk has to be analysed per story of the building above infrastructure (h_0, h_1, … , h_n) as presented in figure 3.

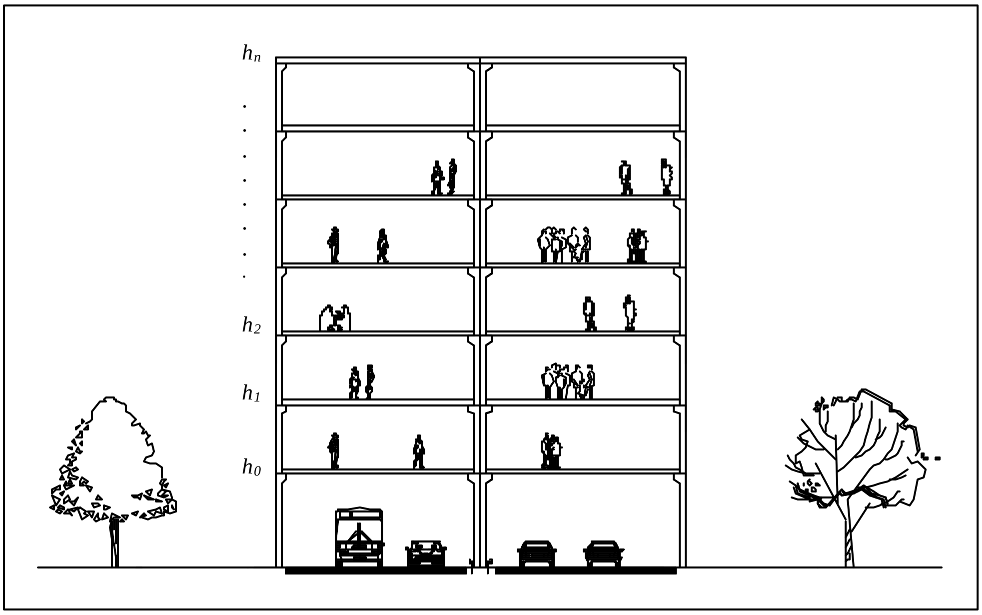

Figure 3: Building above infrastructure.

The consequences of accidents with infrastructure dominate the safety of people in the building. These accidents, however, all have a different impact. 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 [Taylor, 1994]. These accidents can also be starting points of others. A fire for instance can cause an explosion and vice versa. The release of toxic gasses hardly initiates other hazards. It is, therefore, important to explore the effect of release of toxic gasses separate from explosive materials on infrastructure. Moreover, to determine the effect of fire on the individual risk on each story, the fire on infrastructure scenario is explored separate from the previous scenarios. In order to set up a risk analyses, the most important factor is weather the building collapses due to an accident or not.

3.2 Programming in Bayesian Networks

A quantitative risk analysis is done for the main scenarios (see 3.1). Fault and event trees are often used for risk analysis in land use engineering [Berrogi, 1999]. A more effective, compact and well-ordered tool for doing a risk analysis is the use of Bayesian Networks [Suddle, 2002[C]]. This technique is used for the quantitative risk analysis as presented in figure 4 and 5. These networks represent the relations between the events on the infrastructure and the building. These relations can be quantified in (conditional) probabilities. The (change of) individual risk per increasing story of the building is considered in these networks. An accident on the infrastructure may cause an explosion, which on its turn can cause a fire followed by the collapse of the building. This results in a variation of the individual risk per story. The node explosion is divided into the classes: a light explosion, a BLEVE and a detonation. An accident on the infrastructure may also cause release of toxic gasses, which influences the individual risk in the building as well.

