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Railway dislevelments influence on the dynamic response of bridges

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Abstract

The main purpose of this paper is to estimate the influence of railway dislevelments on the dynamic response of railway bridge structures subject to the load of a passing vehicle. The study covers six types of bridge structures: four steel structures and two prestressed concrete ones. A parameter study is performed to determine the dynamic amplification factor values and their variability as a function of railway dislevelments characteristics: amplitude and length. A special computer programme developed by the authors is used in the respective parameter study.

1. INTRODUCTION

The purpose of this study is to determine the influence of the railway dislevelments on the dynamic response of railway bridge structures, under the action of a passing vehicle. A parameter study has been performed, determining the values of the dynamic amplification factor and its variation depending on the characteristics of the railway dislevelmens (amplitude and length). The adopted values for these two characteristics correspond to those accepted by the Romanian Regulations [5, 6] in force. The parameters' calculation is performed by means of a specific computer programme, elaborated by the authors.

Six case studies are considered, representing existing railway bridge structures:

(i) four steel structures namely deck with plate girder web bottom way, of 21.0 m span; deck with plate girder web, top way, of 30.0 m span; deck of truss girder, bottom way, of 21.0 m span; deck of truss girder, top way of 33.08 m span;

(ii) two structures with deck of precast prestressed section girder with post – tensioned reinforcement, of 22.0 m span (4 girder in cross section) and respective 30.0 m span (2 girders in cross section).

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2. THEORETICAL APPROACH

The hypotheses and the modelling of the ensemble structure / vehicle is specified in the figure 1, respectively:

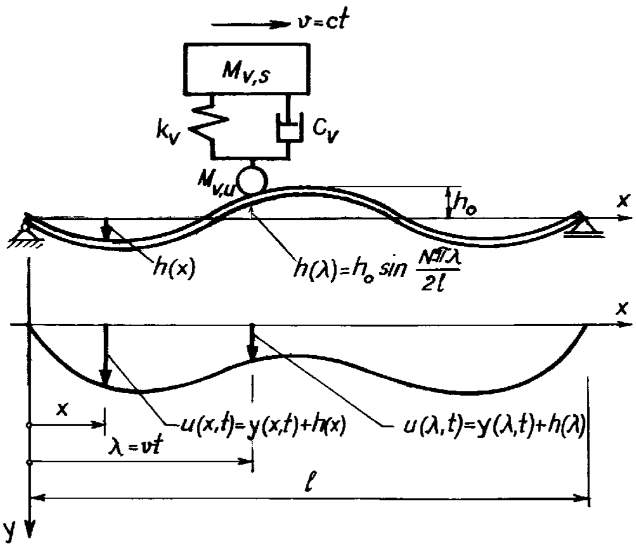

Figure 1. The modelling of the ensemble structure / vehicle

- The structure is modelled with dislevelment. The structural damping is introduced through the fraction of critical damping;
- The vehicle is modelled as a one degree of freedom dynamic system, consisting of a suspended masse, a non-suspended masse, a spring and a damper (elastic and damping characteristics).

The following simplifications are considered:

- The girder is simply supported ;
- The shape of dislevelments is sinusoidal;
- The vehicle is unique, modelled as a one degree of freedom dynamic system.
- The non-suspended mass is in permanent contact with the rolling surface.

Only the midspan section of the girder is considered in the analysis.

The used computer programme - OSIE1 - includes:

- INDOS1 input data programme;
- CALCOS1 analysis programme;

- DESOS1 drawing programme.

The central difference method is used in order to solve this system. The mathematical procedure is the step by step integration. The integration step is t/400 (where t is the necessary time for the vehicle movement on the beam of "l" span, with "v" velocity). A number of five velocities have been taken into account, namely v_0 = 5 km/h (at which the static deformation is obtained), v_1 = 60 km/h, v_2 = 90 km/h, v_3 = 120 km/h and v_4 = 160 km/h.

The dynamic amplification factor is obtained as a ratio between the maxim dynamic and the maxim static displacement values at the midspan section of the girder.

