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RISK ANALYSIS OF CROSS WIND ON HS/HC ROME-NAPLES RAILWAY LINE

Federico Cheli[*], Francesco Ripamonti[*], Daniele Rocchi[*], Gisella Tomasini[*], Mario Testa[†]

[*]Politecnico di Milano
Dipartimento di Ingegneria Meccanica, Campus Bovisa, Via La Masa 1, 20156 Milano, Italy
[†]RFI, Roma
e-mail: federico.cheli@polimi.it, francesco.ripamonti@polimi.it, daniele.rocchi@polimi.it, gisella.tomasini@polimi.it, mario.testa@rfi.it

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1 INTRODUCTION

When a train is running on a railway line, one of the most critical problem related to safety is the risk of overturning associated to the cross wind action. Within the new European Technical Specification for High Speed Interoperability (TSI), the cross wind represents one of the main themes: the standard defines the limit values for the Characteristic Wind Curves (CWC) that represents the wind speed that lead the vehicle to the overcoming of specific safety limits. Nevertheless, by the side of infrastructure, the TSI requires the infrastructure manager to identify the most critical sections of the line but no specific methodologies are defined.

In order to analyse the problem from the point of view of the infrastructure, a risk analysis, based on the study of the wind-train interaction, is needed: this study depends on both the wind characteristics along the line and the dynamic behaviour of the train. The second part the European project “Aerodynamic in Open Air” (AOA), was specifically devoted to assess the risk analysis on high speed lines related to cross wind effects (Ref. [5]). Within the AOA project, for the meteo analysis specific numerical tools, more or less refined, have been developed but, at the present, a common standardized method has not been assessed. About the train stability, the CWC are a commonly accepted method to define the overturning limit even if discrepancies remain if they have to be evaluated through stochastic or deterministic values. As a consequence, the risk assessment that consists in combing the information coming from the meteo analysis and from the CWC’s, at present, is still under definition.

This paper leads to the comparison between two approaches for the risk analysis developed within the AOA project: a stochastic methodology (STM, Ref. [1]) and a deterministic methodology (DEM, Ref. [8]). The two methods will be applied to samples of the new Rome-Naples high speed line.

2 THE RISK ANALYSIS

The risk analysis consists in the evaluation of the rail vehicle overturning probability when it is running on a railway line under the action of cross wind.

Fig. 1 shows the flowchart of the general procedure, common for both the methodologies described in this paper, for the risk analysis.

The first step of consists in the definition of the line properties, both in terms of topographic layout (global coordinates, orientation to the north, height of the track with respect to the sea) and in terms of local characteristics (infrastructure scenario, curve radius, cant, design speed, etc.). According to this line description, the overall line has been divided into homogeneous sections. Moreover, the line analysis provides the input necessary to carry out both the meteo study and the CWC calculation. The same infrastructure database has been adopted for both the methodologies.

The meteo analysis allows to define the wind characteristics in each homogeneous section of the line. In particular, in this paper, the meteo study carried out by the University of Genoa (Ref. [3]) for the RM-NP line has been adopted for both the DEM and the STM. Starting from the meteo databases of the anemometric stations of the Italian Air Force (AM) in the neighborhood of the line, a probabilistic analysis of the wind speed and direction along the line was performed. The final outputs of the meteo analysis are the directional cumulative probability distributions $\mathbf{p_w}$ of mean and gust wind speed for the discrete probability values (iso-quantile), defined for each homogeneous section of the line.

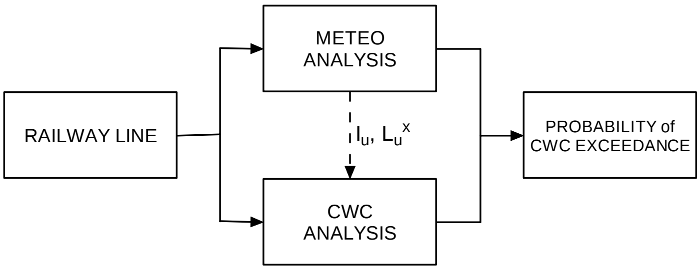

Figure 1. The risk analysis flowchart.

On the other side, the Characteristics Wind Curve (CWC) are evaluated. In this paper, two different alternative procedures for the definition of CWC along the line and, consequently, for the evaluation of the cross wind risk, are presented: a stochastic methodology (STM), developed by the researchers of the Mechanical Department of Politecnico di Milano, and a deterministic methodology (DEM), based on a procedure proposed, within the AOA project, by the SNCF group.

The last step of the flowchart in Fig. 1 is the calculation of the probability of CWC exceedance (POE) along the line: it is undertaken, according to both STM and DEM, by combining the wind probability of occurrence, evaluated through the meteo study, and the wind speed that leads the vehicle to the overcoming of safety limit (CWC). Nevertheless, with the STM both the wind distribution and the CWC distribution are treated as stochastic variables while, with the DEM, the CWC represents a threshold, defined as a function of the train speed and the wind direction, that the wind overcomes with an associated probability.

3 THE CWC CALCULATION

Both the methodologies described in this paper compute the Characteristic Wind Curves (CWC) for each homogeneous section of the line through MultiBody Simulations (MBS) of the train dynamic response under aerodynamic cross wind forces (Ref. [1], Ref. [5]).

The main difference between the two methodologies is that while, with the STM, the wind-train interaction is considered as a random process, with the DEM, the dynamic response of a train to turbulent wind is evaluated through a deterministic approach.

