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TRAIN-INDUCED VIBRATIONS: A CASE STUDY

SUMMARY

The paper is discussing a train-induced vibration analysis related to the new railway station “Belgrade-Center” in Prokop. The station is not jet built, but above the station area of approximately 400 x 100 m a huge RC plate, supported on the corresponding columns, is built. That platform is going to support the future commercial area, of about 120 000m^2, so the train-induced vibrations are an important issue for the future objects on the platform. Combined numerical simulations of vibration propagation and corresponding measurements related to the station in general and particularly to that platform are presented in the paper.

Key words: Train-induced vibrations, Soil-structure interaction, Numerical modeling

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УПАТСТВА ЗА ПОДГОТОВКА НА ТРУДОТ

РЕЗИМЕ

Соопштението треба да биде подготвено почитувајќи ги следните правила: вкупниот број на страници не треба да надминува 6, со исклучок на воведните и повиканите соопштенија, кои се ограничени на 12 страници. Текстот треба да биде напишан на македонски или англиски јазик, а резимето на двата јазика. Текстот треба да биде напишан во **Arial** фонт (со македонска подршка) 11 pts, без проред помеѓу редовите, а 6 pts проред пред секој параграф. Првата страница започнува со името аавторот/авторите,а

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1. INTRODUCTION

1.1 Train-induced vibrations

Ground-borne vibration analysis due to railway traffic represents a relatively new field in Structural Dynamics. It is especially important in large cities and urban areas in general. Railway traffic may be conducted dominantly on the ground surface (light metro, tramways, intercity rail), but it can also be underground, i.e. through the metro tunnels in large cities. If the distance between the railway lines and surrounding objects, especially buildings, is close enough, which is now more and more the case in large cities, the problem of train-induced vibrations becomes an important aspect, not only in design of new buildings, but also in the analysis of vibration effects on humans, sensitive equipment, etc in the existing buildings.

Train-induced ground-borne vibrations have three interconnected elements or links: generation of vibrations at the "source", propagation of vibrations through the "medium" and reception of vibrations by the "receiver", as schematically presented in Fig. 1.

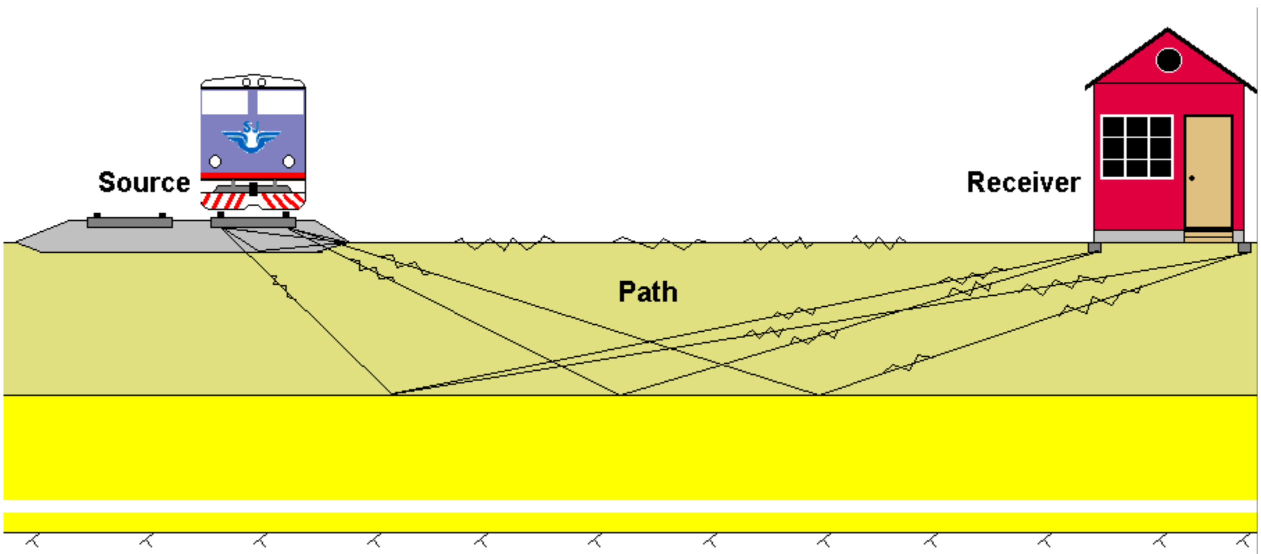

Fig. 1 Three links in train-induced vibrations: source, path and receiver of vibrations

