Risk evaluation of road and railroad overbuilds

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ABSTRACT

Railroad and road overbuilds are a kind of substructures that involves large costs which often leads to a need for increased land use close to and on top of the overbuild. If the transportation network which is overbuilt includes transportation of dangerous goods, the risk situation will be complex related to rare events with a potential to cause substantial damage, e.g. collapse of buildings on the over site development.
In Sweden there are at present no national or regional rules or guidelines showing how to address or evaluate this risk situation. The lack of guidelines leads to difficulties in implementing this type of project.
Brandskyddslaget has developed a proposal for what the basis for such risk assessment decisions might look like. We believe that a cost/benefit analysis will make an important piece of the puzzle in the decision-making basis for the selection of dimensional explosive load and thereby accepting the resulting residual risk, as it gives a more complete picture of the actual risk-reducing effect which leads to a less subjective risk evaluation. This can serve as one of several perspectives addressed in risk-informed decision making.

KEYWORDS: overbuild, decking, capping, tunnel risk analysis, cost-benefit, accidents, dangerous goods, explosion, spatial planning.

PURPOSE AND OBJECTIVES

The purpose with this paper is to clarify the challenges with railroad and road overbuilds and risks that can lead to catastrophic consequences. As the research within this area is quite sparse, we find it urgent to start an international debate and inform the research community of the need to pay more attention to this issue in order to facilitate sustainable development of crowded cities with transportation networks through densely populated areas. This paper aims to describe the challenges and present a feasible method for risk evaluation that facilitates decision-making concerning overbuilds and the associated risks.

INTRODUCTION

Background

In Sweden and other countries an increasing need for housing and recreation areas, as well as accessibility to infrastructure compete with an increasing claim for military defense and food supply, climate change etc. over, for instance, accessible land. The Swedish government addresses this issue by assigning a special investigation on national spatial planning [1]. Despite a small decrease during the pandemic, many factors still point to further urbanization [2] and thereby additional need for accessible land in cities.

Due to the lack of accessible urban land, railroad and road overbuilds, i.e. capping or decking, is considered more often, in Sweden, as in other countries.

This type of development connects to sustainability in several ways. For one thing, the infrastructure in question does usually have a vital societal function and is critical to the maintenance of the national public transportation network and the impact on this function and the conditions for traffic are hence very important. The climate change is also an important factor that affects the need to overbuild infrastructure, especially railroads, since a higher density in population close to public transportation nodes decreases car traffic. In combination with large construction costs for this kind of substructures this often results in a need for development close to and on top of the overbuild.

Railroad and road overbuilds bring challenges linked to risks that can have consequences exceeding a few fatalities and where the damage outcome can be more extensive compared to a corresponding accident above ground, e.g. major fires or accidents with dangerous goods [3] [4] [5]. The largest impact will occur underground, and the damages can largely be equated with damages due to major accidents in e.g. road and rail tunnels for which there are regulations and accepted methods for performing risk assessment (e.g. [6]). The main difference though is that the impact outside of a road or rail tunnel will be limited due to a low population density whereas overbuilds mostly are planned in areas with a high density of population. Hence the damage outside the overbuild has a high contribution to the overall risk. For spatial planning outside a tunnel or overbuild there are guidelines of how to assess and evaluate risk but for land use on top of an overbuild there are no regulations or established guidelines. Also, common practice is sparse and relies on a weak knowledge base. Hence risk assessment concerning those areas is uncertain and complex.

If an accident occurs below the deck in a location where the population density is high, the consequences could, under certain circumstances, be very high, even disastrous. Even though the accidents primarily will affect safety below the deck there are certain accidents, especially associated with dangerous goods and detonations, which can cause impact on surrounding buildings on top of, or close to, the overbuild. At the same time the substructure can reduce the impact on the surroundings by limiting the damages of a number of other types of accidents.

The challenges with combining urban land use very close to, or on top of, infrastructure with transportation of dangerous goods is numerous and have been described previously [7], including the difficulty to handle changing conditions accordingly and the lack of measurement of the actual risk – particularly regarding a certain aspect of risk impact. Overbuilding roads and railroads assigned for transportation of dangerous goods introduces a particular challenge related to rare events, such as dangerous goods accidents in tunnels, with a potential to cause substantial damage, e.g. collapse of structures and buildings on the over site development. Since there are no guidelines as how to handle those catastrophic scenarios which is often inevitable in such projects if additional development is the driver.

Risk assessment on catastrophic scenarios

Generally, accidents that could lead to catastrophic scenarios with thousands of casualties are seen in society as unacceptable and should, as far as possible, be avoided. However, the knowledgebase on how to assess this risk is weak at present [7]. Completely eliminating such risks could either lead to restrictions that will cause unacceptable limitations in the use of the infrastructure or obstruct the overbuild project due to insurmountable costs or insufficient exploitation volume.