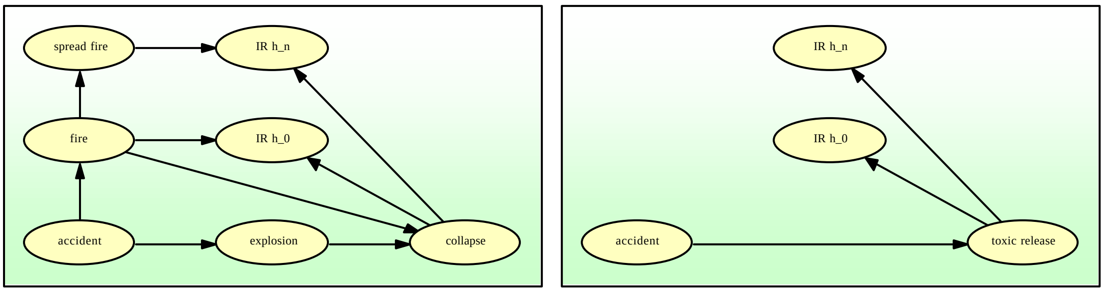

Figure 4: Bayesian networks; explosions on infrastructure (left), release of toxic gasses (right) on infrastructure.

Figure 5 presents the scenario fire on the infrastructure. Fire on the infrastructure varies between 20 MW (passenger cars), 100 MW (busses/trains) and 300 MW (trucks/trains). The higher the intensity of the fire the higher the probability that it will spread to higher stories. Besides, high fire intensity can lead to a collapse of the building.

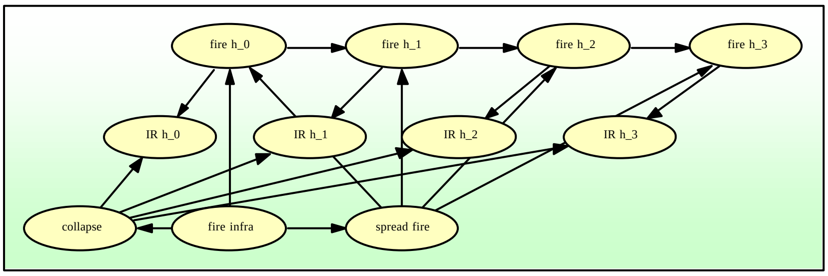

Figure 5: Bayesian networks: and fire on infrastructure.

3.3 Results risk analysis

The results of the risk analysis are presented in table 1. The table consists of the individual risk per story and the ratio of individual risk per story (IRh_i) in comparison with the individual risk at the infrastructure (IRh_{-1}). The ratio IRh_i/IRh_{-1} presents the increase or decrease of the individual risk on the concerned story (IRh_i) compared to individual risk at the infrastructure (IRh_{-1}).

LEVEL	**Explosion**		**Release of toxic gasses**		**Traffic accidents towards building structure**		**Fires**	
	IRh_i	IRh_i/IRh_{-1}	IRh_i	IRh_i/IRh_{-1}	IRh_i	IRh_i/IRh_{-1}	IRh_i	IRh_i/IRh_{-1}
Infrastructure	10^{-9}	-	10^{-8}	-	10^{-6}	-	$1 \cdot 10^{-6}$	-
h_o	10^{-9}	1	10^{-10}	0,01	$7 \cdot 10^{-7}$	0,7	$7{,}1 \cdot 10^{-7}$	0,71
h_1	10^{-9}	1	10^{-10}	0,01	$7 \cdot 10^{-7}$	0,7	$6{,}7 \cdot 10^{-7}$	0,67
h_2	10^{-9}	1	10^{-10}	0,01	$7 \cdot 10^{-7}$	0,7	$6{,}2 \cdot 10^{-7}$	0,62
h_3	10^{-9}	1	10^{-10}	0,01	$7 \cdot 10^{-7}$	0,7	$5{,}7 \cdot 10^{-7}$	0,57
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
h_n	$1 \cdot 10^{-9}$	1	10^{-10}	0,01	$7 \cdot 10^{-7}$	0,7	10^{-7}	0,1

Table 1: Results of the risk analysis.

When considering the scenarios explosion possibly combined with fire, the individual risk in the top story (h_n) is almost as high (in some cases higher) as inside the infrastructure. This ”relative decrease” is because of the risk of collapse of the building, which has a dominant influence. If the building collapses, one may assume a great number of fatalities will occur in the building (e.g. 99%). Explosions, traffic accidents towards building structure and fires can initiate the collapse of the building. It can be noted that functional and structural measures to prevent a collapse by traffic accidents or fires can be taken, but measures to stop a detonation are much more difficult to take and in terms of economics non-proportional expensive. The results of table 1 are presented in figure 6 and 7. In these figures, the increase or decrease of relative risk contours are concerned.