According to the STM, different CWC, all referred to the same wind scenario, can be defined (Ref. [1]). With this procedure, in each point of the line, a distribution of CWC is calculated accounting for the wind properties of the considered section (turbulence intensity I_u and integral length scale ^xL_u), evaluated through the meteo analysis (dashed line, Fig. 1).

On the other hand, according to the DEM, the CWC is evaluated with the TSI approach (Ref. [2]), where the effect of turbulent wind is modeled through an equivalent impulsive input gust (Chinese hat profile). According to this methodology, the wind properties are fixed (I_u=24.5% and L_u^x=96m) and the CWC is calculated through just one simulation of the dynamic response of the vehicle to the equivalent gust.

The second difference between the two approaches consists in the application of CWC to the whole line. From a theoretical point of view, for the risk analysis, the CWC should be evaluated, in each point of the line, accounting for the specific infrastructure characteristics of the site through the aerodynamic coefficients (Ref. [1]): this should lead to a lot of wind tunnel tests to estimate the aerodynamic coefficients of the considered train with all the infrastructure scenarios (flat ground, viaducts and embankments of different geometries) present along the line. Obviously, this approach is not feasible. The methodologies described in this paper propose different approaches, both based on empirical formula, that allow to extrapolate the CWC calculated for the standard scenarios (Ref. [2]) to all the real infrastructure scenarios present along the line. In particular, for the embankment/cut scenario, the STM considers that the flat ground scenario is equivalent, in terms of aerodynamic coefficients, in the range 0°-30° of angles of attack[1], to the embankment/cut scenario, provided that the accelerated wind speed on top of the scenario is adopted as the reference one (Ref. [4]). As a consequence, according to the STM, the CWC distributions are evaluated only for the flat ground scenario, demanding to the meteo study the task to calculate the wind speed over the track, through empirical formula. Differently, the DEM starts from the deterministic CWC calculated, through the TSI approach (Chinese Hat, Ref. [2]), for the standard 6m-high embankment. By means of transposition coefficients, empirically evaluated, the CWC is then opportunely scaled in order to consider the different embankment/cut geometries.

For the viaducts, both the methodologies adopt the CWC calculated for the flat ground.

As an example, in Fig. 2 a comparison between the CWC calculated for a viaduct, for the same wind properties, by both the methodologies is reported (the CWC calculated through STM is represented in terms of mean value and corresponding spread band). The deterministic CWC is ranged, at all angles of attack, within the spread band of the stochastic curve but it does not correspond to its mean value.

4 PROBABILITY OF CWC EXCEEDANCE (POE)

According with the stochastic method, the probability of CWC exceedance (POE) is evaluated as the combined probability that contemporary three events occur:

1. the wind comes from the β direction;
2. the gust wind speed is higher than a threshold $\bar{U}_g$;
3. for a gust wind speed equal to the threshold $\bar{U}_g$ and coming from the β direction, the limit of stability of 90% unloading of the wheels (that is the safety limit for the CWC definition) is overcome.

In correspondence of all the homogeneous sections along the line, the combined probability of the three events $\mathbf{p_{i,\beta}}$, for the a specific wind direction β and homogeneous section **i**, is calculated as the integral of the product between the wind speed cumulative probability distri-

[1] This range represents the interesting range for the cross wind analysis of high speed trains.

bution $\mathbf{p_w}$, that represents the combined probability of the first two events, and the CWC distribution $\mathbf{p_{CWC}}$, associated to the probability of the event described at point 3. The POE for the i-th section along the samples is the integral over the angles of the calculated combined probabilities $\mathbf{p_{i,\beta}}$.

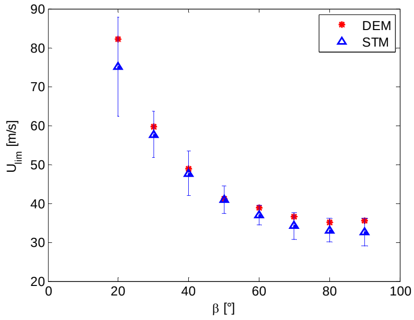

Figure 2. CWC for alignment on viaduct, V_{tr}=250 km/h, I_u=24.5% and L_u^x=96m: STM vs DEM.

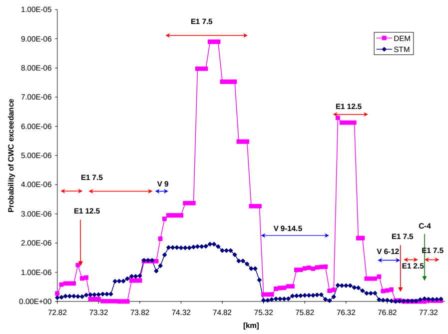

Figure 3. Probabilities of CWC exceedance for a sample of RM-NP line: STM vs DEM.

Differently, according to the deterministic methodology, the CWC does not represent a stochastic distribution but a fixed threshold. Consequently, the POE corresponds to the probability that the wind speed, coming from the β direction, is higher than the CWC value $\bar{U}_g$ calculated for a wind direction β. Also in this case, the POE for the i-th section along the samples is the integral, over the angles, of the calculated $\mathbf{p_{i,\beta}}$.

Fig. 3 shows, as an example, the POE evaluated for a sample of the RM-NP line through the stochastic (STM) and the deterministic (DEM) methodology. It is possible to observe that the POE evaluated by DEM is significantly higher, except for few sections, than the corresponding POE calculated by STM, independently from the scenario.

In the full paper, the sensitivity of the probability of CWC exceedance to variations of the CWC associated to the accounting for the wind properties, to the different definition of the CWC, as probability distribution or a threshold and to the different way of extrapolating the CWC for different embankment/cut geometries will be shown.

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