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Structures built over railway lines - Construction requirements in the track zone

Constructions situées au-dessus des voies ferrées - Dispositions constructives dans la zone des voies
Überbauung von Bahnanlagen - Bautechnische Maßnahmen im Gleisbereich

UNION INTERNATIONALE DES CHEMINS DE FER
INTERNATIONALER EISENBAHNVERBAND
INTERNATIONAL UNION OF RAILWAYS

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VII - Way and works

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Warning

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Contents

Summary

This leaflet sets out recommendations for managing the risk from derailed trains near structures built over railway lines. It distinguishes between structures that are generally occupied (for example, multi-storey office blocks) and those that may not be occupied (for example, bridges). Different methods are proposed for these two types of structure. The methods take into account those people most at risk and the likely speed range for rail traffic passing under these structures. It is made clear that, in assessing the risk, some parameters are the responsibility of the railway and not the engineer.

1 - General

The object of this leaflet is to recommend suitable measures to reduce as far as is reasonably practicable the effects of an accidental impact from a derailed vehicle against the supports of structures located above tracks and supports carrying superstructures. This leaflet refers to both preventative and protective measures (including static design measures).

The recommendations apply to the following:

- Class A structures over lines where trains travel at speeds up to and including 120 km/h,

- Class B structures over lines where passenger trains travel at speeds up to and including 300 km/h,

- Class B structures over lines where freight trains travel at speeds up to and including 160 km/h.

For class B structures, the recommended procedure requires input from the relevant authority.

2 - Classification of structures

Depending on their utilisation, structures built above tracks are divided into two classes:

2.1 - Class A structures

Superstructures supporting elevated structures that are permanently occupied (such as offices, lodgings, business premises) or serve as a temporary gathering place for people (such as theatres and cinemas) as well as all the multi-storey structures which are only subject to short-term occupancy (such as multi-storey car parks and warehouses).

2.2 - Class B structures

Superstructures not supporting elevated structures, such as roadways, road bridges, railway bridges, footbridges and similar structures. Single-storey structures not providing long-term occupancy (e.g. parking areas, warehouses) should be allocated to this class.

The provisions of this leaflet do not apply to any type of roof construction or platform awnings.

3 - Factors influencing recommended measures

3.1 - General factors influencing risk for Class A & Class B structures

3.1.1 - Class A structures

The risk from derailed trains to Class A structures built over tracks and to people affected by these structures depends upon the following:

- the number of people occupying the structure,
- the permissible speed of trains using the line,
- the number of tracks,
- the structural configuration of the structure,
- the presence of switches and crossings in the vicinity of the structure.

The following factors also affect the risk but to a lesser extent:

- the type of train using the line (passenger, freight),
- the curvature of the track.

3.1.2 - Class B structures

The risk from derailed trains to Class B structures built over the tracks and to people affected by these structures depends mainly upon the following:

- the number of people travelling in the train,
- the presence of switches and crossings,
- the permissible speed of trains using the line,
- the number of trains using the line,
- the number of tracks,
- the structural configuration of the structure.

The following factors also affect the risk but to a lesser extent:

- the number of people using the structure,
- the curvature of the track.

3.2 - Danger zones for class A structures

For Class A structures, three danger zones require consideration:

ZONE 1: The distance from the nearest track centre line is less than 3,0 m (Appendix B, Fig. 1 - page 20)

ZONE 2: The distance from the nearest track centre line is 3,0 and 5,0 m (Appendix B, Fig. 2 - page 20)

ZONE 3: The area behind track ends (Appendix B, Fig. 3 - page 21)

3.3 - Class B structures

For new Class B structures, the risk from derailed trains should take into account the following factors:

- the predicted rate of derailed trains on the approach to the structure,
- the permissible speed of trains using the line,
- the predicted deceleration of derailed trains on the approach to the structure,
- the lateral distance a derailed train is predicted to travel,
- whether the line is single or not in the vicinity of the structure,
- the type of train (passenger / freight) passing under the structure,
- the predicted number of passengers in the train passing under the structure,
- the frequency of trains passing under the structure,
- the presence of switches and crossings on the approach to the structure,
- the static system (structural configuration) of the structure and the robustness of the supports,
- the location of the supports to the structure relative to the tracks.

The following factors also affect the risk from derailed trains, but to a lesser extent:

- the curvature of the track in the vicinity of the structure,
- the number of tracks, where there are more than two.

The effect that any preventative and protective measures proposed have on other parts or other users of the adjacent infrastructures should also be taken into account. This includes for example the effects on signal sighting distances, authorised access, and other safety considerations relating to the layout of the track.

4 - General design principles

The design of the structure should also take into account the factors influencing the risk as set out in point 3 - page 4.

When designing structures that are to be built over tracks, the reasonably foreseeable development of railway infrastructure, particularly the track layout and the structural clearances, should be taken into consideration.

For class A structures covering large areas and characterised by a large number of supports, the areas under the construction which are unobstructed by supports should be as large as possible in order for subsequent modifications of the track to be carried out. A plan with a description and graphical representation of all supports, detailing the allocated zone and group, should be produced for acceptance by the relevant authority.

The structure (including the supports) should also be designed so that the installation of temporary structures required during the construction phase and future maintenance can be carried out as far as possible without interfering with traffic operations.

5 - Class A superstructures

5.1 - Field of application

The following provisions apply to the design and construction of supports (walls, wall-type sections and columns) which have to carry loads from the elevated structures and are located within Zones 2 and 3. For supports situated within Zone 1 separate provisions should be laid down by the railway. The provisions laid down in Appendix D - page 23 may be used as a basis for these.

5.2 - Group allocation

Supports situated within ZONE 2 are allocated to the following groups depending on track utilisation (type of traffic, maximum permissible speed) of each track running alongside them. The track with the highest occupancy rate or the greater maximum speed will determine the group classification.

Group 1: Supports alongside tracks with a regular service of trains running at speeds of between 50 km/h and 120 km/h, and trains with rolling stock that does not meet the latest standards and running at a maximum speed of 100 km/h.

Group 2: Supports alongside tracks with a regular service of trains running at a maximum speed of 50 km/h.

Group 3: Supports alongside tracks used only for shunting or marshalling (maximum speed of 20 km/h).

When allocating supports to one of the 3 groups, attention should be given, if possible not only to current track utilisation but also to the anticipated future alterations in the pattern of utilisation.

5.3 - Basic provisions for all groups

5.3.1 - Equivalent loads for derailments

When dimensioning the supports, the impact forces exerted by derailed vehicles on the supports should be taken into account in the form of horizontal equivalent loads acting at a height of 1,80 m above the top of the rail in the direction stipulated under the following paragraphs.

In addition to these equivalent loads, all permanent loads together with the applied traffic loads should be taken into consideration.

Also, the effect of the equivalent loads on the immediately - adjacent structural member of the superstructure above the relevant supports and on the foundations below should be taken into consideration if these are immediately under the relevant supports.

5.3.2 - Supports situated on platforms

For supports situated on platforms or loading ramps with a minimum height of 38 cm above the top of the rail, the equivalent loads allocated to the respective groups may be reduced by half.

The total loss of individual supports does not have to be considered.

5.3.3 - Check of residual cross selection in the case of an accident

A check should be made on all supports designed to resist equivalent loads to see that half the cross section can support all anticipated loads from the superstructure.

5.4 - Design, equivalent static forces and other measures for supports in ZONE 2

5.4.1 - Group 1 supports

5.4.1.1 - Design

1. In principle, supports should be designed as continuous walls. The provision of non-continuous walls, in other words walls constructed from individual wall-type sections, is permissible.

2. If the wall is built up from a number of wall-type sections, collapse of the superstructure due to impact from derailed railway vehicles should be prevented by choosing adequate dimensions for the individual sections. The dimensions, particularly the length of the sections parallel to the track, should be chosen in such a way that total loss of load-bearing capacity due to the impact of a derailed train cannot be expected.

   Minimum dimensions:

   $$L:W = 4:1 \qquad W \geq 0{,}8\ \text{m} \qquad L \geq H/2$$

Where	L =	length of support
	W =	width of support
	H =	height of support (measured from ground level)

3. If platforms or elevated foundations with a height of 55 cm or preferably 76 cm above the top of the rail are provided, supports do not have to be designed as walls.

5.4.1.2 - Equivalent loads

All walls and wall-type sections should be designed for an equivalent load of:

1. 4 000 kN parallel to the track axis and,

2. 1 500 kN at right angles to the track axis.

The design should be checked for each load case separately

5.4.1.3 - Other measures

If, in individual cases, the minimum dimensions cannot be chosen in compliance with point 5.4.1.1, total loss of these supports should be assumed when designing the superstructures. Such supports should not be used as the first in a row of columns or located one after another.

5.4.2 - Group 2 supports

5.4.2.1 - Design

1. Supports should be designed in accordance with point 5.4.1.1 - page 8.

2. If this is not possible due to technical reasons, they may be designed as individual columns.

   A crash barrier should be provided in front of the first column in a row or in front of any column that is located in an area where there is a high risk of derailment. These crash barriers should be designed in such a way as to provide for the deflection function and should be easily replaceable.

3. To protect supports subject to an impact risk, a platform or an elevated foundation with a minimum height of 55 cm above the top of the rail should be provided.

5.4.2.2 - Equivalent loads

The supports as well as the crash barriers should be designed to withstand an equivalent load of:

1. 2 000 kN parallel to the track axis and,

2. 750 kN at right angles to the track axis.

The design should be checked for each load case separately.

5.4.2.3 - Other measures

The design should allow for the loss of one column following an accident. The loss of several columns arranged one after the other in the track direction does not have to be considered.

5.4.3 - Group 3 supports

5.4.3.1 - Design

1. If required for operational reasons (to give better visibility for shunting operations), supports should, in general be designed as individual columns, otherwise the wall-type sections should be preferred to individual columns.

2. Crash barriers in accordance with the provisions of point 5.4.2.1 (2) should be arranged in front of the first column in a row or in front of columns which are at risk because they are located within switching zones. In addition to crash barriers, the provision of a check rail is recommended if this is technically possible.