Risk assessments are often based on a comparison of the results of a risk analysis and criteria for risk acceptance. The acceptance criteria are often presented in regional or national recommendations or guidelines and forms the base for decision making. Even though there are guidelines and practices regarding risk assessment for developments close to risk objects such as railroads and roads with transportations of dangerous goods, there are still some issues about how to treat different risks. E.g. the suggested criteria for societal risk signed DNV on behalf of Swedish Civil Contingencies Agency [8], which for long has been a practice in rural development, is based on ALARP-methodology. However, there are no guidelines or practices on how to actually evaluate whether measures are considered reasonably practicable or not when the risk level is sought to be ALARP. This means that decisions based on a comparison of the calculated risk level and applied acceptance criteria may be based on insufficient information of the proposed measures.

There are also issues about how to treat catastrophic scenarios. For instance, most criteria for societal risk, has an upper limit on 1,000 casualties. It is not given that an extrapolation of the criteria beyond this point is equal to an acceptable risk. The suggested criteria mentioned above doesn´t include an upper limit, however the report highlights the importance of not basing the risk assessment beyond 1,000 casualties merely on quantitative risk analysis. The report doesn´t include any guidelines on how to design the risk assessment beyond this limit.

The lack of guidelines and practices both regarding how to make the risk assessment within ALARP and how to treat catastrophic scenarios makes it even more difficult as it comes to overbuild and the issues described earlier. As a result of there being no specific guidelines or accepted practice, at the moment, there is a need for project-specific adaptations. There are several different solutions that have been applied within different projects. One quite common solution is that the DNV's criteria are extended and that the same valuation principles as for fewer than 1,000 fatalities are used. However, this means that the background to the criteria is not followed (see above). In one large overbuild project where there were several building blocks planned, it was chosen to apply relatively extensive physical measures, among other things concerning the dimensional explosive load. This approach was accepted by the authorities and the detailed development plan gained legal force. After this, the authorities became unsure whether the measures taken were sufficient and therefore chose to introduce restrictions concerning transportations with explosive loads on the road that had been overbuilt. The result of that work was thus both extensive technical requirements and restrictions on the transport route, which also constitute a national interest for communication and was thus limited. In another project where buildings are planned close to, but not on top of, the overbuild, the design accident load for the decking has been chosen on a very loose basis which can lead to unmotivated high building costs or insufficient measures. Other examples exist where no consideration has been given to this type of accidents due to their low probabilities, which could result in risks that would be deemed unacceptable if highlighted.

In general, it can be said that there is a great deal of uncertainty concerning accidents that can lead to catastrophic consequences. The uncertainty is caused by many factors, e.g. limited statistical basis due to that this kind of accidents occurs very rarely, insufficient information about how large quantities of the relevant substances that are transported on one and the same vehicle, and uncertainty about the reliability of calculations and measures. It is also difficult to model the effect on the buildings above the decking which introduces additional uncertainties.

In a large project where extensive construction on top of the decking is planned, the lack of guidelines has led to project-specific guidelines. The guidelines include a method for risk assessment above the substructure and one for the area below, i.e. the platform room. The guideline for risk assessment for areas below the substructure has been developed by the Swedish Transport Administration. The guideline is formulated as: "The safety in the platform room under the overbuild must be at a similar level as in other modern platform rooms".

In the guideline for risk acceptance above the decking, developed by the City of Stockholm (shown in figure 1), demands are made for carrying out an advanced analysis of potential barriers by identifying and assessing barriers that can reduce the probability of, or the consequence of, catastrophic scenarios, i.e., events that could lead to more than 1,000 casualties. Barriers here refer to physical or non-physical measures for to prevent, control or mitigate studied accidents. Barriers can include such technical and physical risk mitigation measures that are usually regulated in detailed development plans. But barriers can also include overall organizational structures and processes that contribute to increased safety, which is more difficult to regulate in a separate development plan. Also included is to consider barriers that include maintenance and control, which takes place through supervision according to several different regulations.

The method for risk assessment is based upon the DNV criteria for fewer than 1,000 fatalities. Furthermore, the limit for unacceptable risk is extrapolated with an unchanged slope into the area with more than 1,000 fatalities (see figure 1). However, for more than 1,000 casualties, there is no corresponding area where the risk is directly considered acceptable. This means that if there is an indication that catastrophic scenarios may occur, specialized analysis of scenarios and barriers must always be carried out in order to determine whether the level of risk can be tolerated or not.

