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Vertical displacements of a steel-concrete superstructure, 51m long, under the Thalys train load, with speeds ranging between 1...110m/s.

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Summary

Objectives:

To determine the maximum deflections of the analyzed superstructure for the considered running speeds and to determine the critical speed that has as an effect the amplification of the vibrations and the increase of the deflections. The paper studies the behaviour of the superstructure from the point of view of the vertical displacements for the case in which the running track is straight (without counter deflection).

Work method:

The running track of the bridge has a special structure: the rails are continuously fixed into the concrete slab using the Edilon corkelast material.

In order to determine the impact of the increased speed upon the vibrations and deflections of a mixed section railway bridge superstructure, this superstructure has been carried into the SAP2000 finite element calculation programme.

Twelve non-linear dynamic analysis have been performed with the Thalys train that covers the analyzed model with speeds: 1, 10, 20...110m/s (3.6...396km/h).

Conclusions:

The paper analyses the vertical deformations of a railway bridge, steel-concrete composition, 50m span, under the action of a high speed train.

The critical running speed for the analyzed superstructure, train, and speed range is 70m/s (252 km/h). The maximum deflection has been recorded at this speed at midspan of the superstructure; its value was 23.10mm, higher than the 17.61mm deflection recorded at the speed of 110m/s (396km/h). Given that the amplification of the vibrations can appear also at the common running speeds of the high speed trains, we can state that a dynamic calculation similar to the one we have made here is recommended or even compulsory.

KEYWORDS: superstructure vibration, mobile load, high speed train, deflection

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1. INTRODUCTION

The increase of the running speed on the railway generates in the bridge superstructures the apparition of certain deflections and vibrations that can be amplified under certain conditions. This paper presents a comparative study of the recorded deflections of a railway superstructure that has a horizontal running track, under dynamic loads (Thalys train), running at speeds between 1...110m/s (3.6...396km/h).

2. OBJECTIVES

To determine the maximum deflections of the analyzed superstructure presented in Figure 1 for the considered running speeds and to determine the critical speed that has as an effect the amplification of the vibrations and the increase of the deflections.

