Italian Multimodal Transportation Corridors: Railway - Motorway Interference

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Synopsis

The design decision to contain the relative distance between important transportation infrastructures in order to decrease their impact on the environment and land acquisition may lead to serious safety problems.
There are many cases in Italy in which the High-Speed Railway (AV) lines run close to Motorways for a considerable length. The safety problem related to the risk of a vehicle running off the motorway and potentially invading the railway line and, on the other hand, to the potential hazard for motorway users due to the possible protective structures that can be installed within the dedicated corridor must be analyzed and solved.

In Italy, at present, the possible solutions to the identified problem have been considered; different safety approaches have been developed which have been applied to the followings Multimodal corridors:

- Milano-Torino Section. The safety aspects of that design has been developed in accordance with the document "Safety Criteria Organization Document", practical recommendations done by Italferr. No probabilistic analysis and numerical simulation models have been studied ad hoc.
- Milano-Bologna Section. In this case a study has been done in order to identify and to solve safety problems by using a probabilistic analysis of the potential interference between the infrastructures. As a consequence numerical simulation models have been developed to define standard safety.
  This study has been developed in parallel with the construction of the railway line. Thus often there was the need of changing the already realized or designed structures.
- Milano-Verona Section. This study follows the same criteria of the one of the Milano-Bologna but with two main differences:
  - at the time being, the Milano-Verona Project is still in the approval phase of Preliminary Design (complete of safety study), evaluated by Italferr;
  - in the case of the Milano-Verona the interference is between the AV and three different Motorways, one already existing (as Milano-Bologna) and the others are new infrastructures, still in the Preliminary Design phase. So three different probabilistic analysis and numerical simulation models have been studied for these different type of interference.

The safety analysis of Multimodal corridors needs generalization of the problem, with the aim of achieving an adequate standard of design reference, which can be provided by:
- evaluating the set of data to perform a probabilistic analysis and related numerical simulation models;
- providing a miscellaneous of standard safety sections to be applied after the results of the studies;
- studying (by research, crash test, finite elements analysis) a wide set of standard protection systems which can be developed case by case.

Italian Multimodal Transportation Corridors: Railway - Motorway Interference

INTRODUCTION

The design decision to reduce the relative distance between important transportation infrastructures in order to decrease their impact on the environment and land acquisition may lead to serious safety problems.

There are many cases in Italy in which the High-Speed Railway (AV) lines run close to Motorways for a considerable length, creating a corridor between the two infrastructures called the “enclosed area” (AI).

The main hazards are substantially three. The first is clearly linked to the possible invasion by a road vehicle of the railway area and even to possible collisions with railway traffic. The second is associated with the possible invasion of the enclosed area, which may contain area maintenance and management personnel and equipment. Lastly, the possibility must be considered of collision with the various motorways structures foreseen within the dedicated corridor by vehicles – or their parts - running off the road, according to the usual road regulations.

The occurrence of such risks is associated with a set of variables that largely depends on the reciprocal position of the motorway and railway systems in the flanking area (distance and height of the embankments) and on the functional characteristics of the road infrastructure.

During analysis and verification activities, reference was made to the basic principles of the “Safety Criteria Organization Document for Preliminary Design”, issued by Italferr (RFI engineering company, supervising AV projects), which defines a combination of horizontal distances and heights of road and railway embankments, making it possible to establish one of the following conditions:

- No interference: absence of any flanking problem, since the railway line is in a planimetric-altimetric position making invasion by run-away vehicles impossible.
- Standard flanking: the railway’s planimetric-altimetric position is susceptible of invasion by run-away vehicles and it is possible to erect protection structures inside the enclosed area.
- Narrow flanking: the railway’s planimetric-altimetric position is susceptible of invasion by run-away vehicles, but the space between the two infrastructures is insufficient tu allow the costruction of appropriate protective works in the AI.

In Italy this safety problem is in continuous evolution, as can be noticed by evaluating the different safety approaches, developed during the years, and concerning the followings Multimodal corridors:

- Milano-Torino Section. The safety aspects of that design have been developed in accordance with the document “Safety Criteria Organization Document for Preliminary Design”. No probabilistic analysis and numerical simulation models have been ad hoc studied in this case.

- Milano-Bologna Section. In this case an in-depth study of the interaction generated by the two infrastructures has been performed, highlighting some aspects underestimated in the first approach.
  In particular, a study has been done in order to identify and to solve safety problems by using a probabilistic analysis of the potential interference between the infrastructures and by considering 100 years as return time for design top event. As a consequence numerical simulation models have been developed to define standard safety protections and cross sections.
  In this application, the possible contribution of motorway safety barriers have not been considered in the models used to perform the simulations.
  This study has been developed in parallel with the construction of the railway line. Thus often there was the need of changing the already realized or designed structures by introducing some adaptations (e.g. protective walls, demolitions) to make them compliant with the safety requirements.

- Milano-Verona Section. The performed study followed the same criteria of the one of the Milano-Bologna Section but with two main differences:

- At the time being, the Milano-Verona Railway Project is still in the Preliminary Design phase and the safety study, evaluated by Italferr, it is not yet approved.
- In the case of the Milano-Verona Railway the interference occurs with three different Motorways, one already existing (the Milano-Bologna Section) and the others are new infrastructures, still in the Preliminary Design phase. So three different probabilistic analysis and numerical simulation models have been studied for the three different situations.
For the new infrastructures it was agreed to account for the contribution of the Motorway safety barriers in the analysis.

The safety analysis of Multimodal corridors needs generalization of the problem, to achieve an adequate standard for design reference.
The present paper aims at offering a contribution in this direction.

MILANO-TORINO SECTION

The new Milano-Torino section of the High-Speed Railway (AV) line runs for some way close to the A4 motorway, creating a corridor between the two infrastructures.

It was necessary to solve the safety problem related to the risk of a vehicle running off the motorway and potentially invading the railway line and the “enclosed area” (AI).

The safety aspects of that design have been developed following the document “Safety Criteria Organization Document for Preliminary Design” issued by Italferr.

The objective of that document is to give general indications about the criteria to reduce the risks connected of interference between railway and motorway. The document remarks that the risk of a possible invasion of the railway system depends by:

- A combination of horizontal distances and heights of road and railway embankments.
- Casual events that happens following probabilistic laws.

These practical recommendations analyze the most important cases of flanking with the aim to give just general criteria that could help the designer to solve the entire possible situation. To simplify the approach to the problem, combinations of horizontal distances and heights of road and railway embankments are defined according to Table 1. As it can be seen, in some cases H4 class motorway safety barriers are just used to solve the interference safety problems without evaluating which protection level this solution offers. The latter in jacts mainly depends on the traffic conditions characterizing the Motorway.

