A new methodology to perform the risk analysis of cross wind on high speed lines

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Abstract

This paper describes a new methodology to perform the cross wind risk analysis on railway lines. This study consists in the evaluation of the probability of rail vehicle’s overturning when it is running on a railway line under the action of cross wind.

According to the new methodology described in this paper, the cross wind risk analysis is based on a meteo study and on a stochastic approach. The former provides the probability of occurrence of wind gusts on the specific site on the line while the latter leads to the evaluation of the Characteristics Wind Curve (CWC) probability distribution. The probability of vehicle’s overturning is calculated as the combined probability of the wind gust velocity occurrence and of the overcoming of the safety limit adopted for the definition of the CWC.

Some preliminary results of the application of this new methodology to the Rome-Naples high speed railway line are also reported.

Introduction

The European regulations for the interoperability of the European High Speed railway system are focused on facilitating the technical harmonisation of the European railway network and at improving its competitiveness, contemporarily fulfilling high levels of safety.

The tool for achieving these goals is the European Technical Specification for High Speed Interoperability (TSI).

These specifications define a series of technical parameters that constitute the interface between the several subsystems of the whole railway transportation system: Infrastructure subsystem, Rolling Stock subsystem, Signalling subsystem, Energy subsystem, etc.. For these interface parameters, limit values are thus established, that are able to ensure the proper interaction between the subsystems involved.

As far as it is the case of the Infrastructure subsystem, the interface parameters are almost exclusively established with the Rolling Stock subsystem: as a rule, “interoperable trains” will run on “interoperable infrastructures” without special supplementary technical requirements.

One of the many interface parameters considered in the interoperability specifications is the cross wind.

At the current state, by the side of the Rolling Stock technical specifications for interoperability, the interface parameter “cross wind” is addressed by defining limit reference values for the wind speed, that indirectly define the Rolling Stock aptitude of being sufficiently stable under severe cross winds. These limit values are described as a set of curves that define the wind speeds, corresponding to a limit reference wheel unloading, in relationship with the train speed and with a limited set of reference infrastructure scenarios.

By the side of the infrastructure, the interface parameters “cross wind” is treated as a commitment for the Infrastructure Manager to identify those regions of a line that can be exposed to severe winds, and to adopt, for these regions, the most appropriate countermeasures in order to ensure the operation safety. These countermeasures can consist either in the installation of alarm systems, able to impose temporary speed restrictions to the trains, or in fixed trackside protections.

As a general remark, the approach outlined by the European Technical Specifications for High Speed Interoperability is valid for any railway line. But, on the other hand, it has to be stressed that the cross wind problem becomes a major topic for the high speed operations on new lines. It is relevant, for the high speed circulations, because the aerodynamic forces depend on the square of the relative wind speed (calculated by composing the wind velocity vector and the train speed) which increases for higher train speeds. Moreover, it is relevant for the new lines
since the construction of new lines, with totally new topographic layouts, can potentially imply the crossing of locally windy regions. In many cases, these two conditions (high speed of the trains and new topographical layout of the line), are both present in a new railway infrastructure investment. The main aspects concerning the assessment of the cross wind risk are: the definition of a standardized methodology leading to comparable results between different lines, and the combination of the probability due to all the aspects concerning the crosswind stability (probability of wind occurrence; probability of wind direction; probability of train load condition; probability of failure of the train suspension system; probability to reach overturning conditions etc.). For all the previous reasons, Rete Ferroviaria Italiana (RFI), University of Genova (Unige) and Politecnico di Milano (Polimi) developed a new methodology to assess the risk analysis on railway lines related to cross wind effects through a cooperation research.

The proposed methodology to assess the cross wind risk analysis consider as a first approach a statistical meteo analysis and a stochastic approach for the calculation of the CWC. This is the first step towards a more complete approach that may overcome the limit to consider the CWC as a deterministic limit as suggested by the TSI standard approach.

In this paper, the proposed methodology has been applied to the new high speed line Rome-Naples, in the south of Italy.