3. If a check rail is provided, it should be installed over a minimum length of 30 m before approaching the support.

5.4.3.2 - Equivalent loads

1. All columns and crash barriers should be dimensioned for an equivalent load of:

   a. 2 000 kN parallel to the track axis and

b. 750 kN at right angles to the track axis.

The design should be checked for each load case separately.

2. In principle, the loss of individual columns need not be taken into consideration.

5.5 - Measures in ZONE 3

5.5.1 - Supports

The shape and dimensions of the supports located within this zone may be chosen freely. For equivalent loads and other measures the same provisions apply as for group 3.

5.5.2 - Track ends

Track ends should be provided with a buffer stop block with a minimum braking capacity of 2 500 kNm and an end impact wall.

For tracks used by passenger traffic, the end impact wall should have a height of at least 1,5 m above the top of the rail and should be dimensioned for an equivalent load of 5 000 kN at a height of 1,0 m above the top of the rail.

In shunting and marshalling areas, the wall should have a minimum height of 2,0 m above the top of the rail and should be dimensioned for an equivalent load of 10 000 kN at a height of 1,0 m above the top of the rail.

When designing such an end impact wall, suitable allowance may be made for the restraint provided by the weight of the vehicles on a tensile base slab supporting the track if it has a fixed and stiff connection to the wall.

6 - Class B superstructures

6.1 - Principles

6.1.1 - General principles

- Incidents where a train derails on the approach to a class B structure and collides with the structure are rare. The potential consequences are very severe however so that the risk should not be ignored.

- Generally, the main risk associated with the impact of a train is harm to persons travelling in the train. The recommendations set out a risk assessment procedure aimed principally at reducing this risk as far as is reasonably practicable.

- In the event of a derailment in the vicinity of the structure, the presence of the supports to the structure increases the risk to people in the derailed train. The procedure allows variations in the lateral clearance of the supports to be taken into account.

- The procedure also allows the effects of other preventative and protective measures to be assessed.

- For existing structures, the relocation of the structural supports is generally not reasonably practicable. At many locations a risk assessment is not required. At locations where the risk is perceived to be high in relation to other risks to the safety of train operations, other measures should be assessed to determine whether they are reasonably practicable. The priority of such assessments should take into account the level of other risks to the safety of train operations (see point 6.5 - page 14 for guidance).

- The risk to class B structures from a derailed train is generally significantly increased where the structure is located near switches and crossings. The recommendations allow this increased risk to be taken into account where it is not reasonably practicable to avoid such situations. Situations where the supports to the structure are in line with the turnout direction of the switch should particularly be avoided unless otherwise justified.

- For new lines, appropriate measures should be considered at an early stage of the project so as to maximise the potential for reducing the risk.

- The risks of harm to people are evaluated by placing a value on preventing a fatality and an aversion factor to take into account the public aversion to multi-fatality incidents. This allows the costs and benefits of various protective and preventative measures to be compared in monetary terms.

- The results of the risk assessment should be used in conjunction with engineering judgement and any other requirements of the relevant authority before finally determining the optimum protective and preventative measures.

6.1.2 - Other factors that may require consideration

When assessing the risk, the following factors may also need to be taken into account:

- the availability of emergency services and accessibility to the site of the accident (these can vary considerably according to country and topography),

- the damage to property (for example damage to the train or to the structure),

- disruption to traffic (for example road traffic, rail traffic).

Where such a situation exists, it may be justifiable to take further action in addition to the recommendations included in this leaflet.

6.2 - Scope

The recommendations apply principally to multi-span structures where the supports next to the track are intermediate supports.

The principles may however be applied to single-span bridges supported on abutments.

The principles may be applied to rail over rail bridges providing appropriate modifications are made to the scenarios of the consequences of a derailed train under the bridge.

6.3 - Recommended preventative and protective measures for Class B structures

The following preventative and protective measures for Class B structures are recommended for consideration in establishing the optimum measures. Where such measures are provided, their effect on the risk assessment should be taken into account.

- Increasing the lateral distance between support and track axis.

- Increasing the longitudinal distance between the structure and any switch on the approach to the structure.

- Avoidance of supports located on a line that is crossed by a line extended in the direction of the turnout of a switch. If this is not reasonably practicable, the provision of dwarf walls should be considered, taking into account their effect on other adjacent infrastructure.

- Provision of continuous walls or wall type supports as detailed in point 6.6 - page 15.

- Provision of deflecting devices and absorbing devices as indicated in point 7 - page 17.

- Provision of a continuous superstructure.

- Avoidance of supports consisting of separate columns (where this is not reasonably practicable, provision of supports with sufficient continuity so that the superstructure remains standing if one of the columns is removed - this measure is only likely to be effective for speeds up to 160 km/h).

- Provision of fixed end connection between foundations and supports (avoidance of pin-jointed piers).

- Provision of robust supports to withstand impact from a glancing impact from a derailed train (see point 6.6 - page 15 and Appendix A - page 18).

6.4 - Method for determining the location of supports for new class B structures (taking into account other preventative and protective measures)

6.4.1 - Main steps in method

The location of supports for new structures should be based upon a risk assessment using the following steps:

- an analysis and evaluation of the perceived risk,

- an evaluation of the costs and benefits, in terms of reduced risk, of reasonable preventative and/or protective measures,

- the determination of the lateral clearances to supports, taking into account any preventative and/or protective measures proposed, engineering judgement and the requirements of the relevant authority.

Appendix F - page 27 sets out, as guidance only, values of the parameters that may be used in the risk assessment. Appendix F does not form part of the recommendations.

Appendix G - page 38 gives an example of the application of the method. Appendix G does not form part of the recommendations.

6.4.2 - Analysis of perceived risk

The risk should be analysed using the following procedure:

- Establishing the type of trains passing under the bridge .

- Estimating the likelihood of a train becoming derailed on the approach to a bridge (see point F.1 - page 27 for guidance) taking into account:

    - the presence of any switches and crossings on the approach to the bridge where it is not reasonably practicable to avoid such situations,
    - any preventative and protective measures provided.

- Identifying and estimating the likelihood of various scenarios as a result of the derailed train passing under the bridge taking into account any preventative and protective measures provided (see point F.6 - page 31 for guidance). The scenarios should include:

    - the train impacting with the bridge (see point F.2 - page 28 for guidance),
    - the bridge collapsing as a result of the impact from the train (see point F.3 - page 29 for guidance),
    - collision with a train travelling in the opposite direction - only for situations where there are more than one track passing under the bridge (see point F.4 - page 30 for guidance).

- Estimating the consequence in terms of harm to people for the various scenarios (see point F.7 - page 31 for guidance).

- Estimating the annual risk (likelihood x consequence) from each of the scenarios in terms of harm to people (see point F.8 - page 33 for guidance).

- Estimating the annual perceived risk by applying an aversion factor to fatalities to the annual estimated risk. The aversion factor to be used is the responsibility of the relevant authority (see points F.9 and F.10 - page 33 for guidance).

- Estimating the total annual perceived risk at a structure by summing the perceived risks from each scenario (see point F.11 - page 33 for guidance).

6.4.3 - Evaluation of annual perceived risk

The evaluation of the perceived risk should be obtained by applying a value placed on preventing a fatality to the total perceived risk at a structure. This enables the perceived risk to be expressed in monetary terms. The value placed on preventing a fatality is the responsibility of the relevant authority (see point F.12 - page 34 for guidance).

6.4.4 - Evaluation of the annual costs and benefits of providing preventative and protective measures

The costs and benefits should be evaluated using the following procedure:

- Estimating the annual cost of providing additional lateral clearances and/or other preventative and protective measures (see point F.13 - page 34 for guidance).

- Estimating the annual reduced perceived risk from providing these additional lateral clearances and/or other preventative and protective measures (see point F.14 - page 36 for guidance).

6.4.5 - Criteria for determining the optimum protective and preventative measures

The criteria for determining the optimum preventative and/or protective measures should be established.

The criteria upon which the determination of the lateral clearances for supports is based are the responsibility of the relevant authority (see point F.15 - page 36 for guidance).

6.5 - Appraisal of measures for existing structures

The following procedure should be followed:

- If for existing structures there are no switches and crossings in the vicinity of the bridge, further measures are not necessary (see point F.2 - page 28 and Table 4 - page 28 for guidance).

- If this criterion is not fulfilled, for the preliminary examination the same procedure should be followed as for new structures. If a situation is acceptable for new structures, it is also acceptable for existing structures.

- If it is established that sufficient measures appropriate for a new structure are not provided, a more detailed appraisal should be undertaken taking into account the principles in point 6.1 - page 11 and using the procedure outlined for new structures.

See point 6.1.1 - page 11 for the prioritisation of these appraisals.

6.6 - Supports for Class B structures

6.6.1 - Dimensions for continuous walls

Supports for class B structures may be considered as a continuous wall if they conform to the following minimum dimensions:

$$L: W \geq 4:1 \qquad W \geq 0{,}6\ \text{m} \qquad L \geq H/2$$

Where L = length of support

W = width of support

H = height of support (measured from ground level)

6.6.2 - Robustness of supports

Unless otherwise justified, supports should be designed to be robust to reduce the likelihood of the bridge collapsing as a result of impact from a derailed train.

The method used to provide robustness should generally be determined on a site-specific basis taking into account the risks from derailed trains and from the bridge collapsing.

Methods that should be considered include the following:

- Provision of sufficient strength to withstand equivalent forces (see Appendix A - page 18 for examples).

- Provision of additional safety factors in designing the supports to withstand normal permanent and variable traffic loads.

- Designing the support so that it is capable of supporting permanent loads with or without reduced traffic loads assuming that part of the support is destroyed by the derailed train, for example:

  - Half the cross section is capable of supporting the permanent loads together with the reduced traffic loads,
  - One third of the cross section is capable of supporting the permanent loads.

6.6.3 - Protection to supports

All supports should be protected by raised foundations at least 76 cm above the top of the rail.

