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IMPACT OF THE LOCAL GEOLOGY ON THE SEISMIC RESPONSE ON THE ROCK MASS

Abstract

This paper studies rock mass response on the surface to mining induced seismic event depending on local geological conditions. Engineering experience and experimental seismological measurements support that local geological conditions can to a certain extent modify responses of the rock mass surface and structures. The paper presents some results of numerical analysis, which were realized using a dynamic module of the software system Plaxis 2D. The results attest to amplifying effects of the soft sedimentary strata that lie in the building foundations as regards deformation responses of the rock mass surface.

Keywords

Mining induced seismic event, seismic load, site effect, mathematical modelling, Plaxis.

Abstrakt

Příspěvek se týká problematiky vlivu místních geologických podmínek na odezvu povrchu na důlně indukovaný dynamický jev. Inženýrská praxe a realizovaná experimentální měření potvrzují, že místní geologické podmínky modifikují určitým způsobem seismickou odezvu povrchu horninového prostředí a stavebních konstrukcí. V příspěvku jsou uvedeny některé výsledky numerické analýzy realizované s využitím dynamického modulu programového systému Plaxis 2D, dokumentující zesilující účinky měkkých sedimentárních vrstev v podloží konstrukce na deformační odezvu povrchu horninového prostředí.

Klíčová slova

Důlně indukovaná seismicita, seismické zatížení, lokální podmínky, matematické modelování, Plaxis.

1 INTRODUCTION

Buildings and structures are subjected to different loads during their realisation and subsequent use. Seismic loads are one of the main types of loads in areas with occurrence of natural earthquakes and/or mining induced seismic events, in concurrence with effects of technical seismicity. The quantitative and qualitative responses of structures to possible seismic loads depend on many factors. Among these factors there are necessary to include seismic load parameters per se (e.g. maximum amplitude, dominant frequency, duration of vibrations), material and construction parameters of the structures, and also geological and hydrogeological conditions of a particular locality, as well as physical and geotechnical properties of underlying strata (e.g. Kaláb, 2004). We

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10.2478/v10160-010-0019-y

cannot provide for a real and impartial report on possible negative impacts of this load without the knowledge of the local geological and hydrogeological data, base information for the so-called site effect, which may decidedly influence the effect of seismic loads (Dowrick , 1987 ; Key, 1988).

2 BASIC FACTORS OF LOCAL GEOLOGICAL CONDITION INFLUENCE

Basic factors of local geological condition influence generally comprise:

- Modification (amplification or attenuation) of seismic load effects by overlying soft sedimentary strata,
- Topographic influences,
- Subsidence of dry underlying layer of sands,
- Liquefying of saturated loose soil.

This paper principally concerns the first issue of the list, namely the modification of surface responses to dynamic impacts as these would be modified by soft underlying strata. Field observations and data from seismological monitoring demonstrate that the presence of the soft sedimentary underlying strata implies amplification of seismic response of strata in given place and inevitably the seismic response of any structures in the locality (Figs. 1 and 2).

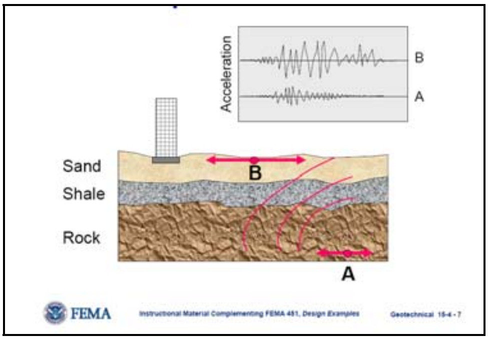

Fig. 1 The soil profile acts as filter modifying the amplitude and nature of the motions - Amplification effect of soft strata (FEMA, http://www.nibs.org/client/assets/files/bssc/Topic15-4-GeotechnicalEarthquakeEngineeringNotes.pdf)