2 Risk analysis: methodology

The risk analysis consists in the evaluation of the rail vehicle’s overturning probability when it is running on a railway line under the action of cross wind. According to the new methodology described in this paper, the cross wind risk analysis is based on a meteo analysis, providing the probability of occurrence of wind gusts, and on a stochastic approach that leads to the evaluation of the Characteristics Wind Curve (CWC) probability distribution.

The probability of vehicle’s overturning is calculated as the combined probability of the wind gust velocity occurrence and of the overcoming of the safety limit adopted for the CWC definition.

From a theoretical point of view, the risk analysis could be carried out starting from the Characteristic Wind Curves evaluated, in each point of the line, accounting for the specific infrastructure characteristics of the site through the aerodynamic coefficients. Nevertheless, according to this approach, it would be necessary to evaluate the aerodynamic coefficients of the considered train with all the infrastructure scenarios (flat ground, viaducts and embankments of different geometries) along the line. In order to avoid all these wind tunnel tests, very expensive in terms of both cost and time, an equivalent alternative approach has been set up ad hoc for this application.

The new methodology proposed in this paper follows four steps:

1. definition of the line characteristics in terms of infrastructure (scenario’s geometry, curve radius, cant, orientation to the north, design speed);
2. probabilistic analysis of the wind speed and direction and definition of the statistical properties of the mean and peak wind speed along the line, at 2m height above TOR, considering also the speed-up and speed-down effects induced by the track scenario;
3. calculation, of the statistic distribution of the Characteristic Wind Curve (CWC) in each point of the line, according to the stochastic approach (Cheli et al. 2004), adopting the flat ground aerodynamic coefficients;
4. evaluation of the probability of CWC exceedance along the line, combining the cumulative probability distribution of the wind speed and the stochastic distribution of the CWC.

With this approach, the speed-up/speed-down effects due to the different scenarios along the line are not considered in the aerodynamic coefficients and, as a consequence, in the CWC (that is evaluated for any scenario using the flat ground aerodynamic coefficients). The scenario’s geometrical characteristics (height, embankment’s slope, …) modify only the wind
speed that is calculated/measured at an height of 2m over the TOR. This approach is based on the assumption that the aerodynamic coefficients measured with flat ground scenario are equivalent to the aerodynamic coefficients measured with different infrastructure scenarios (viaduct/embankment) by adopting, as reference wind speed, the wind velocity measured over the track, in correspondence of the train position, without the train. Figure 1 shows the rolling moment aerodynamic coefficients measured through wind tunnel tests on an high speed train with different scenarios (Bociolone et al, 2003). In particular, Figure 1 shows a comparison between the coefficients measured in three different ways:

- flat ground configurations (blue points);
- 6-m high standard embankment with wind speed measured in free stream P₁ (green point);
- 6-m high standard embankment with wind speed measured at an height of 2 m over the TOR, in correspondence of the train position but without the train (P₂ – red points).

For the high speed trains, the direction of the relative wind train speed is ranged between $\beta_w=[0°-30°]$, where $\beta_w$ represents the angle between the relative wind speed and the line, in the horizontal plane. It is possible to see that, in the interesting range of angles of attack, the agreement between the aerodynamic coefficient relative to the flat ground and the one relative to the embankment, evaluated by the wind speed measured on P₂, is significantly high. Good agreements have been found also for the other main aerodynamic coefficients.

In the following sections, the four steps of the methodology are analyzed in details and the methodology for the calculation of the probability of rail vehicle overturning is presented.

**Figure 1.** Rolling moment aerodynamic coefficients on flat ground (blue points) in terms of comparison with the corresponding coefficients measured on embankment with the wind speed measured in P₁ (green points) and in P₂ (red points).

