Road and Railway Traffic Seismicity Effect Comparison on Historical Building in Slovakia

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Abstract. The road and the railway traffic generate material and immaterial emissions. The immaterial emission produced by traffic is divided to the noise and the vibrations. All these aspects attacking the environment should to be assessed. For the assessment the national and international standards can be used. This paper contains only the vibration assessment and the comparison of the dynamic parameters influence in this process. The heritage buildings have more conservative criteria as another building. This approach is performed via experimental and numerical study and identification of the basic dynamic parameters. It is presented on two case studies of important historic buildings in Modra and Žilina (Slovakia). For both case studies buildings, the FEM (Finite Element Method) numerical models were created. The modes of the natural vibration and natural frequencies were obtained as the relevant results from numerical models. These parameters are very important for this type of assessment. For the FEM models the Scia Engineer were used as the numerical software system. The experimental measurements were realised for FEM model verification. Also these measurements were used for the assessment according Slovak standards. These models can be tuned based on the experimental measurements. The tuned FEM models can be used for the further extrapolations. The main part of the investigation was to compare traffic seismicity effect on the historical buildings. Both buildings were assed in the frequency and time domain. The comparison of the traffic seismicity effects was realised also in frequency and the time domain. It is necessary to taking to account this assessment for the heritage buildings.

1. Introduction
The building structures design in regions with more seismic active regions needs a thorough analysis of SI under load due to technical seismicity. In this days is technical seismicity part of environmental issues. The different traffic load has an unfavourable impact on building constructions and the people living there. The greatest effects of technical seismicity are regard to buildings, that are located close road or railway communications. The comprehensive theoretical and experimental analysis of the dynamic response of the structure must be solved as a part of the task.

This article presents theoretical and experimental dynamic analysis of a two historical buildings located very close vibration sources due to technical seismicity. The first case study (CS1) is King Stephen’s parish church distant from the road of 2nd class 9m, that produced dynamic load due to technical seismicity. The second case study (CS2) is Budatin castle distant from the railway communication 20m, that produced dynamic load due to technical seismicity.
2. Description of the location
The first analysed objects (CS1) are located in the city of Modra, in the west of Slovakia. Location of Modra is at the southern foot of the Little Carpathians. Modra is located 23.5 km northeast of the regional town Trnava and 27.5 km southwest of the capital city Bratislava. Stoličný stream flows through the town. The second analysed objects (CS2) are located in the city of Žilina, in the northwest of Slovakia. Location of Žilina is at the confluence of the Vah and Kysuca. Žilina is located on the slopes of the Duben hill. Capital city Bratislava is at the distance 200 km. Location booth of them is shown in the Figure 1, [1].

3. Description of the analysed objects
3.1. Case study CS1
The first (CS1) investigated object (Figure 2.) is the King Stephen’s parish church built in 1873-1876. The construction of the church was incorporated into the structure already existing town tower. The main tower has a height of 65.025 m and the church has a height of 23.750 meters. Outer and inner walls of the buildings are composed of aggregates in combination with mortar. Their thickness is variable and varies in the range of 1845 mm 820 mm, [1].

3.2. Case study CS2
The second (CS2) investigated object (Figure 3.) is the Budatin castle built in the end of 12th century and as presented renovated in the year 2014. The design has a convex-concave floor plan with three floors and dominant tower. The tower has the 7th floor. The main tower has a height of 20 m and 12 m diameter. Outer and inner walls of the buildings are composed of aggregates in combination with mortar. Their thickness is variable and varies in the range of 1500 mm 700 mm, [2].
4. Description of the computing system

Computer model was done in software system Scia engineering worked with finite element method (FEM) - deformation variant designed for static and dynamic analysis of structures and their proposal to appropriate standards. The system is used for numerical analysis of structures consisting of beams or flat elements such as slabs, walls and shells. The program consists of three parts:

- **Pre-processing** - All inputs are specified in graphical form. The user can define the environment, e.g. frame XZ, a general system XYZ, grid XYY, lattice XZ, subsequently defining the model itself, a load functions, support, combination and of non-linear parts. The working environment in which the user works can be modified to meet your needs. Communication with the program is done through files and elements Graphical User Interface (GUI). The environment which involves modelling is the same as the CAD program.

- **Numerical solver** - Allows develop the following types of calculations: static analysis (geometric non-linear), dynamic calculation of seismicity, stability calculation (natural frequency), static (geometric non-linear) calculation, static (linear) calculation, dynamic calculation of natural frequencies and costume shapes.