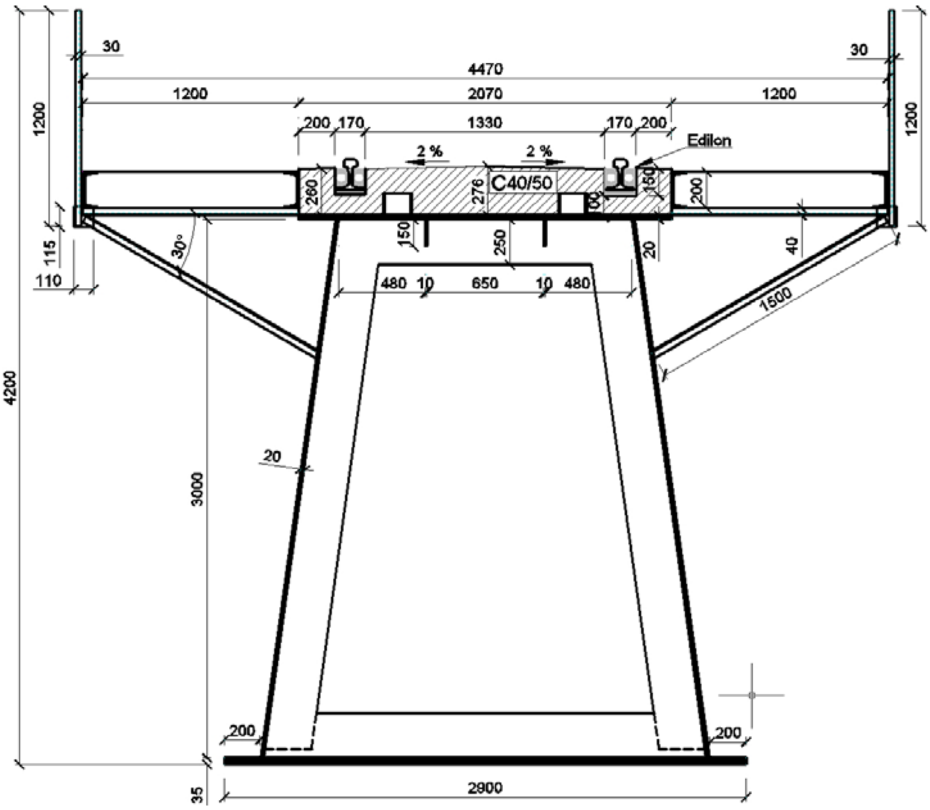

Figure 1. Cross section of the superstructure.

ISSN 1582-3024

3. WORK METHOD

The superstructure of a mixed section railway bridge without ballast bed, 50m span and the cross section as shown in Figure 1, has been divided and carried into the SAP2000 finite element calculation programme considering elements of 0.5m along the bridge. Thus, 103 characteristic sections have been obtained, and the analyzed model is presented in Figure 2.

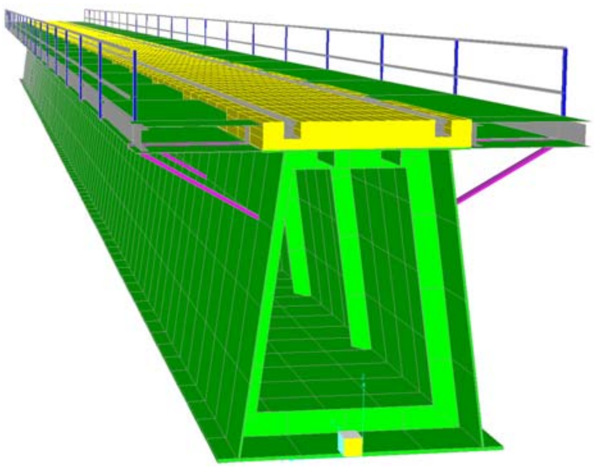

Figure 2. Structure analyzed with the SAP2000 programme

The analyzed superstructure is made up of “shell” plane elements, the rails and the linear elements of the sidewalks have been inserted as “frame” type elements, the concrete slab the rails are fixed into has been inserted as “solid” type elements.

In Figure 3 is presented the high speed train Thalys, made up of 2 engines and 8 intermediary cars, with axle loads between 7.25 and 8.5 tons, the distance between the car bogies of 18.7m. The total length of the train is Lconv=193.14m.

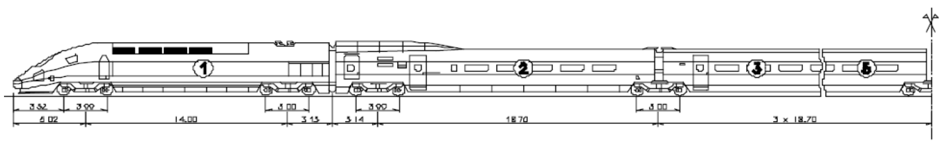

Figure 3. The high speed train Thalys.

From the moment the first axle enters the superstructure until the last axle leaves the superstructure, the train covers 102 elements 0.5m long, resulting 490 successive loading steps. The vertical deflections of the superstructure have been recorded at the rail level, for all the 490 loading steps.

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The dynamic analysis are non-linear and they have been made using the direct integration method, with a 5% damping coefficient, directly proportional with the weight. The deflections recorded by the SAP2000 programme in 3 of the 103 characteristic sections, namely the ones situated at L/4(red), L/2(yellow), and 3L/4(green), are represented in the graphics below.