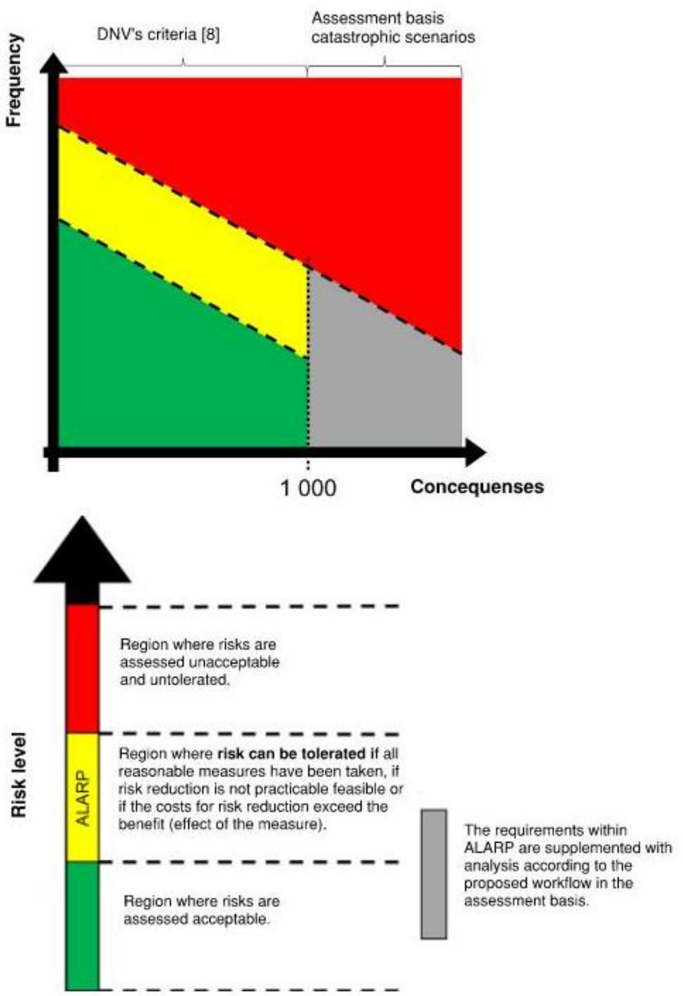

Figure 1. Example of risk assessment criteria for societal risk development by the City of Stockholm, explaining how to assess risk for more than 1,000 casualties.

The method for risk assessment for impact above and close to the overbuild is based on a risk informed approach with focus on:

- The risk level
- The number of barriers
- The availability of barriers over time
- Cost-efficiency
- Uncertainties

As there is an inherent potential for disaster, a specialized analysis needs to focus on it to increase knowledge and reduce uncertainties. Other features of the risk level that may affect the need for barriers have to be identified. The risk level controls the scope and depth of specialized analysis. Both technical/physical and organizational barriers are considered to achieve safety, throughout the system.

Different types of barriers are taken into account and evaluated, both within the infrastructure facility, within other parts of the planning area, readiness of actors on site and society's emergency preparedness. The barriers must be possible to ensure/regulate over time.
Since there is no definition of acceptance level for catastrophic risks, the assessment method does not provide the answer to which barriers are required to achieve an acceptable risk. Instead, the decision-maker is expected to take a position on this upon the basis that different combinations of barriers and their risk-reducing effect are reported and what responsibility that will follow for the stakeholders. The assessment method further states that the choice of barrier combination needs to be the result of, among other things, reducing the risk level, safety level and whether the uncertainties associated with it can be accepted or not. In summary, the assessment method requires a more comprehensive decision basis than is normally produced in the spatial planning process. Despite this, the decision maker is faced with a challenging situation with limited guidance on what is a reasonable solution or not. The assessment method means that decision-making goes from being risk-based to being risk-informed, which means that additional factors, in addition to the quantitative risk level, form the basis for decision-making.

Several of the factors that, according to the assessment method, need to be included and evaluated is based on qualitative assessments. One of the assessment factors that is most likely to actually be based on quantitative criteria is the cost-efficiency, i.e. is a barrier reasonably practicable based on the cost of the barrier relative to its benefit (risk reduction).

Potential barriers
There are a number of barriers that all can affect safety to different extents. Some barriers induce a reduction in frequency of an accident, while others lead to a reduction of consequences. In general, measures that reduce the frequency of an accident are difficult to implement in the municipal planning process since the municipality does not have control over the relevant infrastructure or the design and load volumes of the transport vehicles. The focus will therefore often be to reduce the consequences, as is the case in projects where substructures over transport routes is mainly driven by a development purpose.

A consequence-reducing measure that has a major impact on the risk level is the extent of the exploitation that is planned. A reduced development in the immediate vicinity to an overbuild will be an efficient measure to reduce the consequences of an accident. By reducing the degree of exploitation and choosing land use that has a low population density, catastrophic consequences can be avoided. In theory, a low exploitation rate is therefore an effective measure. However, an overbuild generally means a large construction cost, which is often financed to some extent by the exploitation. This can therefore not be too limited. The dilemma then becomes that a high degree of exploitation is necessary to be able to carry out an overbuild (which has many positive effects, for example concerning noise and particles) at the same time, the high degree of exploitation can entail the risk of catastrophic consequences in the event of an accident. Another barrier that also has a consequence-reducing effect is the substructure and its inherent resistance to accidents that can cause catastrophic consequences. Dimensioning substructures for a high load can be both expensive and challenging construction-wise. It is therefore important to investigate which type of accident forms the basis for the design of the structure and the scope of measure.

