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MODELING OF VIBRATION EFFECT WITHIN SMALL DISTANCES

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ABSTRACT
The growth in the field of construction of shallow underground structures has been associated with construction of new roads, collectors and other structures. This contribution deals with modeling of distribution pattern of the maximum velocity amplitude (blasting vibration field) on surface basement. This basement will be situated within small distance from source of technical seismicity that is used as a part of technological processes. The model represents seismic effect of blasting operation in shallow tunnel. Plaxis 2D modeling system and its dynamic module based on finite element method are used for this presentation.

KEYWORDS: technical seismicity, blasting operation, finite element method

INTRODUCTION

In the Czech Republic, a tremendous expansion in the construction of tunnels and underground structures in general occurs, which also brings certain problems because a lot of structures already built or planned are there in built-up areas and at relatively small depths below the ground. The majority of tunnels are constructed by using a New Austrian Tunnelling Method, an integrated part of which is rock disintegration by blasting operations and continuous geotechnical monitoring including also seismic monitoring. Blasting operations are a source of technical seismicity that may cause surface damage to equipment in buildings or to the whole buildings. Seismic monitoring in the course of construction of an underground structure should prevent all this. On the basis of measured data, parameters of blasting operations are modified so that the surface effects of driving a shallow underground structure may be minimized. (Holub, 2006; Kaláb, 2007; Rozsypal, 2001).

This work is to show, by means of a mathematical model, a non-uniform distribution of maximal amplitude of vibration velocity along the length of spread footing, which occurs at a "small" distance (i.e. one hundred meters) from the source of technical seismicity. In the model, as a source of technical seismicity a blasting operation executed in the course of driving a tunnel tube shallowly below the ground was considered. Into the model, which was created by the program PLAXIS 2D based on the principle of finite element method, this blasting operation was implemented by means of a so-called dynamic model. Results of the mathematical model were evaluated statistically and also graphically in a form of vibration velocity waveforms and sectional views of spread footing. (Manual of the program PLAXIS 2D)

A REAL PATTERN FOR THE MODEL

As a pattern for the processing of the mathematical model, a structure of motorway Klimkovice tunnel was used, where during whole tunnel construction the seismic monitoring of technical seismicity induced by blasting operations was performed, and sensors were located also on the building of a family house with the house number 798. (internal materials of INSET company).

The Klimkovice tunnel is a part of structure of D47 motorway and belongs to the construction stretch, Stavba 4707 Bílovec – Ostrava, Rudná. It is composed of two one-directional two-lane tunnel tubes. The tunnel A is situated as a right tunnel tube in the direction of stationing and is designed for the Brno – Ostrava direction of traffic; the tunnel B is designed for the Ostrava – Brno direction of traffic (Fig. 1). The driven part of tunnel A is 857.40 m long and the trenched part at the Brno side is 158.90 m long and at the Ostrava side 39.41 m; the driven part of tunnel B is 867.90 m long and the trenched parts are 159.50 m and 39.60 m long at the Brno and at the Ostrava side, respectively. The heavy section of both the driven tunnels is 116.4 m^2 (with an emergency lay-by of up to 155.3 m^2); the tunnel finished cross-section for traffic is constant for the driven and the trenched tunnel parts, namely 71.8 m^2. An extraordinary

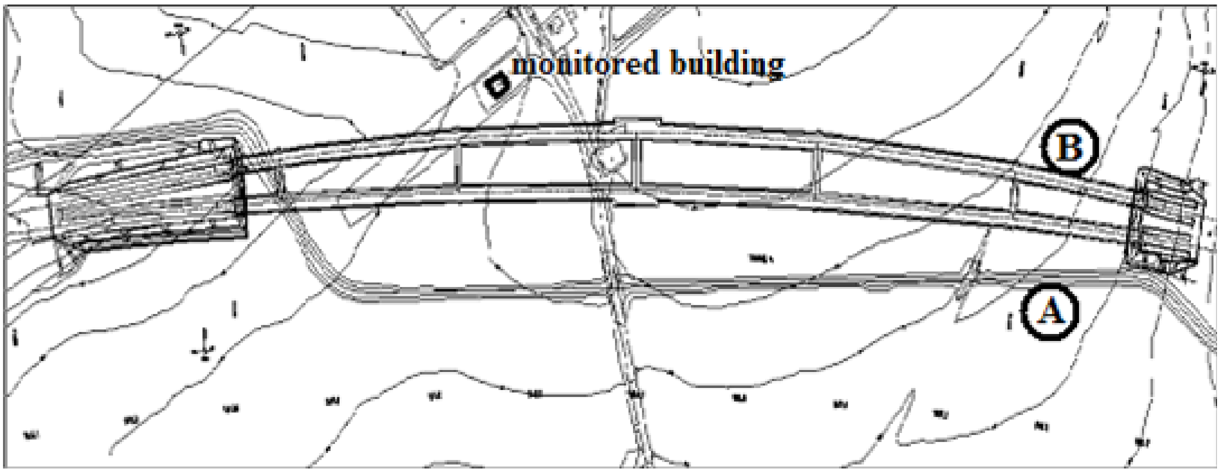


Fig. 1 Klimkovice tunnel – situation plan.

attention is paid to safety parameters of the tunnel. Both the tunnel tubes will be equipped, according to the strictest European criteria, with a monitoring device, an adequate ventilation system, will be interconnected with five tunnel connecting passages for the safety escape of persons and will have regularly distributed tunnel alcoves with a necessary number of SOS boxes with the separate air supplies. In the place of central connecting passage, the cross-section of both the tunnel tubes is right-hand extended by emergency lay-bys for the emergency parking of vehicles. The central tunnel connecting passage is also interconnected with the surface via a vertical shaft in which connecting cables and feed water pipes for fire-fighting are placed. (Franczyk and Kotouček, 2006; Pechman, 2006).