Tab 1: Level of flanking and actions by a combination of horizontal distances and heights

<table>
<tr><th>H
(Height difference between railway and motorway embankments)</th><th>L
(Distance between railway and motorway embankments)</th><th>Condition of flanking</th><th>Protective elements to be costructed in the enclosed area</th><th>Protective elements to be installed on the Motorway</th></tr>
<tr><td rowspan="4">H ≤ 3.00 m</td><td>0 ≤ L < 16.50</td><td>NARROW</td><td>-</td><td>H4 CLASS SAFETY BARRIERS</td></tr>
<tr><td>16.50 ≤ L < 30.00</td><td rowspan="2">STANDARD</td><td>EARTH WORKS
(If there is enough space)</td><td>H4 CLASS SAFETY BARRIERS
(In alternative to earth works)</td></tr>
<tr><td>30.00 ≤ L < 50.00</td><td>EARTH WORKS</td><td>-</td></tr>
<tr><td>L ≥ 50.00</td><td>NO INTERFERENCE</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">H > 3.00 m</td><td>0 ≤ L < 6.00</td><td>NARROW</td><td>-</td><td>SAFETY BARRIERS
(In accordance with the law)</td></tr>
<tr><td>L ≥ 6.00</td><td>STANDARD</td><td>-</td><td>SAFETY BARRIERS
(If there is a retaining wall of the railway embankment)</td></tr>
</table>

MILANO-BOLOGNA SECTION

Probabilistic analysis

To reduce the impact on the environment and land acquisition, the new Milan-Bologna section of the High-Speed Railway (AV) line, designed according to the Italian AV geometric, planimetric and altimetric standards, runs for some extent close to the A1 motorway. A corridor between the two infrastructures, named “enclosed area” (AI), has been created, having an approximate length of 125 km and a width - measured from the foot of the AV embankment to the foot of the A1 embankment (4^{th} lane) – varying as follows:

- From 6m to 13m for about 21% of its total length.
- From 13m to 20m for about 22% of its total length.
- From 20m to 80m for about 39% of its total length.
- Over 80m for about 18% of its total length.

During the early design phase, all the necessary data to perform the safety study was acquired with the co-operation of *Italferr* and *Autostrade per l’Italia* (the company that manages the A1). The most important design criteria which has been defined were that the motorway barriers should not be relied on to protect the AV and that the future construction of the 4^{th} motorway lane in both directions should also be taken into account.

A study was thus undertaken to identify, through a probabilistic analysis, the conditions of potential interference between the A1 and the AV (possible invasion of the railway by a vehicle running off the A1), on the basis of the accident charecteristics, road traffic volumes, traffic mix and operative speeds of the A1 motorway along the flanking section, and to solve the related safety problems, taking into account of a 100 years return time (RT) for the design top event.

Numerical simulation models were consequently developed to study protection works for the AV in the event of interference with unacceptable return times. Standard safety protection measures were then defined and were lastly applied to the flanking sections (standard layouts and sections).

The description of the criteria adopted in performing the safety analysis, of the analitical models developed have been previously reported in DOMENICHINI et al. 2004.

The simulations showed that, according to the planimetric-altimetric features of the railway/motorway embankments, a vehicle going off the road could be an hazard for railway traffic up to a distance of about 80 m (maximum range of interference), measured from the foot of the AV embankment to the foot of the A1 embankment (4^{th} lane).

The finding, according to the stated design criteria, does not take into account any safety barrier at the edge of the A1 roadbed and/or any existing or foreseen natural obstacles (hedges, trees, etc.).

Design of the protective structures

The protection structures adopted were of two kinds: the first one is associated with earth works, in particular with earth dunes (slope 2/3), or insurmountable reinforced earth dunes. The second type of defence is an r. c. wall, which can be erected in the AI, or as a support for or on top of the AV embankment.

Number 33 standard sections have been definitively identified in applying the various solutions for the installation of a “minimum configuration” of the principal protection structures along the stretch.

The description of the standard protection solutions developed and their structural design is detailed in Buzzetti et al., 2004.

Owing to the implementation of the AV and its safety structures in the AI, the A1 motorway restrain system was also upgraded, involving the modification of the current barriers at the edge of the motorway in order to limit the consequences to road users of a vehicle running off the road.

In order to guarantee plenty safety for the motorway users, the following actions have been adopted, according to the current law and recommendations:

- The existing protection structures at the edge of the A1 motorway remain unchanged because they are adequate.
- The class of existing barriers will be changed for the new configuration of the area near the motorway.
- New protection barriers will have to be installed on the motorway.

The impact force employed for sizing purposes equaled the equivalent mean and peak static forces during the impact. These values were evaluated considering the approach proposed by three different Authors (Hirsch 1978, Bloom 1978, Buth 1978). The first provides considerably lower values than the second and third.

In the case of a “whole” vehicle (tare + load), coming from ground elevation, to collide against a r. c. wall, the transversal force values considered for calculation were chosen from among the upper limit of maximum force, focusing particularly on a value at ¾ of the range between the upper extreme (maximum forces estimated according to Bloom and Buth) and the lower limit (maximum forces estimated by Hirsch).

In the event of impact by the vehicle with its entire load, the highest transversal forces encountered in the most serious standard cases were 1650 kN for r. c. walls and 700 kN for earth dunes.

As far as the standard earth dunes with 2/3 slopes are concerned, on the other hand, their higher deformable nature was taken into account, assuming the mean value provided by Hirsch.

Reinforced earth dunes (see Figure 1, dunes are currently being experimented near Reggio Emilia, at the time being without environmental mitigation) were envisaged in the areas classified as “normal flanking” areas, where it was possible to avoid building walls, but impossible to erect normal dunes with a 2/3 slope.

Whereas a vehicle running off the motorway can surmount the latter, the aim of the reinforced earth dunes was to provide – owing to their geometry and mass – an insurmountable obstacle in view of the increased slope of their sides.

