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**Tomáš PETŘÍK<sup>1</sup>, Eva HRUBEŠOVÁ<sup>2</sup>, Martin STOLÁRIK<sup>3</sup>, Miroslav PINKA<sup>4</sup>****PARAMETRIC STUDY ON THE EFFECTS OF SOIL TO OSCILLATION VELOCITY****PARAMETRICKÁ STUDIE VLIVU TYPU ZEMINY NA AMPLITUDU RYCHLOSTI KMITÁNÍ****Abstract**

The paper focuses on the possibility of evaluating the influence of character of the soil to oscillations velocity induced dynamic loads. Mathematical modeling is used to solve the parametric study. Models are created in software Plaxis 2d based on finite element method. Dynamic load is based on experimental measurements on the stand in the area of the Faculty of Civil Engineering, VSB-TUO. Soil properties are determined from the normative indicative characteristics.

**Keywords**

Dynamic load, oscillation velocity, Plaxis, properties of soils.

**Abstrakt**

Príspevek je zaměřen na možnost posouzení vlivu charakteru zemin na amplitudu rychlosti kmitání vyvolanou dynamickým zatížením. Pro řešení parametrické studie je využito matematického modelování ve výpočetním programu Plaxis 2D založeného na metodě konečných prvků. Dynamické zatížení vychází v příspěvku z experimentálního měření provedeného na standu v areálu Fakulty stavební, VŠB-TUO. Vlastnosti zemin vycházejí ze směrných normových charakteristik.

**Klíčová slova**

Dynamické zatížení, amplituda rychlosti kmitání, Plaxis, vlastnosti zemin.

**1 INTRODUCTION**

During the execution of building structures, including geotechnical ones, the builders make efforts to prevent the production of defects on the structures and their propagation such as [2]. These defects are primarily caused by incorrect building technology and foundations. To a considerable extent, they can be caused also by seismic loading, not only by the influence of nature itself [10], but primarily by human activities [8]. The most significant activities induced by man, resulting in seismic oscillations are, for example, blasting operations [9], sheet piling [5] or soil compaction [6]. We can

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prevent the undesirable effects that may be caused by these activities by selection of a proper building technology for the given locality. One of the means how to contribute to correct and reliable selection of building technology is the utilization of mathematical modelling of the given problem.

There are many parameters that must be included in the models that have influence on propagation of seismic oscillations. One of these parameters is the environment itself through which the waves propagate. The objective of this paper is a study of influence of individual soils on the amplitude of oscillation velocity induced by a dynamic load in a simple mathematical model. Individual types of soil are entered in the model according to representative standard characteristics (hereinafter RSCs only). Evaluation and analysis of results of mathematical models may assist in prediction of propagation of seismic oscillation through the real-world environment. Due to this, building technology can be modified accordingly.

## 2 CHARACTERISTICS OF MODELS

A two-dimensional version of Plaxis computer program was selected which was upgraded to a newer version (Plaxis 2D, 2010) within the framework of the project "Creation and internationalization of top research teams and increasing their excellence at the Faculty of Civil Engineering, VSB – Technical University of Ostrava" (CZ.1.07/2.3.00/20.0013). Due to time and data saving, the mathematical models are simplified (e.g. one layer of soil only, or omission of groundwater effects). The models were made as rotary-symmetrical ones within the range of  $100 \times 50$  m (length  $\times$  width). The selection of a compacting machine resulted from experimental measurements [7] on the test stand in the FAST premises [1]. 18 parametric models altogether are made according to types of soil from RSCs.

### 2.1 Fundamentals of applied calculation method

Plaxis is a computer program intended for two-dimensional and three-dimensional deformation and stability analysis of geotechnical tasks. This program is based on the finite element method and it is the product of the Dutch PLAXIS BV. This computer program includes a calculation dynamic module to analyse dynamic tasks using MKP. The computer program itself is noted for the simple visual environment (see Fig. 1).

The dynamic analysis in the Plaxis computer program stems from the equation (1) of Newton's motion law [4].

$$F = m \cdot a_g \quad (1)$$

Where:

- $F$  – force [kN];
- $m$  – body mass [kg];
- $a_g$  – acceleration [ $\text{m}\cdot\text{s}^{-2}$ ].

The elementary equation for calculation of time-dependent deformation changes under dynamic loading is then defined using a matrix notation for the entire area under consideration according to formula: (2).

$$a \cdot M + v \cdot C + u \cdot K = F \quad (2)$$

Where:

- $M$  – mass matrix;
- $u, v, a$  – displacement, velocity and acceleration can vary with time;
- $C$  – damping matrix;
- $K$  – stiffness matrix;
- $F$  – load vector.

