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A methodology to study the influence of train parameters variation on the dynamic response of a bridge

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Abstract

This article addresses the influence of the variation of certain train parameters on the dynamic response of a precast prestressed concrete bridge. A continuous bridge with maximum spans of 35 m has been selected because it is one of the most commonly used solutions on European high-speed lines.

The choice of the cross section of the bridge consisting of four prefabricated box girder beams, in addition to obtaining a slimmer solution, is aimed to optimize the three phases of any prefabricated element: production, transportation and assembly.

A study of the dynamic response of the precast prestressed concrete bridge for the passage of articulated train (AT) typology is presented. Several scenarios with ranges of variation for each of the geometric parameters defined in EN1991-2 were defined, the distance D corresponding to the length of the distance between regularly repeating axles and the spacing of axles within a bogie, dBA. All considered random variables have uniform distributions.

In order to take into account the increase in the maximum speed achieved by high-speed trains, the study was conducted at a speed range of [140; 500] km/h at intervals of 10 km/h.

The definition of new geometric solutions for trains requires that all possible variation scenarios be covered, so this study was carried out through simulations.

For each speed and for each of the situations presented above, 100.000 simulations were performed.

The methodology developed in this study can be used to predict the structural performance of existing bridges and new bridges, in order to verify the structural codes requirements when new high-speed trains, in terms of loads, total length and relationships between different existing geometric distances, are proposed.

Keywords: Railway bridges, Train parameters, Simulations, Precast bridges

1 Introduction

High-Speed Railway (HSR) is now a mature system of transport, however it has not yet voiced its last words. The network is still rapidly expanding worldwide and, therefore, innovation remains essential for the railway, being particularly important for high-speed rail to innovate in the face of competition from other transport modes. Even when rail transport is head and shoulders (private car, bus and air) ahead, improvements and innovations are of utmost necessity.

For rolling stock, future requirements concern: basic dimensions and performance (capacity, loading gauge, axle load, train and car length, configuration of trainset, compatibility with infrastructure, maximum speed, acceleration and deceleration) [1].

The growing need to respond to market demands as well as prepare for the challenges of the future is driving rolling stock manufacturers in search of new geometric solutions for carriages, locomotives as well as the train in general [2]. To validate the new solutions to be developed, the behavior of new and existing structures must be verified. Studies will need to be developed in order to assess the structural response of existing structures regarding the solutions proposed for new trains.

This work is aimed to study the influence of the variation of certain train parameters on the dynamic response of a precast prestressed concrete bridge. A continuous bridge with maximum spans of 35 m has been selected because it is one of the most commonly used solutions on European high-speed lines.

A study of the dynamic response of the precast prestressed concrete bridge for the passage of articulated train (AT) typology is presented. Several scenarios with ranges of variation for each of the geometric parameters defined in EN1991-2 [3] were defined, the distance D corresponding to the length of the distance between regularly repeating axles and the spacing of axles within a bogie, dBA.

The definition of new geometric solutions for trains requires that all possible variation scenarios be covered, so this study was carried out through simulations [4].

For each speed and for each of the situations presented above, 100.000 simulations were performed.

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2 Methods

For this study, a bridge representing the European high-speed lines was selected, consisting of five continuous spans with 27 + 3x35 +27 m each, making a total length of 159m.

Each section of the deck is composed by four precast concrete box girder beams and cast concrete slab (Figure 1).

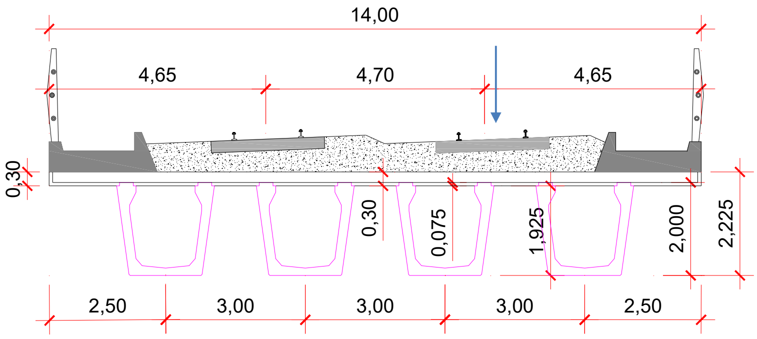


Figure 1 - Cross section and transverse position of the load path

The dynamic analyzes were performed through the moving loads methodology using the characteristic values of the loads referring to the articulated trains defined in EN1991-2. Figure 2 shows the load model representative of the articulated train currently existing in the European high-speed network.