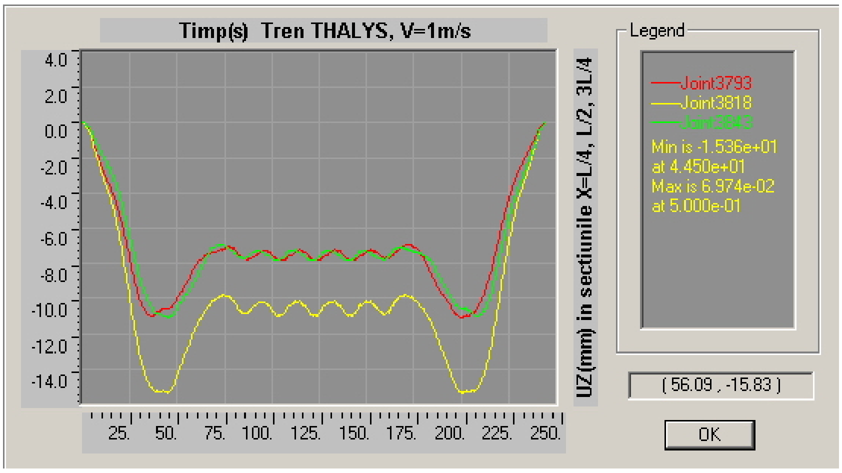
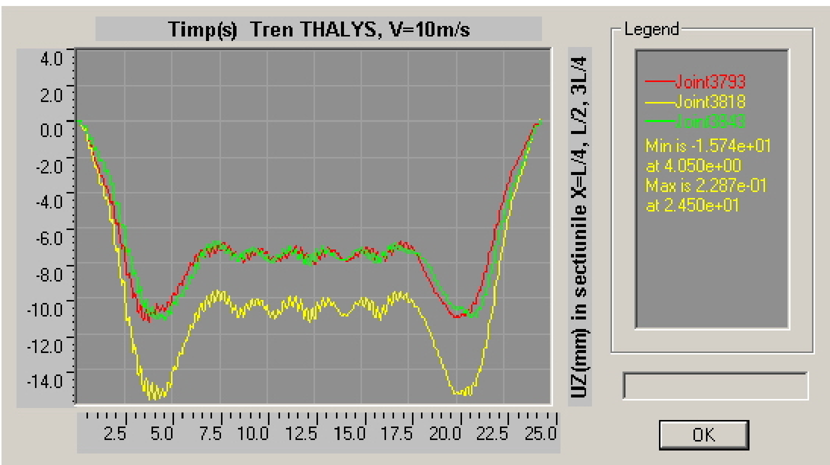


Figure 4. Deflections UZ(mm), Thalys, V=1m/s (3.6km/h)

At the speed of 1m/s, Figure 4, the maximum value of the recorded deflection of the superstructure is 15.36mm. The results are recorded for 245 seconds, the time needed by the train to cover the 51m-long superstructure with the speed V=1m/s. Because of the low speed, the deflection recorded for every loading step can be considered as static deflection for that particular Thalys position on the bridge.



ISSN 1582-3024

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Figure 5. Deflections UZ(mm), Thalys, V=10m/s (36km/h)

When the Thalys speed is 10m/s, Figure 5, vibrations start to appear in the superstructure.The results are recorded for 24.5 seconds, the time needed by Thalys to cover the 51m-long superstructure with the speed V=10m/s. The maximum value of the recorded deflections at L/2 (midspan) is 15.74mm.