ENGINEERING – GEOLOGICAL CONDITIONS OF THE LOCALITY

The whole tunnel structure, including parts of the structure is situated in the cadastral area of the town of Klimkovice. Land immediately above the tunnel and in its vicinity has prevailingly the character of farm land. From the geomorphological point of view, the locality of Klimkovice tunnel is there on the edge of Vítkovská vrchovina Uplands that are part of the Nízký Jeseník Mts. Typologically, this is a case of rough uplands in the area of fold-fault structures.

QUATERNARY COVER

In the locality of the tunnel, the Quaternary cover is formed mainly by gravitational (deluvial) sediments of clay-sandy loams with the admixture of fragments of parent material. The content and the size of fragments grow with depth, when the deepest layers of cover obtain even the character of loamy gravels with angular fragments and debris. In the Quaternary cover, four basic types of soils were defined (according to the norm ČSN 73 1001 – Foundation of structures: Subsoil under shallow foundations):

- alluvial and gravitational sediments of the character of loamy sandy gravels, class G3 to G4, symbols GM – GC
- gravitational and glacial sediments of the character of clay to clay-sandy loams with gravel – fragments of underlying solid rocks, classes F2 and F4, symbols CG and CS
- alluvial – gravitational and glacial clay loams and loams with fragments in the amount less than 15%, class F6, symbols CL, CI
- glacial clays, class F8, symbol CV.

The total thickness varies in a rather wide range from about 0.90 to 11.40 m and more. In some places, a boundary between the Quaternary cover and the weathered bedrock is almost indistinctive.

BEDROCK

The whole locality of the tunnel is composed of sedimentary rocks of “unproductive” Carboniferous – culm. Clay sediments – claystones and siltstones are the most frequent petrographic type. They are usually dark grey, thinly laminated, massive in places. The occurrence of flysch formations built of clayey and sandy rocks – greywacke sandstones and greywackes is frequent. The colour of the rocks is grey, when the colour of rather coarse-grained rocks is always lighter. Sandy sediments – greywackes and greywacke sandstones are the least abundant. Those are mostly indistinctly bedded to massive. They contain very often thin laminae of clays that indicate the bedding of them.

MATHEMATICAL MODEL

The dynamic model of seismic effects of blasting operation was implemented in the program system Plaxis 2D as an axially-symmetric model. The general procedure of dynamic model creation is analogous to

Table 1 Propeties of rock environment.

Identification		γ_{unsat} [kN/m^3]	γ_{sat} [kN/m^3]	μ [-]	E_{ref} [kN/m^2]	c_{ref} [kN/m^2]	φ [°]
quartenary cover		18	21	0,35	2000	10	19
graywacke		22.65	24.65	0.25	2000000	80	42
claystones and sillstones	heavily mouldered	20.55	22.55	0.25	1500000	20	36
	lightly mouldered	22.7	24.7	0.25	2000000	60	38
	undisturbed	24.3	26.3	0.25	2800000	80	42

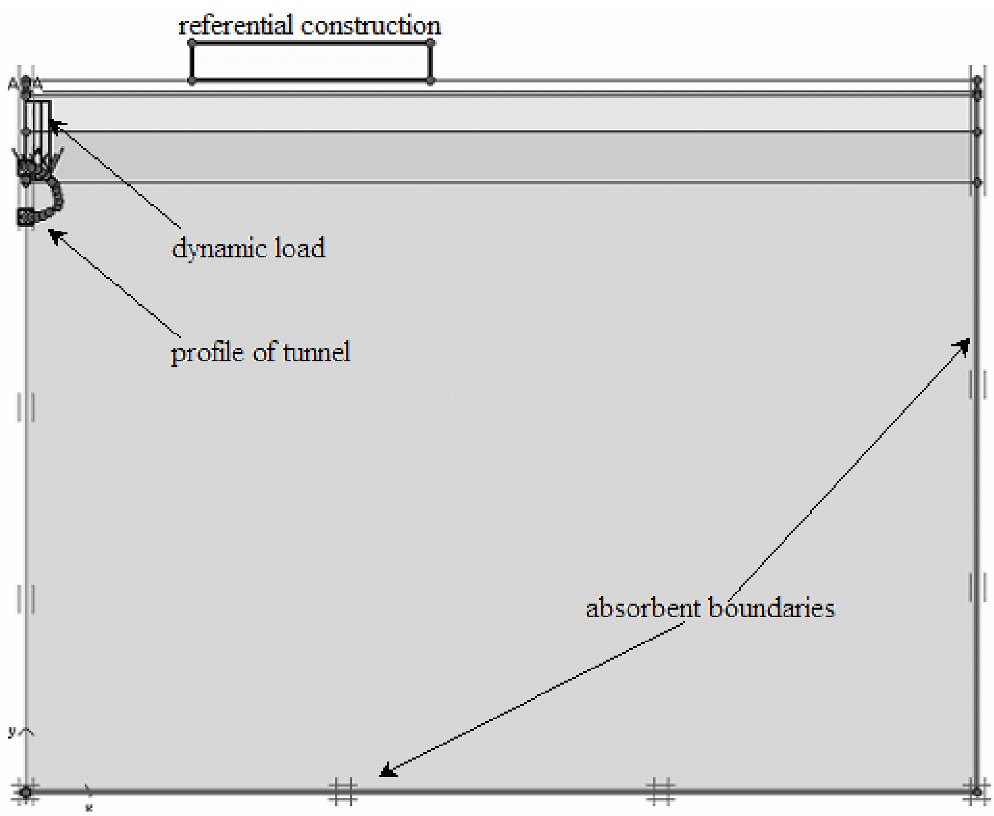


Fig. 2 The overall geometry of symmetric model.

that of static analysis. It includes the setting of model geometry, the definition of boundary conditions, the generation of grid, the setting of initial conditions, the setting of input geometric and material characteristics of rock environment and constructional elements and the determination of load characteristics. (Hrubešová and Aldorf, 2004).