3. WORK METHODOLOGY

The study is performed in two stages, namely:

- *The first stage* of study consists in the determination of the natural vibration characteristics of the structures, mainly the type bending vibrations in vertical plan. The study is performed by modelling the structures with one and two - dimensional finite elements. For each structure many natural mode shapes are determined until the first three type bending mode shapes in vertical plan have been obtained.

Another study for determining the influence of the second and the third mode of vibration upon the dynamic response of the structures, under the vehicle action, was initially performed. It was concluded that they have a small contribution (5% is the highest value obtained only for the deck with truss girder, bottom way, of 21.0 m span at a speed of 160 km/h).

- *The second stage* of study consist in determining the dynamic amplification factor for:

- the case of ensemble: structure with railway without dislevelment / vehicle, situation named "standard";
- determination of the dynamic amplification factor for several situations of the railway with dislevelment, by varying the amplitude and the length of the sinusoids modelling the dislevelments / and the same vehicle as the standard situation. The standard vehicle is a railway engine with following features: the suspended mass = 10.0 t, the non–suspended mass = 2.8 t, the stiffness of the spring = 1740 tf/m, the damping of spring = 360.0 tf s/m.]

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4. SITUATION OF STUDY CONCERNING THE VARIATION OF DISLEVELMENT

The Romanian Regulations in force requires a maximum value of the dislevelment amplitude of 10 mm with a junction of 12.0 m (the length of the sinusoid is 24.0 m). It means maximum one sinusoid (S=1), for the structures of 21.0 m span and maximum one and half sinusoid (S=3/2) for the structures of 30.0 m respective 33.08 m.

It has been noticed as interesting the combined situation – number of sinusoid (S) with the value of their amplitude (h_0). Therefore a combination of the number of sinusoids (S=1/2, S=1, S=3/2, S=2) with values of the amplitudes varying around the maximal value required by the standard of 10 mm for railway (h_0 = 2.5, 5, 10, 15 and 20 mm) is proposed. In all cases the vehicle was the standard vehicle. The velocities for the vehicle movement were of 60,90,120 and 160 km/h.

As a result, the study comprised a number of 80 variants of combinations – h_0, S, v – for each structure, respective a total of 480 situations of analysis for six structures.

5. CASE STUDIES

In figure 2 is presented the deck of prestressed precast concrete of 30.0 m span and two girders in cross section = the general scheme of calculation, the discretized model, the forms 1, 2, 3 of type bending vibration in vertical plan. From the first stage of study it have been kept the natural characteristics of vibration for the structures.

In table 1, there are showed the geometric and dynamic characteristics for the six decks, used in the second stage of study.

Table 1

Deck type	**l (m)**	**M ($tf.s^2/m$)**	**ω (s^{-1})**		
			I	**II**	**III**
Plain girder web – bottom way	21.0	7.187	42.43	143.1	224.3
Plain girder web – top way	30.0	14.679	30.94	130.8	209.6
Truss girder – bottom way	21.0	6.486	58.69	130.8	161.6
Truss girder – top way	33.08	13.802	28.04	80.5	123.1
Concrete – 4 girders in section	22.0	45.31	35.08	120.7	261.7
Concrete – 2 girders in section	30.0	51.23	32.88	99.68	212.2

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The second stage of study is performed by means of the specific computer authors' programme. In figure 3 is presented the way of processing the input data and the output data for the programme. It is chosen the deck of precast prestressed concrete of 30.0 m span for the case of the sinusoid of 10 mm height and of a number of 3/2 sinusoids on the span. The four drawings of the figure are according to the four velocities considered in the study. The graphic representations comprise: the displacements of the weight's centre of the vehicle, the structure with the sinusoidal displacements, the dynamic and static displacements of the midspan section of the deck. The next showed values refer to some parameters of the study.

Important observation: In the graphic representations of the values of dynamic *amplification factor a deformed scale is* adopted, [(the values of dynamic amplification factor – 1) x 1000]. Therefor, some *values from the graphic are below "1"*.