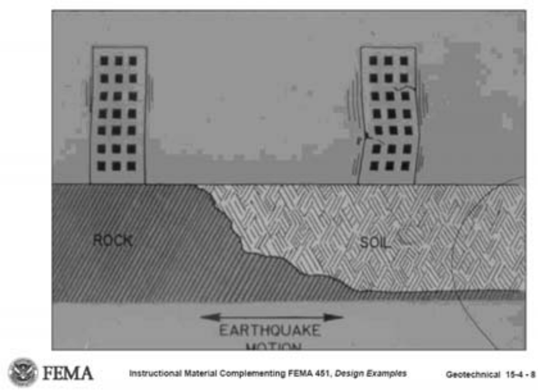

Fig. 2: Structures founded on soils, especially if soft, tend to be subjected to stronger shaking with longer-period motions. The conservation of energy and the amplification process is important to illustrate here. (FEMA, http://www.nibs.org/client/assets/files/bssc/Topic15-4-GeotechnicalEarthquakeEngineeringNotes.pdf)

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3 MODEL ANALYSIS OF LOCAL GEOLOGICAL CONDITION IMPACT

3.1 Basic geometrical and material characteristics of the model

The simulation analysis for evaluating local geological condition impact on surface seismic responses was performed by the finite element method utilising a dynamic module of the software system PLAXIS 2D [1]. The planar model is 100 metres wide and 70 metres high. The model analysis was performed assuming existence of an isotropic rock environment and a Mohr-Coulomb constitutive model. The underlying geological strata profile comprises both underlying rock mass and quaternary strata. Geotechnical parameters are in accordance with the characteristic parameters of the given locality, Karviná Coal District, (Muellerova, Mueller, Grmela, 2008). Strong mining induced seismic events occur in this locality and than it is a good example for studying of seismic responces. The geotechnical parameter specific values of the carboniferous and quaternary rock mass formations are given by Tab. 1. The wave velocity values, Vp and Vs, were calculated by these equations:

$$V_p = \sqrt{\frac{E_{oed}}{\rho}} \quad ,E_{oed} = \frac{(1-\mu)}{(1+\mu)(1-2\mu)}, \quad \rho = \frac{\gamma}{g} \qquad\qquad V_s = \sqrt{\frac{G}{\rho}}, \quad G = \frac{E}{2(1+\mu)}$$

where

E – Modulus of elasticity

μ – Poisson´s number

γ– unit weight of rock mass

g – gravity acceleration

Tab. 1: Geotechnical parameters of carboniferous and quaternary rock mass

Parameter	Unit	Quaternary	Carboniferous
Unit weight	kg /m3	1800	2300
Poisson´s number	-	0.3	0.2
Modulus of elasticity	MPa	3.4	9000
Cohesion	kPa	15	100
Friction angle	°	11	25
Wave velocity, Vs	m/s	27	1264
Wave velocity, Vp	m/s	50	2064

3.2 Basic characteristics for the model seismic loads

The model calculations analysed influence of measured data of stronger mining induced seismic event in the Karviná Region (Fig. 3). The duration of this event was about 15 seconds, maximum vibration velocity amplitude 0.0075 metres per second. This event was recorded by a seismic station at Stonava, which is operated in the framework of a Research Project, Institute of Geonics, Academy of Sciences of the Czech Republic, in Ostrava.