The stratified rock environment corresponds to the geological conditions characteristic of the given area and was simplified for the needs of the model. Individual layers of various dips and thicknesses changing in the geological section were implemented into the model as horizontal layers of equal thickness. (Fig. 2). Physical properties of soils and thicknesses of individual layers were implemented into the model on the basis of results of engineering-geological exploration (internal materials of INSET company) and supplemented by tabular values (ČSN 73 1001) (Table 1). The influence of groundwater was not, for the reason of simplification of mathematical calculation, considered.

In the model, a reference structure 50 metres long replaces the building of a family house.

In the course of modelling seismic influences, it is always necessary to insert into the calculation, in addition to standard geometric boundary conditions, the conditions of model interface absorption, because without introducing these absorption boundary conditions, the unreal reflection of seismic waves back into the model and their interaction would occur. Absorbed normal and tangential stresses depend on the spread velocities of P waves V_p and S waves V_s, on the density of material ρ and on relevant determined velocities of mass point vibration $\dot{u}_x, \dot{u}_y$. For the given type of dynamic task, the presented absorption boundary conditions are set for the right and the lower model boundary.

In a case of modelling dynamic influences, it is necessary to set, in addition to the basic characteristics of rock environment (strain, strength, descriptive parameters), the velocities of wave spread in the rock environment and the characteristics of material attenuation. The velocities of wave spread can be set either directly or these parameters can be calculated on the basis of modulus of elasticity E or E_{oed}, Poisson number μ and specific weight γ according to general relations (g is the normal acceleration of gravity being 9.80665 $m.s^{-2}$):

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

$$V_s = \sqrt{\frac{G}{\rho}}, \quad G = \frac{E}{2(1+\mu)} \qquad (2)$$

To take into account material attenuation, so-called Rayleigh parameters of attenuation alpha and beta must be set. For the axially symmetric model, it is often sufficient to consider merely so-called geometric attenuation following from the radial spread of waves through the environment, and material attenuation may be omitted in this case (Rayleigh attenuation coefficients are null). (Hrubešová and Aldorf, 2004)

The dynamic modulus, by means of which a dynamic load is put into the mathematical model, is characterised by amplitude, vibration frequency and phase shift (Fig. 3).

The phase shift was not considered in this task, because the introduction of phase shift did not cause any changes. The load amplitude was calculated by using a relation by Prof. Fotieva (Bulyčev, 1988) for dynamic loading p_{dyn}:

$$p_{dyn} = \frac{1}{2\pi} \cdot Kc \cdot \gamma \cdot Vp \cdot To \approx 92 \quad [kPa] \qquad (3)$$

where

Kc – coefficient of seismicity (*Kc* = 0.05)
γ – average specific weight (γ = 22.7 kN/m^3)

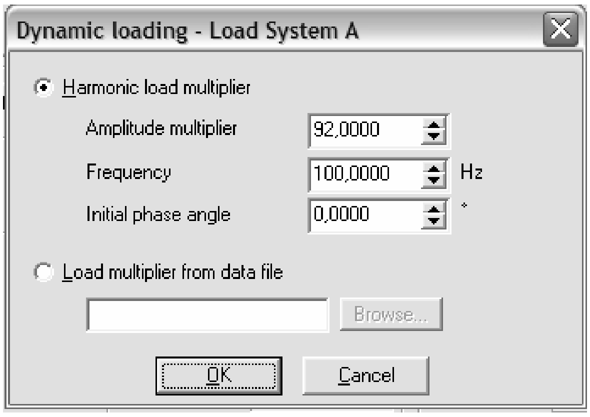


Fig. 3 Dynamic load – Plaxis 2D.

To – prevailing period of seismic vibration of rock particles (To = 0.5 s)
V_p – velocity of P-wave spread (V_p = 1018 $m.s^{-1}$) is given by relation (1) in which the following items are considered:
E – modulus of elasticity (E = 2 000 000 kPa)
μ – Poisson number (μ = 0.25)
g – acceleration due to gravity (g = 9.80665 $m.s^{-2}$)
ρ – rock density (ρ = 2.314 g/m^3)

The frequency of vibration was introduced into the mathematical model from a real record of vibration velocity waveform obtained in the course of monitoring of technical seismicity on the building of a family house No. 798 due to blasting operations performed at the point of calotte on the tunnel tube B when driving was carried out at the smallest distance from the building being monitored, i.e. at the stationing 141,576.65 (Fig. 4, Table 2).