### 3 Line data specification

In order to carry out the risk analysis, the line has been divided into homogeneous sections in terms of meteo features and general infrastructure features. For the aspects linked to the general infrastructure features, the topographic layout and the relevant cinematic parameters must be precisely described. In the case of a double track line with the two tracks running with a constant distance between the track centres, the topographic position of the line is sufficiently represented by the position of just one of the two tracks. This position is established in the framework of a general reference topographic system that must be consistent with the general topographic reference system used.
in the meteo studies. The general layout is then constituted by the position (x and y coordinates) of the reference track in the top view, by the height (z coordinate) of the reference track above the see level and by its orientation with respect to the geographic North. The points along the track that describe its topographical position are spaced of about 50 m. Each of these reference points is associated not only to the set of topographic coordinates (x, y, z) and track orientation (β), but also to its progressive distance from the origin of the line (line_km position).

Considering each reference track point, the height of the reference track above the surrounding ground is then recorded. In case of embankment or viaduct, the ground points, that are closest to the infrastructure, are considered. In case of cut, the closest points to the cut's upper edge are considered.

In a first step, both left hand and right hand sides of the line, are considered. But with a further step a simplification is made: at each line_km position the worst situation is assigned. That is to say that in the case of an embankment or of a viaduct, the higher value of the embankment's height is assigned to both sides of the line; if it is the case of a cut, then the lowest value of the cut's depth is assigned to both sides of the line.

In the case of a tunnel, no description of the line is carried on, except for the positions of tunnel entrance and tunnel exit.

Using the same reference points along the reference track, the cinematic relevant features of the line are described as: the radius of curvature, the cant of the track and the uncompensated acceleration, considered with respect to the highest train speed allowed at that line_km.

In the transition curves, the uncompensated acceleration linearly increases from zero (alignment) to the maximum value in the curve. When describing the transitions curves, a conservative simplification is made: each transition curve is simply assigned the uncompensated acceleration associated to the adjoining curve.

The line referred to in the present paper is located in the northern part of the line and is surrounded by an even terrain. This part of the line is characterized by a quite constant height above terrain and not very high viaducts and embankments (heights of around 8 meters for the embankments and heights between 10 and 15 meters for the viaducts). No cuts nor tunnels are present. This line is almost fully situated in correspondence of two adjoining curves having different radii and cants, where the uncompensated acceleration is 0,40 m/s² and 0,58 m/s², respectively. The maximum allowed train speed is 300 km/h.

4 Meteo analysis

4.1 Numerical simulation of wind fields along the Rome-Naples HS/HC railway line

A numerical model of the territory and two distinct and complementary numerical simulation methods have been adopted and compared to perform the probabilistic analysis of the wind speed and direction along the HS/HC Rome-Naples railway line. The analysis makes use of the meteorological databases of the anemometric stations of the Italian Air Force (AM) in the neighborhoods of the line, and of the anemometric measures recorded by RFI at some points along the line.

The numerical modeling of the territory, where high-resolution simulations have been performed, requires mainly two bi-dimensional fields: the topography and the terrain roughness derived from the land cover.

The numerical simulations have been performed by means of the mass-consistent model WINDS (Sherman 1978, Ratto et al. 1990, Ratto et al. 1994, Georgieva et al. 2003). Firstly, the code has been applied as a stand-alone model to simulate a set of mean wind scenarios under idealized barotropic atmospheric conditions corresponding to a number of combinations of wind velocities aloft. Then the code has been used inside an operational chain composed by the mass-consistent model nested into the mesoscale meteorological model BOLAM (Buzzi et al. 1994) to downscale the BOLAM low-resolution wind fields and simulate a number of strong-wind situations under baroclinic conditions. For further details see Burlando et al. (2007).
4.1.1 Numerical territory modelling

The numerical territory modeling mainly involves two groups of data: the soil topography and its roughness derived from the land cover.

Soil topography is described by a digital terrain model of about 230 m resolution, provided in digital form by the Italian Istituto Geografico Militare (IGM).