For the area under the decking, it is primarily accidents involving dangerous goods and fire in vehicles that have a major impact on the risk level and which therefore need to be mitigated. For areas on top of and close to an overbuild, it is mainly accidents that lead to ruptures in the loadbearing structures that can lead to catastrophic consequences. Accidents that affect the structure's stability and durability are primarily very extensive fires and explosions of the type detonation. Around the openings of a tunnel other scenarios can cause extensive consequences, for example leakage of toxic gas. The impact can be equated with an accident that occurs in the open air, which rarely leads to catastrophic consequences. Spatial planning along roads and railroads on the surface is affected by requirements for protective measures which entails a low population density close to the infrastructure, but these are not necessarily sufficient or even relevant for overbuilds.

When it comes to the impact from fires, there is a lot of knowledge and available technology how to reduce the size of damage. Accidents that lead to fire can therefore often be managed to such an extent that catastrophic consequences can be avoided. This implicates that perhaps the most important practically feasible barrier is to dimension the substructure for explosions. However, which dimensional load is suitable is not obvious and must be investigated. Dimensioning of dynamic explosion load for the overbuild's load-bearing system is regulated in TRVINFRA-00233 [6] where it is stated that if transports of dangerous goods in ADR/RID class 1, 2 and 5 according to Ordinance (SFS 2006:311) on the transport of dangerous goods is allowed in the tunnel, the dimensional explosive load must be determined through a special analysis. However, no guidance is given on how such a special analysis shall be conducted or what content that is expected at the moment. A knowledge gap exists.

When it comes to dimensional explosive loads, there is a lack of distinct and accepted methods and practices for which load might be suitable for an overbuild. A challenge in most overbuild projects is therefore to define how large an explosive load the substructure should be dimensioned for. Measures that alleviate the consequences of an explosion are often very costly and have a large climate footprint and are therefore not obvious to take. The potential benefit (i.e. the risk-reducing effect) of the measure therefore needs to be put in relation to the cost and other negative effects.

There are currently no accepted values for various input parameters that are required to make a complete analysis regarding the benefit of measures' effect on the level of risk for third parties. Basically, this is due to the fact that there are no defined risk ratings per casualty or injury to third parties. In order to make an overall assessment of the benefits of the measures, a method and principle for risk assessment has been chosen in projects from the accident assessment of traffic accidents according to the Swedish Transport Administration's "Analysis method and socio-economic calculation values for the transport sector", ASEK 7.0 [9].

Purpose and objectives of the developed method

The overall purpose of the completed work is to evaluate the benefit of different dimensional explosive loads for the load-bearing substructures and the risk reducing effect relative to the cost of the measure. The work is performed by examining a method for cost/benefit analysis to see if it is suitable to use when evaluating risk-reducing measures in the spatial planning process. The focus has initially been to study the method for measures that reduce the impact on the loadbearing substructures in the event of an explosion causing detonation. The initial scenario has been an accident involving the transportation of dangerous goods. The work has been carried out within a specific project where the results are included in the risk analysis that forms the basis for the municipality's detailed development plan.

The objective is to be able to supplement the decision-making basis for risk assessment and selection of measures with a substantiated investigation of the effect of various barriers on the risk level and associated cost/benefit analysis.

Delimitations

The work is based on a project that includes an railroad overbuild situated in a densely populated area. The focus is on accidents with transportation of dangerous goods that lead to explosions and possible adaptations of the intended construction to reduce the impact from these accidents. Different dimensional explosive loads are studied. The used method has so far only been applied to explosion-reducing measures in the substructures. The method has not yet been applied om impact from other types of accidents or measures.

METHOD

General
The basis for the methodology is cost-benefit analysis (CBA). The benefit-part of the CBA is based on a quantitative risk analysis (QRA) studying the impact on the societal risk. The initial step is to calculate the residual societal risk for a proposed development on top of an overbuild for different cases, where the load bearing system for each case is designed for a specific dimensional explosive load.

The quantitative risk analysis is based on a relatively classic structure and methodology with definition of the studied system, inventory and identification of risk sources and possible accidents, quantitative assessment of the scope of the risks (frequencies and consequences) and evaluation of the risk level based on established acceptance criteria.

Basis
As an initial input to the risk analysis a basic design for the overbuild is chosen. The design complies with applicable regulations, but no special consideration has been taken of accidents with dangerous goods. The basic design is defined as a baseline and a minimum requirement for the substructures dimensional load. The effect on the construction has been assessed and the number of fatalities estimated based on the extent of the damage.

With the purpose to increase the robustness and reducing the consequences of potential explosion scenarios, alternative designs of the overbuild are then studied where the dimensional explosive load is gradually increased. At this stage, a dialogue with experts should be initiated to identify possibilities and limitations regarding the technically feasible dimensional explosive load. For example, to include theoretical measures that turn out to be unfeasible only risks complicating the continued process introducing excessive hopes about what potential technical possibilities there are to deal with the risks.

