Numerical and Experimental Case Study of Blasting Works Effect

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Abstract. This article introduces the theoretical and experimental case study of dynamic monitoring of the geological environment above constructed highway tunnel. The monitored structure is in this case a very important water supply pipeline, which crosses the tunnel and was made from steel tubes with a diameter of 800 mm. The basic dynamic parameters had been monitored during blasting works, and were compared with the FEM (Finite Element Method) calculations and checked by the Slovak standard limits. A calibrated FEM model based on the experimental measurement data results was created and used in order to receive more realistic results in further predictions, time and space extrapolations. This case study was required and demanded by the general contractor company and also by the owner of water pipeline, and it was an answer of public safety evaluation of risks during tunnel construction.

1. Introduction
Drilling and blasting still remain the only possible ways of tunnelling in very adverse geological conditions. Some structures as the high dimension pipelines situated close to the road tunnel may be insecure. The evaluation of the danger involved by dynamic excitation due to blasting works is needed [1]. For this purpose, it was possible to create the numerical simulation in tunnel design phase. During the tunnel construction works this pipeline can be experimentally monitored. All the results from the analyses can be used for further evaluation of structures during structural lifetime.

2. Description of the case study
The source of the vibration is road tunnel construction blasting works effect. The length of the road tunnel is about 800 meters and it is part of the new built highway D3 from Žilina to Čadca direction. The locality of the case study is near Žilina and it will be connecting Považský Chlmc and Vranie villages, [2]. The affecting structure is the high diameter (800 mm) steel pipeline which supplies drinking water to the whole city of Žilina and surroundings, [3]. The plan situation of the tunnel and the pipeline is on Figure 1. The geological locality of this structure is mainly bedrock. From geological point of view, area of interest belongs to Central Carpathian paleogene region – North part of Žilina basin in the vicinity of Outer Carpathian Klippen zone, [4].
3. The numerical approach

The basic dynamic parameters monitored during blasting works are compared to the FEM (Finite Element Method) calculations and to the Slovak standard limits [3, 4]. The FEM simulation is based on planar linear viscoelastic approach modelled in numerical software VisualFea. The dynamic numerical calculation was processed at a time domain as time iteration linearized simulation. The FEM model was created using the 2D planar elements. The process of the model creation can be seen in Figure 2.

The numerical model and its material and geometrical parameters respect the geological report and tunnel design, [5]. The dynamic load was performed in the time domain as the kinematic excitation based on experimental test data. The material properties were verified using ISM (Impulse Seismic Method) in situ measurement, [4]. Figure 3 shows the input data (dynamic load) for 100 kg of the explosive and the FE model with cross sectional situation description.
4. The experimental approach and the results comparison
The results from the experimental measurement are presented as a parametric dependence of explosive mass and nearest distance of blasting works from pipeline [3, 5]. However, this data from the experimental measurement were recorded during road tunnel construction from November 2014 till May 2016. The data evaluation was performed via amplitude and spectral analysis software.

Figure 4. The velocity vibration time histories, recorded during the pipeline dynamic monitoring. [2]
The following equipment was used for the experimental measurements:

- Vibration velocity sensor (Insens 100, triaxle, contact, amplifier integrated), Serial number SV 0305.
- Monitoring Central Unit with Measuring interface card AT-MIO-64E-3, Serial number AB65A8.

The recorded time histories of the vibration velocity are presented as an example in Figure 4.

The vibration velocity sensors were situated above the pipeline and the tunnel crossing (the most extensive point) and it is the same point as in the FEM analysis evaluation. Using the amplitude analysis verified by spectral analysis by National Instruments software, the peak particle velocities and RMS (Root Mean Square) values were evaluated during the long term vibration monitoring. The results obtained from the dynamic motoring of the pipeline vibration example are displayed in Figure 5.

![Figure 5. Experimental measurement – amplitude analysis example](image)

According to the main aims of the study, the comparison of numerical and experimental results was realised. The most important parameter of the pipeline vibration involved by technical seismicity due to blasting works is the maximum velocity of the vibration ($v_{max}$) in the dominant vibration direction – z axis, [4, 5, 6]. This parameter is compared with the Eurocode standard criteria using its National annex. During the blasting works in tunnel tubes, this parameter was observed. The FEM simulation was performed for the maximal limits of explosive weights in each time step. The limits were set as to not exceed the standard limit criteria. The comparison of the numerical and experimental results is showed in Figure 6.

5. Conclusions

Based on the experimental and numerical results of the case study, it is possible to conclude following points:

- The numerical FEM model is a useful tool for risk assessment, induced by seismicity effect due to blasting works, [7, 8].
- In this case, it was necessary to verify the basic material properties of geological environment, which were verified by geological survey report and by using results from ISM method.
- The numerical model must be tuned for further dynamic analysis and for any dynamic load.
- Experimental results obtained from long term dynamic monitoring must be sorted, evaluated and filtered for further engineering comparison and arrangements.
- The spectral analysis is one of the control factor for RMS data obtained values.
- Vibration levels (maximal velocities of pipeline vibration) must not exceed the European Commission standard limits.
- Tuned FEM model simulation results are relatively in a good coincidence with experimental results.

Figure 6. Comparison of the numerical and experimental results– attenuation curve

The engineering structures such as water supply steel pipelines are important underground structures and monitoring of the vibration levels during blasting construction works is required. Mainly, it is very important if they supply cities with over 100,000 inhabitants. This case study shows the simplified approach of how to ensure safety around built underground structure using FEM and experimental methods [6].

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