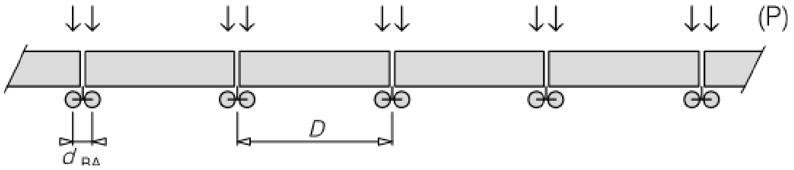


Figure 2 – Articulated train

The following geometric characteristics that define the articulated train were considered as random variables: distance D [m] corresponding to the length of the distance between regularly repeating axles and spacing of axles within a bogie, dBA [m].

All considered random variables have uniform distributions in the ranges shown in Table 1.

Six groups with ranges of variation were defined for each of the random variables. The first group concerns the ranges defined in EN1991-2, the remainder were defined to assess the influence on the dynamic structure response when values for parameters of D and dBA outside that ranges are considered.

D1	170	$18 \leq D \leq 27$	$2.5 \leq d_{BA} \leq 3.5$
D2	170	$27 \leq D \leq 30$	$2.5 \leq d_{BA} \leq 3.5$
D3 *	170	$27 \leq D \leq 30$	$2.5 \leq d_{BA} \leq 3.5$
D4	170	$15 \leq D \leq 18$	$2.5 \leq d_{BA} \leq 3.5$
D5	170	$18 \leq D \leq 27$	$2.0 \leq d_{BA} \leq 2.5$
D6	170	$18 \leq D \leq 27$	$3.5 \leq d_{BA} \leq 4.0$

* Limit of 22 vehicles, not Lmax =404 m

Table 1 – Scenarios considered for articulated train

The Train Signature (S0 (λ)) represents the dynamic excitation characteristics of a particular train and is independent of the characteristic of a structure [5].

The Train Signature (S0 (λ)) is a function of axle spacing and axle load only, were λ is the wavelength of excitation in m (λ = v / f0)

Figure 3 shows the articulated train (AT) signature for the considered 6 scenarios.

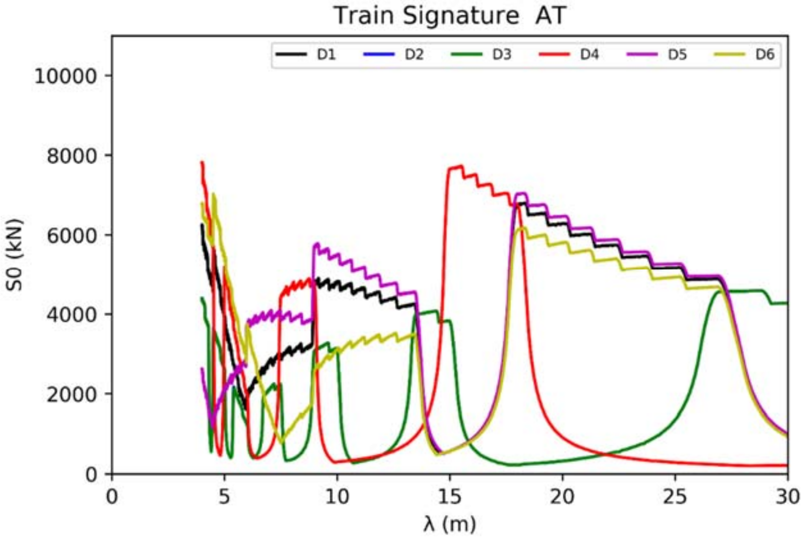


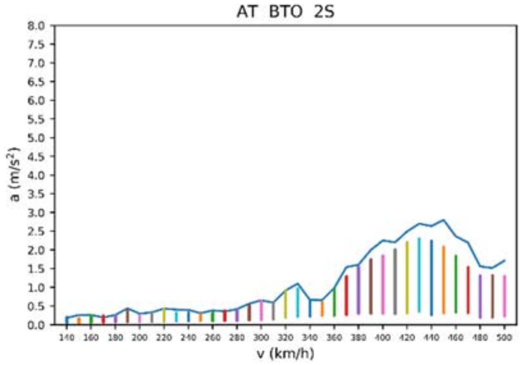
Figure 3 - Train signature for the considered 6 scenarios