Risk identification
The risk analysis studies accident that may have an impact on third parties on top of and close to the overbuild. The substructure will work as a shield against several accident that could, in the event of an accident in the open, affect the surroundings, e.g. accident with flammable liquids, gas leaks, etc. Due to this shielding effect, the risk analysis, and further analysis of measures/barriers, will mainly focus on explosion scenarios.

Dangerous goods are categorized into nine different classes depending on their specific characteristics. Of all the classes, it is the transport of a few individual classes that, in the event of an accident, can lead to explosion with extensive impact on the surroundings. The classes concerned are 1.1 – mass explosive substances and 2.1 – Combustible gases. In addition, there are certain substances belonging to class 5 – Oxidizing substances and organic peroxides which if, for example, involved in a fire or exposed to high pressure or mechanical impact can disintegrate extremely violently and involve explosive firer with equivalent forces as mass explosive substances.

Essential inputs
If possible, the risk analysis should be based on local statistics on dangerous goods to be able to calculate as realistic a risk level as possible. However, consideration generally needs to be given to the fact that dimensioning based only on this input data may lead to future restrictions regarding transportation on the road or railway in question. For example, if statistics show very small transport quantities of explosive substances while there are no restrictions preventing larger transport quantities from being transported, dimensioning based on very small quantities can call for restrictions of transport with larger quantities of explosive substances.

Another aspect that needs to be considered specifically for overbuilds is that it may be relevant to study a more nuanced distribution between different explosion scenarios. The reason is that potential scenarios have a more significant contribution to the risk level in the event of an accident under an overbuild since the impact can be catastrophic. This means that a more distinct distribution between different explosion scenarios has a greater impact on the risk level compared to a risk analysis of infrastructure on the surface where more accidents (also probably with higher frequency) contribute to the risk level. The importance of nuanced distribution between different explosion scenarios is particularly important to provide a basis for further investigations regarding the need for risk-reducing measures. Otherwise it can be difficult to distinguish the risk-reducing effect of different measures, for example, with a distribution only including extreme values, e.g. very small explosions (which barely affect the F/N curve either with or without measures) and very large explosions (where realistic protective measures may have very limited effect on the consequences, i.e. the accident may have very large consequences both with or without measures).

Essential output

The output of the quantitative risk analysis results is different curves (risk levels), one for each of the studied cases, which are plotted in an F/N diagram, see example below.