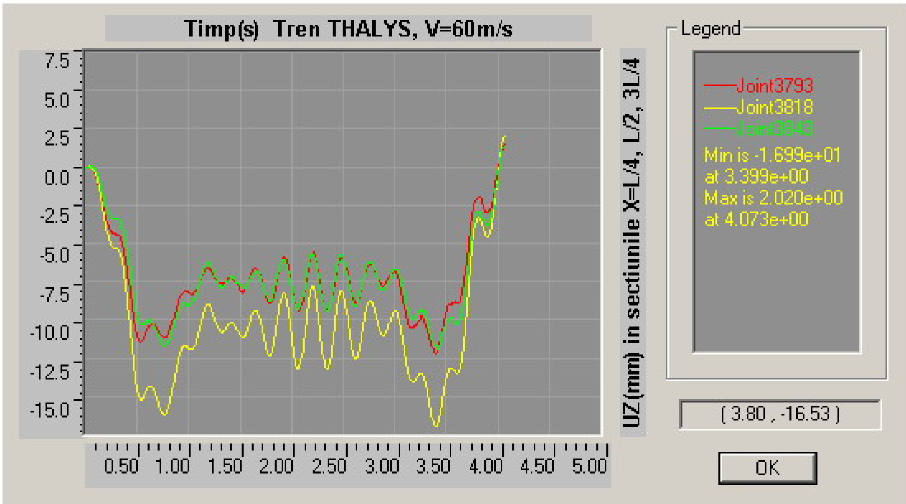

Figure 6. Deflections UZ(mm), Thalys, V=60m/s (216km/h)

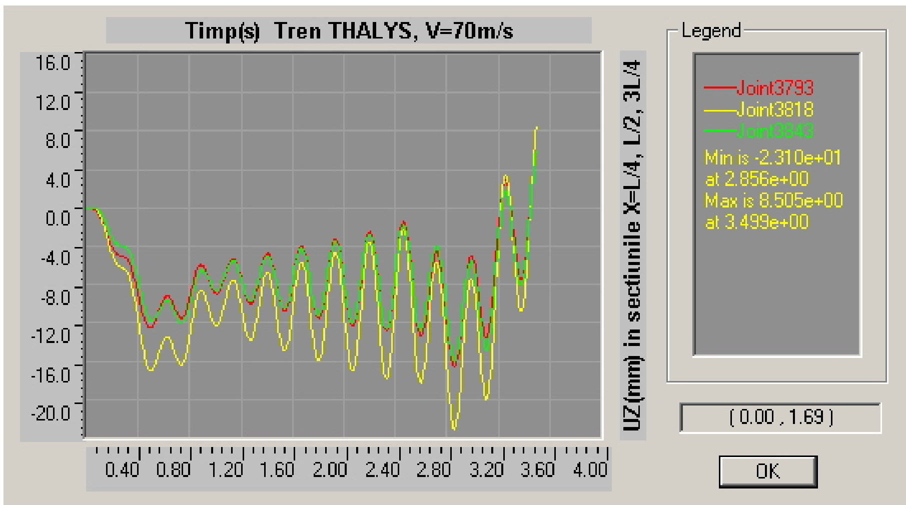

Figure 7. Deflections UZ(mm), Thalys, V=70m/s (252km/h)

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At 60m/s, Figure 6, the vibrations amplitude increase, and at 70m/s, Figure 7, will appear the resonance phenomenon. The maximum recorded deflection is 23.10mm.