Land cover is obtained from the European project CORINE database. This database is derived from satellite images (LANDSAT TM) at scale 1:100.000 collected in the years 1996-2000. It consists of maps in vectorial format, converted into a raster format by a geographical information system. The resolution of this discretization is about 230 m, in order to define the land cover matrix exactly over the topography matrix.

The roughness length is derived from the land cover, with the same discretization, using the conversion criteria proposed in Stull (1988), Wieringa (1993), Davenport et al. (2000), Wieringa et al. (2001), and Baklanov and Joffre (2003). Moreover, continuous roughness models have been implemented in the neighboring areas of the meteorological stations, with the aim of improving the local wind simulation.

The simulation domains, with horizontal resolution of about 200 m, consist of five rectangular areas, partially overlapped each other, which cover the whole railway line as shown in Figure 1.

Figure 2. The simulation domains represented by the five dashed. The railway line (solid line) and the AM anemometric stations (♦) are also shown.

4.1.2 Numerical simulations of high-resolution wind fields

As a first approach, the mass-consistent model WINDS has been applied to evaluate a set of mean wind scenarios coherent with different uniform mean wind speeds and directions at the top of the atmospheric boundary layer. Following this approach, vertical profiles of the wind velocity based on similarity-theory formulations (Zilitinkevich et al. 1998) have been used at the initialization step to define the first-guess wind field. Moreover, a module for the parameterization of the development of internal boundary layers has been used to take into account steep changes of the surface roughness parameter, i.e. sea-land transition.

The wind scenarios consist of 36 simulations with an initial imposed geostrophic wind intensity of 50 m/s, and wind directions ranging from 0° to 360° with 10°-wide sectors. The atmosphere has been assumed neutrally stratified, as this is the only stability condition appropriate in case of strong winds. This procedure has provided a complete characterization of the wind...
climatology in the areas where the line lies, and the correlation matrices to transfer local anemological measurements to wind field estimates along the railway line.

In the second approach, the mass-consistent model WINDS has been nested into the mesoscale meteorological model BOLAM, which is used operationally at the University of Genoa since June 2003. The version of the code used in the present research runs within a domain centered over Italy with a spatial resolution of 10 km both in longitude and latitude. The 12 windiest meteorological events from June 2003 to May 2006 have been selected, and the corresponding wind fields have been downscaled onto the simulation domains of Figure 1. These meteorological events have provided a description of the wind patterns associated to strong-wind events over the considered domain. For instance, Figure 2 shows an example of simulated wind field at 10 m above ground level corresponding to a mistral event in the western Mediterranean, which determines a south-westerly flow over central Italy. The maximum wind intensity is around Naples.

The information from both kinds of simulation has been used also to identify the windiest parts of the railway line where new anemometers should be installed by RFI in order to detect the data relevant to the alarm system.

4.2 Probabilistic analyses

The numerical simulations described in the previous section have been used to extract the wind speed at the meteorological stations and at the line. The extraction of the mean wind speed in a set of points of the line is a delicate task because wind speed relevant to train operations is close to ground, and such a speed is strongly influenced by the local terrain conditions. Thus, suitable post-processors of the territorial mean wind fields have been developed to account for the presence of embankments, cuts, and viaducts by means of relationships based upon wind tunnel tests (Tielkes and Gautier, 2005) and itemized numerical simulations (Engineering
Sciences Data Unit, 2002). Such post-processors evaluate the wind speed for the whole railway line, at 2 meters over the track plane. Peak wind speeds have been estimated by processing mean wind speeds and turbulence intensities through the gust factor technique (Solari, 1993). The estimation of the mean and peak wind speeds at the line, at the meteorological stations and in ideal reference conditions (i.e. open and homogeneous flat ground with roughness length equal to 0.05m) by means of a complete set of scenarios allows to evaluate two sets of transmission coefficients, i.e. the parameters expressing the change of the wind speed and directions at different locations. They have been evaluated from the stations to reference conditions and then from reference conditions to the railway line, at a height equal to 3m above the ground (i.e. 2m above the track). The passage to reference conditions has been adopted to make the data of the stations more homogeneous, and then to allow a former comparison of the results of the probabilistic analyses before the projection of the databases to the line. Thanks to the transmission coefficients, it became possible to transfer the databases of the anemological records from each stations to any point of the line, and to submit them to probabilistic analyses. The parent population has been regressed by using a hybrid Weibull model to get the wind velocity having assigned exceedance probability. The extreme distribution of the wind speed with assigned return period has been obtained by means of three alternative methods: the asymptotic model of the first type (Gumbel distribution), the POT Pareto technique and the process analysis. The process analysis has also been implemented to avoid biased values due to discontinuous acquisitions, missing data and wrong wind calms. The final distributions of the wind speeds and directions along the line are expressed as a weighted average of the distributions of the wind speeds and directions associated with the different stations through appropriate weighting coefficients. Figure 3 illustrates for a generic point along the line, the polar representations of the mean and peak wind speed with assigned exceedance $P_w$ probability. The whole sequence is reported more in detail in Solari et al. (2007).