- **Post-processing** - It is the last part of the system, which is used for graphical and numerical analysis of individual computationally. The one part of Postprocessor is assessing and proposes construction according to valid EN standards [3], [4].

5. The 3D FEM models and the Results

5.1. Case study CS1

The computational model for the dynamic analysis of the historical building (King Stephen’s parish church) was developed in a software Scia engineer. The model required the assessment of traffic vibration influence.

In the calculation of own shapes, it has been considered 7048 of 2D elements, 3004 of 1D elements, and 7690 of network nodes. The calculation required assembling of 53,157 equations. For the mass group combination CM1 we used 10 natural frequencies. Amount of materials for x-direction is 631,245.95 kg, the y-direction is 631,245.95 kg and the z-direction is 638,694.21 kg. The calculation was carried out on the basis of Lanczos and Mindlin bending theory [5].
5.2. Case study CS2
The computational model for the dynamic analysis of the historical building (Budatin castle) was developed in a software Scia engineer. The model required the assessment of railway vibration influence.

In the calculation of own shapes, we considered 24168 of 2D elements, 18541 of 1D elements, and 23610 of network nodes. The calculation required assembling of 141,660 equations. For the mass group combination CM1 we used 10 natural frequencies.
Amount of materials for x-direction is 3,771,371.70 kg, the y-direction is 3,771,371.70 kg and the z-direction is 3,756,228.17 kg. The calculation was carried out on the basis of Lanczos and Mindlin bending theory [6].

Table 2. FEM model – Example of the natural frequencies results.

| Natural mode no. | Natural frequency [Hz] | Vibration type |
|------------------|------------------------|---------------|
| 1                | 4.97                   | asymmetrical  |
| 2                | 5.25                   | asymmetrical  |
| 3                | 6.61                   | asymmetrical  |
| 4                | 9.35                   | asymmetrical  |
| 5                | 9.87                   | asymmetrical  |

6. Experimental measurements and results
Dynamic response of real tangible environment (half-space structure) by random excitation was measured by 2 lines of accelerometers with a frequency range of 1 ÷ 4000 Hz (Brüel-Kjaer). Accelerometers measure the response in the vertical direction. Dynamic response in the observed points were measured in the form of vibration velocities (m/s), in three orthogonal directions x, y, z. The measurement was performed using the "off-line". The, recorded signals are simultaneously stored on storage media PC/DX4 (program DISYS) and PCs AMILO - PC FS (NI CompactDAQ program). Evaluation of the measured data was carried out in laboratory conditions KSM - FCE - ZU based on the evaluation of software lines KSM (VL - KSM).

The measuring unit consisted of:
- piezoelectric accelerometers BK 8306 (Brue - Kjaer)
- integration amplifier BK-2693-014 (Brüel-Kjaer), measuring PC/DX4 Notebook
- NI cDAQ™ -9191NI CompactDAQ One-Slot Wireless Chassis
- Moxa AWK-3121 With NI CompactDAQ.

6.1. Case study CS1

Figure 6. Time domain \( v_2(t) \) direction x (\( v_{RMS} = 0.0046 \) mm.s\(^{-1}\))
6.2. Case study CS2

Figure 7. Frequency domain $v_2(t)$ direction x - $G_{11}(f)$

Figure 8. Time domain $v_2(t)$ direction x ($v_{RMS} = 21.1 \text{ mm.s}^{-1}$)

Figure 9. Frequency domain $v_2(t)$ direction x - $G_{12}(f)$
7. Conclusions
Analysis and case studies of this type demonstrate the necessity of the interconnection between numerical and experimental approach. This paper aim is to compare road and railway seismicity effect on historical buildings. Each building CS1 and CS2 described in paper is different. That is the reason why it is possible to evaluate results for only the main effect in frequency domain. Experiments in both case studies were in according with the same conditions. The reference point was situated in interactive area on the fundaments of the historical buildings. Comparison of the spectral characteristics and the numerical results (natural frequencies) for CS1 and CS2 give followed conclusions:

Road traffic generate the vibration in relatively lower vibrations level. Subsoil transfer higher frequencies to interactive area between fundaments, building and soil for road traffic seismicity.
Lower frequencies are dumped and that is the reason why the structure is lower excited in lower frequencies band near first natural frequencies in CS1. For the railway traffic subsoil dumped higher frequencies and the excitation is nearer to first natural frequency. The vibration levels are higher and the frequency bands are lower. For further analysis and case studies the precision and interactive FEM model using is recommended. The increased vibration level in CS2 can be caused by slower speed train and rail joints passing. The levels of vibrations levels are with sufficient reserve comparing with EC standard limits, [7].

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