The raised foundations should be profiled (boat shaped) to reduce the likelihood of a head-on impact with the end of the support.

Consideration should be given to separating any protective raised foundation plinth from the support to a structure to allow the plinth to absorb energy from a derailed train without damage to the support.

6.7 - Structure-specific risk analysis

If a situation differs significantly from the defined basic scenarios or presents specific risk-increasing factors, a structure-specific risk analysis and appraisal should be carried out.

7 - Additional measures - Protection arrangements

As an additional measure to protect against impact and minimise the consequences, railways may use protective devices in accordance with the prevailing local circumstances and taking into account other requirements of the railway (for example, maintenance requirements, safe working arrangements for people working on or about the track etc.).

7.1 - Deflecting devices

- raised foundation plinths,
- platform edges, loading ramps,
- guide walls,
- check rails.

Raised foundation plinths, platforms and loading ramps are efficient means of reducing the impact risk. These measures are appropriate for all categories of speed.

Guide walls are suitable only if they can absorb high horizontal loads and have a high degree of ductility. Moreover, the guide wall should comply with the provisions for raised foundations with a minimum height of 76 cm above the top of the rail. The guide walls should be installed as close to the track as possible taking into account any clearance required for the safe passage of trains.

Check rails are an efficient means of protecting structural elements located within the shunting or marshalling zone (Class A, Group 3) and subject to the risk from impact.

7.2 - Absorbing devices

- crash barriers
- absorbing devices

These are construction elements with the ability to absorb kinetic energy progressively.

Absorbing devices should be able to absorb the kinetic energy of impacting rolling stock.

<u>For Class A structures</u>, crash barriers are suitable for low speeds (Groups 2 and 3) for the protection of individual columns. They should be designed in such a way as to ensure maximum deflection. The bracing should be so designed that there is a break point to prevent the foundation from being torn out and to allow the impact block to be replaced.

<u>For Class A structures</u>, absorbing devices are recommended principally for the protection of ZONE 3 and for low speeds (Group 3). For ZONE 1 these devices are not suitable due to the great deformation distance needed to guarantee sufficient energy absorption, which rarely exists in structural elements located within ZONE 1. The kinetic energy of rolling stock running at high speeds cannot reasonably be absorbed by construction measures

<u>For Class B structures</u>, absorbing devices should be agreed with the relevant administration.

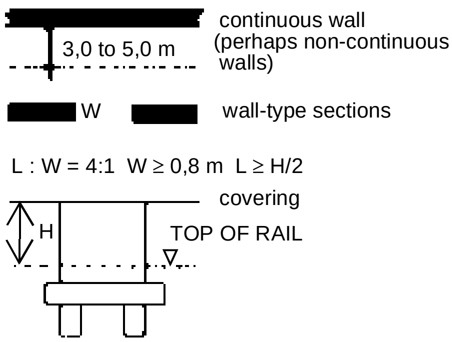
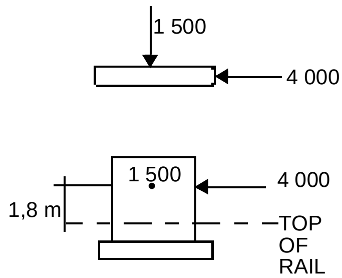
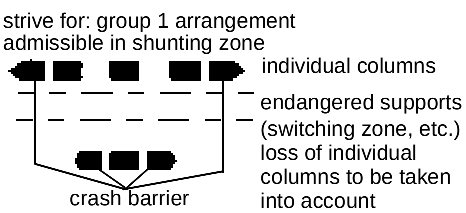
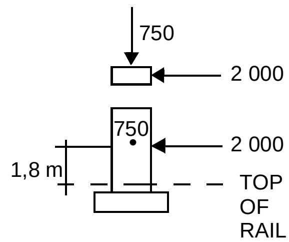
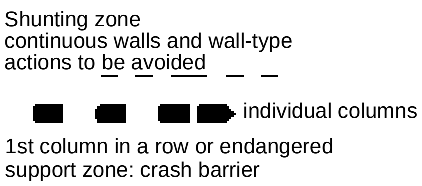
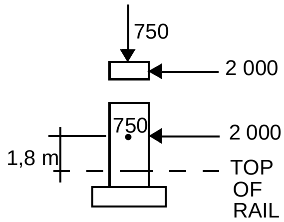
R

Appendix A - Provisions for Class A superstructures located within ZONE 2 and ZONE 3

Superstructures with elevated structures

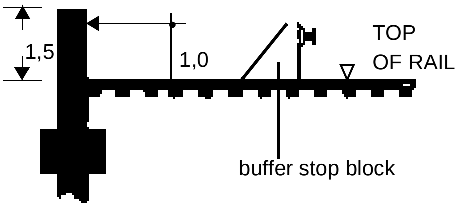
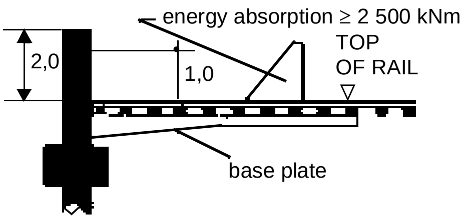
Superstructures providing long-term occupancy (such as offices, lodgings, business premises) or serving as temporary gathering place for people (such as theatres and cinemas) as well as multi-storey structures not subject to long-term occupancy by people (such as multi-storey car parks and warehouses).

Table 1 : Supports located within ZONE 2

Group	Support	Construction	Detailing [kN]
1	alongside tracks v > 50 km/h		
2	alongside tracks v ≤ 50 km/h		
3	alongside tracks used for shunting or coupling		

ZONE 3 - Arrangement of supports as in group 3

Table 2 : ZONE 3 - Rails and walls

Tracks serving passenger traffic		5 000 kN at 1,0 m above top of rail
Tracks for shunting and coupling		10 000 kN at 1,0 m above top of rail