![Figure 4. Mean and peak wind speed with assigned exceedance probability evaluated in a generic point of the railway line.](image)

5 CWC evaluation

The CWC for the calculation of the probability of rail vehicle overturning have been evaluated through the stochastic methodology developed, during these last years, by the researchers of Mechanical Department of Politecnico di Milano (Cheli et al. 2004, Cheli et al. 2003). According to this approach, since the wind-train interaction is a random process, the CWC are defined by a stochastic approach: the final output of this procedure is a probability distribution of CWC, defined in terms of mean CWC and corresponding spread band. The main steps of the methodology are presented in the flow chart of Figure 5:
1. experimental wind tunnel tests on reduced-scale physical models, in low turbulent flow, for the evaluation of the static aerodynamic coefficients;
2. starting from the wind speed statistical properties of each point of the line (roughness length, Power Spectral Density, coherence function), calculation of the turbulent wind speed experienced by a point moving with the vehicle;
3. evaluation, by a numerical algorithm based on static aerodynamic coefficients and aerodynamic admittance function, of the aerodynamic forces acting on a vehicle subjected to real turbulent wind. This algorithm accounts for the actual turbulent wind speed distribution as a function of space and time and for the vehicle’s geometry;
4. the dynamic loads evaluated at point 3 are the input for the multi-body model that allows to simulate the dynamic behaviour of a specific rail vehicle subjected to real turbulent wind;
5. starting from the output of the numerical simulation, evaluation of the CWC by adopting, as stability limit, the 90% unloading of the wheels, in agreement with the TSI (Technical Specification of Interoperability).

Starting from given wind statistical properties (point 2), it is possible to define different wind speed time histories, all satisfying the same statistical properties. By performing the steps from 3 to 5 for different wind velocity time-histories (output of step 2), different CWC, all referred to the same wind scenario, can be defined. A statistical analysis of the obtained results allows evaluating the corresponding CWC probability distribution.

As far as point 1 is concerned, as already described in the section 2, the aerodynamic coefficients are evaluated for the only flat ground scenario because the speed-up/speed-down effects due to the scenario are not accounted for the aerodynamic coefficients but are considered through the wind speed distribution that is calculated at the height of 2m over the TOR. Moreover, the aerodynamic forces depend also on the vehicle’s geometry and, as a consequence, the calculated CWC and the corresponding probability of vehicle overturning are variable according to the considered train. In order to characterise the high speed line independently from the specific operating railway vehicle, an equivalent interoperable train as been adopted. The interoperable train is the ideal train characterised by the CWC limits reported in HST TSI standard.

![Flow chart of the stochastic methodology for the CWC calculation.](image)

Once fixed the aerodynamic coefficients (relative to the interoperable train on flat ground), the CWC evaluated through the stochastic method depend only on:
wind statistical properties (turbulence intensity \( I_u \), integral length scale \( x_{Lu} \), ...);
- track layout (alignment/curve, cant deficiency).