In the geometry of the mathematical model, the proper load simulating the blasting operation was located in a form of uniform continuous load in the place of calotte (Fig. 5). The duration of dynamic load was 0.01 s. This value followed from the prevailing frequency measured on the building being monitored, i.e.:

$$T = \frac{1}{f} \quad [s], \qquad \mathrm{f} = 100\,\mathrm{Hz} \qquad (4)$$

Table 2 Parameters of record of blasting operation.

	vertical component	longitudinal component	transversal component	space component
maximum velocity amplitude [mm.s-1]	1,6	-1,8	-1,7	2,2
frequency [Hz]	111,1	90,9	126	**100**

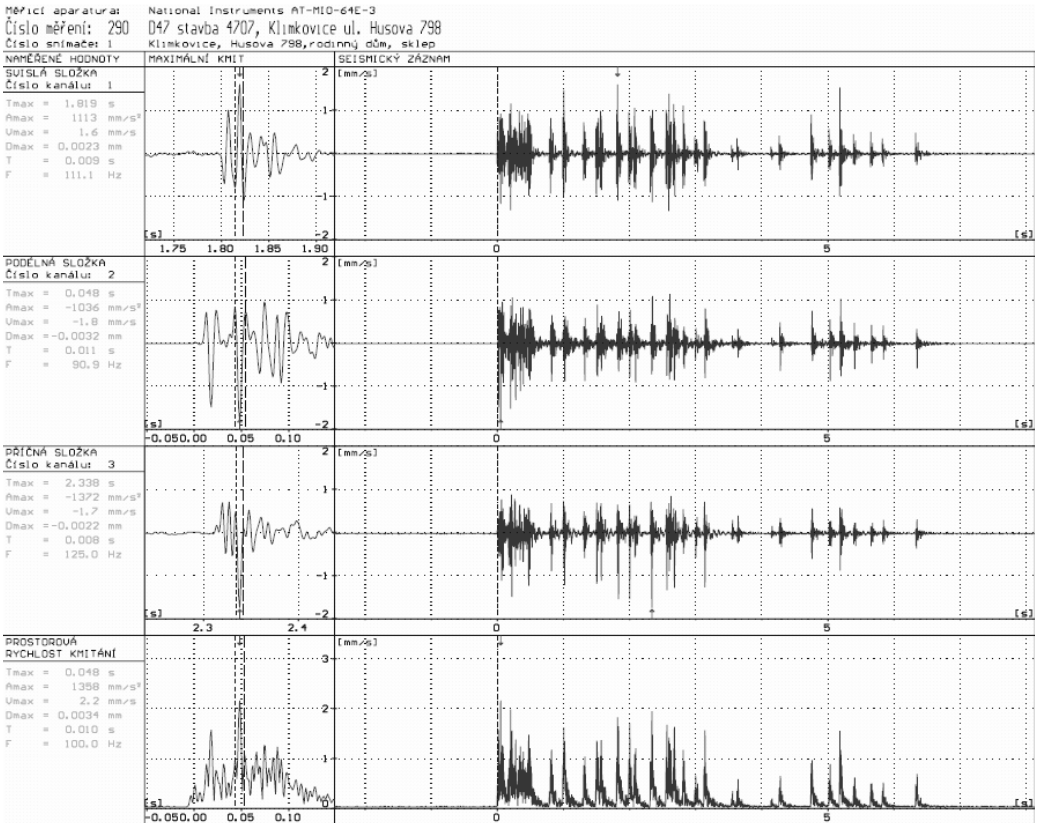


Fig. 4 A record of blasting operation – tunnel tube B, stationing 141,576.65, calotte.

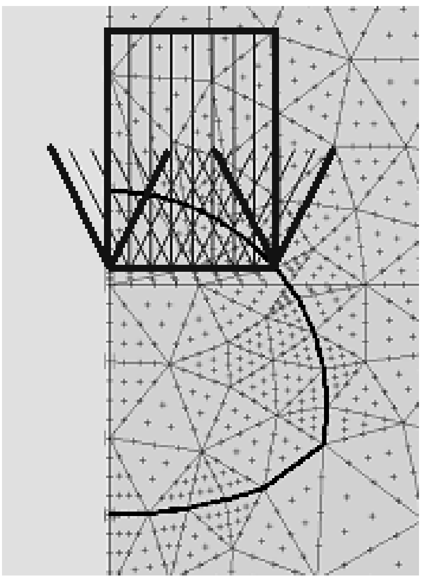


Fig. 5 Calotte load diagram.

OUTPUTS AND INTERPRETATION OF RESULTS OF MATHEMATICAL MODEL

The goal was to observe the distribution of maximum amplitude of vibration velocity along the foundations of reference structure 50 m long representing e.g. factory building or storage facility. Along the basement slab length, twenty six monitoring points were arranged (Fig. 6) in the mathematical model before the beginning of calculation. At the points, the maximum amplitudes of vibration velocity were subsequently evaluated.

In Figures 7 to 9 the areal distribution of vibration velocity along the length of foundations obtained from outputs of the mathematical model is processed graphically. To each of twenty six observed points, maximum amplitudes of vibration velocities in the horizontal and the vertical direction and in the vertical plane (in the model area) correspond (Stolárik, 2007).

Furthermore, a change in the maximum amplitude of vibration velocity in relation to the distance from the source of dynamic load was observed as well. The distance ranged from 42.36 m (shortest distance between the calotte and point 1) to 84.26 m (shortest distance between the calotte and point 26). Correlations of maximum amplitude of vibration velocity with the distance from the source of

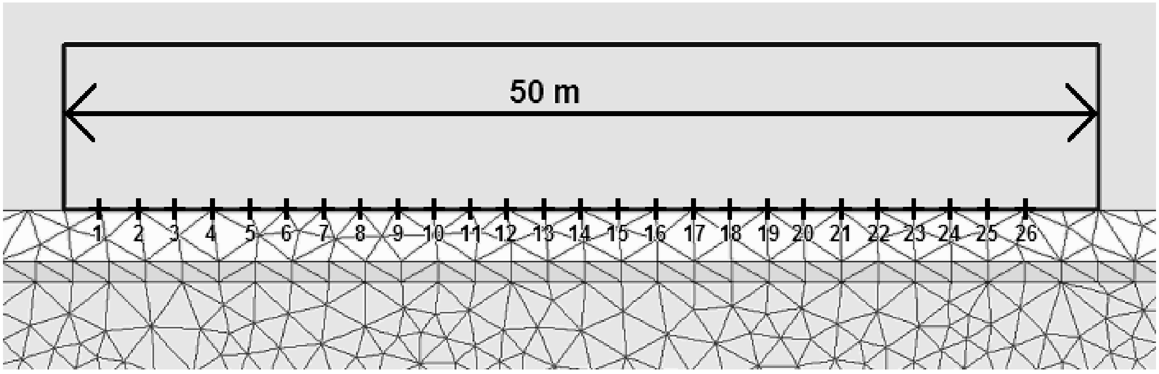


Fig. 6 The layout of points observed.