The values of the dynamic amplification factors obtained for the variation of the three parameters S, h_0, v are systematized in figures: 4 (a, b, c, d) - deck of plain girder web, bottom way of 21.0 m span (4a – S=1/2, 4b – S=1, 4c – S=3/2, 4d – S=2); 5 (a, b, c, d) - deck of plate girder web, top way of 30.0 m span; 6 (a, b, c, d) - deck of truss girder, bottom way of 21.0 m span; 7 (a, b, c, d) - deck of truss girder, top way of 33.08 m span; 8 (a, b, c, d) the deck of precast prestressed girder of 22.0 m; 9 (a, b, c, d) – the deck with precast prestressed girder of 30.0 m.

For the case in which the amplitude of the dislevelments "h_0" is kept invariably, namely at the maximum value admitted by the Romanian Regulation [5] (10 mm) and the others two parameters (S and v) are varying, the graphic representations are showed in the figures 4e, 5e, 6e, 7e, 8e, 9e.

In the figures 4f, 5f, 6f, 7f, 8f, 9f are represented the values of the dynamic amplification factors for the next situation: the maximum number of sinusoids required by the Romanian Regulations [5] depending on the span of each deck, the standard situation (railway without dislevelments), the value of the maximum dynamic amplification factor admitted by the Romanian Regulations [6] for each deck, for obtaining some comparisons.

6. COMMENTS. CONCLUSIONS

For steel structures (figures 4, 5, 6, 7), the following are to be noted:

1. The general shape of the graphs which represents the values of the dynamic amplification factor with the same number of sinusoids is similarly for all the structures.

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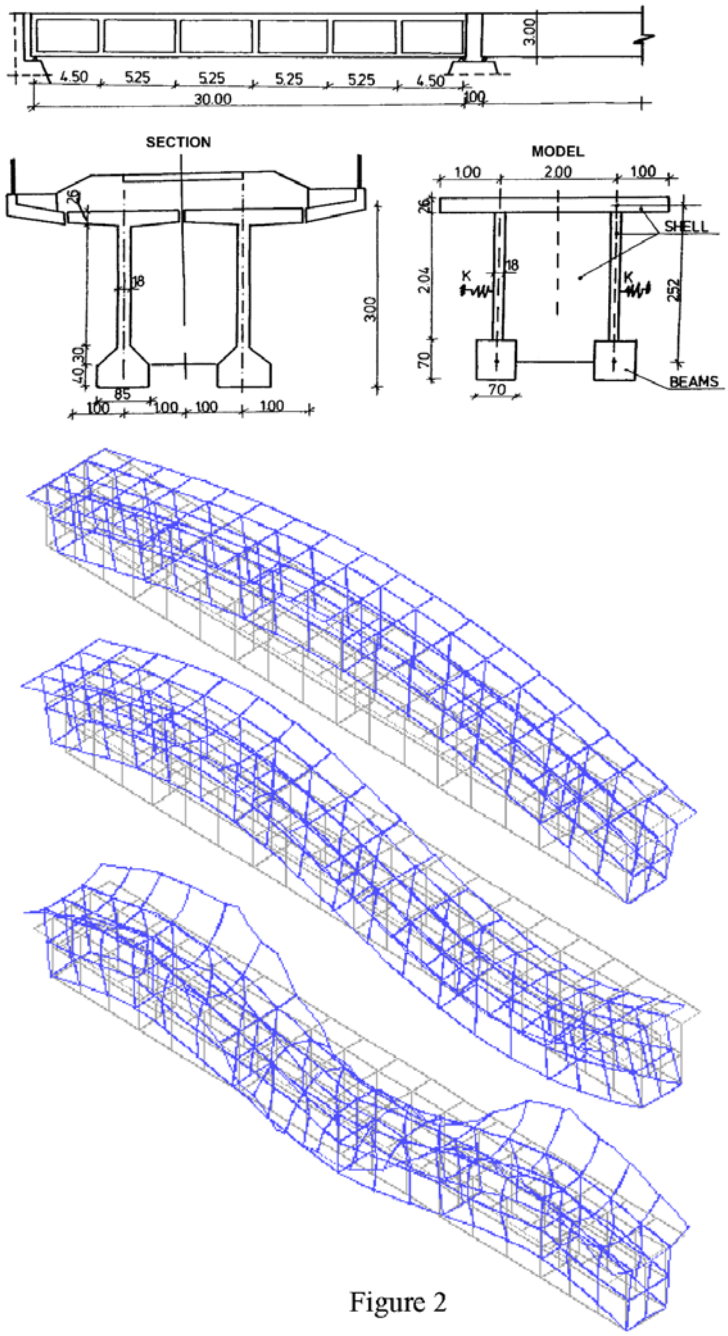
SECTION
MODEL
SHELL
BEAMS
30.00
4.50
5.25
5.25
5.25
5.25
4.50
3.00
100
200
100
300