Different macro-categories have been defined as a function of both wind characteristics and track layout (uncompensated acceleration) typical Rome-Naples line. Each meteo point along the line has been categorised according to these macro-classes.

In order to highlight the effects due to these parameters on CWC, Figure 6 shows CWC in terms of gust wind speed \( U_g \), evaluated in alignment for different wind scenario, with a train speed \( V_{tr} =300 \text{ km/h} \). In particular, Figure 6 shows CWC calculated for the train running in alignment with three different wind scenarios as a function of the angle between wind speed and train direction \( \beta_w \): it is possible to see that, increasing the turbulence intensity, the mean value of CWC increases. The differences in terms of CWC mean value between the two extreme wind scenarios are ranged between 0.5 m/s at \( \beta_w =90^\circ \) to about 6 m/s at \( \beta_w =20^\circ \). On the other hand, the wind scenario with an higher turbulence intensity is characterised by an error bar twice the corresponding error bar calculated for \( I_u =0.22 \) and \( x_{Lu} =60\text{m} \). As a consequence, at almost all wind angles of attack \( \beta_w \), the lower value, between the minimum values of the analysed CWC distributions, is relative to \( I_u =0.55 \) and \( x_{Lu} =20\text{m} \).

6 Calculation of probability of exceedance

The probability of CWC exceedance (POE) is evaluated as the combined probability that three events contemporary occur:

1. the wind direction \( \beta \) with respect to the north is ranged within the s-th angular sector, 30° wide (s=1:12);
2. the gust wind speed is higher than a threshold \( U_g \);
3. for a gust wind speed equal to the threshold \( U_g =\bar{U}_g \) and coming from the sector s, the limit of stability of 90% unloading of the wheels (that is the threshold for the CWC definition) is overcome.

As described in the previous section, in correspondence of all the sections along the line, for each angular sector s, the meteo study leads to the definition of the wind speed cumulative probability function \( p_w \), while the CWC distribution \( p_{CWC} \) is calculated through the stochastic approach.

The wind speed cumulative probability function \( p_w \) represents the combined probability that the wind comes from the sector s (point 1) and that, contemporary, the gust wind speed is higher
than the specific threshold (point 2). The CWC distribution \( p_{\text{CWC}} \) represents the probability that a gust wind speed equal to the specific threshold \( \bar{U}_g \), coming from the angular sector \( s \), leads the safety index to the overcoming of the limit of stability (point 3).

As an example, Figure 7 shows, for a specific point of the Rome-Naples line, a polar representation of both the CWC distributions and the wind speed cumulative probability for three value of \( p_w \): the angle is referred to the north (0°) and the black arrow represents the line direction in the considered point.

The combined probability of the three events \( p_{i,s} \) for the angular sector \( s \) and for the section \( i \), is calculated as the integral over the gust wind speed of the product between the wind speed cumulative function \( p_w \) and the CWC distribution \( p_{\text{CWC}} \), with the following expression:

\[
p_{i,s} = \mathbb{P}(\beta \in s | \bar{U}_g > \bar{U}_g | U_{\text{CWC}} \leq \bar{U}_g) = \int_{-\infty}^{+\infty} p_w(U_g,i,s) \cdot p_{\text{CWC}}(U_g,i,s) dU_g
\]

The probability of CWC exceedance for the \( i \)-th section \( P_{\text{sec}_i} \) along the line is the integral over the angles of the calculated combined probabilities \( p_{i,s} \): due to the fact that the combined probabilities have been evaluated for a discrete number of angular sectors \( s \) (\( s=1:12 \)), the probability of CWC exceedance for the \( i \)-th section \( P_{\text{sec}_i} \) is calculated as the sum of the combined probability evaluated for each angular sector:

\[
P_{\text{sec}_i} = \sum_{s=1}^{12} p_{i,s}
\]

The probability of CWC exceedance calculated starting from the wind cumulative probability function and the CWC distribution, does not depend on the length of the section.