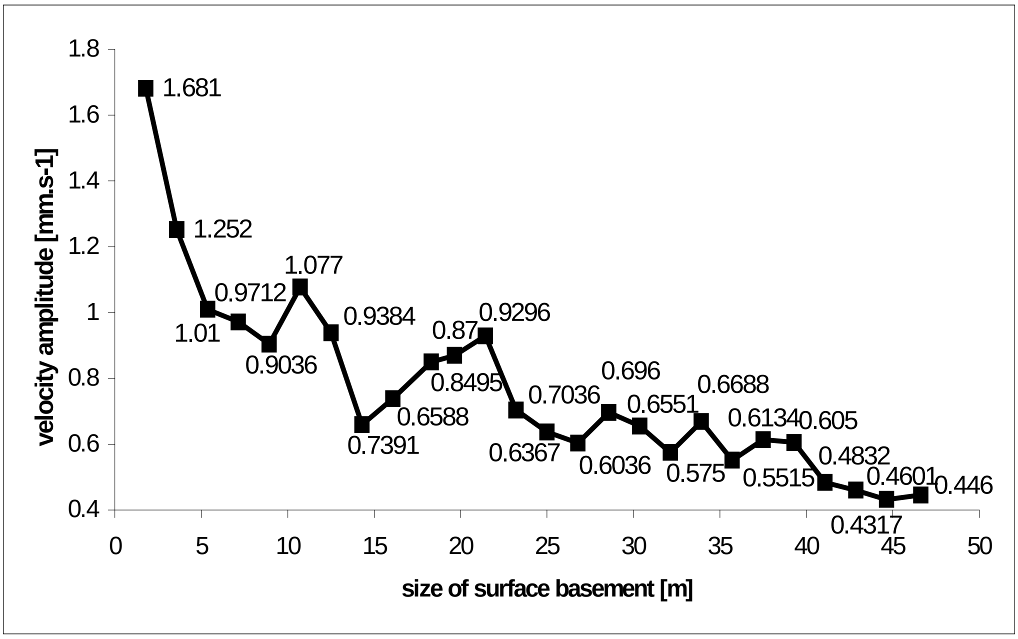


Fig. 7 Distribution of velocity amplitude on surface basement in horizontal direction.

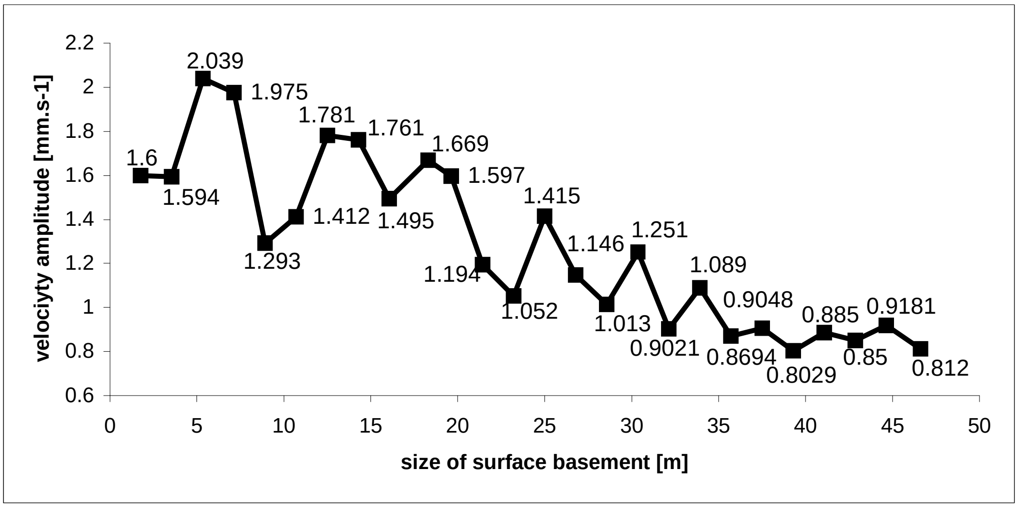


Fig. 8 Distribution of velocity amplitude on surface basement in vertical direction.