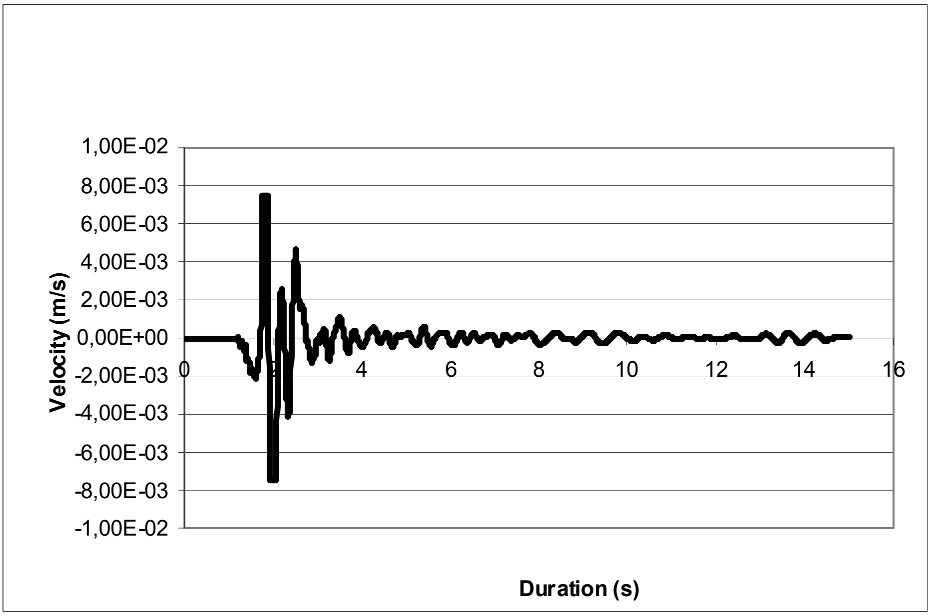


Fig. 3: Record of vibration velocity of the mining induced seismic event from Stonava, Karviná Region

3.3 Initial formula for the method and basic boundary conditions of the model

The dynamic analysis implementation is based on the Newton's Second Law of Motion, F=ma, which provides for a matrix notation of a system of equations:

$$M\ddot{u} + C\dot{u} + Ku = F$$

where individual letters mean: M – mass matrix, u – displacements vector, C – damping matrix, K – stiffness matrix, and F – load vector. The values of displacements u, velocity $\dot{u}$, and acceleration $\ddot{u}$, are subjected to time dependant change.

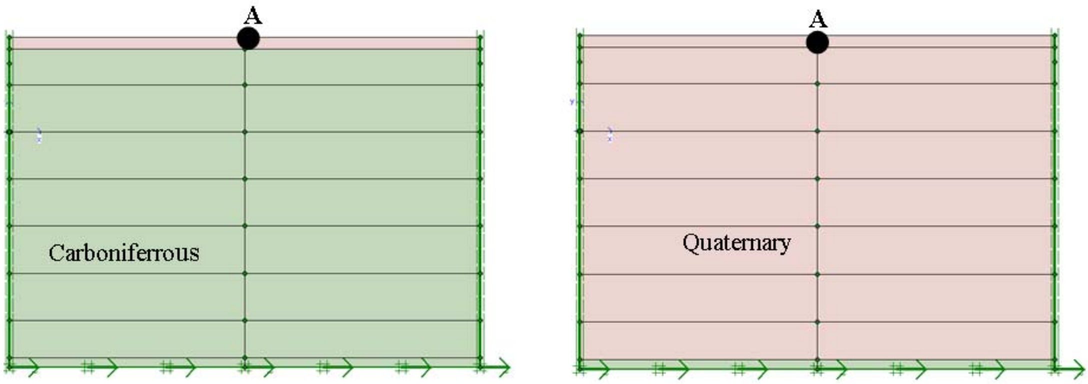
The damping matrix, C, is a linear combination of Rayleigh damping coefficients, α_R and β_R, which account for material damping ability as well as mass and stiffness matrixes.

$$C = \alpha_R M + \beta_R K$$

The dynamic calculation implementations started with two boundary conditions. The so-called absorption boundary conditions enable absorption of stress increments that result from seismic loads at the model's boundary. These conditions disable unrealistic seismic wave reflection back into the model and their interference. The second type of boundary conditions is an input for the model bottom boundary and relates to magnitudes of the measured values of velocity of induced seismicity in individual time steps.

3.4 Evaluation of Mathematical Modelling Results

This chapter describes assessment of results of modelling deformation responses to seismic events. Two variants of underlying geological strata structure were investigated (Fig. 4). In case of the variant, a), the underlying geological structure consists of quaternary soils that are only 2.5 metres deep. Beyond this thin quaternary layer, only carboniferous strata are located. In case of the variant, b), the surface quaternary stratum is 68 meters deep, and carboniferous layer depth below is only 2 metres. The following diagram, Fig. 5, illustrates assessments of horizontal displacements at the surface point, A monitored by the model.