Vibration is generated due to interaction of the moving train with the track which lies on the underlying soil. The train consists of one or more cars and each car consists of a car body, a bogie, set of axes with wheels and a suspension system (primary and secondary). Railway track consists of a pair of rails, connected by special fastening elements to the sleepers, which lie upon the ballast and sub-ballast, representing the upper part of the track. A lot of different factors contribute in a complicated way to generation of dynamic interaction forces between the wheels and the rails. The final effect of these dynamic interaction forces transferred through rails, sleepers and ballast upon the underlying layers of soil is generation of the corresponding stress waves, or ground vibrations. Besides stress waves in soil, or ground-borne vibration, also the sound (i.e. acoustic) waves in air, or air-borne noise, is generated by the moving train. However, air-borne noise propagation and its effects are not the subject of interest here.

1.2 Subject of investigations

The subject of investigation is related to train-induced vibrations in the new railway station in Belgrade, called "Belgrade-Center", or "Prokop". It is supposed to replace finally the existing railway station, but, due to various reasons, it is not jet built. Presently, it has two railway tracks in use, out of ten in future, and above the tracks a relatively huge reinforced concrete platform, supported by a set of columns, is built. Approximate dimension of the plate above the tracks is 400 x 100m and the plate is going to support various buildings, i.e. the future commercial center of about 120 000 m^2 of useful area. Fig. 2 represents a global view showing the station area (eastern part), with two tracks and the platform above the tracks.

Fig. 2. Eastern view to the future railway station "Belgrade-Center" in Prokop

Having in mind the future plans to complete the station, also to build the metro line bellow the railway tracks with direction which is perpendicular to direction of the railway tracks, and particularly having in mind the future structures that will be built on the existing platform, the main task of conducted investigations was to analyze the train-induced vibration effects upon the existing plate above the tracks.

Also, in order to reduce the possible train-induced vibrations for future structures that will be part of the new railway station, it was decided to change the railway tracks and, instead of the standard gravel ballast and concrete sleepers, to use the continuous reinforced concrete plate without sleepers and to apply the special fastening system called Vanguard, designed by Pandrol. Vanguard fastening system consists of a pair of steel "claws" which are holding rails, instead of sleepers, at every 50-60cm along the track, see Fig. 3. It was recently designed with the special purpose to reduce the train-induced vibrations at the very source of vibration generation. As may be seen in Fig. 3, the rails are being held by the Vanguard fastening in air, with the vertical distance from the RC plate of about 2cm, so the main part of train-induced vibrations is performed as the dominant vertical vibrations of rails. So, part of investigations was related also to numerical modeling of the vibration transmission with the configuration corresponding to the new tracks with Vanguard fastenings.

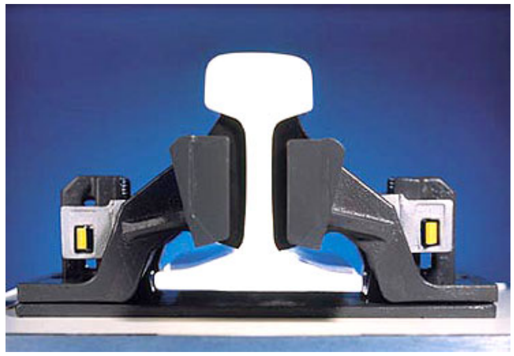

Fig. 3. Vanguard fastening system

2. CONCEPT OF CONDUCTED INVESTIGATIONS

The main goal was to make the proper assessment of the train-induced ground-borne vibrations and its effects upon the existing platform structure above the tracks. Railway tracks are not directly connected with the structure above. However, bellow the upper part of the tracks and the corresponding soil layers, which are 5-7m thick, there are, somewhat inclined, deposits of the lime-stone rock. RC columns that support the platform above the tracks are founded on isolated foundation blocks that are resting upon the lime-stone rock. Therefore, train-induced vibrations that are generated at the level of rails are transmitted through the underlying soils downwards to the level of lime-stone rock, and then reflected and transmitted upwards through foundation blocks and columns up to the platform above the railway tracks.