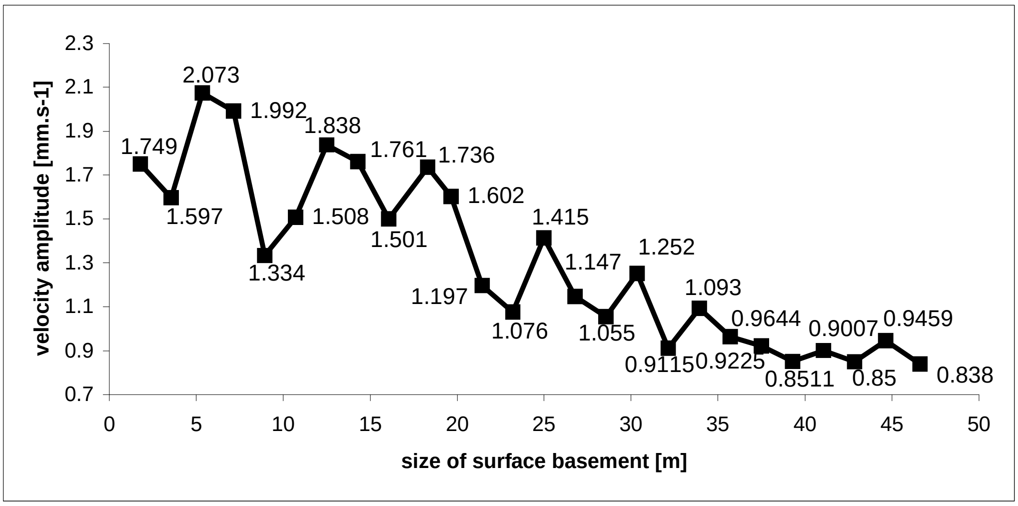
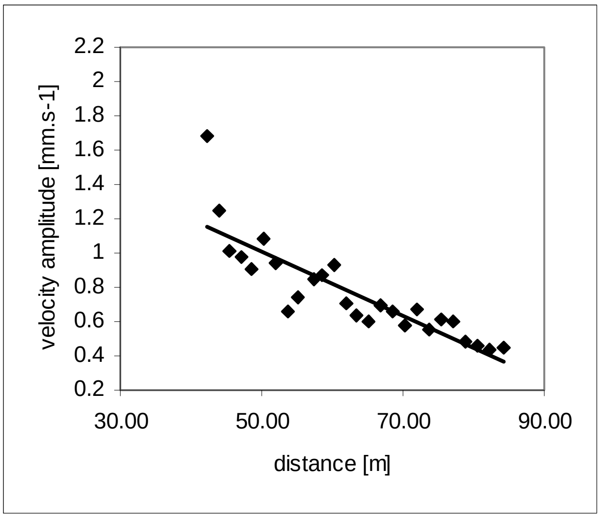


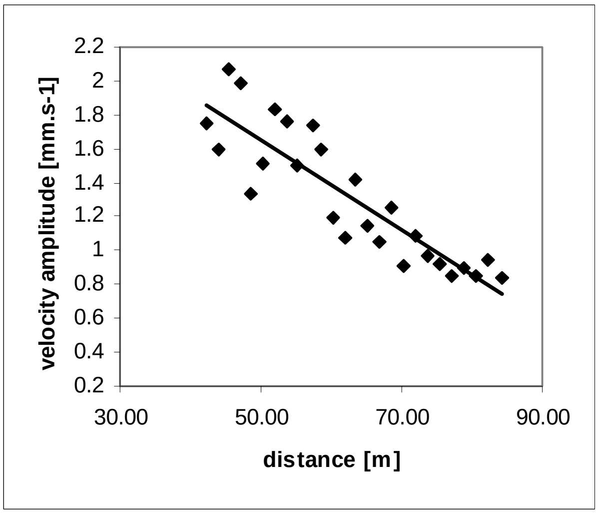
Fig. 9 Distribution of velocity amplitude on surface basement in vertical plane.

dynamic load were done and adequate correlation coefficients were calculated. The correlations were subsequently graphed again for the maximum amplitudes of vibration velocities in the horizontal direction, the vertical direction and in the vertical plane. (Graphs 1, 2, 3).

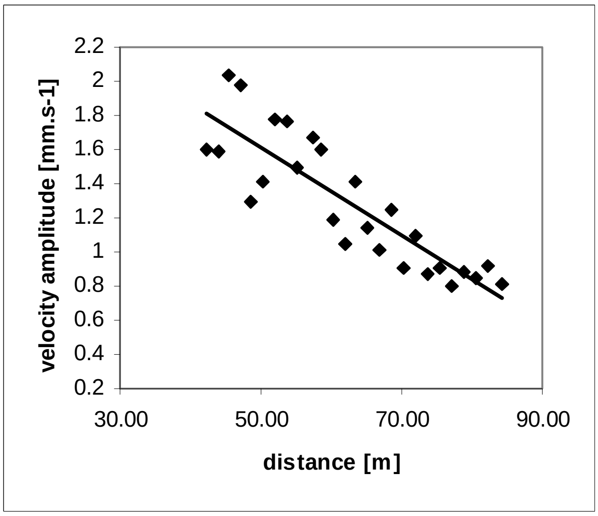
A general overview of the calculated maximal amplitudes of vibration velocities in the horizontal



Graph 1 Correlation of maximum velocity amplitudes on distances of surface basement from source of dynamic load – horizontal direction of velocity amplitude
Correlation coefficient: - 0.8556369



Graph 2 Correlation of maximum velocity amplitudes on distances of surface basement from source of dynamic load – vertical direction of velocity amplitude
Correlation coefficient: - 0.8711178



Grahp 3 Correlation of maximum velocity amplitudes on distances of surface basement from source of dynamic load – velocity amplitude in vertical plane
Correlation coefficient: - 0.8851067

Table 3 A comprehensive overview of maximum amplitudes of vibration velocities.