In case of a release of toxic gasses on infrastructure, the individual risk contour decreases rapidly. This is because of the effect of toxic gasses are for the greater part restricted to the infrastructure when it is covered (see figure 6). The toxic gasses can only reach the open-air and the building at the both ends of the tunnel.

It is important to note that the three-dimensional cross section approach must be linked to the two-dimensional approach ground level approach in order to be really three-dimensional.

When considering the fire scenario on infrastructure, the individual risk contour decreases a factor ten within five/six stories. Traffic accidents (e.g. derailing trains or traffic accidents) can cause a mechanical load on the structure that can lead to the collapse of the building. So, for the individual risk contour, this scenario ranges between the explosion on infrastructure scenario and the fire on infrastructure scenario (see figure 7).

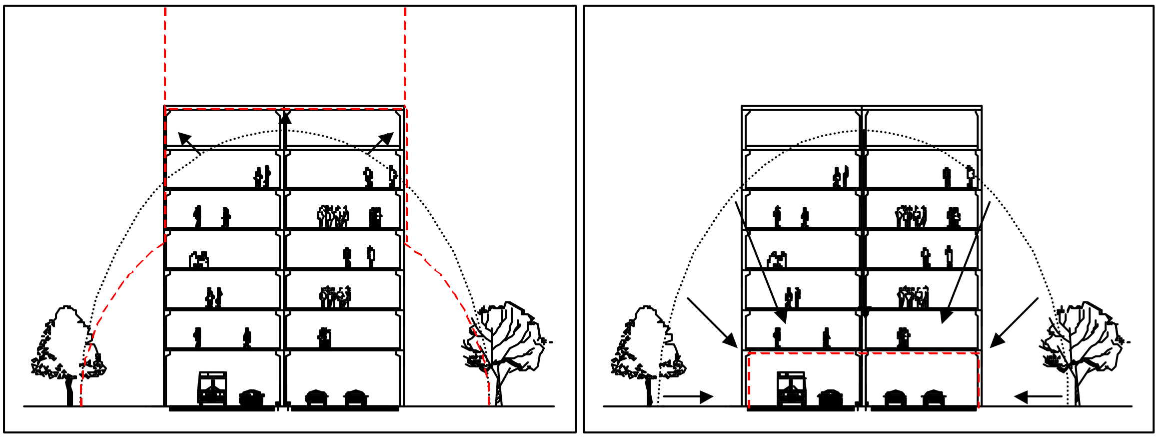

Figure 6: The influence of the individual risk contour: fire and explosions (left) and release of toxic gasses (right).

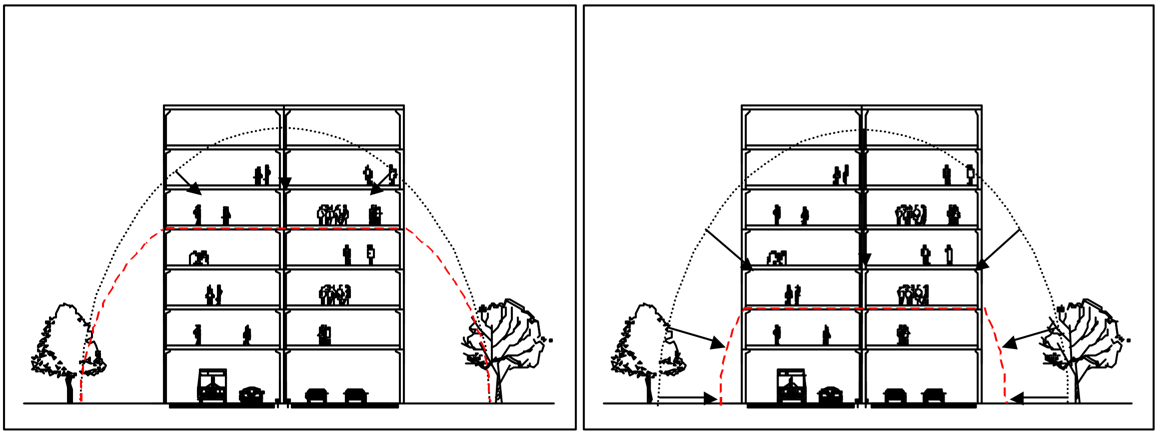

Figure 7: The influence of the individual risk contour: traffic accidents towards the structure of the building (left) and fire on the infrastructure (right).