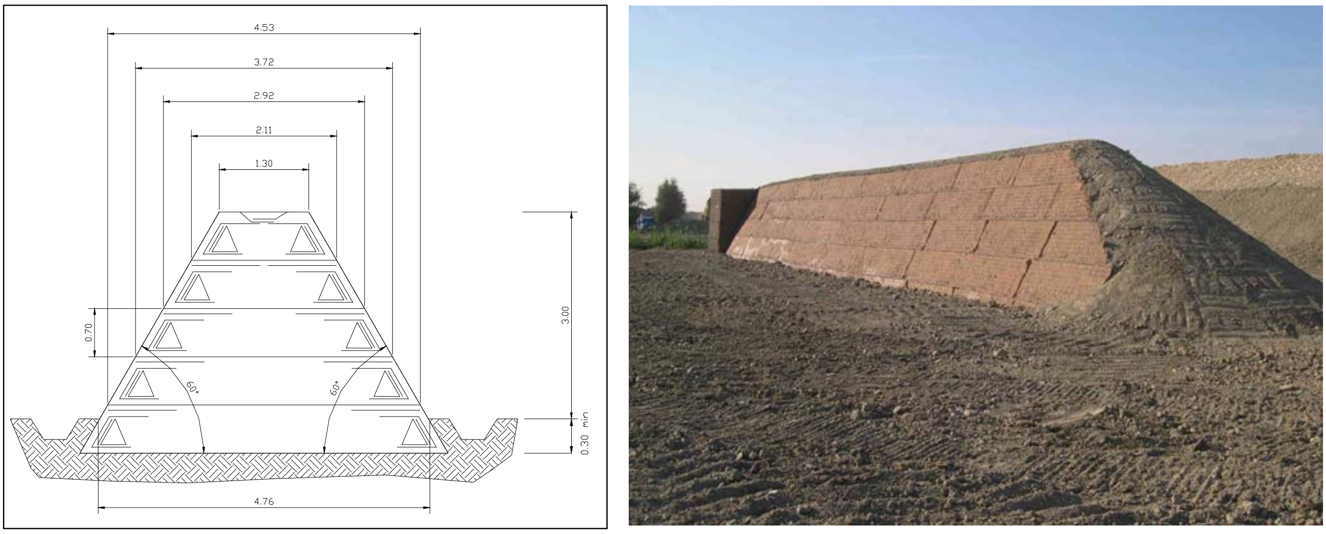

Figure 1: Symmetrical dune arrangements with slopes of 60°

At present, no significant anti-run-off experiments and applications have been yet carried out with such structures in Italy. In defining their specifications, reference has consequently been made to similar studies on boulder protection embankments, usually applied over extended areas to intercept, deviate or stop falling stones with high kinetic energy (Paronuzzi 1989, Guasti 1999, Castiglia 2001, Peila 2001, Agostinacchio 2002).

Therefore, the following test are deemed necessary to validate the selected design sections:

Penetration by Projection Test: this kind of test is clearly fundamental to ascertain the effectiveness of the dune as a protection system. The calculation procedure has to establish the dune’s optimal geometric requirements to ensure its function of intercepting vehicles running off the road, eventually with their load.

Embankment Stability Test: this test is one of the usual ones for embankments, and has to ascertain whether the standard section geometry provides a sufficient safety factor against collapse, in relation to the resistance to shearing stress of the material employed.

Break-through Test: assessment of the local effects on embankments subjected to high propulsive loads is very complex, because so far no final definition has been given to the dissipation of energy inside the embankment and to structural collapse. The assumptions made and the design precedures considered are detailed in Buzzetti et al., 2004.

Summit Testing: the summit of the dune is the only point at which it is not possible to apply the same assumptions or calculations used to describe the static behaviour following a collision of the dune itself. Therefore, specific tests should be performed to verify the “header” structural performance and the “collaborating zone” extention.

Environmental Mitigation for the Protective Structures

The construction features and sizing of the safety structures required architectural and environmental interventions to insert the structures in their territorial context. For this purpose, specific landscaping guidelines have been drawn up to identify eventual mitigation of the impact of the dunes and walls.

The guidelines, forwarded to Italferr for a definition of the mitigatory solutions to be submitted to the Environmental Observatory (Organ appointed by the Ministry for the Environment to supervise the safeguarding of the environment for the Milan-Bologna AV project), identify three different “thematic” solutions. In order to minimize the visual impact, three basic criteria have been identified for the interventions, in order to ensure homogeneity and maintain the natural trends of the landscape:

- DYNAMISM instilled into the infrastructures that flank, cross and entwine with each other along the line, to which must be added the speed and continuous movement of traffic. The lines introduced by the project accompany and accelerate movement on this infrastructure dedicated to speed. From concrete structures to vegetation arrangements, everything must be subject to the concept of dynamism.

- NATURALNESS, featuring components of little construction, on principle vegetation, but including structures with an organic aspect, recalling natural elements.
- SIMPLICITY, with the intent of creating uniform surfaces, tranquil, easy to read and comprehend.

MILANO-VERONA SECTION

Description of the site

The new Milan-Verona section of the High-Speed Railway (AV) line runs for some way close to different motorways, creating a corridor between the infrastructures (approximately 100 km of interference) and creating safety problems as well we have seen in the others sections.

At the time being, the Milano-Verona Project is still in the approval phase of Preliminary Design (complete of safety study), evaluated by Italferr.

The Motorways that have interference with the Milano-Verona AV section are classified in two categories as follow:

1) New road infrastructures which are still in design phase:

- Motorway BRE.BE.MI, designed with a two-lane section for each carriageway and already arranged for a three-lane upgrade.
- Connection Road from the Motorway to the city of Brescia, designed with a two-lane section for each carriageway.
- Motorway A.C.P., designed with a two-lane section for each carriageway (upgrading to highway standards of the Provincial Road SP 19).

2) Existing motorway:

- Motorway A4, section Milano-Venezia, with a three-lane section for each carriageway.

The “interference sections” in this case have been classified as follow in Tab 2:

Tab 2: List of interference sections between Railway and different Motorways

Km AV line	Flanking Motorway
28+630 – 72+500	Motorway BRE.BE.MI
0+000 - 5+200 (Connection of Brescia West)	
0+000 – 1+000 (Connection of Treviglio East)	
9+200 11+770 (Connection Brescia West)	Connection road from the Motorway to the city of Brescia
72+500 – 97+000	Motorway A.C.P.
97+000 – 131+120	Existing Motorway A4
0+000 1+900 (Connection of. Brescia East)	

The study of the safety problem has been developed following the next steps:

- Acquisition of the minimum necessary data for the first phase of the study and hypothesis about the data that were missing.
- Analysis of traffic, circulation and accidents data.
- Identification of the conditions of potential interference between the Motorways and the AV line through probabilistic analysis.
- Definition of the Standard safety sections by numerical simulation models and of the safety defences by the related tests.
- Application of the safety standard sections to the flanking sections (standard layouts)

The following hypothesis has been done for the two different categories of Motorway:

A) Interference with new infrastructures still in design phase

To identify the conditions of potential interference between the Motorways and the AV line, the motorway safety barriers have been relied on. The containment level of the safety barriers has been conservatively defined equal to the one characterizing the H2 class, according to the national law.

B) Interference with the existing infrastructure

In this case, the motorway barriers have not been relied on to protect the AV line, as done for the Milano-Bologna section.

In all cases in which the distance between the two infrastructures is less that that of the "no-interference" identified, protection structures of different kind and consistency have to be considered. In order to guarantee AV protection, the following protection structures have been adopted, classified according to their location and function:

- *works located in the enclosed area*

Acting as protection against vehicles running off the motorway and any load carried;

- *works erected on the AV embankment to contain the permanent way*

Acting as protection against vehicles running off the motorway and any load carried;
Acting as protection only against vehicles running off the motorway (to be used when protection from the load carried is guaranteed by the height of the railway embankment itself);

Evaluation of the "no-interference" distances in the different flanking conditions

The first issue in designing the AV line protection has been to identify the minimum distance a vehicle running off the motorway section can reach. For this purpose the simulation model developed for the Milano-Bologna section, as described in Domenichini et al, 2004, has been eased.