spot	placing of spot on the basement [m]	distance from dynamic load [m]	maximum velocity amplitude - horizontal direction [mm.s-1]	maximum velocity amplitude - vertical direction [mm.s-1]	maximum velocity amplitude - in plane [mm.s-1]
1	1.79	42.36	1.681	1.6	1.749
2	3.57	43.92	1.252	1.594	1.597
3	5.36	45.50	1.01	2.039	2.073
4	7.14	47.08	0.9712	1.975	1.992
5	8.93	48.69	0.9036	1.293	1.334
6	10.71	50.30	1.077	1.412	1.508
7	12.5	51.94	0.9384	1.781	1.838
8	14.29	53.58	0.6588	1.761	1.761
9	16.07	55.22	0.7391	1.495	1.501
10	18.3	57.29	0.8495	1.669	1.736
11	19.64	58.54	0.87	1.597	1.602
12	21.43	60.22	0.9296	1.194	1.197
13	23.21	61.88	0.7036	1.052	1.076
14	25	63.57	0.6367	1.415	1.415
15	26.79	65.26	0.6036	1.146	1.147
16	28.57	66.95	0.696	1.013	1.055
17	30.36	68.65	0.6551	1.251	1.252
18	32.14	70.35	0.575	0.9021	0.9115
19	33.93	72.06	0.6688	1.089	1.093
20	35.71	73.76	0.5515	0.8694	0.9644
21	37.5	75.48	0.6134	0.9048	0.9225
22	39.29	77.20	0.605	0.8029	0.8511
23	41.07	78.92	0.4832	0.885	0.9007
24	42.86	80.64	0.4601	0.85	0.85
25	44.64	82.36	0.4317	0.9181	0.9459
26	46.62	84.28	0.446	0.812	0.838

direction, the vertical direction and in the vertical planr at single points with adequate locations of the points on the foundations and relevant distances from the source of dynamic load is given in Table 3. In Table 4 the calculated maximum amplitudes of vibration velocities calculated by using the finite element method at point 1 and the maximum amplitudes of vibration velocities measured on the building of the family house in the course of monitoring technical seismicity are presented for comparison. The location of these points in the vertical section in reality corresponds to that in the mathematical model. Small differences between the calculated and the measured amplitudes of vibration velocities can be imputed to a considerably simplified model of very complicated situation, values, which were obtained partly from engineering-geological exploration and partly from tables, used in the model, and the implementation of dynamic load that was generated in the model by using a real record and calculation. In Figures 10 to 12, there is the program system Plaxis 2D graphical output of waveforms of vibration velocity at point 1 again in the horizontal direction, the vertical direction and the vertical plane.

Table 4 A comparison of results of mathematical model and IN-SITU measurements.

SPOT 1	maximum velocity amplitude - horizontal direction [mm.s-1]	maximum velocity amplitude - vertical direction [mm.s-1]	maximum velocity amplitude - in plane/in space [mm.s-1]
QUANTIFIED	1.681	1.6	1.749
REAL	1.7	1.6	2.2

Differences in the maximum amplitude of vibration velocity at observed points along the length of foundations (very small distance between the points, about 3 metres) are up to 100%. These vast differences over small distances may cause a considerably non-uniform distribution of load on a basement slab and may lead to its possible vibration and subsequent possible damage to the basement slab

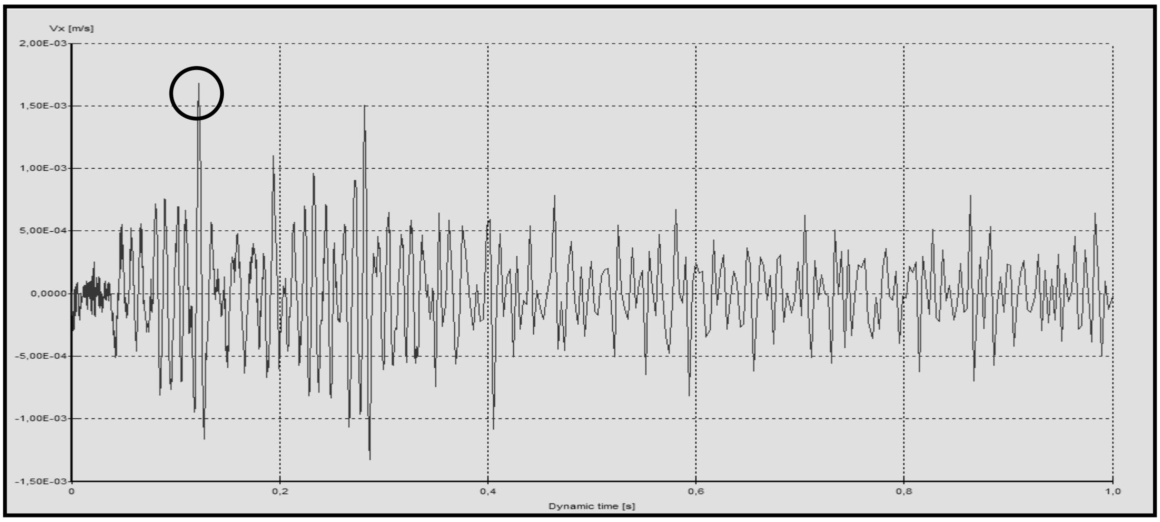


Fig. 10 Velocigram – Horizontal direction of velocity amplitude.