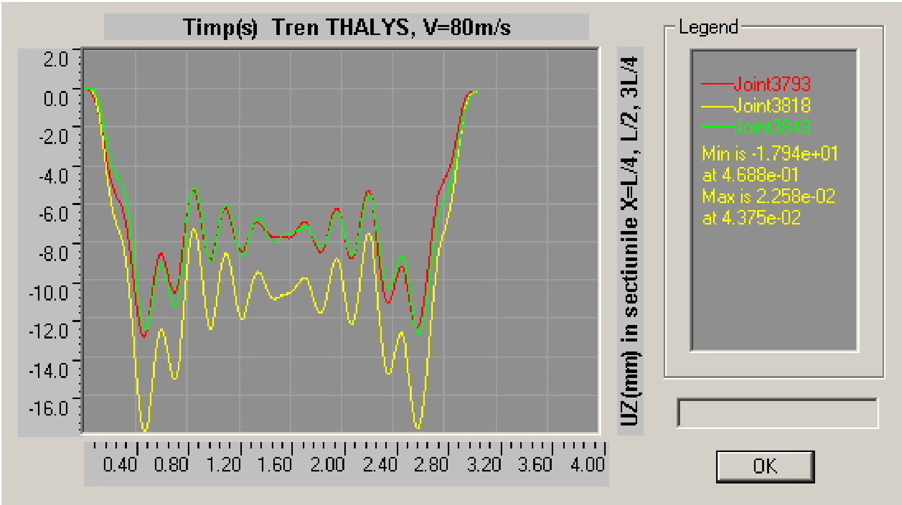

Figure 8. Deflections UZ(mm), Thalys, V=80m/s (288km/h)

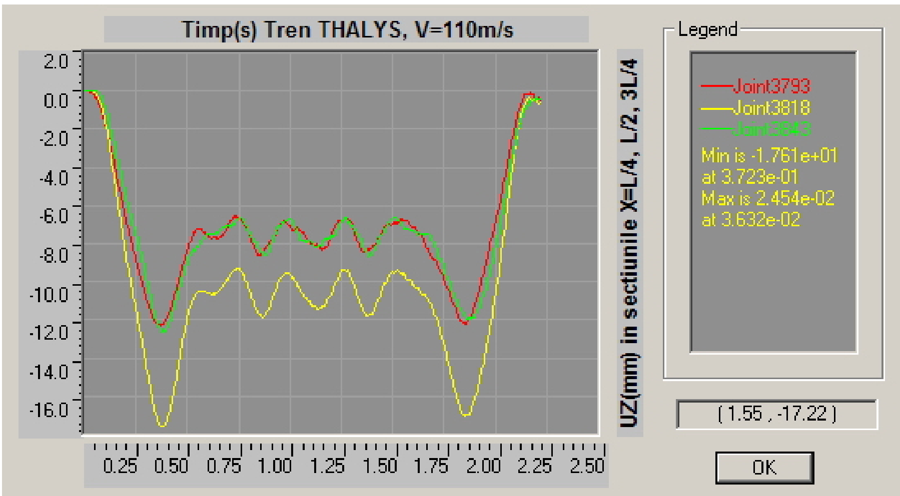

Figure 9. Deflections UZ(mm), Thalys, V=110m/s (396km/h)

When the Thalys speed is 80m/s, Figure 8, the superstructure vibrations amplitude decrease in comparison with 70m/s.

When the loading speed with the Thalys train is 110m/s, Figure 9, the superstructure offer the best high speed behaviour from the vibration point of view.

4. OBSERVATIONS

In the presented graphics we notice that, as the speed increases from 1 to 110m/s, the time needed to cover the 51m-long superstructure decreases from 245s to 2.227s. At the speed of 70m/s (252km/h) a phenomenon of amplification of the vibrations is recorded, the maximum recorded deflection of the superstructure being 23.10mm. At the speed of 110m/s (396km/h) the analyzed superstructure has a much better behaviour, the amplitude of the vibrations decrease, the maximum deflection is 17.61mm.

Table 1 is presented below. It comprises the centralization of the results obtained from the loading of the 51m-long superstructure with a Thalys train.

Table 1. Maximum deflections recorded at the rail level.