3.4 Evaluation height of individual risk contour

Considering the previous, it may be concluded, when realising buildings above infrastructure, the height of the individual risk contour indeed can be influenced. But it has to be noted that the (internal) risk at the infrastructure will increase. The form of the individual risk contour depends on a number of aspects:

- The amount of explosive and toxic materials transported on the infrastructure:
  If the transport of explosive and toxic materials is prohibited the individual risk contour will be enclosed to the infrastructure.
- The measures to protect the building from the main four scenarios (explosion, release of toxic gasses, traffic accidents towards building structure and fires):
  These measures can be divided into functional [Wiersma & Molag, 2001] and structural measures.

4 Influencing building parameters

Given the fact that transport of hazardous materials is allowed, the building and infrastructure parameters can be influenced by their configuration. This will result in the variation of the form of the risk contour for the building above the infrastructure and for the surroundings. The main influencing building and infrastructure parameters are the width and height of the tunnel, possibly combined with the length of covering infrastructure, and the height level of the infrastructure. These influencing parameters are suggested in this part of the paper.

4.1 The effect of the width and height of the tunnel

The height of the tunnel depends on the height of the lowest story of the building (h_o). The width of the tunnel depends on the span (l) of the building. These two parameters form the basis for the possible scenarios at the infrastructure. Suppose h_o is designed at a minimum of 4 meters. This can initiate problems by truck drivers at roads, which can result in an accident.

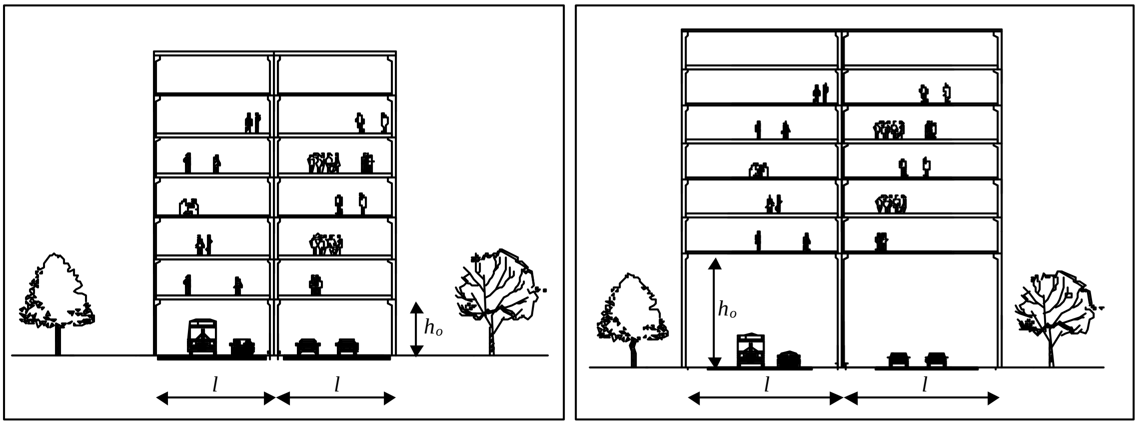

Figure 8: The height of the lowest story of the building and the width of the building: standard variant (left) and the variant with a higher lowest story and a bigger width (right).

According to Baker [Baker, 1983], an explosion consists of four components: a blast wave, atmospheric and ground effects, fragmentation and missile effects and thermal radiation effects. Implementing a big diameter (a high level for the lowest story h_o and a bigger span l) in the design of the building leads to smaller probabilities for the explosion, BLEVE and detonation scenario. If one likes, one can design a building from the shape of a risk contour as well. This is illustrated in figure 9. This is of course no general design solution and mostly the result of architectural considerations.

Figure 9: The Haagse Poort in The Hague (The Netherlands).

4.2 The effect of the length of covering infrastructure

Multiple use of space begins to be interesting if the infrastructure is covered for long distances. This is, however, not always possible because of safety considerations. The probability of an accident on the infrastructure is correlated with the covering length of the infrastructure, while the consequences of an explosion increase rapidly with the length of the tunnel [Berg et al., 2001].