The study was conducted at a speed range of [140; 500] km/h at intervals of 10 km/h.

For each speed and for each of the situations presented above 100.000 simulations were performed, evaluating the maximum value of vertical acceleration in two control points: middle point of 2nd span (2S) and middle point of 3rd span (3S), under the defined load path and considering the trains moving on one lane only (BTO).

3 Results

Figures 4 and 5 show the graphs of maximum vertical acceleration as a function of speed for scenario 1 (train parameters defined in EN1991-2). The values obtained are compared with the maximum vertical acceleration values calculated by passing the High-Speed Load Model - A (HSLMA) and real trains defined in EN1991-2.



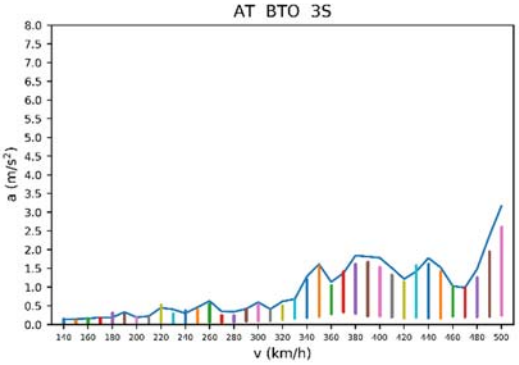
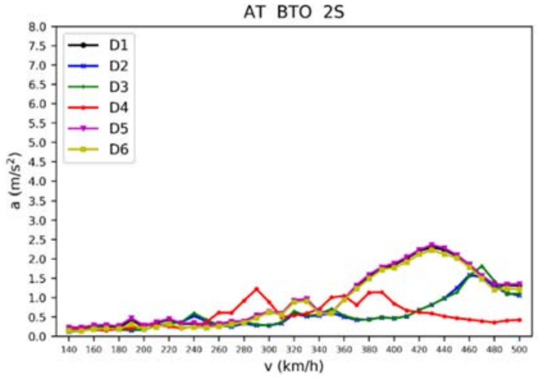


Figure 4 - Maximum vertical acceleration 2nd span Figure 5 - Maximum vertical acceleration 3rd span

It is possible to observe that all values are below the maximum value of 3,5m/s2 [6], and that the curve defined by the passage of the real trains and HSLMA is an envelope of the values obtained with the 100.000 simulations per speed (only rarely exceeded and by negligible values).

Figures 6 and 7 show the graphs of maximum vertical acceleration as a function of speed for the 6 scenarios considered (D1train parameters defined in EN1991-2; D2 to D6, intervals defined to study the influence of certain train parameters).



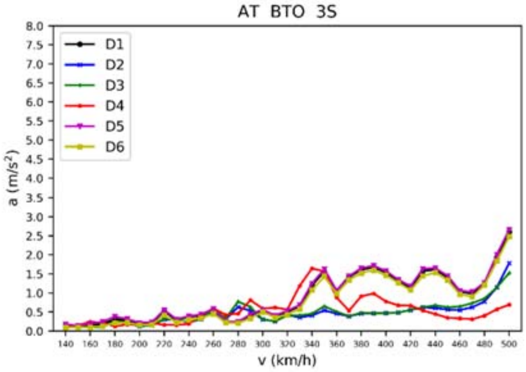


Figure 6 - Maximum vertical acceleration 2nd span Figure 7 - Maximum vertical acceleration 3rd span

The shape of the curve is equal for D1, D5 and D6.