This simulation model allows to define the maximum interference distance (L_P) as a function of:

- distance between the carriageway lane considered and the motorway free edge;
- traffic volumes and traffic mix distribution;
- speed distribution in each trafficked lane;
- required return time (number of years within which only one event is considered acceptable);
- motorway embankment height;
- railway embankment height.

The model was developed to analyze a 4 lanes motorway. A preliminary sensitivity analysis showed that the return time and the motorway embankment height have a rather limited effect of the value of L_P. while this is considerably affected by the railway embankment height and by the number of carriageway lanes (2, 3 or 4 lanes).

The basic assumption in the development of the Milano-Bologna model was that the analysis should not consider any possible contribution of the safety barrier installed on the motorway, being this an existing motorway which was built before the Italian Standard for roadside protection, dated 1992. This has been proven to result in the fact that the most critical vehicle is always the passenger car and therefore the return time is calculated as a function of the probability distribution of this type of vehicles.

As discussed earlier in the Milano-Verona project a considerable part of flanking occurs with motorways which are still in their design stage and that will therefore have to comply with the new regulations.

Furthermore the flanking motorways have sections with 3 or 2 lanes per carriageway and, as indicated earlier, this have a considerable influence on the no-interference distance.

For this reason the models developed earlier had to be modified in order to account for the effect of the different types of safety barriers installed on the motorway body and for the influence of the different number of lanes per carriageways.

The influence of a safety barrier installed at the motorway edge has been taken into consideration assuming the following behavior of the vehicle after the impact with the barrier:

- if the energy calculated with reference to the side component of the speed (E_T) is lower or equal to the containment level of the safety barrier (L_C, as defined by the EN standard 1317-2) the vehicle will be safely contained in the carriageway and therefore there will be no runoff from the motorway;
- if the value of E_T exceeds the containment level the assumption is made that the barrier will be broken by the impacting vehicle. After the impact, the vehicle is assumed to maintain the same trajectory (therefore with the same runoff angle, with a residual energy associated with the side component of the speed (E_{T_R}) obtained by subtracting the L_C value from the energy prior to the impact ($E_{T\_R}=E_T - L_C$).

  Furthermore it is assumed that the damage to the vehicle due to the impact doesn't affect the possibility of the vehicle to keep on running off the motorway section.

  Under these assumptions the residual speed with which the vehicle will leave the motorway section towards the railway track has been calculated as follows:

$$v = \frac{\sqrt{\frac{2\cdot\left(E_T - L_C\right)}{M}}}{sen\alpha}$$

where:

- v, is the vehicle speed in m/s;
- M is the vehicle mass in tons;
- α is the runoff angle;
- E_T and L_C are given in kJ.

The analysis conducted for the Milano-Bologna (Domenichini et al, 2004) has lead to the conclusion that even in the most critical conditions, with a 4 lane carriageway, the values of E_T for passenger cars range between 127 and 129 kJ with a very limited effect of the return time considered in the design.

This value is equal to the minimum containment level of an H1 class barrier (127 kJ) which is the minimum class allowed for side barriers for motorway and primary highway by the Italian regulations (Ministero Infrastrutture e Trasporti, 2004).

This means that if a barrier is installed on the motorway edge according to the Italian regulations no passenger car will be able to reach the railway track. On the other side there are several possible combinations of commercial vehicle class and speed that can reach the different LC levels of H1, H2 and H3 class barriers and it is therefore not straightforward the identification of the critical vehicle type.

A given L_P value can be reached by a given type of vehicle with a given probability and by another type of vehicle with another probability. The total probability ($P_{T,P}$) that there will be a vehicle reaching the railway track at the given distance L_P needs to be calculated as the sum of all the probabilities of the different vehicles ($P_{i,P}$) to reach a distance (L_i) greater or equal to L_P as indicated in the following equation:

$$P_{T,P} = \sum_i P_{i,P}\left(L_i \geq L_P\right)$$

The return time (RT) associated to a given $P_{T,P}$ value can be determined as:

$$RT = \frac{1}{P_{T,P}}$$

For each design condition a chart can be drawn as in the example of Figure 2 where different railway embankment height (Hf) and one single motorway embankment height (Hs) are considered. If the return time is set to 100 years the corresponding L_P value for each design condition can be determined as shown in the Figure 2.

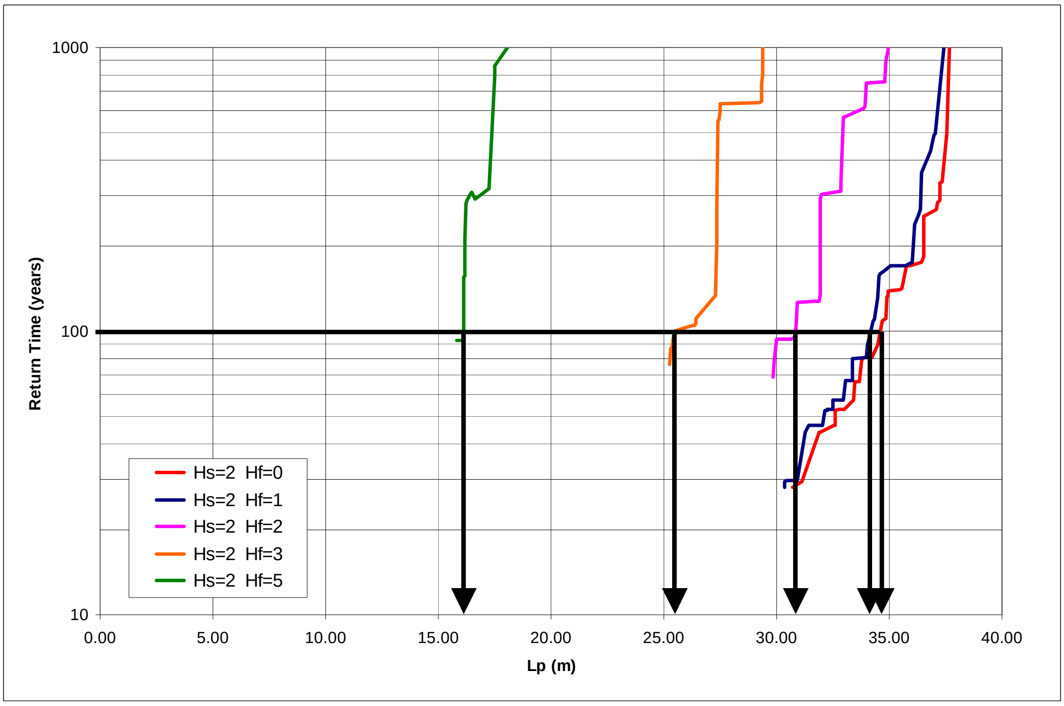

Figure 2: example of diagram for the evaluation of the no-interference value (L_P) considering the effect of safety barriers at the motorway edge

To evaluate the effect on the L_P values of the protection offered by the motorway safety barriers a set of simulation have been conducted considering the following input values:

- two different motorway cross sections with 2 or 3 lanes;
- constant traffic and length. For this analysis a total number of km traveled by commercial vehicles in 1 year has been set to $113 \cdot 10^6$ (approx. $560 \cdot 10^6$ km traveled per year by all vehicles), which is the traffic of the BRE.BE.MI segment;
- the return time has been set to 100 years;
- 5 different railway embankment height (0 to 5 m);
- 3 different motorway embankment heights (0, 2 and 5 m);
- two different class of safety barriers. Even though the Milano Verona project has been conducted considering the H2 class, which is the minimum required for the specific traffic conditions of the considered motorways, according to the Italian Regulations, different design charts will be presented in this section considering both an H2 and an H3 safety barrier at the motorway edge.