Appendix B - Presentation of zones

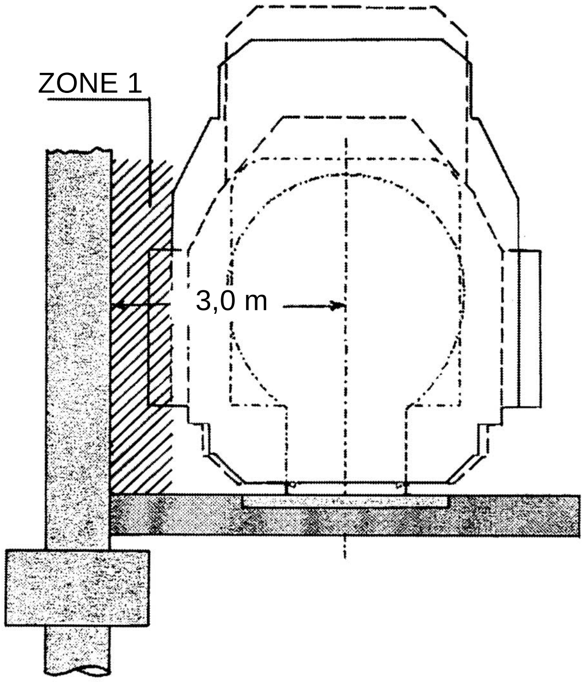


Fig. 1 - ZONE 1

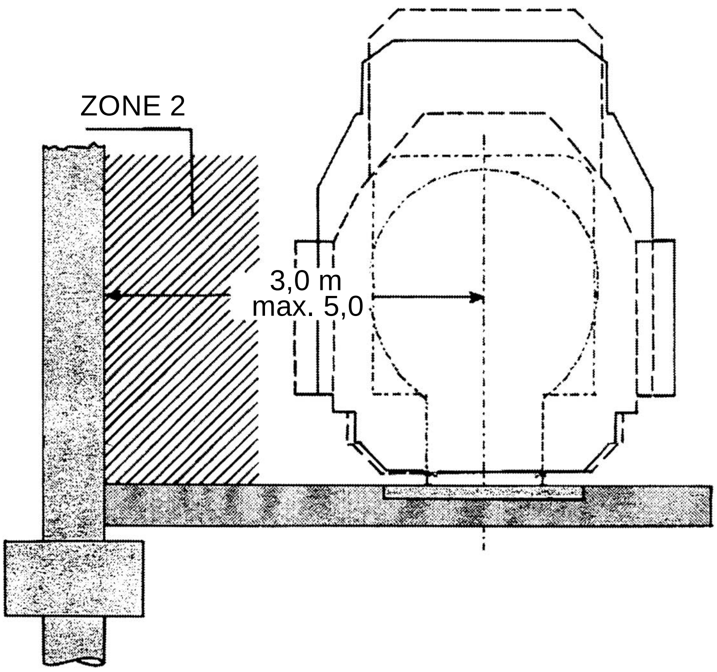


Fig. 2 - ZONE 2

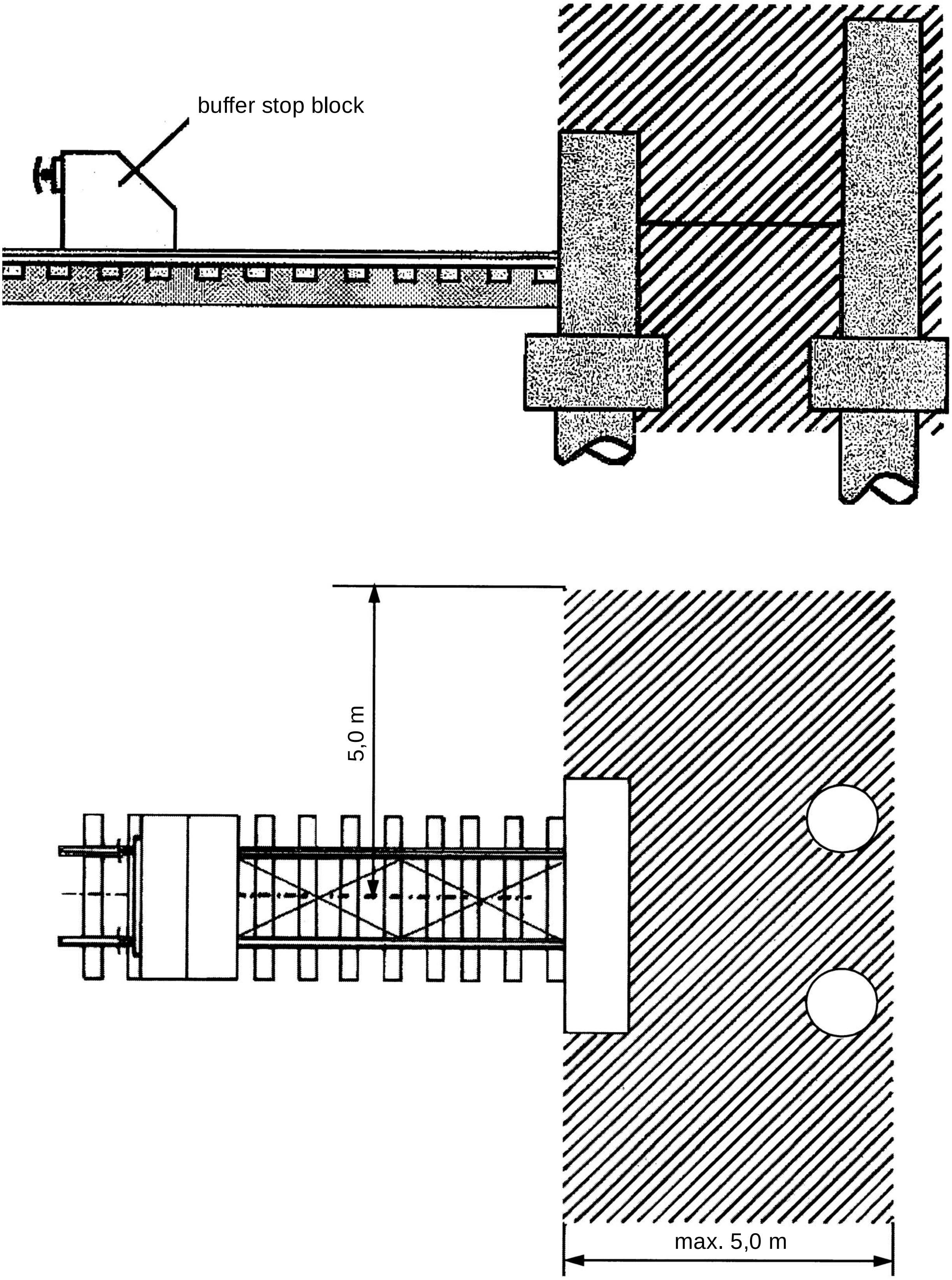


Fig. 3 - ZONE 3 (behind rail end)

Appendix C - Comments concerning ZONE 1 and ZONE 2

"Derailment of vehicles"
Train movement interruption criteria

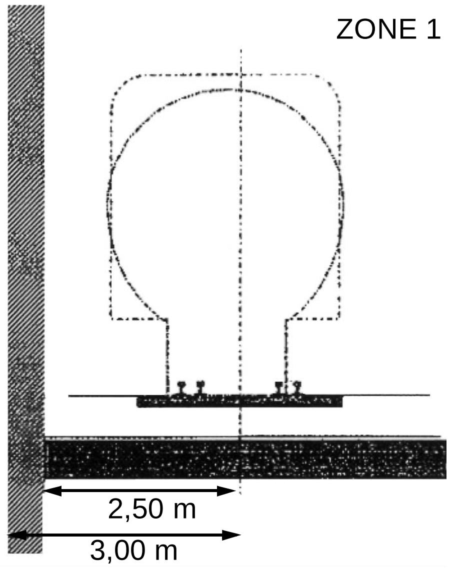
In the most likely incident of train movement interruption - derailment of vehicles incorporated in a train due to wheel or axle breakage, especially in heavy haul trains - the vehicles will deviate from the track until, following a displacement of about 1,35 m, the running rail on the derailment side stops the vehicle (the wheelsets), thus serving as check rail and avoiding further deviation from track.

Study of the most frequent causes of train derailment shows that when the wall distance (a) was ≥ 3,0 m, the train only came into contact with it in a few cases since the derailed vehicles were checked by the rail nearest to the wall (which takes over, to a certain degree, the function of a check rail).

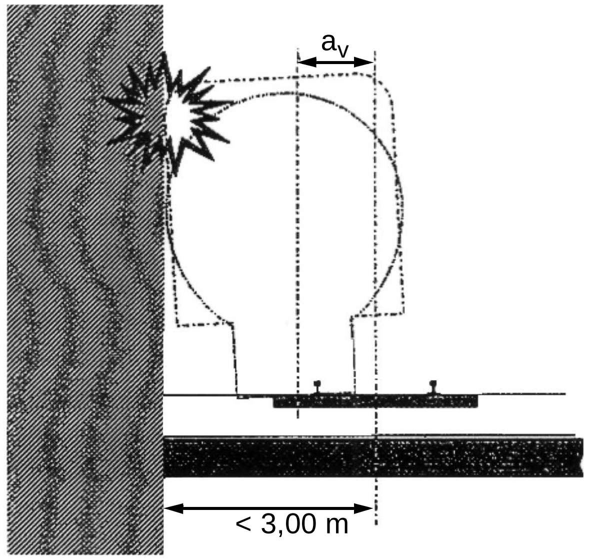
The standard case, to which this leaflet applies, is therefore limited to considering the supporting elements located within ZONE 2.

For supporting elements located within ZONE 1, additional measures should be adopted in line with the prevailing conditions of the particular case concerned.

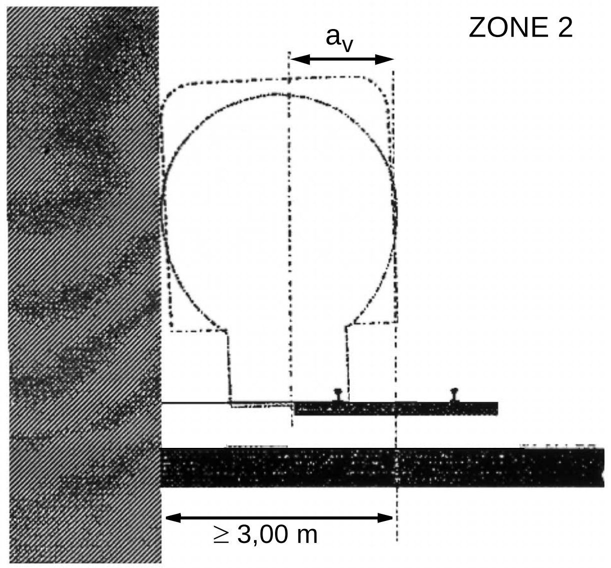
These additional measures may include: check rails, platforms, crash barriers or any other solution based on the special provisions in Appendix D - page 23.



Minimum distance to wall according to clearance-gauge requirements a = 2,50 m



Contact with the wall occurs if the track distance is < 3,00 m. The wall serves to check the derailed vehicles; this function is fulfilled satisfactorily if there are no major protections, thus allowing the accident consequences to be reduced to a minimum.



a_v = 1,40 m displacement factor. From a wall distance of ≥ 3,0 m upwards the rail situated nearest to the wall will act as check rail.

Appendix D - Provisions concerning Class A supports located in ZONE 1

D.1 - Design

In principle, supports should be designed as continuous walls. Arrangement of non-continuous walls according to Fig. 4 - page 23 is permissible. Protection bays are not rated as non continuous walls.

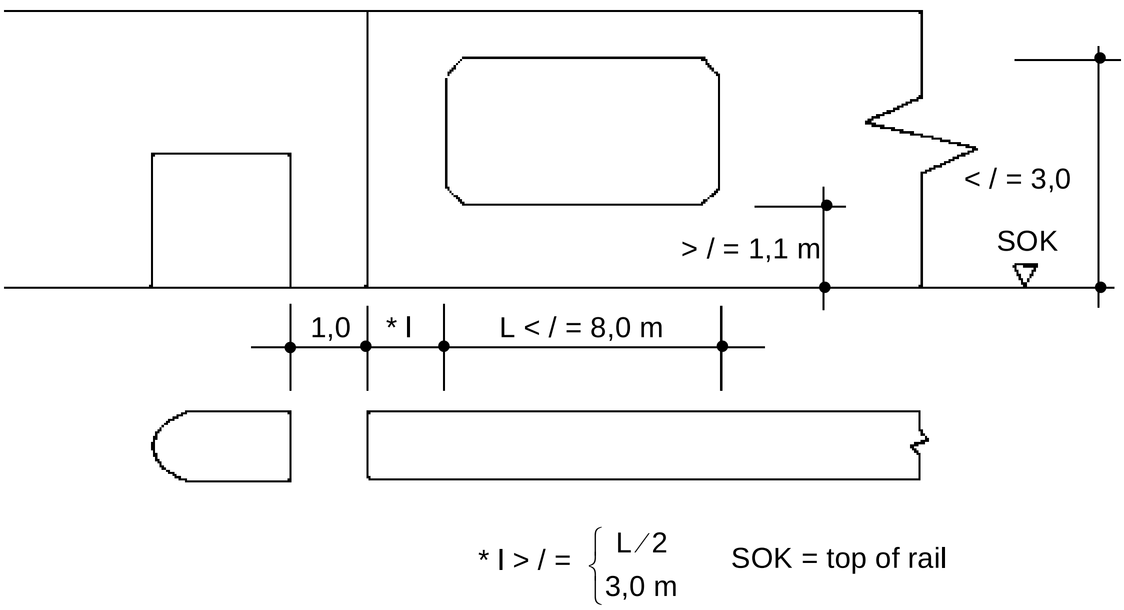


Fig. 4 - Geometric dimensions

D.2 - Equivalent loads

The values and points of application of the equivalent loads are contained in Fig. 5 and 6 - page 24.

Forces F1 and F2 are applied to the first wall section.