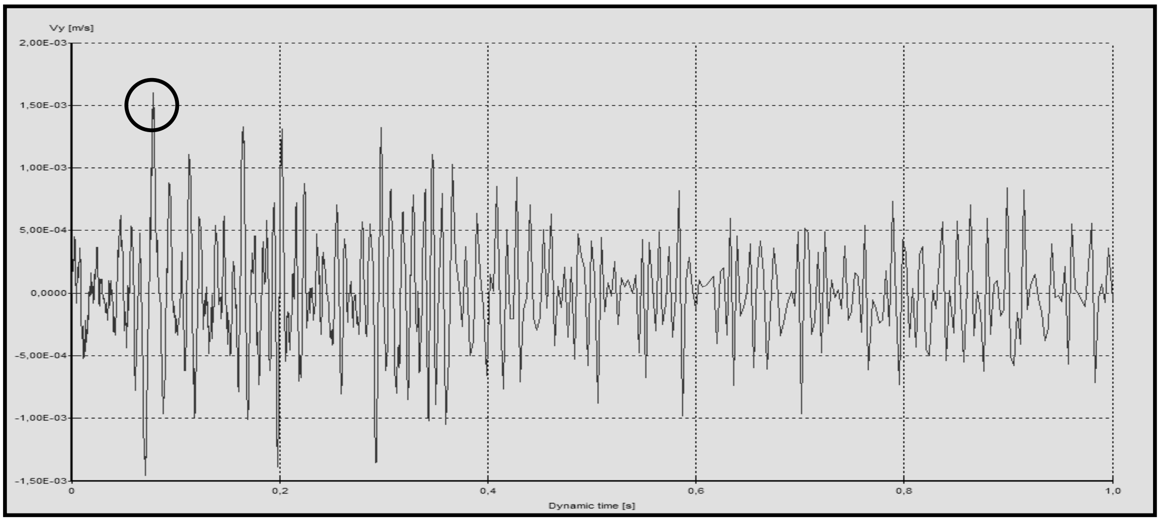


Fig. 11 Velocigram – Horizontal direction of velocity amplitude.

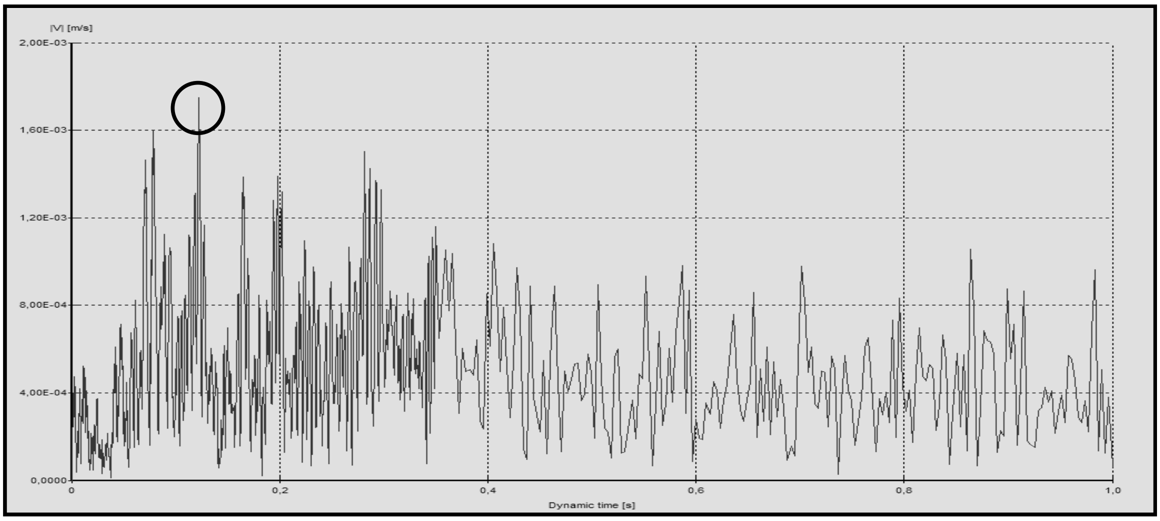


Fig. 12 Velocigram – Velocity amplitude in vertical plane.

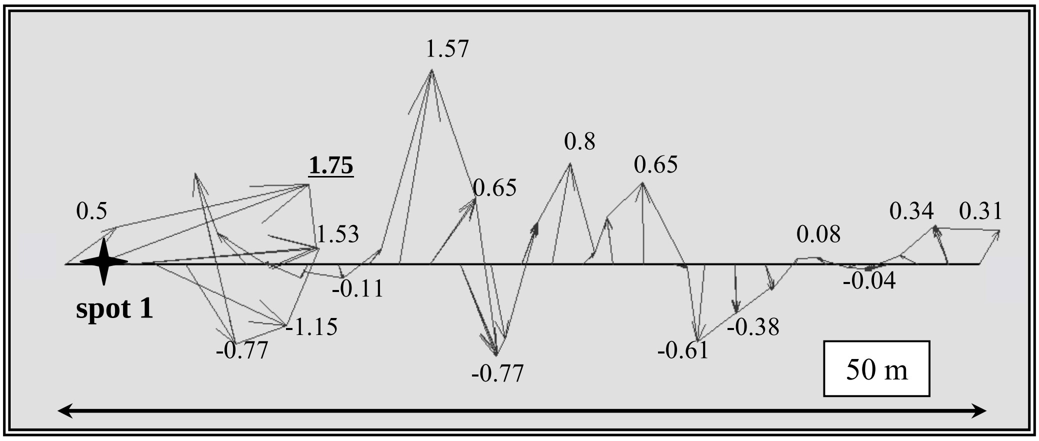


Fig. 13 A section through the basement slab.

and the building. As an example Figure 13, which represents a section through the foundations of reference building at the time when at point 1 the total maximum amplitude of vibration velocity in area of 1.749 mm.s^{-1} was recorded, may be given. It is necessary to realize that in this contribution the mathematical model is merely two-dimensional, and thus considerably simplified.

CONCLUSION

In this work, the applicability of program system Plaxis 2D to the modelling of seismic effects of blasting operations carried out in a shallowly constructed underground structure situated at a small distance from a built-up area was verified.

At a small distance (i.e. the first hundred meters) from the source of dynamic load (specifically blasting operation), the existence of indirect dependence of distance from the source of dynamic load on the maximum amplitude of vibration velocity was confirmed by means of a mathematical model This is proved by favourable values of correlation coefficients.

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