With this approach a set of 6 design charts have been developed allowing to account for different combinations of motorway and railway embankment heights with the following combinations of variables:

- 2 lanes with no safety barriers (Figure 3);
- 2 lanes with H2 safety barriers (Figure 4);
- 2 lanes with H3 safety barriers (Figure 5);
- 3 lanes with no safety barriers (Figure 6);
- 3 lanes with H2 safety barriers (Figure 7);
- 3 lanes with H3 safety barriers (Figure 8).

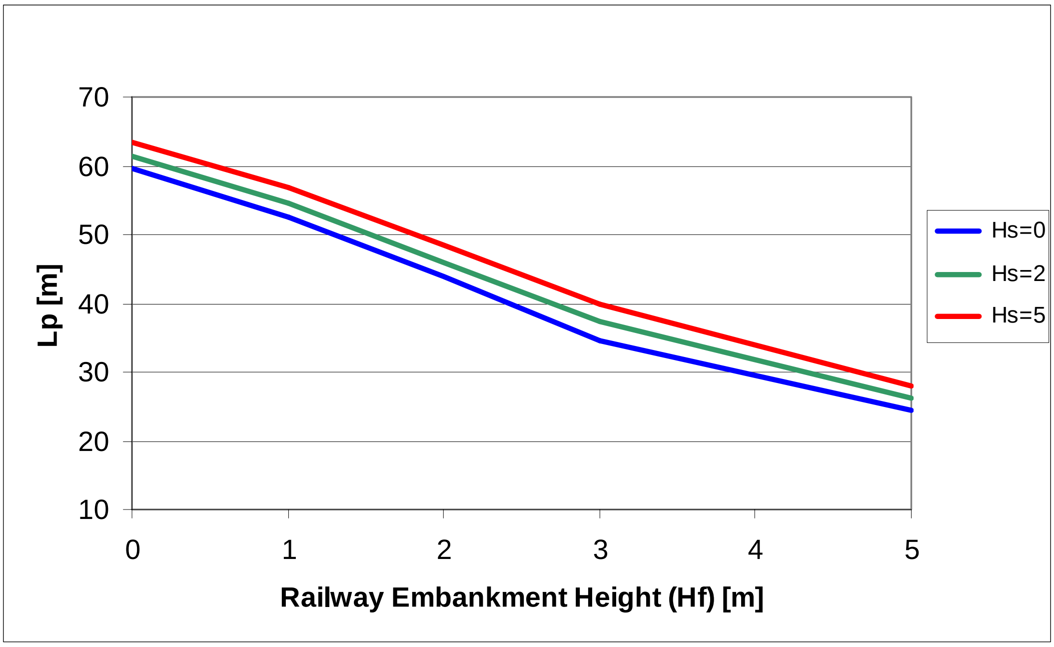

Figure 3: design chart for defining L_{P} with different railway and motorway embankment heights in 2 lanes sections with no safety barriers

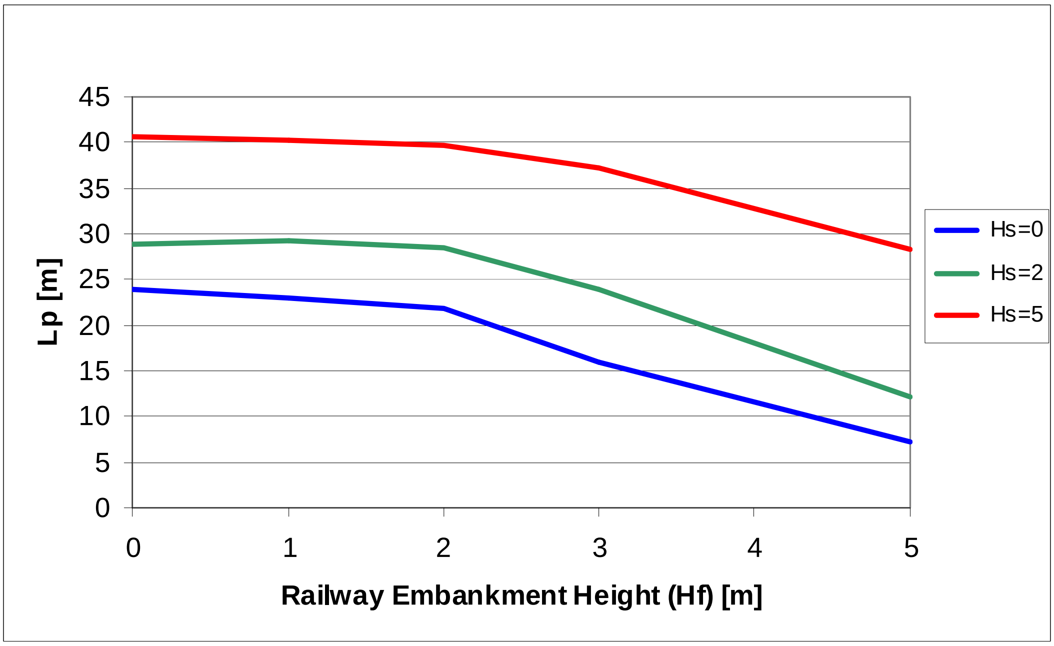

Figure 4: design chart for defining L_{P} with different railway and motorway embankment heights in 2 lanes sections with H2 safety barriers