Variant a) Carboniferous   Variant b) Quaternary

Fig. 4: Underlying strata analysis for Variant, a) quaternary stratum, magnitude, 2.5 metres; variant, b)quaternary stratum, magnitude, 68 metres

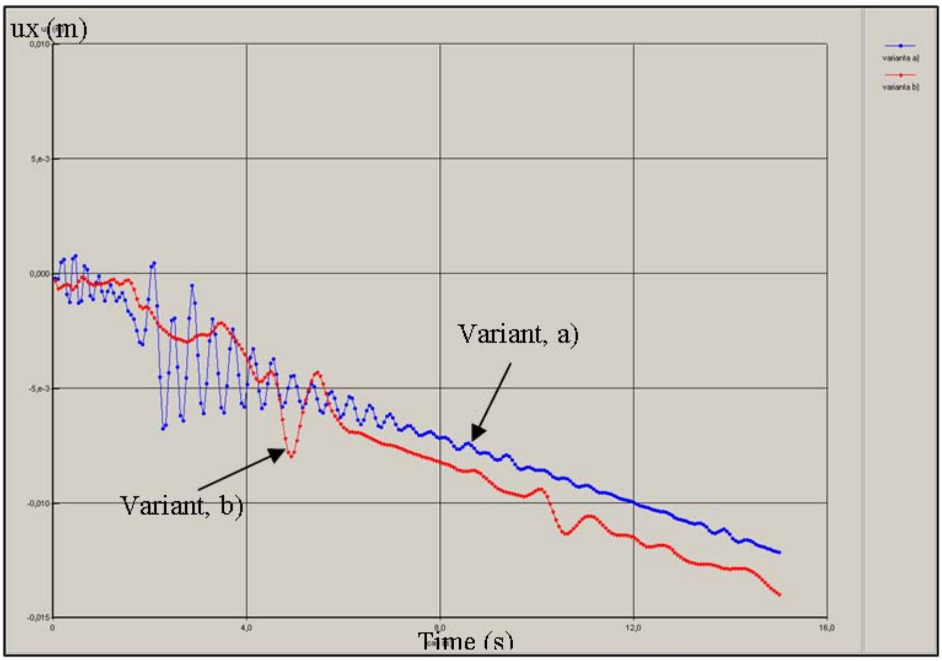


Fig. 5: Horizontal displacements timing for the surface point A monitored by the model

Taking into account the modelling results, it can be concluded that

• Variant, b), demonstrates higher horizontal displacements in comparison with the Variant

a) For the time, *t*=15.02 s, relating to the end of seismic event, the horizontal displacements increment is about 17%.

• Variants with quaternary soil layers of greater magnitudes relate to wave frequency attenuation.

4 CONCLUSION

The mining induced seismicity in the Karviná Region represents not only a factor of environmental deterioration in general but mining induced seismic events can significantly influence on structure wear. In spite of the fact that mining activities in the area have been considerably reduced, the occurrence of induced seismic events has not diminished accordingly, accounting both for seismic energy and number of them. This is the outcome of deep mining in difficult geomechanical conditions. The seismic event from 4th December 2008 (local magnitude of 3.2) provides a good example. The maximum velocity values of this event exceeded 20 mm.s^{-1} in records performed at Darkov seismic station. Such magnitude may lead to damage to structures.

Mathematical modelling should provide for more accurate data that might be used for prediction of seismic events in places, where realisation of building project is planned or where buildings have been already built (e.g., Pitilakis, 2007). This specific example demonstrates influences of local geology on the surface response to impact of induced seismicity, namely the amplifying effect of quaternary strata.

From the mathematical modelling point of view, the dynamic model analysis - in comparison with statistical calculations – is more demanding taking into account both contents and accomplishment time needed. It is especially difficult to determine characteristic dynamic parameters for the rock mass environment, inclusive parameters of the material dynamic damping capacity, as well as to characterise the seismic loads per se. The dynamic module of the programme system Plaxis 2D, demonstrated its ability of application for solving of planar dynamic tasks. Up to now, the firm Plaxis, has not developed any dynamic module for 3D modelling and, as such, it is necessary to utilise other SW systems – like CESAR LCPC, MIDAS GTS – for mathematical modelling and solving of 3D tasks of dynamic calculations. The Department of Geotechnics and Underground Engineering, Faculty of Civil Engineering, VSB-Technical university of Ostrava, anticipates utilising them for future investigation projects.

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