THALYS train speed	Maximum and average deflections UZ (mm) measured in the L/4, L/2, and 3L/4 sections						Maximum rail deflections, Afferent section, average maximum rail deflections (mm) throughout the loading time		
V m/s (v km/h) (0)	X=L/4 (13m)		X=L/2 (25.5m)		X=3L/4 (38.0m)				
	UZ(-) max (1)	UZ(-) avg. (2)	UZ(-) max (3)	UZ(-) avg. (4)	UZ(-) max (5)	UZ(-) avg. (6)	UZ(-) max (7)	X (m) (8)	UZ(-) avg. (9)
1m/s (3.6)	11.07	7.25	15.36	10.12	11.06	7.25	15.38	24.5	9.67
10 (36)	11.33	7.25	15.74	10.12	11.23	7.25	15.74	26.0	9.86
20 (72)	11.08	7.25	15.40	10.12	11.12	7.25	15.42	24.5	9.70
30 (108)	11.53	7.23	15.98	10.09	11.40	7.23	15.98	25.0	10.03
40 (144)	11.43	7.25	15.81	10.12	11.41	7.25	15.81	25.0	9.95
50 (180)	11.57	7.25	16.24	10.11	11.51	7.25	16.26	24.5	10.11
60 (216)	12.25	7.25	16.99	10.11	11.86	7.25	16.99	25.0	10.55
70 (252)	16.57	7.28	23.10	10.16	16.04	7.28	23.10	25.0	14.33
80 (288)	12.96	7.25	17.94	10.12	12.83	7.25	17.94	25.0	11.21
90 (324)	13.03	7.25	18.21	10.12	12.90	7.25	18.21	25.5	11.32
100 (360)	13.15	7.23	18.13	10.09	12.83	7.23	18.16	24.5	11.33
110 (396)	12.28	7.26	17.61	10.13	12.62	7.26	17.61	26.0	10.92

ISSN 1582-3024

The significance of the values in the table:

- for a certain running speed, the SAP2000 programme records in all the 103 characteristic sections of the superstructure all the deflections that occur in the 490 load steps with the Thalys train;

- out of all these sections we have selected the ones from L/2, L/4, and 3L/4 and out of the 490 values recorded in these three sections under loads we have selected only the maximum deflections, inserted in columns (1), (3) and (5);

- for the three analyzed sections we have made the arithmetical average of the 490 values of the deflections recorded in the 490 loading steps (all throughout the time when axles of the train are present on the superstructure) and we have inserted them in the table in columns (2), (4) and (6);

- for each running speed, the highest deflection recorded in the superstructure at the level of the rail is given in column (7), the section where it was recorded is given in column (8), and the average of all the maximum deflections recorded in all the 103 sections is inserted in column (9);

- the sign (-) that appears near Uz means that all the deflections in that column are below the horizontal line of the track in the absence of the train;

5. CONCLUSIONS

The first observation regarding the values in the table refers to the value of the maximum deflections that have been recorded. We notice that the critical running speed for the analyzed superstructure, train, and speed range is 70m/s (252 km/h). The maximum superstructure deflection has been recorded at this speed at midspan; its value was 23.10mm, higher than the 17.61mm deflection recorded at the speed of 110m/s (396km/h). Given that the amplification of the vibrations can appear also at the common running speeds of the high speed trains, we can state that a dynamic calculation similar to the one we have made here is recommended or even compulsory.

Based on a calculation similar to the one we have presented here, the critical speeds that have as an effect the amplification of the vibrations can be pointed out. Afterwards the designer will find through several attempts the critical speed (for this particular case, the attempts with 69m/s, 70m/s, 71m/s, etc., speeds around 70m/s, as shown in the table).

Another observation based on the analysis of the values in this table refers to the variation of the average deflections. This table shows that in the L/4, L/2 and 3L/4 sections, the average values of the deflections recorded in the rail vary insignificantly in relation with the speed of the train (the average values of the

ISSN 1582-3024

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recorded deflections in the middle of the superstructure vary between 10.12mm for V=1m/s and 10.13mm for V=110m/s, the maximum value being 10.16mm for V=70m/s).

This fact allows us to state that regardless of the speed of the train, the bridge records vibrations that are close to an average deflection for all the sections of the beam. This value can be considered to be the static deflection recorded in that particular section from the current position of the train.

Based on the average values of the deflections recorded at mid-span with a straight running track, the designer can suggest more shapes of counter deflection to be studied (parabolic, linear side ramps with circular curve in the central area, etc.) so that the maximum value of the designed counter deflection will be around 10...12 mm for this superstructure.

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