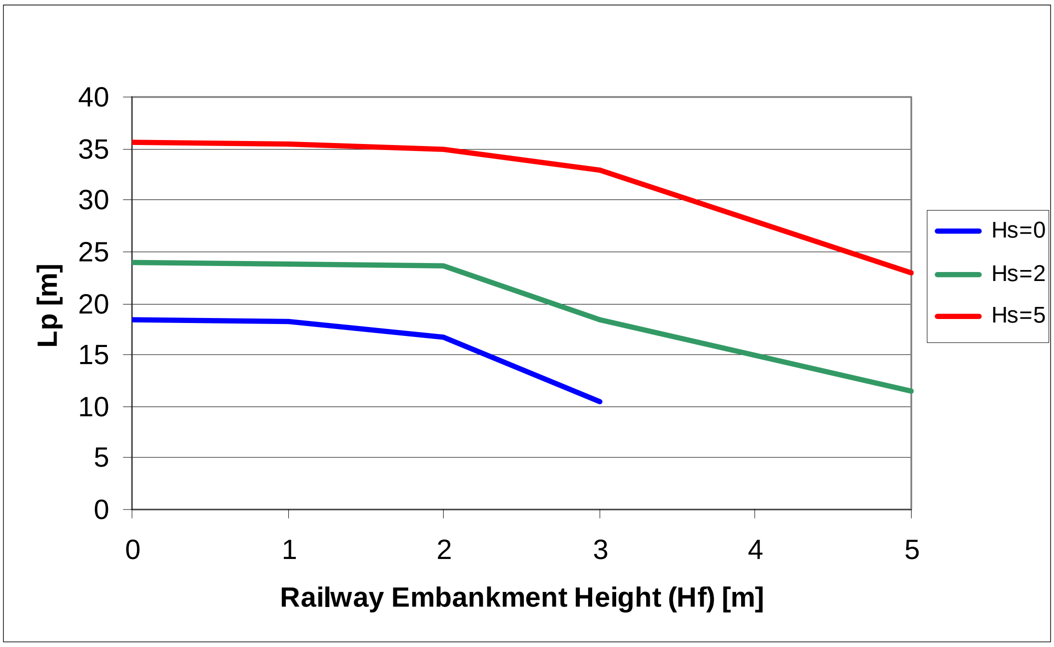

Figure 5: design chart for defining L_P with different railway and motorway embankment heights in 2 lanes sections with H3 safety barriers

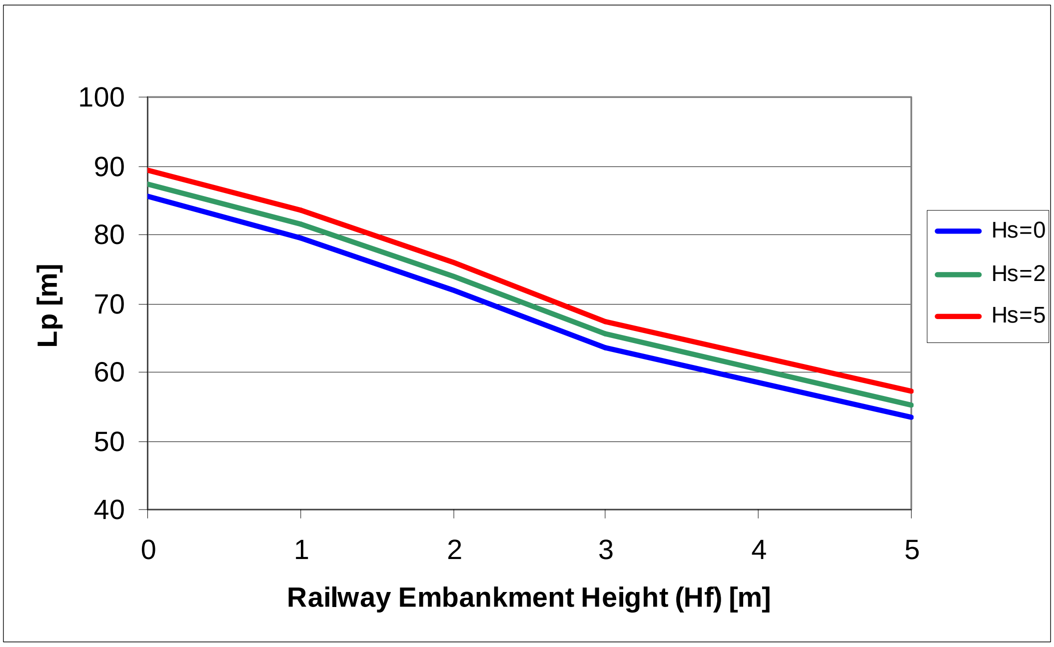

Figure 6: design chart for defining L_P with different railway and motorway embankment heights in 3 lanes sections with no safety barriers

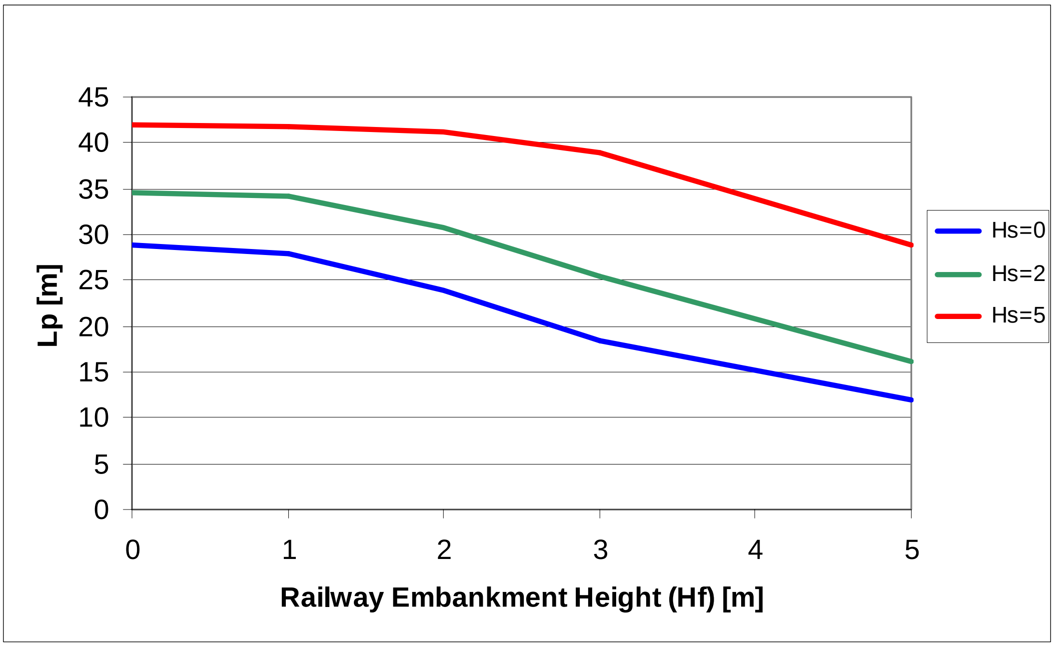

Figure 7: design chart for defining L_P with different railway and motorway embankment heights in 3 lanes sections with H2 safety barriers