Figure 2

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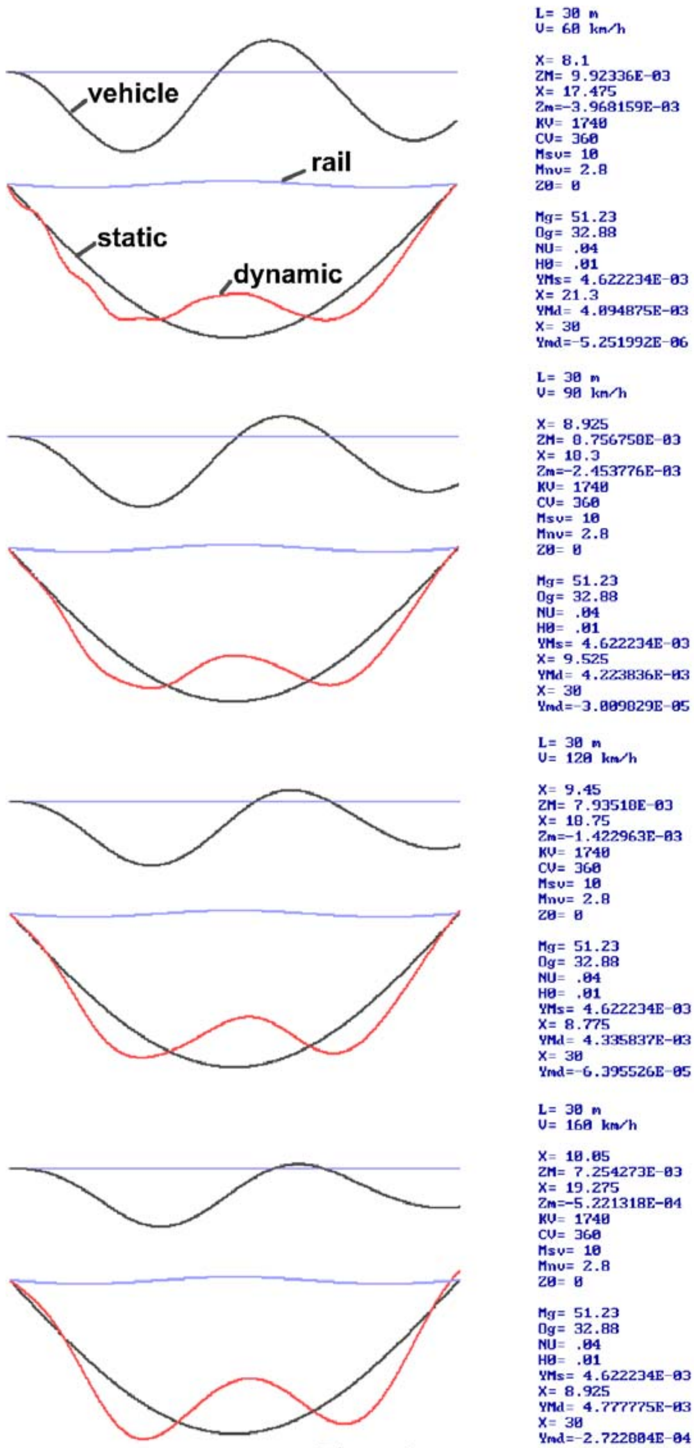