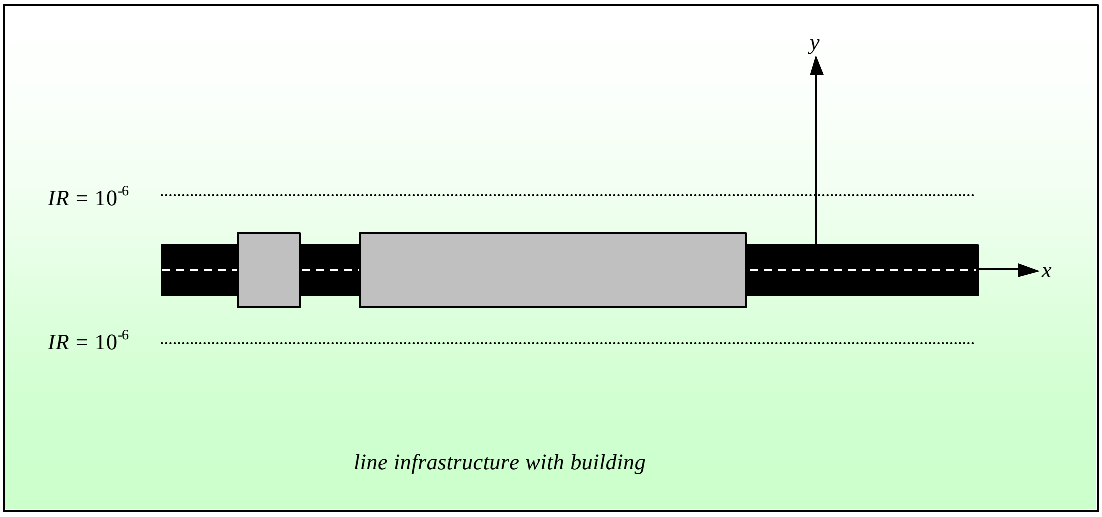

Figure 10: A small (left) and a long (right) covering length of infrastructure.

The effect of the covering length of infrastructure for the main scenarios is presented in table 2. One can read that a small covering length of infrastructure is positive regarding the explosion scenario. The advantages on toxic gasses are however not achieved.

COVERING LENGTH	Explosive materials	Release of toxic gasses	Traffic accidents towards the building structure	Fires
Long	- -	+	-	+
Small	0	0	0	0

Table 2: The effect of the covering length of infrastructure on the building above and the surroundings.

In case of prohibiting the transport of explosive materials, one can cover infrastructure for longer distances. When the infrastructure is covered for long distances with a building, some hazards can be enclosed into the infrastructure. In this regard, the (individual) risk for the surroundings can decrease in comparison to the building built above infrastructure. The individual risk increases for the surrounding area at both ends of the building.

This increase and decrease must be compared in order to determine whether the risk increases by building over infrastructure. An example of the shield that is formed by a covering of the infrastructure for toxic gasses is shown in figure 11. This is not valid for small coverings.