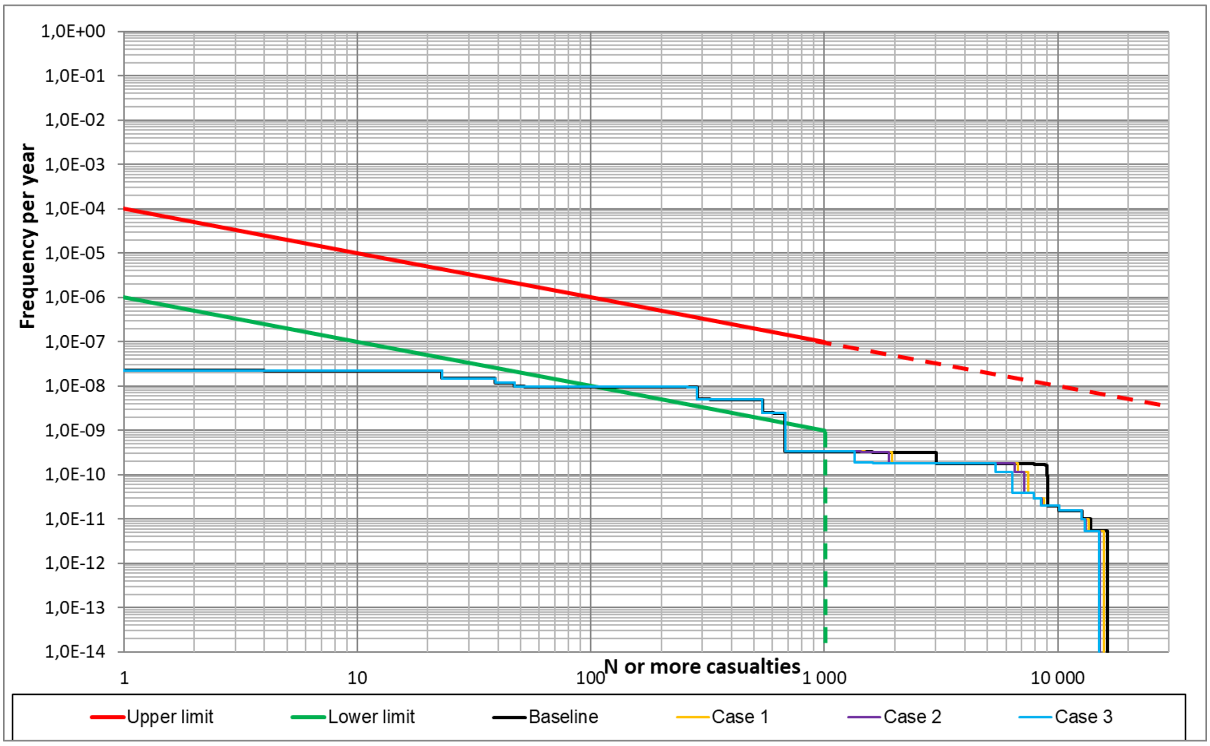

Figure 2. Example of a F/N diagram that shows the societal risk level for third parties regarding risks that may involve consequences on top of an overbuild depending on the dimensional explosive load.

Based on the F/N diagram, it is possible to get an overall image of how each measure (case) affect the societal risk in relation to the baseline and to each other. The example above shows that the difference between studied cases mainly applies to consequences with more than 1,000 casualties. To make it easier to illustrate the differences between the studied measures, we zoom in on the F/N diagram, see figure 3.

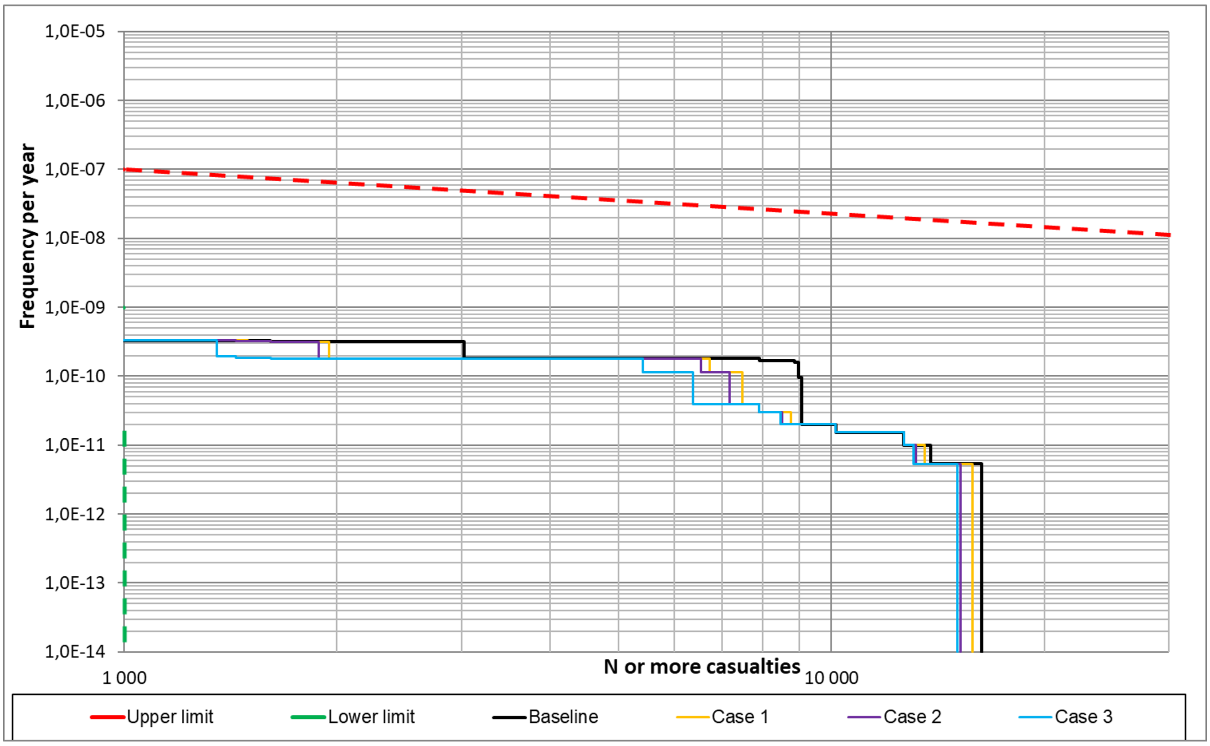

Figure 3. Same example as figure 2, but zooming in on more than 1,000 casualties.

The zoom in on the F/N diagram shows that the studied measures have a quite similar affect on to the societal risk, A gradually increasing dimensional explosion load will lead to a gradually decreasing number of casualties, but there are no giant steps on the curve. The difference between the baseline and the studied measures are mainly within consequences between 1,000 and 10,000 casualties. However, for the most extreme scenarios (with regard to damage areas and population density, etc.), the studied measures have a limited damage reduction.

This strongly indicates that there is a technical limit to what is possible to dimension the constructions for, and this limitation probably goes far below the very largest explosion scenarios.