Figure 3

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2. The values of the dynamic amplification factor increase at the same time with the dislevelment amplitude rising (h_0).
3. The variation of the number of sinusoids (S) leads to an random behaviour , i.e.:
   - The most favourable situation is for the case S=3/2 (which means exceeding the maxim number of sinusoids admitted by norms with almost 3/4 sinusoid for the decks of 21.0 m span and at the most the maxim number of sinusoids admitted by the Romanian Regulations for the decks of 30.0m span), figures 4c, 5c, 6c, 7c.
   - The most unfavourable situation is that one for S=2; a sudden increase of the dynamic amplification factor at the velocity of 120 km/h as a phenomenon of punctual resonance.
4. If is to be remained below the maxim number of sinusoids admitted by the Romanian Regulations – related to the span of each deck (figures 4e, 5e, 6e, 7e) – then the greatest values of the dynamic amplification factor are noticed for the case S=1/2 (a semi-sinusoid which overlaps under the static deformation of the structure).
5. From the graphs 4d, 5d, 6d, 7d it results that:
   - All the combinations S, h_0, v that are below the values admitted by the technical regulations in force (design speed = 120 km/h) leads to values of the dynamic amplification factor smaller than those allowed by the loads Regulations.
   - The case of speed of 160 km/h, (speed which is greater than the design speed), h_0=10 mm, S=1/2 leads to values of the dynamic amplification factor which exceed the maxim allowed value (excepting the deck of the truss girder of 21,0 m span).

For the concrete structures (figures 8, 9) it is to be notice that:

1. The influence of dilevelments is unfavourable in most of the combination of S, h_0, v parameter cases.
2. The values of dynamic amplification factor increase at the same time with the speed values.
3. The values of the dynamic amplification factor are generally rising at the same time with increasing the amplitude of the dislevelment.
4. The values of the dynamic amplification factor are decreasing at the same time with the deck length increasing with approximately 7%.
5. The greatest values of the dynamic amplification factor are obtained for the case in which the maxim amplitude allowed by the Romanian Regulations for the dislevelments (h_0=10 mm) is to be combined with a dislevelment length of one semi-sinusoid (S=1/2) on the whole span, a shape of the dislevelment which overlaps to the static deformed shape of the deck.
   - For this case the given value by the Romanian Regulations in force for the dynamic amplification factor is exceeded with about 6-8%.

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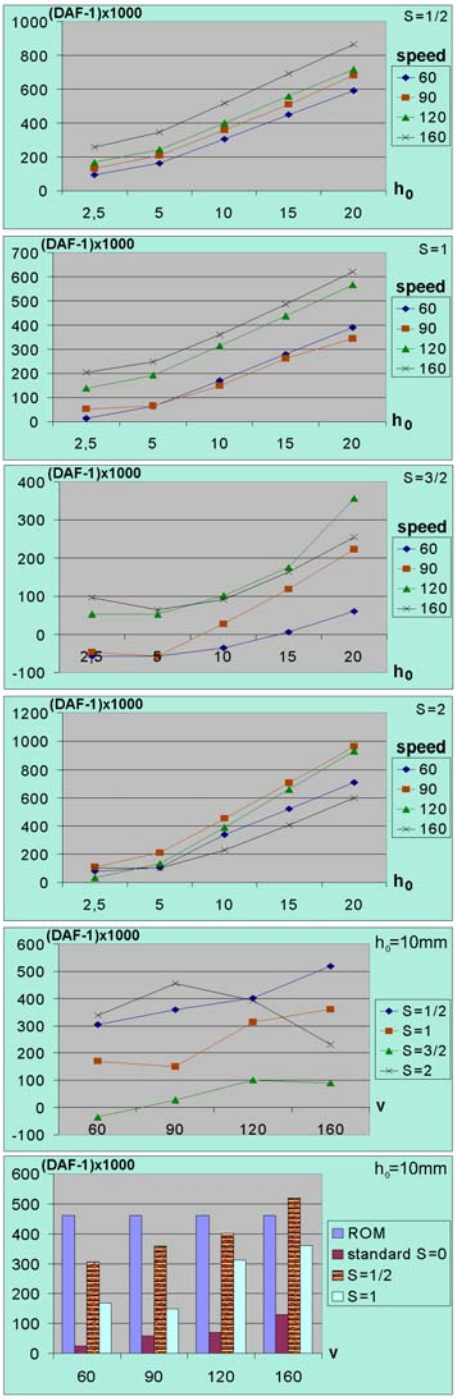

a.
b.
c.
d.
e.
f.