Forces H1 and H2 are applied to all other wall sections.

F1 =	10 000 kN	parallel to track axis
F2 =	3 500 kN	perpendicular to track axis
H1 =	4 000 kN	parallel to track axis
H2 =	1 500 kN	perpendicular to track axis

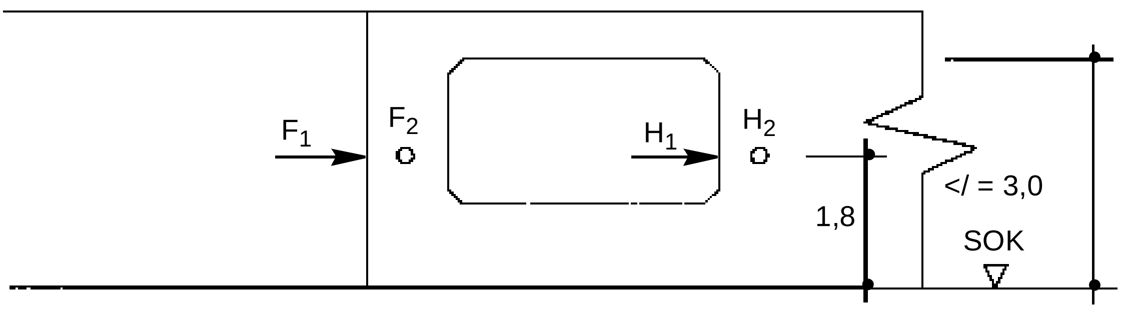


Fig. 5 - Points of application of equivalent loads

D.3 - Other measures

If forces F1 and F2 cannot be carried by the first wall section, an impact fender should be arranged according to Fig. 6. In this case, forces F1 and F2 will be applied at a height of 1,50 above the top of the rail.

Forces H1 and H2 should be carried by the first wall section.

Verification according to point 5.3.3 - page 8 is required.

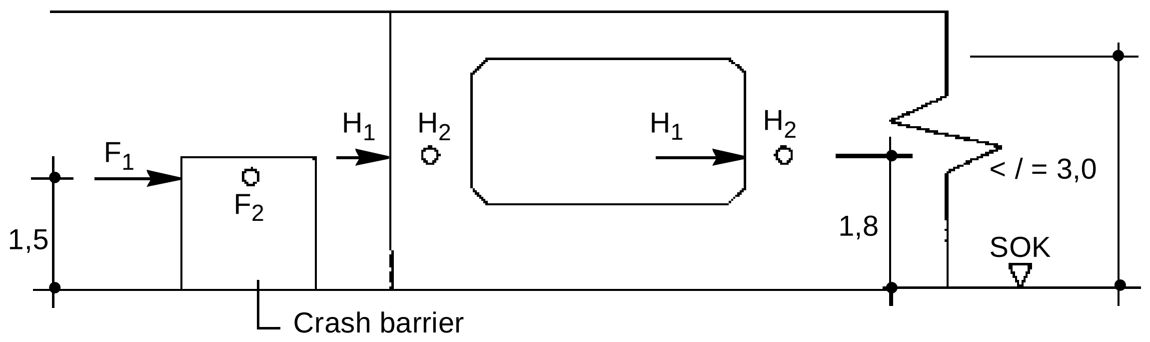


Fig. 6 - Points of application of equivalent loads

Appendix E - Definition and list of influencing factors

E.1 - Definitions

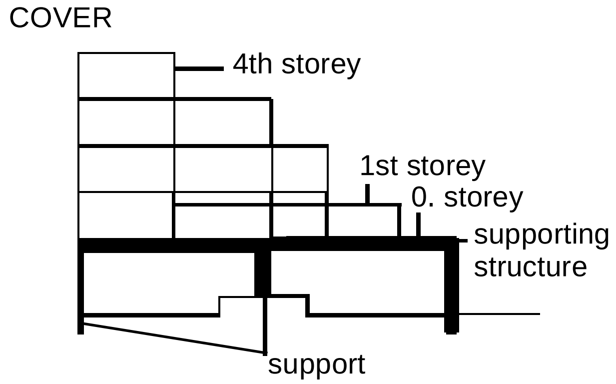


Fig. 7 - Superstructures with elevated structures

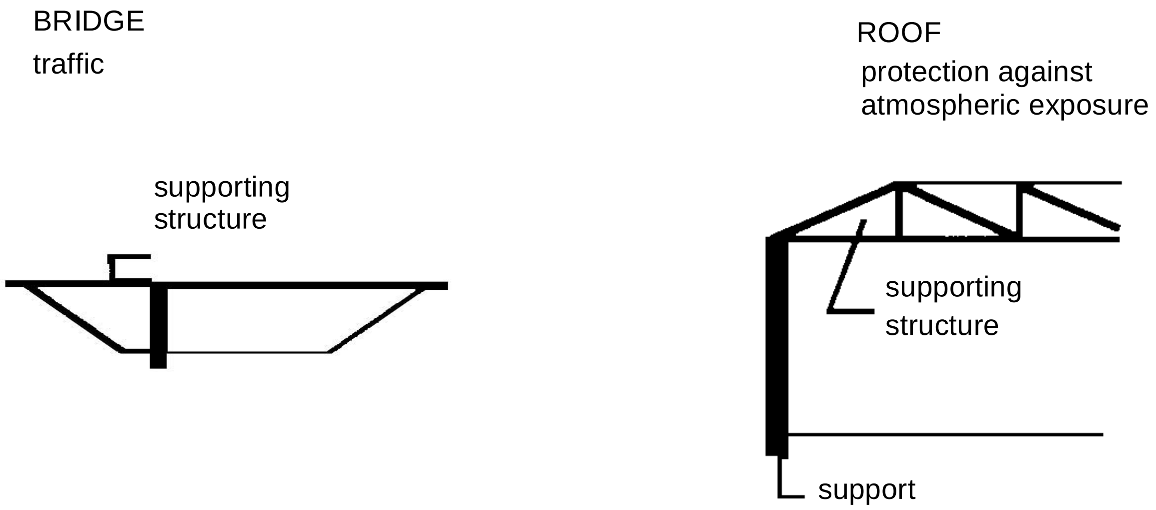


Fig. 8 - Superstructures without elevated structures

Supporting structure	Supporting construction above the clearance gauge of tracks (cover, bridge deck plate, hall roof, etc.)
Storey	Enclosed space of a limited height
Elevated structure	One-storey or multi-storey construction the load of which is carried by the supporting structure
Support	Structural element which transfers the forces from the superstructure into the ground (column, row of columns, wall, wall-type section)

NB : The elements or structural members that are addressed in this leaflet are the isolated and visible supports of overtrack structures that are susceptible to impact by railway vehicles.

E.2 - List of influencing factors

Accidents involving impact from railway vehicles can be caused by many factors and entail many consequences; their interaction, however, cannot be shown by simple analysis.

Examples include:

- human failure,
- technical failure (safety installations),
- speed; mass and direction of impacting rolling stock,
- rigidity and construction of the structural elements concerned by the impact,
- track layout and geometry (curves, switches, ...),
- static system of the over-track supporting structure,
- place of incident in relation to the static system of the supporting structure,
- usage of over-track structure at time of the incident,
- usage of track area at the time of the incident,
- construction measures available for protection against impact from rolling stock,
- act of sabotage.

Appendix F - Values of parameters that may be used in the risk assessment procedure for class B structures

Guidance and not part of the recommendations

F.1 - Likehood of a train becoming derailed on the approach to a bridge

The likehood (P1) of a train becoming derailed on the approach to a bridge may be determined from equation 1.

Equation 1: $$P1 = e_r \times d \times Z_d \times 365 \times 10^{-3}$$

Where: e_r = the derailment rate for trains per train kilometre

d = longest derailment path in metres = $V^2/80$ (assuming a deceleration of 3 m/s^2 and a derailment path parallel to the track)

Z_d = the number of trains per day

Based on average statistics from the UIC and other sources e_r, may be taken from Table 3. A structure may be assumed to be clear of switches and crossings if the structure is further than "d" from the switch.

Table 3 : Derailment rates for track with and without switches

	Track without switches (plain track) (train-kilometres)	Track with switches (based on station areas) (train-kilometres)
Passenger trains	$0,25 \times 10^{-8}$	$2,5 \times 10^{-8}$
Freight trains	$2,5 \times 10^{-8}$	25×10^{-8}

Based on average usage, the average number of trains passing under the structure may be taken as:

- 100 trains /day for single tracks
- 200 trains/day for double tracks

F.2 - Likelihood of the train colliding with the bridge

The likelihood (P2) of the train colliding with the bridge may be calculated from equation 2a or 2b

Equation 2a (single track): $P2 = [(b-a)/b]^2 \times 0{,}5 \times c/d$

Equation 2b (double track): $P2 = \{[(b-a)/b]^2 + [(b-(a+4,2))/b]^2\} \times 0,25 \times c/d$

Where:
- d = as previously defined
- V = speed of train in kilometres per hour at point of derailment
- b = the predicted maximum lateral deviation in metres of derailed train; b may be taken equal to $V^{0,55}$
- a = lateral distance (metres) between centre line of track and face of structure
- c = the distance parallel to the tracks at a lateral distance 'a' exposed to the risk of impact from a derailed train and may be calculated from equation 3. This takes into account the predicted derailment paths.

Equation 3: $c = (d/b) \times (b-a)$

For values of b > a.

For values of b < a, c may be taken as zero

Values of c in metres based on equation 3 and using values of b and d calculated according to the expressions contained in point F.2 and point F.1 - page 27 are set out in Table 4.

Table 4 : Values of c depending on lateral clearance a and speed of derailed train

Lateral Distance (a) (m)	Speed at derailment (km/h)			
	120	160	230	300
3	141	261	562	978
5	115	222	494	880
7	89	183	428	783
10	51	124	328	636

The calculation of (P2) from equation 2a or 2b assumes that the extent of lateral deviation of a train following derailment increases with speed and takes no account of the restraint provided by the rails in restricting lateral deviation of a derailed train. Values of (P2) based on equation 2a or 2b are given in Tables 5 and 6 - page 29.