Regarding the lack of guidelines and practices for risk assessment for more than 1,000 fatalities that is described earlier in this article, section "Risk assessment on catastrophic scenarios", figure 2 shows no limit for acceptable risk for more than 1,000 fatalities. Based on this, the assessment is that all studied cases fall within the boundaries of ALARP for consequences that lead to more than 1,000 casualties. A societal risk level within ALARP means that the risks must be carefully considered and reasonable measures must be taken to reduce the risks.

Comparing the societal risk for different levels of the deck's dimensional explosive load, it is found that the impact is limited to the most extreme scenarios of societal risk. That is, how big the maximum consequences can be for the scenarios with the lowest frequency. An increasing level of dimensional explosive loads will have a gradual reducing effect on the maximum consequences, but the consequences can still be of catastrophic potential. Due to the lack of criteria for maximum acceptable consequences, we find the need to add a different approach to the decision basis which need to be transparent and publicly accepted for overbuild projects.

Simply studying and comparing the F/N curves for studied cases to identify which case presents the lowest risk does not constitute a sufficient basis for the decision on dimensional explosive loads because it does not provide a distinct answer as to whether the measure actually is reasonable or not. Additional parameters needs to be taken into account in evaluating the measure's risk-reducing effect.

Cost-benefit analysis

In order to evaluate the plausibility of studied levels of the dimensional explosive load, a cost/benefit analysis is carried out which compares the cost of the measure with the expected benefit.

The following steps are followed in the analysis:

- Definition and delimitation of the measure
- Identification and quantification of relevant effects
- Valuation of relevant effects in Swedish kronor
- Discounting of future benefits and costs to a present value
- Calculation of net present value ratio
- Sensitivity analysis

The first two steps are handled in the quantitative risk analysis. However, moving on to the cost/benefit analysis the societal risk for each case is converted into Potential Loss of Life (PLL), which is the expected number of fatalities within a specific population per year. PLL is the total of summarizing frequency (per year) x consequences (casualties) of each scenario, i.e. $PLL = \sum(F_i \times N_i)$.

The effect of increasing the dimensional explosive load is shown as a comparison in relation to the defined baseline.

Since there are currently no accepted values for various input parameters that are required to make a cost/benefit analysis for third parties, in particular no defined risk ratings per casualty or serious injury, we need to look elsewhere. In order to assess the benefits of the barrier, risk ratings for third parties will be based on risk ratings for road traffic accidents according to the Swedish Transport Administration's "Analysis method and socio-economic calculation values for the transport sector", ASEK 7.0 [9].

ASEK 7.0 reports risk ratings for road traffic accidents in millions of Swedish kronor per person injured or killed in traffic accidents. For the injured, different risk assessments are given for the levels seriously injured, very seriously injured and not seriously injured, respectively. The risk ratings according to ASEK for each category consists of a risk assessment and an assessment of material costs. The risk assessment consists of a human value that reflects society's loss of utility in the event of the loss of a human life or the sacrifice due to physical and psychological suffering for those injured in a traffic accident. Material costs for a traffic accident consist of costs for medical care, net loss of production due to personal injury and/or loss of life, administration and damage to vehicles and other property.

Table 1. Risk ratings for road traffic accidents, per person injured or killed in traffic. Price level in 2040 (in 2017 monetary value). Material costs are stated including general VAT surcharge. In SEK and €.

	SEK Million 2040				€ Million 2040		
	Material costs	Risk ratings	Total		Material costs	Risk ratings	Total
Casualties	6,23	62,07	68,3		0,55	5,52	6,08
Seriously injured	0,97	18,24	19,21		0,09	1,62	1,71
Very seriously injured	4,53	18,7	23,23		0,40	1,66	2,07
Not seriously injured	0,04	6,44	6,48		0,004	0,57	0,58

Property damages	0,015	0	0,015		0,001	0,00	0,001

The result of a third-party cost/benefit analysis based on risk ratings for road traffic needs to be used with caution. There is ongoing research regarding individuals' risk assessment of public transport which suggests that there may be a higher willingness to pay to reduce risks when traveling in this way. In other words, there may be factors that mean that risk ratings for road traffic should only be used as an approximation in analyzes of measures for other types of traffic, e.g. rail traffic. Likewise, risk ratings for road traffic should only be used as approximations in third-person analyses. There are additional parameters that need to be considered in the assessment of the benefits of the measures, including impact on material damage and impact on national interest and urban functions, etc.

In order not to underestimate the risk ratings linked to the fact that ASEK refers to the transport sector instead of third parties, a sensitivity factor is applied to the risk ratings. This sensitivity factor also takes into account the fact that measures valued according to ASEK are generally about managing accident risks with relatively small consequences (few fatalities), while current measures aim to limit very large consequences, i.e. the sensitivity factor also partially takes into account the fundamental valuation principle of disaster avoidance. Based on this we add a quite high sensitivity factor on the risk ratings, approximately 10 times the risk ratings in ASEK.