$a_{max, D5}$ = 2,36 m/s^2 (v = 430km/h) (increase of 2,9% $a_{max, D1}$)
When the distance between regularly repeating axles is greater than the limits defined in EN 1991-2 (D2, D3) the shape of the curve is equal, and the acceleration begins to grow at higher velocities (420 km/h).
$a_{max, D2}$ = 1,59 m/s^2 (v = 460km/h) (reduction of 30,8% $a_{max, D1}$)
When the distance between regularly repeating axles is lesser than the limits define in EN 1991-2, the most important resonance effects disappear.
$a_{max, D4}$ = 1,22 m/s^2 (v = 290km/h) (reduction of 46,9% $a_{max, D1}$)

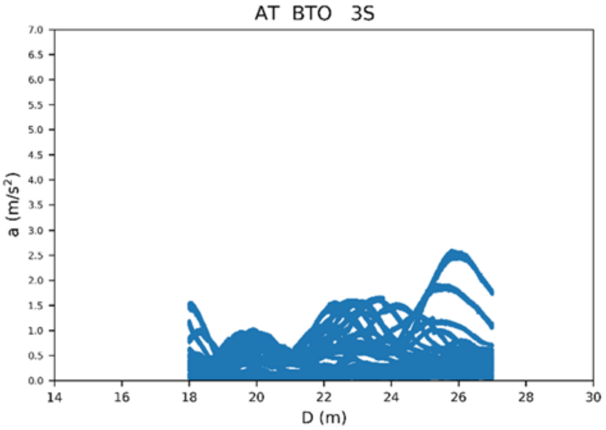


Figure 8 - Maximum vertical acceleration in 3rd span

Considering the speeds of 350 km/h and 500 km/h and the third mode of vibration (figure 9) with frequency 5,377 Hz, it is obtained, through the expression λ = v / f, λ = 18,0 m and 25,8 m.

It is possible to observe that these values (λ = D / i (i = 1, 2, 3, 4)) are in agreement with the graph of figure 8, and the value of the maximum acceleration is obtained for D = 25,8 m.

Note that for the 3rd span there are acceleration values that are not filled for all D values. This is due to the fact that, for certain frequencies of the structure, the vertical accelerations are nullified by the accelerations obtained for other frequencies.

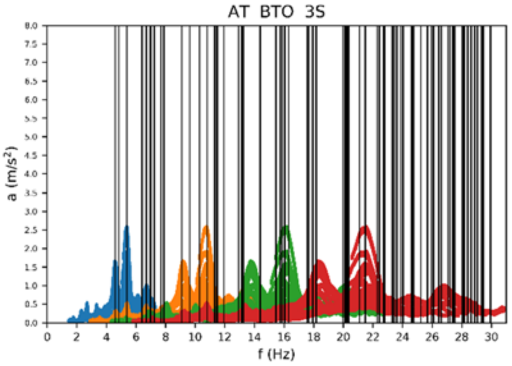


Figure 9 - Maximum vertical acceleration in 3rd span as a function of frequency

4 Conclusions and Contributions

The growing need to respond to market demands as well as prepare for the challenges of the future is driving rolling stock manufacturers in search of new geometric solutions for carriages, locomotives as well as the train in general. To validate the new solutions to be developed, the behavior of new and existing structures must be verified. Studies will need to be developed in order to be able to assess the structural response of existing structures to solutions proposed for new trains.

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The definition of new geometric solutions for trains requires that all possible variation scenarios should be covered, so the study was carried out through simulations.

From the results of these analyzes it was possible to conclude that, for the train typology range studied, the safety of the structure is verified in all situations with respect to the maximum vertical acceleration of 3,5 m/s2 defined in EN1991-2.

It is also possible to observe that the curve defined by the passage of the real trains and HSLMA is an envelope of the values obtained with the 100.000 simulations per speed (only rarely exceeded and by negligible values).

The methodology developed in this study can be used to predict the structural performance of existing bridges and new bridges, in view of the development of new high-speed trains in terms of loads, total length and relationships between different existing geometric distances.

A complementary study is underway in which, in addition to all existing train types, articulated, conventional and regular, continuous bridges with 5 spans, in the range of [15, 40] m with 1,0 m increments will be considered.

Acknowledgements

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