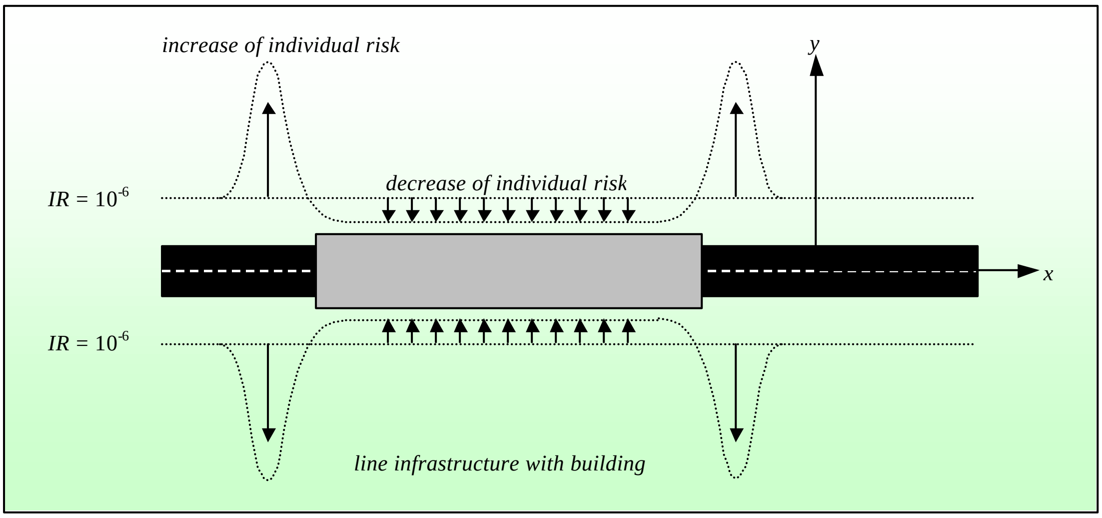

Figure 11: Local decrease and increase of individual risk by enclosing infrastructure for toxic gasses.

4.3 *The effect of the height level of the infrastructure*

There are four different levels of height for infrastructure that can be distinguished; underground, subsurface, ground level and elevated. In figure 12, these different positions in height are drawn for railway infrastructure.

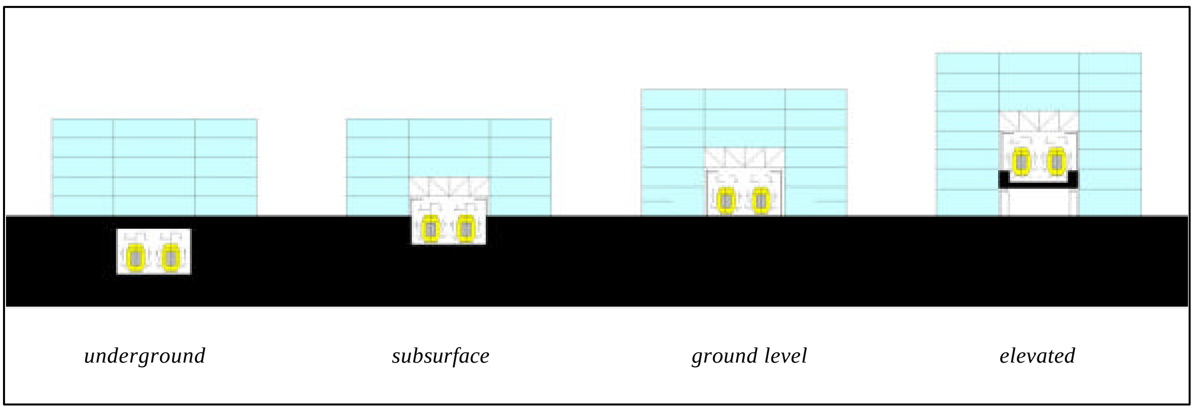

Figure 12: Different positions in height of railway infrastructure.

The effect of the height of infrastructure for the main scenarios is shown in table 3. The higher the level of the infrastructure, the higher the risks for the building. If the infrastructure is located in the underground, the effect of the hazards on the building and surroundings is much smaller than when the infrastructure is elevated. If one can utilize independent foundations for the infrastructure, one can reach safety advantages.

LEVEL OF INFRASTRUCTURE	Explosive materials	Release of toxic gasses	Traffic accidents towards the building structure	Fires
Underground	0	+	+ +	+
Subsurface	-	0	+	0
Ground level	-	0	-	0
Elevated	-	-	-	-

Table 3: The effect of the covering length of infrastructure on the building above and the surroundings.

5 Conclusions and discussion

Lack of spaces forces designers to explore the possibilities of building over infrastructure. Rules and regulations for the third dimension in risk analysis have however not been developed yet. Generally accepted computer models for calculation of the risk also lack a three-dimensional approach. The third dimension of the risk contour of infrastructure can be set up as a half cylinder. When this infrastructure is covered, the risk contour changes. The changes of the risk have been indicated for four representative calamities: fire, mechanical loads, toxic gas release and explosions. A possible collapse of the building is dominant in the risk analysis. If a collapse can be prevented, a covering of infrastructure can be safer for individual risk for surroundings and the building. Further development of the methods will enable a systematic an more appropriate evaluation of these risks than the flat plane approach which is employed dominantly to date.

6 Literature

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