The values in Tables 5 and 6 assume an equal probability of the train deviating to the right or left.The values for double-track lines are less because the train has to deviate across the adjacent track before colliding with the supports on the far side of the adjacent track. The values also assume that there is no support between the tracks. The values are based on a distance between tracks of 4,2 metres and do not take into account any resistance provided by the second track to the lateral deviation of the derailed train.

Table 5 : Probability of impact (P2) on a single track line

Distance from structure (m)	Speed at derailment (km/h)			
	120	160	230	300
3	0,24	0,27	0,31	0,33
5	0,13	0,17	0,21	0,24
7	0,06	0,09	0,14	0,17
10	0,01	0,03	0,06	0,09

Table 6 : Probability of impact (P2) on a double track line

Distance from structure (m)	Speed at derailment (km/h)			
	120	160	230	300
3	0,17	0,20	0,24	0,27
5	0,08	0,12	0,16	0,19
7	0,04	0,06	0,10	0,13
10	0,01	0,02	0,04	0,07

F.3 - Likelihood of the bridge collapsing as a result of the impact

The likelihood (P3) of the bridge collapsing as a result of the impact may be calculated from equation 4.

Equation 4: $$P3 = \{1 - 2/3[t(2b - 2a - t)/(b - a)^2]\} \times \alpha$$

For: $b - t - a > 0$

Where: $t = (a \times d')/(d - d')$

t = the lateral deviation over which the remaining speed of the derailed train has fallen below 60 km/h

d’ = the longitudinal distance of the longest derailment path (parallel to the track) over which the remaining speed of the train has fallen below 60 km/h. A constant 45 m may be assumed based on a constant deceleration of 3 m/s^2.

α = a dimensionless factor to take into account the robustness of the supports and the degree of continuity provided by the structural configuration.

If a value of $\alpha = 1$ is used, this assumes that all impacts with the structure lead to collapse of the structure if the speed of the train on impact with the support of the structure is greater than or equal to 60 km/h.

In practice, not all impacts above 60 km/h result in collapse. Other values of α , based on engineering judgement or on data available from previous incidents, may be used instead. Such values should however be justified. It should be noted that the amount of energy that is required to be absorbed from the impact of a train with a structure generally increases with the square of the speed.

F.4 - Likelihood (P4) of a train travelling on another track colliding with the derailed train.

Only required if two or more track pass under the bridge.

A value for (P4) = 0,1 may be taken.

This is a similar value to that often used for fatigue checks when estimating the likelihood of trains crossings on a bridge.

A higher value should be considered where:

- the line carries more than 100 trains per day
- the trains using the line are restricted to a narrow speed band (for example dedicated high speed passenger lines or high-throughput freight lines)

F.5 - Type of train travelling in the opposite direction

Only required if two or more tracks pass under the bridge

The train travelling in the opposite direction should be assumed to be either a passenger train or a freight train.

F.6 - Likelihood of the resulting scenarios

The likelihood of the resulting scenarios (P_{szi}) may be calculated from an event tree as shown in Fig. 9.

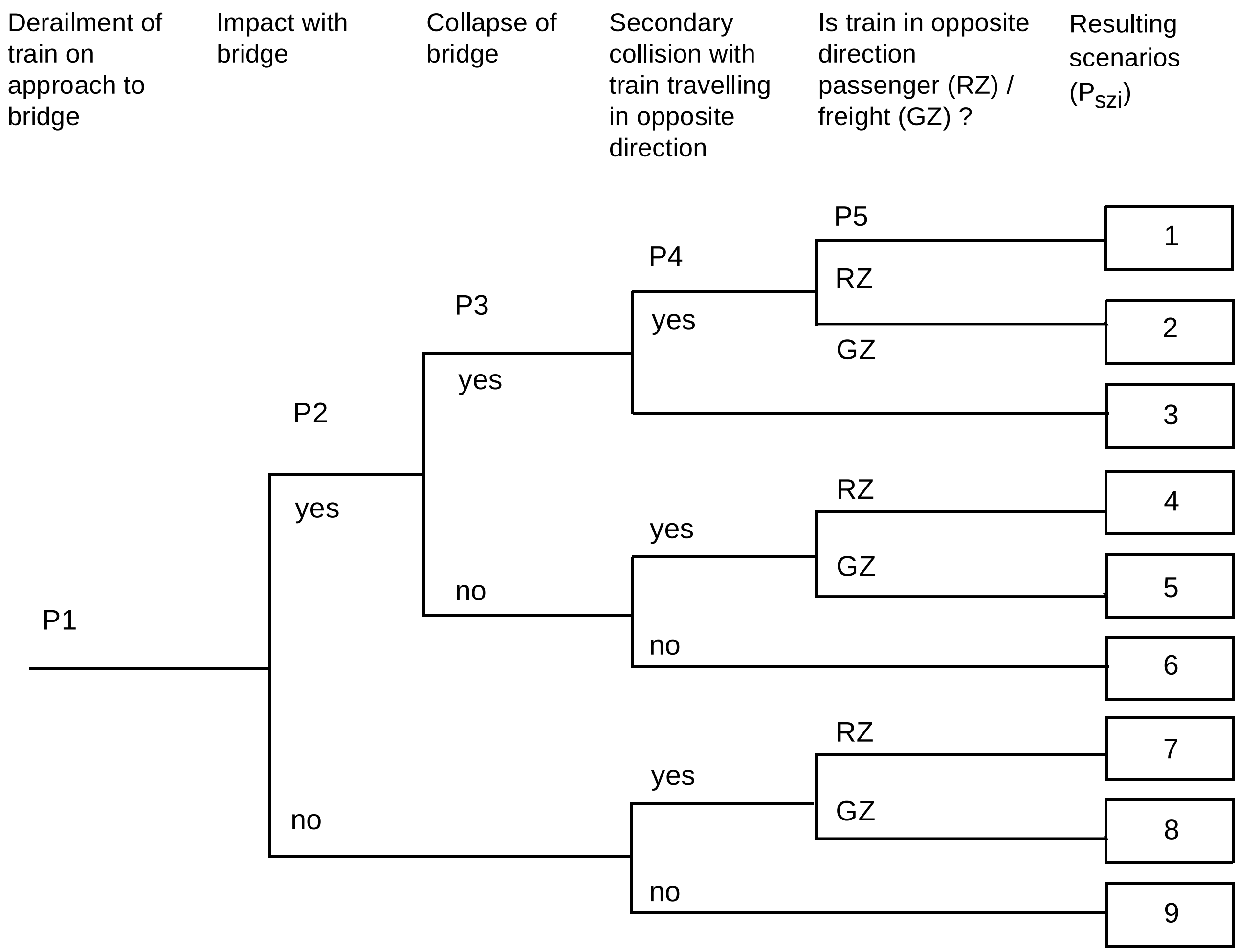


Fig. 9 - Event tree and the resulting scenarios for which the likelihood should be calculated.

P_{szi} is obtained from equation 5.

Equation 5: $P_{szi} = P1 \times P2 \times P3 \times P4 \times P5$ (for each scenario)

F.7 - Extent of harm to people for each scenario

The extent of harm to people (D_{szi}) for each scenario may be taken from Table 7. Sz1 to Sz9 relate to passenger trains and Sz10 to Sz18 relate to freight trains. The values are based on 300 people travelling in a passenger train and one person travelling in a freight train.

NB : The consequences are derived from the extent of harm to people because, in assessing the consequences, the harm to people is generally a much greater loss than damage to the infrastructure or the train. This is nonetheless a simplification, which moreover does not consider losses from the other factors that may require consideration as identified in point 6.1.2.

Table 7 : Average extent of damage per scenario and speed category (number of fatalities)

Scenario for extent of damage	V = 120 km/h	V = 160 km/h	V = 230 km/h	V = 300 km/h
Sz1	15	27	56	96
Sz2	10	18	36	62
Sz3	8	14	30	51
Sz4	11	20	41	70
Sz5	7	12	25	43
Sz6	5	10	20	34
Sz7	9	16	33	56
Sz8	6	10	20	34
Sz9	3	5	10	17
Sz10	13	7	-	-
Sz11	3	2	-	-
Sz12	3	2	-	-
Sz13	8	5	-	-
Sz14	0,3	0,2	-	-
Sz15	0,04	0,02	-	-
Sz16	6	4	-	-
Sz17	0,3	0,2	-	-
Sz18	0,02	0,01	-	-

The various scenarios are defined in Table 8 for derailed passenger trains (RZ) and Table 9 - page 33 for derailed freight trains (GZ).

Table 8 : Definition of scenarios for derailed passenger trains

Scenarios	Sz1	Sz2	Sz3	Sz4	Sz5	Sz6	Sz7	Sz8	Sz9
Impact	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Collapse	Yes	Yes	Yes	No	No	No	No	No	No
Opposite train	RZ	GZ	No	RZ	GZ	No	RZ	GZ	No

Table 9 : Definition of scenarios for derailed freight trains

Scenarios	Sz10	Sz11	Sz12	Sz13	Sz14	Sz15	Sz16	Sz17	Sz18
Impact	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Collapse	Yes	Yes	Yes	No	No	No	No	No	No
Opposite train	RZ	GZ	No	RZ	GZ	No	RZ	GZ	No

F.8 - Calculation of annual risk from each scenario

The annual risk D_{szi} from each scenario is obtained from equation 6.

Equation 6: $$D_{szi} = P_{szi} \times Szi$$

F.9 - Application of an aversion factor (A_{pf})

In order to calculate the perceived extent of harm, an aversion factor is applied to the number of fatalities identified in Table 7 - page 32. The aversion factor is the responsibility of the relevant authority.

An example using an aversion factor is set out in Appendix G - page 38.

The value chosen for the aversion factor is likely to have a significant effect on the perceived risk.

F.10 - Calculation of annual perceived risk from each scenario

The annual perceived risk R_b from each scenario (likelihood x consequence) is calculated from the extent-of-damage scenario and the aversion factor as set out in equation 7.