Figure 4. Plain girder web (21.0 m)

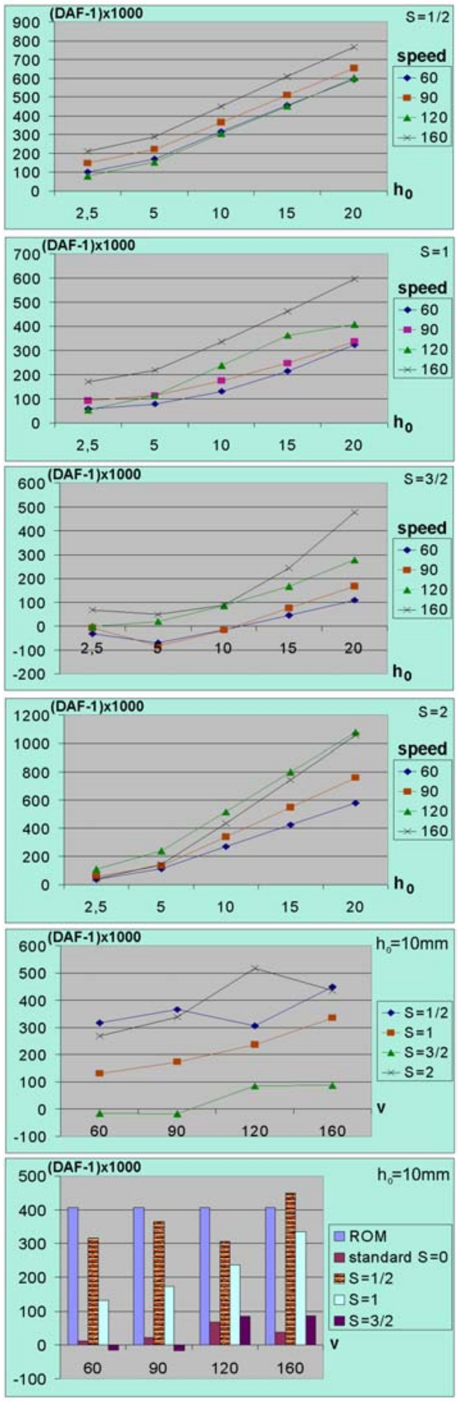

Figure 5. Plain girder web (30.0 m)

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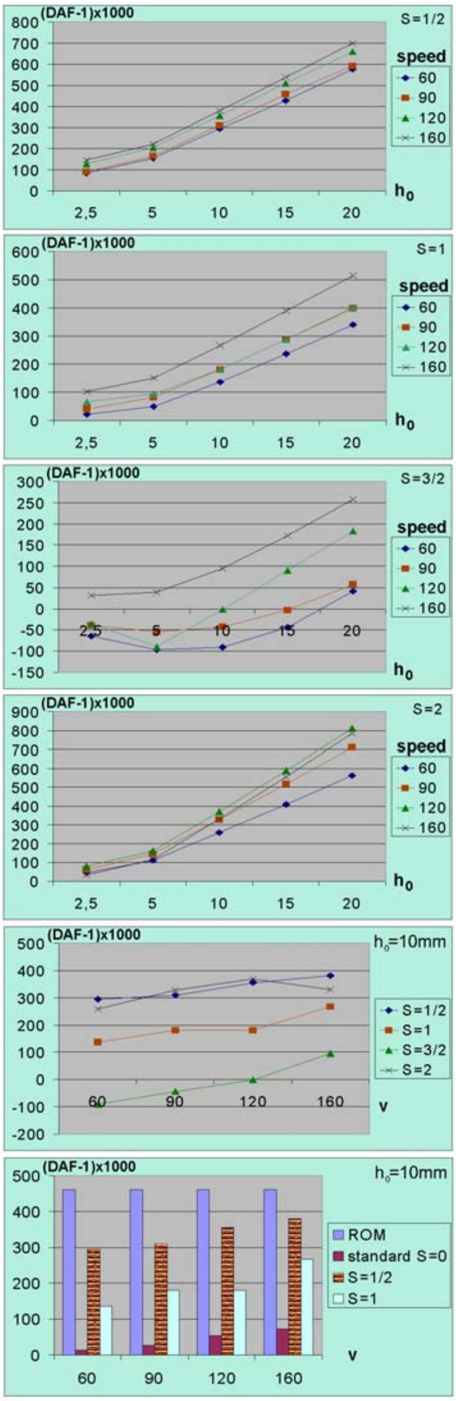