As an example, Figure 8 shows the local probability of CWC exceedance (POE) evaluated for the Rome-Naples line. In the figure, the symbol \( V \) indicates the viaducts, the symbol \( E1 \) corresponds to embankments while the symbol \( C \) is referred to cuts: each symbol is followed by the corresponding scenario height.

It is possible to highlight that the POE does not seem very influenced by the scenario characteristics: the most critical zone is composed both by embankments 7.5m high and viaducts 9m high while the less critical zone is composed also by embankments and viaducts higher than respectively 7.5m and 9m.

As a consequence, this analysis highlight that the wind speed distribution over the line has the main influence on the calculation of the POE.

From the risk analysis, it appears that one of the most critical angular sectors in terms of POE is \( \beta=15^\circ \). Figure 9 shows the cumulative probability functions of the gust wind speed (evaluated at a height of 2m over the track for all the scenarios) for the probability values \( p_w=\{10^{-6} 10^{-7} 10^{-8}\} \), as a function of the kilometre of the line. In all the figures, the sections characterised by viaducts are indicated by the marker \( x \), the sections characterised by embankments are indicated by square markers while the sections in correspondence of the cuts are indicated by circle markers.

From these figures it is possible to see that the higher wind velocities are calculated in correspondence of the first two viaducts of the analysed sketch of the line (x marker). On the other hand, Figure 8 shows that the first viaduct (V9), set in correspondence of the most exposed zone, presents a POE similar to that calculated for the following embankment (E1 7.5m high); moreover, the second viaduct (V9-14.5m high) is characterised by a much lower POE.
In order to understand the reason of this trend, Figure 10 and Figure 11 show a comparison between the CWC and the wind cumulative probability functions respectively for a point representative of the first viaduct and for a point of the following embankment, 7.5m high. This trend is justified by the observation that for the viaducts the maximum wind speed is directed parallel to the line direction: actually, Figure 10 shows that the wind speed is lower where the CWC decreases, and, as a consequence, the corresponding POE is not very high.

Figure 11 shows that the CWC distribution relative to the embankment case is very similar to that calculated for the viaduct (it depends only on the wind scenario and on the track layout that, for the two analysed points, are equal). On the other hand, it is possible to observe that, for the embankment case, a maximum of the wind speed distribution corresponds to a minimum of the CWC. This is due to the fact that, the speed up effect associated to the embankment is higher for wind directions perpendicular to the scenario, where the CWC is lower. Therefore, with the embankment case, the angular distributions of the wind speed and of the CWC are such as to maximise the POE. As a consequence, for the embankment case, the POE trend is mainly due to the wind speed distribution along the line while, for the viaducts, the POE value is strongly influenced also by the wind coming directions with respect to the line.
Finally, the less exposed zone of the line, ranged between km 76.72 to km 77.52, is composed by embankments of different heights (12.5m-7.5m-2.5m) and also by a viaducts: as shown in Figure 8, the reason of this behaviour is due to the fact that, along this zone, the gust wind velocities are the lowest of the overall sketch of the line.

7 Conclusion

A new methodology that allows to perform the cross wind risk analysis on high speed railway lines has been set up.

According to the new methodology described in this paper, the cross wind risk analysis is based on a meteo study providing the probability of occurrence of wind gusts on the specific considered site and on a stochastic approach that leads to the evaluation of the Characteristics Wind Curve (CWC) probability distribution. The probability of vehicle's overturning is calculated as the combined probability of the wind gust velocity occurrence and of the overcoming of the safety limit adopted for the definition of the CWC.

The preliminary results shown in the paper allows to understand that the probability of CWC exceedance is very influenced by the wind speed distribution along the line, both in terms of modulus and in terms of direction. Moreover the proposed methodology gives a more realistic approach to consider also the statistic distribution of the CWC limits in the risk assessment. It represents a first step towards a more complete risk definition that may take into account in a probabilistic way all the other important aspects for the running stability for example the train operating conditions.

8 References


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