Equation 7: $$R_b = A_{pf} \times D_{szi}$$

F.11 - Calculation of annual perceived risk (R_{bp}, R_{bf}) from a derailed train on the approach to a structure

The annual perceived risk from a derailed train on the approach to a structure is calculated from the sum of the perceived risk from each scenario as follows:

$$R_{bp} = \sum_{i=1}^{i=9} R_b$$ for passenger trains

$$R_{bf} = \sum_{i=10}^{i=18} R_b$$ for freight trains

F.12 - Evaluation of annual perceived risk from a derailed train in monetary terms

In order to evaluate the annual perceived risk (R_{bpm}, R_{bfm}) from a derailed train in monetary terms, a value (V_{pf}) is required to be placed on preventing a human fatality.

This is the responsibility of the relevant authority.

The value chosen for preventing a fatality is likely to have a significant effect on the evaluation of the perceived risk.

The annual perceived risk in monetary terms is calculated from equations 8 and 9

Equation 8: $R_{bpm} = (V_{pf}) \times R_{bp}$ for passenger trains

Equation 9: $R_{bfm} = (V_{pf}) \times R_{bf}$ for freight trains

F.13 - Determination of the cost of providing preventative and protective measures.

In order to compare the cost of preventative and/or protective measures with the annual reduction in risk, the theoretical annual cost is calculated. This is made up of the annual (discounted) investment cost together with the annual cost of future maintenance.

Equation 10 may be used for calculating the theoretical annual (discounted) investment cost of the superstructure.

Equation 10: $A = [C_s \times (1+Z)^N \times Z] / [(1+Z)^N - 1]$

Where: C_s = Investment cost of the measure = $\Sigma(A)/(1+Z)^n$ for values of n = 1 to n = N

A = Theoretical average cost per year (as defined above)

N = Expected design life (years)

Z = Average annual rate of interest

The average rate of interest is the responsibility of the relevant authority.

A value of Z = 5 % may be used subject to the agreement of the relevant authority.

The annual cost of future maintenance may be added to cost (A) derived from equation 10.

The total annual cost (C_{tot}) is then calculated from equation 11.

Equation 11: $C_{tot} = A + (Y \times C_s)$

Where Y = Average annual maintenance costs as a proportion of the investment cost

A value of Y = 2 % may be used.

Where additional lateral clearances are being considered as a measure, the following method may be used to determine the investment cost C_s.

For new structures it is often sufficient to consider only the increased cost of the longer superstructure of the span crossing the railway.

The cost per square metre for a deck of span L in metres may be calculated using equation 12.

Equation 12: $C = C_o \times (L / L_o)^k$

Where:

Where:	C	=	cost per square metre for a deck of span L in metres
	C_o	=	cost per square metre for a deck of 11 m span
	L_o	=	11 m (span of a two-track bridge with 3 m clearance)
	L	=	span provided assuming an increasing lateral clearance (a)
	k	=	a constant.

As a reasonable simplification for increasing lateral distances up to 7 metres (between track centres and face of support), the costs per square metre (C) for different spans may be compared taking k = 1 in equation 12.

The costs are tabulated in Table 10 based on C_o = 2 000 euro/m and equation 12 with k = 1 and relate principally to new bridges over new lines. The costs of new bridges built over existing lines are likely to be higher.

Table 10 : Variation of C (cost/m^2) with a (lateral distance) and L (span)

a (m)	3	5	7
L (m)	11	15	19
C (euro)	2 000	2 725	3 455

The total investment cost of the span (C_s) is given by equation 13.

Equation 13: $C_s = C \times L \times W$

Where W = Width of bridge (metres) and other symbols are as defined previously.

For greater lateral clearances, a similar comparison may be used, but because of land requirements, increasing construction depth and the resulting increase in length of approach roads, the cost per square metre is likely to rise at a greater rate.

A similar comparison may be used for structures spanning a single track.

F.14 - Determination of the perceived risk reduction of preventative and protective measures

The determination of the perceived risk reduction for a particular measure is obtained from the following:

1. the evaluation of the perceived risk for a simply supported structure with a 3 m lateral clearance (or with the minimum clearance normally provided) - the base situation

2. the evaluation of the perceived risk if preventative and/or protective measures are provided (for example increased lateral clearance, continuous structure, robust support)

3. subtracting the reduced perceived risk as a result of the provision of preventative and/or protective measures (2) from the perceived risk from base situation (1).

F.15 - Determination of optimum protective and preventative measures

In order to determine the optimum protective and or preventative measure(s), the perceived annual risk reduction (benefit) is compared with the total annual investment cost (cost).

Subject to agreement with the relevant authority, the determination of the optimum protective and preventative measures may be based on either of the following criteria:

1. The measure(s) that provide the greatest reduction in the perceived annual risk which, when expressed in monetary terms, is equal to or less than the annual cost of providing the measure.

2. The measure(s) that provide a benefit/cost ratio greater than 1 where the benefit/cost ratio of any additional measures to reduce the risk further is less than 1.

F.16 - Determination of optimum protective and preventative measures

New structures only

The optimum measure(s) may be derived using a graphical method shown in Figures 10 and 11 - page 37. The total annual investment costs of providing the protective and/or preventative measure(s) are plotted against the annual perceived risk reduction in monetary terms using the same scale for both costs and reduction in risks. In the examples, only measures relating to increasing the lateral clearance are compared.

Figure 10 shows how the measure that meets criterion (1) as set out in point F.15 is determined. The optimum lateral clearance is identified by drawing a line at 45° from the level of risk for a 3 metre clearance to intersect with the costs axis (Line BB). The optimum lateral clearance is the first point to the LEFT of line BB which is intersected by a horizontal line moving upwards from the cost axis. In the example given, a lateral clearance of 7 metres meets criterion (1).

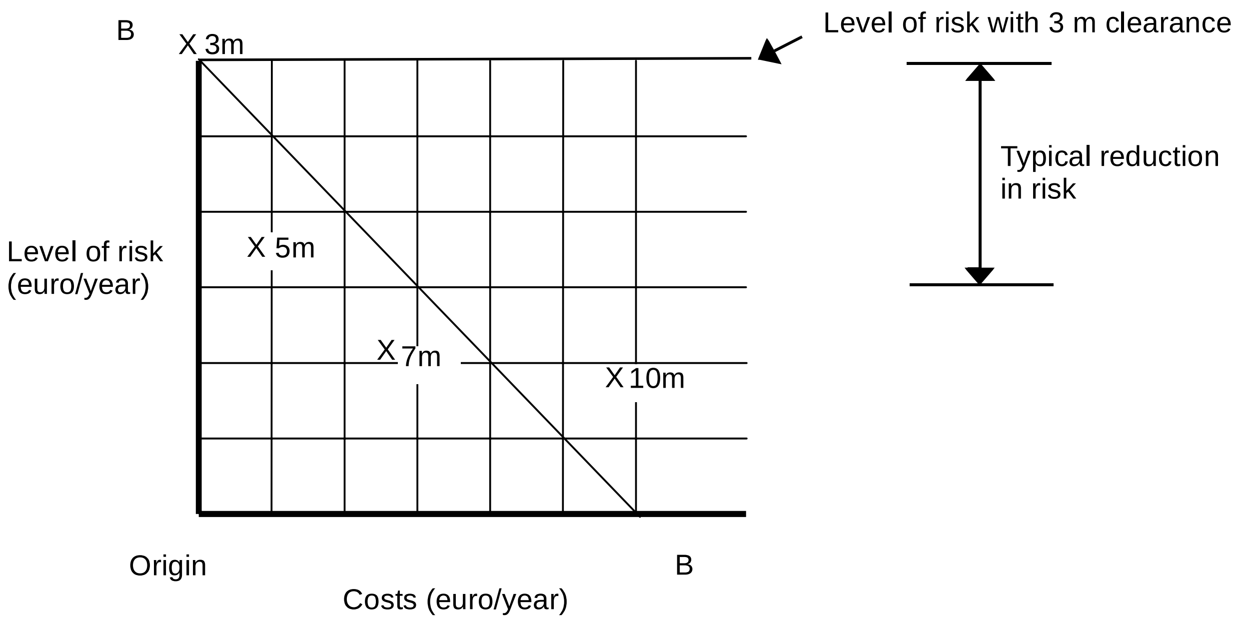


Fig. 10 - Graphical method of determining lateral distance of supports according to criteria (1) in point F.15

NB : At any point on line B-B the reduction in risk is equal to the cost of provision of measure(s) to mitigate the risk.

Figure 11 shows how the measure that meets criterion 2 as set out in point F.15 is determined. The optimum lateral clearance is identified by the first plotted point that is intersected by a line DD drawn at an angle of 45° moving away from the origin towards the plotted points. In the example given, a lateral clearance of 5 metres meets criterion 2.