Figure 6. Truss girder (21.0 m)

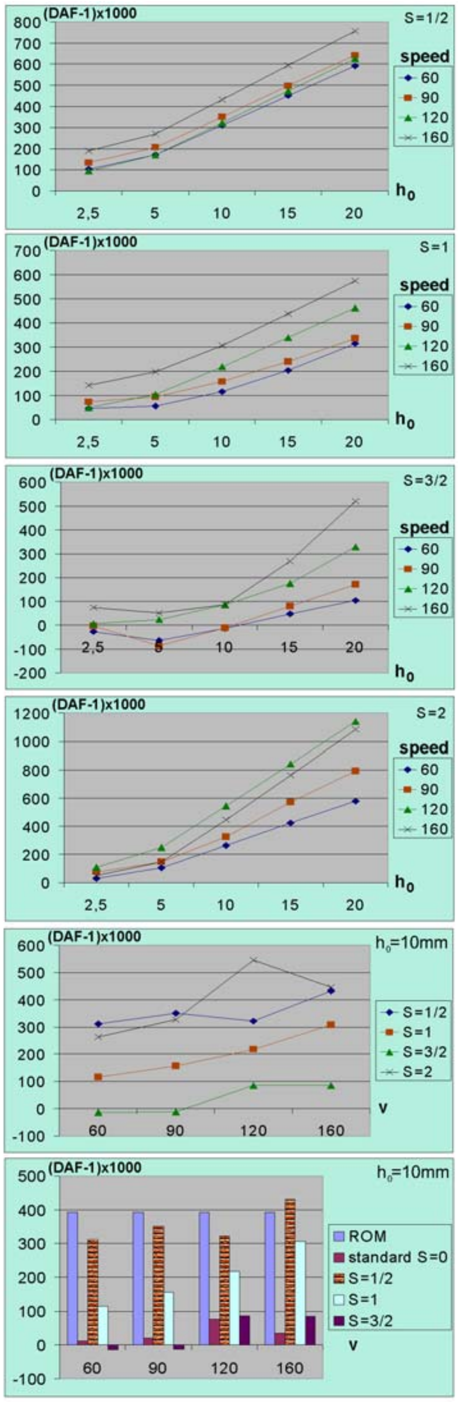

Figure 7. Truss girder (33.08 m)