Furthermore, the methodology according to ASEK states that the present value of the proposed measure must be calculated based on a discounting of future amounts due to today by reducing the future amounts by a certain interest rate. The recommended economic lifetime for new tunnels is stated in ASEK at 60 years. The real socio-economic discount rate must be set at 3.5%, which gives a zero sum factor (in Swedish nusummefaktor, NSF) over the lifetime of the overbuild of:

$$NSF = \frac{1-(1+0{,}035)^{-60}}{0{,}035} = 24{,}9$$

Also, with regard to this parameter, we apply a sensitivity factor taking into account that an overbuild with buildings on top may have a longer recommended economic life or that the discount rate is not the same. Not to underestimate the benefits of studied measures based on a potentially long lifetime, we add a quite high sensitivity factor on the zero zum factor, 10 times the value according to ASEK.

Additional estimation of consequences

The output of the risk analysis only include potential number of casualties since neither societal risk or individual risk consider potential number of injured. As mentioned above ASEK 7.0 reports risk ratings per person injured or killed. To be able to use ASEK 7.0 as input, an additional estimation has to be done of potential number of injured for each scenario, severely and slightly. We make an assumption that for every fatality, 5 people are seriously injured (very seriously injured according to ASEK 7.0), i.e. the number of seriously injured is 5 times as high as the number of people killed in an accident. The number of slightly injured (not seriously injured according to ASEK) is assumed to be 10 times as high as the number of fatalities. However, the sum of fatalities, severely injured and slightly injured is limited to the expected number of people within the studied area.

Costs

The calculated benefit of each case (i.e. dimensional explosive load) in relation to the stated baseline needs to be compared to the estimated cost increase of each case. This cost estimation could be more or less detailed. There are a number of inputs that could be included in the cost estimation, such as potentially increased maintenance and limitations on exploitation. One input that has to be included is the expected additional cost for reenforcing the substructure to manage a higher dimensional explosive load in relation to the baseline. This requires input from the constructor.

Comparing costs and benefits

In ASEK 7.0 the assessment of measures based on a cost/benefit perspective is performed by subtracting the cost from the expected benefit. > 0 means that the measure is assessed to be reasonably practicable, and a negative ratio points to a not reasonably practicable measure.

The downside to this approach is that it provides a rough, and potentially loose, basis for deciding whether measures should be implemented or not. The report "Evaluation of Risk" funded by the Swedish Civil Contingencies Agency, [8] alerts the problem of dismissing measures on the grounds that they are marginally more costly than the benefit they can achieve. Adding a grossly disproportionate factor (GDF) to the assessment is applied in several areas and countries (see examples in, among others, [10] and [11]). In these cases, the assessment of whether studied measures are reasonably practicable or not is based on dividing the cost by the benefit to obtain the ratio between these two parameters. For a measure not to be judged to be reasonably practicable, this ratio needs to be > 1 x GDF.

Nor here there are guidelines, neither national nor international, on what is an acceptable level for GDF, i.e. the degree of "disproportionality". Normally, the GDF is determined by the actual risk level within ALARP. If the risk is low (i.e. close to the lower limit of ALARP) a low GDF can be considered, but with a high risk (close to the upper limit of ALARP), the GDF should increase. GDF greater than 10 is uncommon. E.g. the British nuclear power industry uses a GDF of 10 as the highest value where the cost of a measure can still be considered reasonable in relation to the measure's benefit [10]. There are few examples of other areas using higher levels of GDF at high levels of risk.

Considering the purpose of the specific measures, i.e. to reduce the risk level of catastrophic scenarios, a risk assessment area with sparse know-how, and practices or guidelines, we recommend that the GDF should be set high. For example, on assessing the most reasonably practicable dimensional explosive load for an overbuild with land use very close to, or on top of, the infrastructure, we set GDF = 100.

CONCLUSION

We are fully aware that risk ratings for road traffic accidents cannot be used directly calculating the benefits in a third-party analysis. The analysis should be regarded as a guideline for the benefit of the studied barrier explosion protection of structural elements. There are a couple of parameters that need to be addressed in the assessment of the benefit, including stricter risk acceptance criteria for third parties compared to road or railroad users, and also the basic risk evaluation principle that suggests that there may be a higher willingness to pay to reduce scenarios with catastrophic potential. We take these parameters in consideration by adding sensitivity factors while estimating the benefit of studied measures (both on risk ratings and zero sum factor of the barrier). On top of that, we recommend adding a grossly disproportionate factor (GDF) to the assessment of whether studied measures are reasonably practicable. Considering the purpose of the specific measures, i.e. to reduce the risk level of catastrophic scenarios, a risk assessment area with sparse know-how, and practices or guidelines, we recommend that the GDF should be set high.

Regardless of the identified uncertainties, we do believe that a cost/benefit analysis will make an important piece of the puzzle in the decision-making basis for the selection of dimensional explosive load and thereby accepting the resulting residual risk, as it gives a more complete image of the actual risk-reducing effect which leads to a less subjective risk evaluation.

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