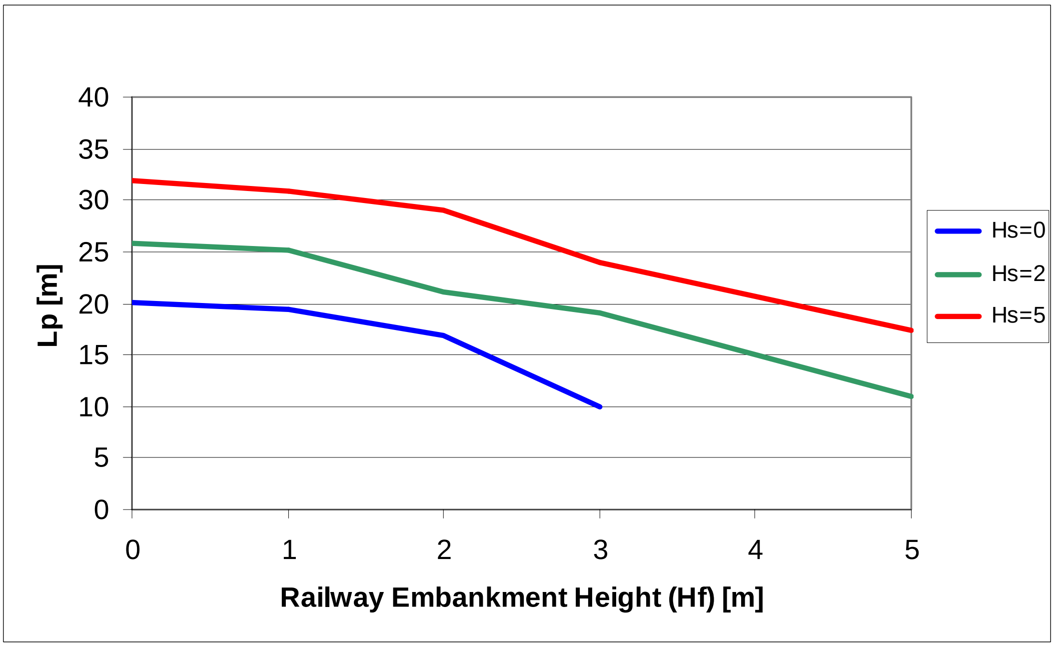

Figure 8: design chart for defining L_P with different railway and motorway embankment heights in 3 lanes sections with H3 safety barriers

The comparison between the different design charts shows that the effect of considering the protection of motorway edge safety barriers is extremely relevant, even if the H2 class is considered. If, as an example, a railway embankment of 3 m and a motorway embankment of 2 m are considered the reduction in the L_P values range from the 13.5m of a 2 lane motorway (from L_P=37.4 m in absence of barriers to L_P=23.9 m in presence of H2 class barriers) to the 40.0 m of the 3 lane motorway (from L_P=65.5 m to L_P=25.5 m).

If an H3 class barrier is considered instead than an H2 class barrier the L_P values have an additional considerable decrease. In the example shown above the L_P values are reduced to 18.3 m of a 2 lane motorway to the 19,1 m of the 3 lane motorway, as compared to L_P values of 37.4 m and 65.5 m calculated without safety barriers.

It should be also noted that the effect of the motorway embankment height becomes considerably more important when the effect of edge safety barriers is considered, as compared with the situation with no safety barriers.

Study of possible interventions to protect the Railway

When the distances between the motorway and the railway were less than the “no-interference” distance, protective measures for the AV line have to be provided in the enclosed area (AI) or on the AV embankment.

The protective elements considered are the followings:

- Earth works (dunes) in the AI.
  - Earth dunes (slope 2/3).
  - Earth reinforced dune.
- Reinforced concrete walls:
  - Reinforced concrete walls in the AI.
  - Reinforced concrete retaining walls of the railway embankment.

Number 7 standard sections have been definitively identified. The number of these sections is so much less that in the case of Milano-Bologna section (33) because the former section is still in the preliminary design phase while the latter is in the final design phase or is already under construction.

Owing to the implementation of the AV line and its safety structures in the AI, A4 border conditions will also change, involving the adaptation of the current barriers at the edge of the motorway in order to limit any consequences to road users of a vehicle running off the road.

The results of the safety study performed shows how it is important to plan the Multimodal corridors considering all the infrastructures that could be involved in the considered area. Taking into account the contribution of the motorway safety barriers and designing the two infrastructures at reasonable distance it is possible to define very easily the standard solutions to be adopted to protect the AV line. To reduce the environmental problems and the costs for upgrading or building of new safety barriers, the design solutions could be defined so as to require, when it is necessary, just earth works instead of invasive solutions requiring extensive reinforced concrete structures.

Taking into account the results of the study performed and considering the other similar experiences gained on the matter in Italy, it would now be possible to draft new guidelines to tackle the problem. The guidelines should include standard protective solutions such as those shown in Figure 9, covering all the possible situations of flanking between motorway and railway systems.

Specific real scale experiments should be performed prior to identify the protective solutions to be included in the guidelines, in order to verify some of the assumptions made in the procedure followed in the studies already completed.

On the basis of the results of the studies concerning the definition of the “no-interference” distances (probabilistic analysis and related numerical simulation models), the guidelines should enable to choose, case by case, the protective solutions necessary for each particular design situation and to develop them with the details needed for the concerned phase of the project (preliminary or final).