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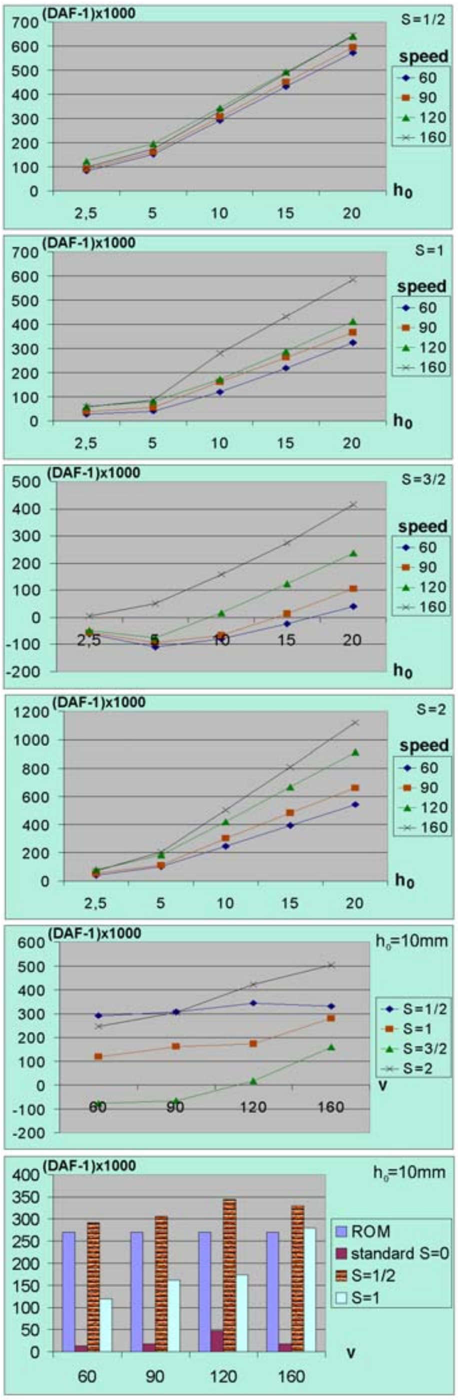

a.

b.

c.

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e.

f.

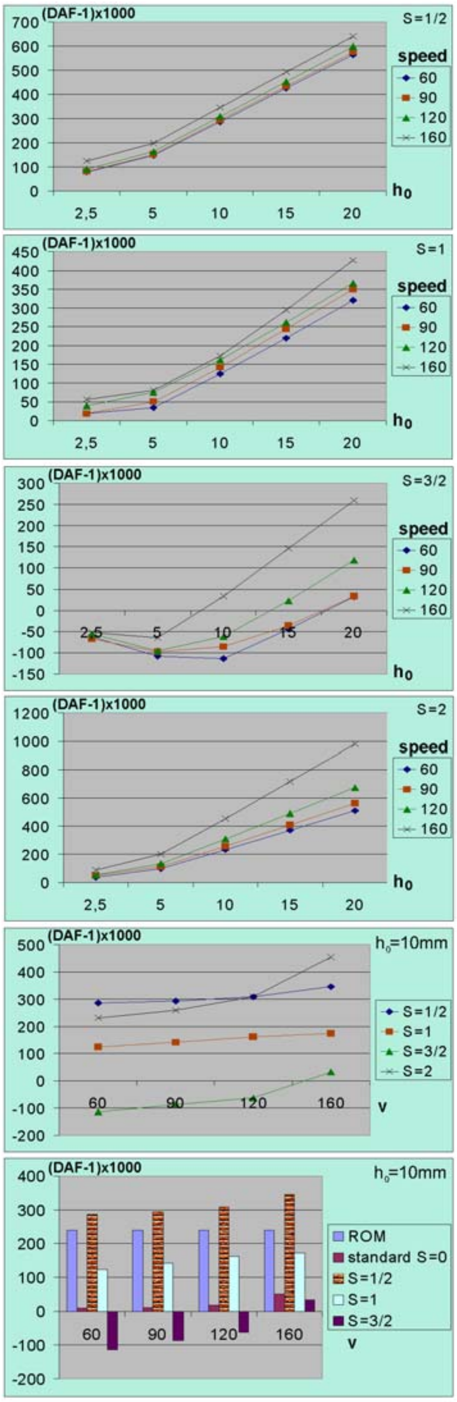

Figure 8. Concrete (22.0 m)

Figure 9. Concrete (30.0 m)

- The most unfavourable response way differs from one structure to another mainly depending on the speed. Thus, the maxim value of the dynamic amplification factor for the structure of 22.0 m is at 120 km/h and for the structure of 30.0 m span at a velocity of 160 km/h.

It is to be noticed that the dumping provided by the ballast prism hasn't been taken into account.

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8. Contract 423 / 1996 MEC Tema A20 / 2001 Influenţa denivelărilor căii asupra răspunsului dinamic al structurilor de poduri de cale ferata" Faza 1: Cale ferată pentru viteze mari – reabilitare poduri Tronson Bucureşti – Ploieşti