The major part of the whole assessment is the proper evaluation of dynamic loading and therefore of induced vibrations due to moving trains at the source, i.e. at rails. Then, the level of vibration attenuation in downward propagation through underlying soils down to the lime-stone rock, and then the assessment of the reflected vibrations and its propagation upwards through foundation blocks, columns *and* finally through the platform above the railway tracks. Finally, obtained vibrations of the platform above the tracks will serve as the input data in corresponding future dynamic analysis of structures that will be built upon the platform. Of course, the whole analysis should be done both for the present railway track configuration and also for the future configuration with the new Vanguard fastening system and thus to try to evaluate the usefulness of the Vanguard system as well.

In order to fulfill all of desired goals, the following concept of investigation was adopted. Corresponding numerical modeling of the existing configuration of railway tracks was to be combined with the corresponding measurements on site. After achievement of acceptable agreement between numerical simulations and measurements for the existing track configuration, numerical modeling of the future track configuration, with the new Vanguard fastening system, was also done. Due to complexity of the railway station area, of about 400 x 100m, with a double "S" horizontal curve of the tracks in station area, two representative locations were selected for measurements and for numerical modeling, Profile 1 and Profile 2. For each location, two different track configurations were considered, the existing one and the future one. Also, for each selected profile and track configuration, two different loading cases were considered: one is representing "Beovoz", which is currently dominant passenger traffic, and the other one representing the "Heavy Train" according to EC definition. Heavy cargo trains are passing through station now, but will be present even more so in the future, so it was important to assess their effect too.

3. EXPERIMENTAL MEASUREMENTS

Experimental measurements were conducted in the Profile 1 for the total of 18 recording of various passing trains. Using the 8-channel "MGCPlus" acquisition system eight acceleration components are simultaneously measured at the three measurement points, see Fig. 4

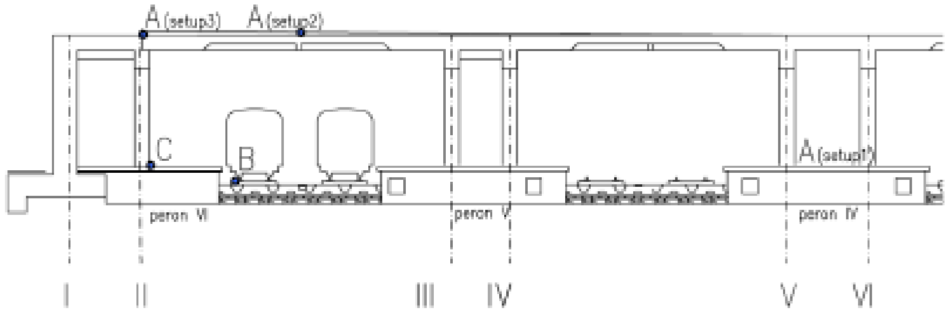

Fig. 4. Measurement points (8 acceleration components at 3 points)

Registration of accelerations was performed with very precise acceleration sensors in the frequency range of 0-300 Hz, measurement range of ±20m/s^2 and precision of ±0.001m/s^2.

4. NUMERICAL SIMULATIONS

Having in mind a three-link situation in train-induced vibration analysis (source, propagation and a receiver), the whole analysis was done using sub-structuring and a two-step approach. The first step was the corresponding moving train representation and stress wave propagation through rails, sleepers, ballast (or Vanguard fastening) and underlying soil down to the lime bedrock, using the SASSI computer program [3]. Obtained displacement time histories at selected points of the FEM meshes were used as input in the second step where the corresponding FEM model of foundation blocks, columns and the platform structure was made using SAP2000. Also, in the independent SASSI analysis the corresponding dynamic stiffness of the foundation blocks on lime-stone was previously obtained and introduced in the SAP2000 models through 6-DOF link elements. Of course, all this was done for both profiles (i.e. selected locations at the station area), with two different 3D models at each location representing two configurations of railway tracks, and in each case for two different dynamic loading conditions, representing movement of a Beovoz and a Heavy Train.