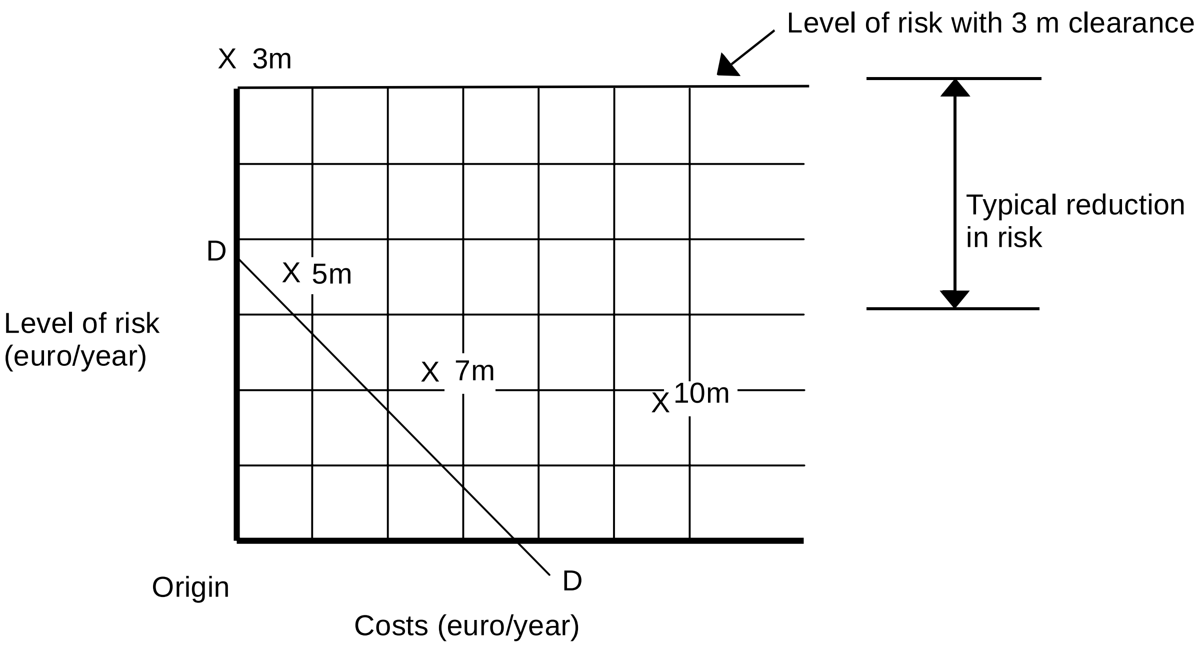


Fig. 11 - Graphical method of determining lateral distance of supports according to criteria (2) in point F.15

Appendix G - Example of use of method for determining the optimum lateral clearance of supports for new class B structures

This appendix sets out an example of the use of the method described in point 6.4 - page 13.

G.1 - Assumptions used in example

The example is based on the following assumptions and parameters:

- Single and double track situations are considered.
- The average number of passengers per train passing under the structure is 300.
- The average number of trains per track per day passing under the structure is 100 (for single track, 50 trains per travelling direction; for double tracks, 100 trains per travelling direction).
- The derailment rate for track with switches is 2,5 x 10^{-8} per train kilometre.
- The derailment rate for track without switches is 2,5 x 10^{-9} per train kilometre.
- The likelihood of the train colliding with the bridge is calculated from either equation 2a or 2b (see point F.2 - page 28) with an additional factor of 0,5 to allow for the restraint provided by the rails.
- The likelihood of the structure collapsing as a result of the impact is calculated from: $P3 = \{1-(2/3)[t(2b-2a-t)/(b-a)^2]\} \times 0{,}5$ i.e. from equation 4 with $\alpha = 0{,}5$ making allowance for robust piers and for the fact that some impacts will be glancing impacts and not lead to the collapse of the structure.
- The likelihood of a train travelling on another track colliding with the derailed train = 0,1.
- The extent of harm from each scenario is as set out in point F.7 - page 31.
- The track is straight in the vicinity of the structure and the ground is generally level.
- Either one or two tracks pass under the structure.
- The value placed on preventing a fatality is 6 000 000 euro.
- The aversion factor is 1.
- The cost of the bridge is based on:
  $C = C_0 \times (L/L_0)^{1.0}$ [equation 12 and C_0 = 2 000 euro/m^2]
  and a bridge width of 9 metres.
- The average rate of interest is 5 % and average annual maintenance costs are 1 %.
- Either a passenger train or a freight train is on the adjacent track where there are two tracks.

- Switches and crossings are assumed to be present if the switch is less than d from the structure where $d = V^2/80$ metres.

G.2 - Diagram showing scenario used in example

The key parameters are shown in Figure 12:

a: lateral distance of structure support from track axis

d_{eff}: Distance between the structure and the beginning of the switch area

w: Length of switch area

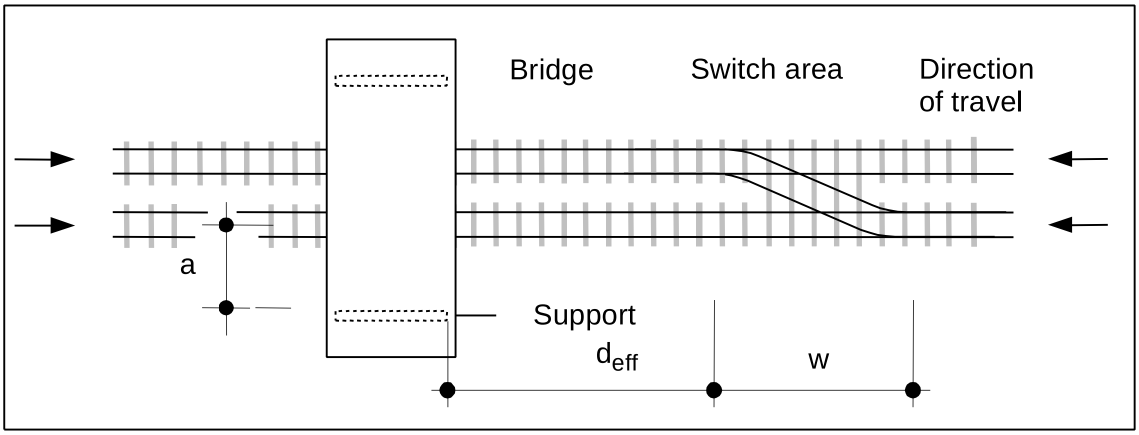


Fig. 12 - Scenario used in example

G.3 - Results of risk assessment using assumptions/parameters set out in point 6.3.1.3

For situations where there are no switches and crossings in the vicinity of the structure, there would be no requirement to provide additional clearances.

For situations where there are switches and crossings in the vicinity of the structure, there would only be a requirement to provide additional clearances where the passenger traffic travels at speeds close to 300 km/h.

Based on both criteria (1) and (2) as set out in point F.15 - page 36, the optimum lateral clearance would be 5 metres although this would be sensitive to changes in the assumptions and parameters used (see Fig. 13 - page 40). Figure 13 only shows the results for V = 230 km/h and V = 300 km/h with switches. For all other situations the results would be less sensitive to any changes in the parameters used in the risk assessment.

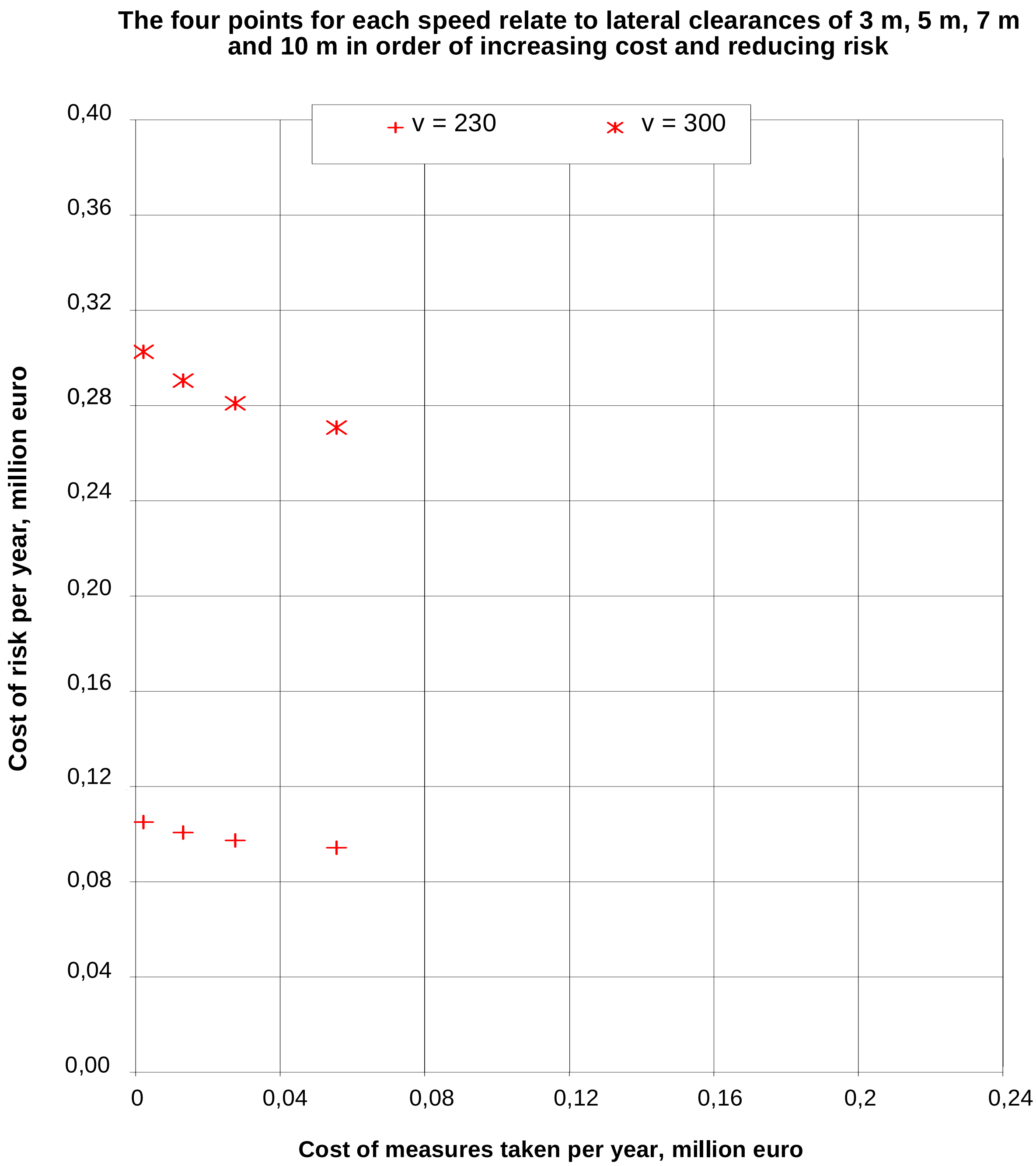


Fig. 13 - Graphical presentation of results using parameters in example (for speeds v = 230 km/h, v = 300 km/h WITH SWITCHES)

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