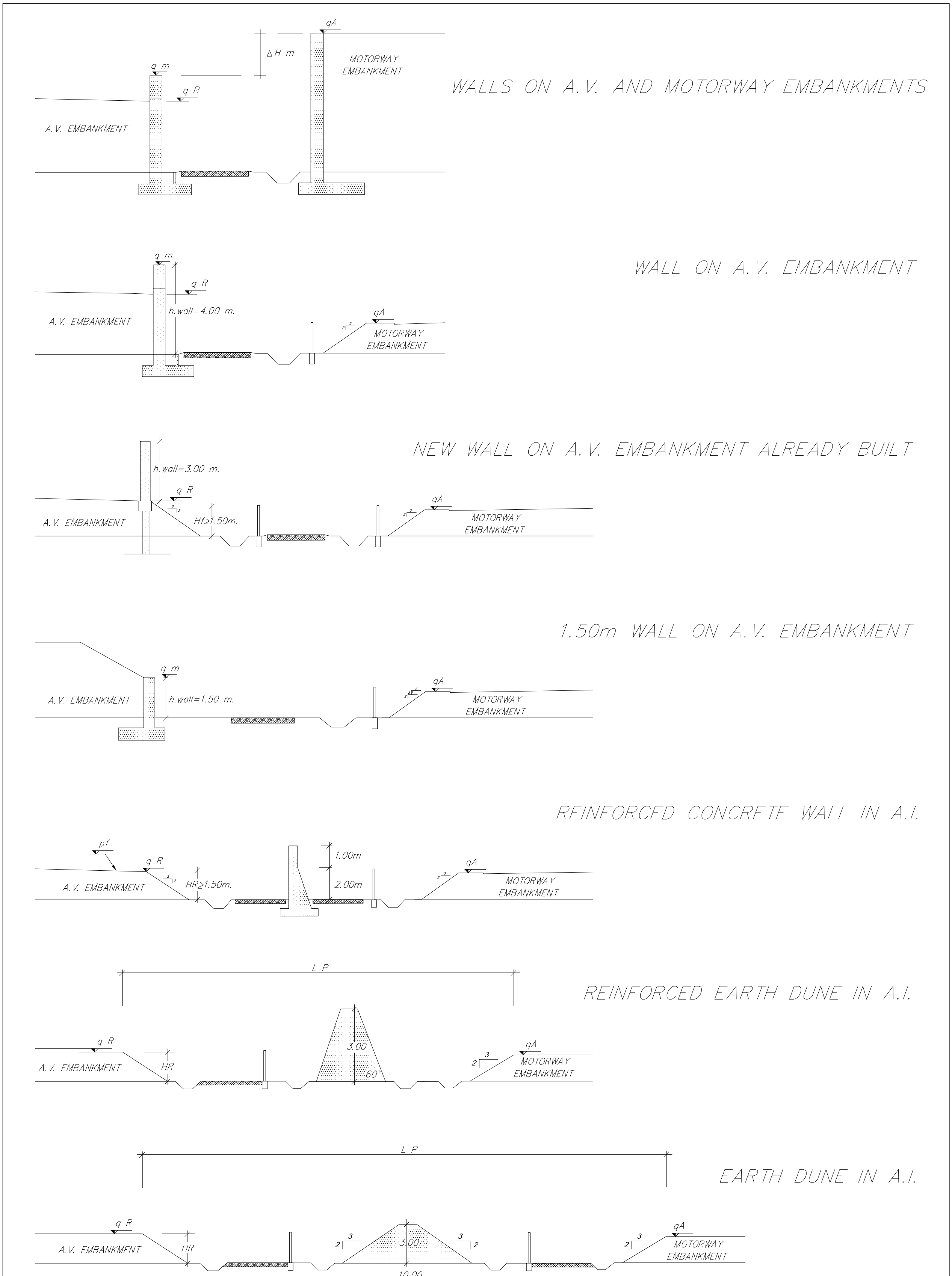

Figure 9: set of general safety sections

CONCLUSION

The design decision to contain the relative distance between important transport infrastructures in order to decrease their impact on the environment may lead to serious safety problems.

The safety aspects of the Milano - Torino section design have been developed analyzing the most important cases of flanking, defined by a combination of horizontal distances and heights of road and railway embankments, and applying the general solutions provided by the existing reference document “Safety Criteria Organization Document for Preliminary Design”, issued by Italferr, without a probabilistic analysis and numerical simulation models studied ad hoc.

In the case of the Milano - Bologna section of the high-speed railway line (AV), an in-depth study of the interactions generated by the two infrastructures was performed. The safety analysis was tailored to the specific design conditions of the Milano – Bologna section, neglecting the possible protective contribution of the existing obsolete safety barriers at the carriageway edge and considering a motorway carriageway composition including 4 lanes. The results obtained were in part unpredictable compared to the approach used in the Milano – Torino section. . Its application to design has involved the inclusion of different types of protective structures, sized so as to reach the safety level required by the Customer.

In the case of the Milano - Verona section, the probabilistic analysis and the numerical simulation models have been further developed and extended to include the possibility to take care of the protective contribution of the safety barriers installed at the motorway edge and to allow the analysis of less critical carriageway compositions, including 2 or 3 lanes only. The results obtained showed that the extent of the interaction problem is consistently reduced as far as the influence of the barriers at the edge of the motorway or of the number of lanes composing the motorway on the value of the “no – interference” distances is very high.

The findings of the studies performed show how it is important to plan at the beginning of the design process (at the feasibility study or preliminary design phases) the definition of the Multimodal corridors in order to optimize the distances of the different infrastructures according to their functional characteristics and to the relative invasive nature of the protective structures to be included in the space between the infrastructures themselves. This could allow a considerable reduction of the involved environmental problems and a reduction of the overall costs.

The experience gained in these problems could provide useful references for a hoped-for generalization of the problem, with the aim of achieving an adequate standard for design reference. In fact, the preliminary bibliographic research performed prior to start the described studies has put in evidence the missing of standards for the protection of the Railways lines and for the Multimodal Transportation Corridors definition in general. On this subject the CEN/TC256 “Railway applications” is active at present but no evidence exists about the inclusion of the stated problems in its working program.

REFERENCES

AGOSTINACCHIO M., OLITA S. (2002): *Elementi di ritenuta paramassi,* EPC LIBRI s.r.l. Rome, Italy;

BLOOM J. A., RUDD T.J., LABRA J.J. (1978): Establishment of Interim guidelines for bridges rails required to contain heavy vehicles, in *Report No. FHWA-RD-75-510*, Federal Highway Administration, January 1975;

BUTH C. E. (1978): *unpublished vehicle crash test data from DOT-FHWA-11-9181,* Texas Transportation Institute, College station, Texas, Oct. 1978;

BUZZETTI M., POLICICCHIO F., DOMENICHINI L., GIORDANO G., LA TORRE F. (2004): Railway System-Motorway System Interference: Design Applications For AV Line Protection On The Milan- Bologna Section, in *Proceedings of the Second SIIV International Conference*, SIIV, Firenze, 27-29 October 2004 – ISBN 888 4532 698.

CASTIGLIA C., OGGERI C., PEILA D. (2001): Linee progettuali per rilevati paramassi, in *International Congress on protection structures against rock fall*, Siusi (BZ), Italy, 89-100;

DOMENICHINI L., LA TORRE F., GIORDANO G., (2004): Safety Analysis Of Multimodal Transportation Corridors, in *Proceedings of the Second SIIV International Conference*, SIIV, Firenze, 27-29 October 2004 – ISBN 888 4532 698.

EN1317-2 Road Restraint Systems – Part 2: performance classes, impact test acceptance criteria and test methods for safety barriers", April 1998

Ministero Infrastrutture e Trasporti, 2004 Istruzioni tecniche per la progettazione, l'omologazione e l'impiego dei dispositivi di ritenuta nelle costruzioni stradali, D.M. 21.06.2004

GUASTI G., PEILA D., RECALCATI P., RIMORDI. P. (1999): Sperimentazione su rilevati rinforzati con geogriglie per la difesa contro la caduta massi, in *XX National Geotechnical Congress,* 3-15 Parma (PR), Italy;

HIRSCH T. J. (1978): Analytical evaluation of Texas bridge rails to contain buses and trucks, Texas Transportation Institute, *Research report 230-2*, Study 2-5-78-230, Bridge rail;

KAR A.K. (1978): Projectile penetration into burried structures, *Journal of Structural Division*, ASCE, vol. 104, Jan 1978, 125-139;

KAR A.K. (1979): Impactive effects of tornado missiles and aircraft, *Journal of Structural Division*, ASCE, vol. 105, Nov 1978 2243-2260;

MONTEPARA A., VIRGILI A. (1990): Definizione di un modello di comportamento teorico per il calcolo delle barriere antisvio mediante analisi limite, *L'Industria Italiana del Cemento*, 3/1990, 235-238.

PEILA D., ORESTE P. P. (2001): Interventi di difesa contro la caduta di massi, in *International Congress on protection structures against rock fall*, Siusi (BZ), Italy, 25-40.