3. SOME OBTAINED RESULTS

Having in mind two locations, two configurations and two loading conditions, analyzed by two computer programs in a unified two-step approach, a lot of results were obtained. However, particular monitoring was done for vibration parameters (acceleration, velocity and displacement time histories) at selected points in numerical models. Selected points in numerical models generally correspond to previously selected measurement points, so the measurement data and calculated data could be compared. Measurement data were obtained during one day (of about 6-7 hours) recordings of accelerations due to passing trains during that time. Remarkably good agreements were obtained with calculated maximum accelerations in vertical direction of the platform above the passing trains with the measured accelerations due to three passing trains. Namely, the ratios of calculated and measured vertical accelerations of the point in the middle of the platform above the tracks were 0.943, 0.828 and 0.832.

The numerically obtained displacements distinguished from the measured data. Namely, numerical solutions consist of dynamic and static part of displacements while in measurement data static component of displacements were removed during data analysis. As an illustration, the numerically obtained vertical displacements in the middle of plate, at the top of column, and at the column base are presented in Fig. 5. The vertical displacements at the top of the column are smaller than displacements of base, but the displacements in the middle of plate are higher than displacements at the top of column, i.e. the vibrations of plate amplifies vertical displacemets. Similar, but smaller values had been obtained using the Vanguard fastening system, [2].

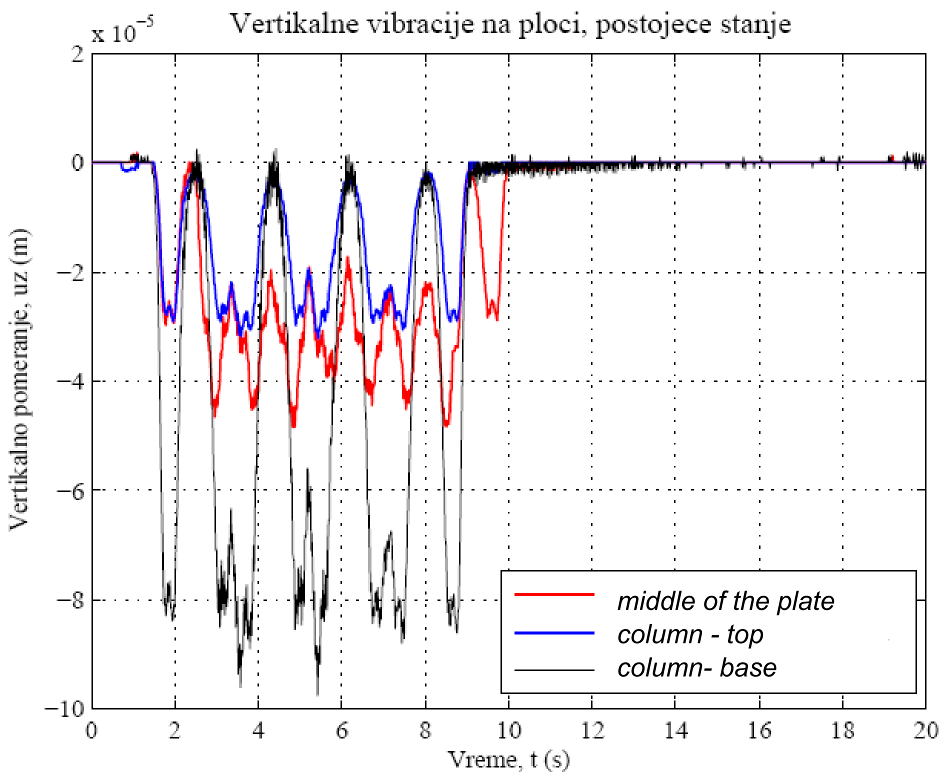

Fig. 5. Vertical vibration in the middle of plate, at the top of the column and at column base

Some of the general conclusions of the whole analysis are as follows:

- At the present track configuration, maximum amplitudes of vertical vibrations of the platform above tracks are in the range of 30-150 microns, with frequency of 0.50-0.90 Hz, due to Beovoz trains movements with speed of 30-50 km/h.
- After reconstruction of tracks and installation of the new Vanguard fastening system, vertical vibrations of the platform above the tracks will be reduced by about 40%.

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