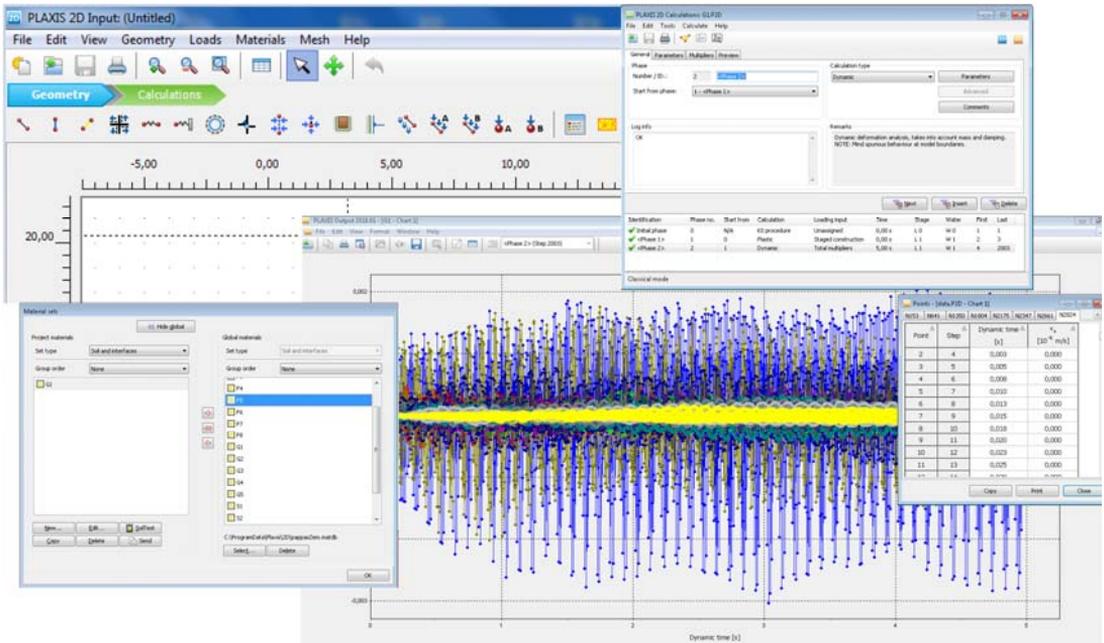


Fig. 1: An example of Plaxis computer program

## 2.2 Input parameters of models – soil

18 models with homogeneous environments are made for parametric calculations for which physical and mechanical properties are determined from median values of representative standard characteristics of soils (G1 – G5, S1 – S5 a F1 – F8) and presented in Table 1-3. The Plaxis computer program cannot count with zero cohesion value so that is why 1kPa is selected for 6 non-cohesive soils (G1 – G3 and S1 – S3) as a minimum value. The longitudinal ( $V_p$ ) and transversal ( $V_s$ ) velocities of propagation of seismic waves are automatically determined in the computer program for individual soils from the parameters entered (elastic parameters and Specific weight) according to equations (3) and (4). Material damping parameters, which are entered in the computer program using Rayleigh damping parameters, are not considered for these models. The groundwater level is not considered in the models.

$$V_p = \sqrt{\frac{E_{oed}}{\rho}} \quad E_{oed} = \frac{E_{def}}{\beta} = \frac{E_{def} \cdot (1 - \nu)}{(1 + \nu) \cdot (1 - 2 \cdot \nu)} \quad (3)$$

$$V_s = \sqrt{\frac{G}{\rho}} \quad G = \frac{E_{def}}{2 \cdot (1 + \nu)} \quad (4)$$

Where:

- $E_{oed}$  – Oedometric modulus [MPa];
- $G$  – Shear modulus [MPa];
- $E_{def}$  – Deformation modulus [MPa];
- $\rho$  – Specific weight of environment [ $\text{kg} \cdot \text{m}^{-3}$ ];
- $\nu$  – Poisson's ratio [-].

Tab. 1: Material properties of fine-grained soils

Soil	Unit weight [kN.m <sup>-3</sup> ]	Poisson's ratio [-]	Friction angle [°]	Cohesion [kPa]	Deformation modulus [kPa]
F1	19	0,35	29	14	17500
F2	19,5	0,35	27	16	14500
F3	18	0,35	26,5	18	9000
F4	18,5	0,35	24,5	20	7250
F5	20	0,4	21	18	10750
F6	21	0,4	19	18	10750
F7	21	0,4	17	14	10500
F8	20,5	0,42	15	12	8500

Tab. 2: Material properties of sandy soils

Soil	Unit weight [kN.m <sup>-3</sup> ]	Poisson's ratio [-]	Friction angle [°]	Cohesion [kPa]	Deformation modulus [kPa]
S1	20	0,28	38	(1)	65000
S2	18,5	0,28	34,5	(1)	32500
S3	17,5	0,3	30,5	(1)	18500
S4	18	0,3	29	5	10000
S5	18,5	0,35	27	8	8000

Tab. 3: Material properties of gravel soils

Soil	Unit weight [kN.m <sup>-3</sup> ]	Poisson's ratio [-]	Friction angle [°]	Cohesion [kPa]	Deformation modulus [kPa]
G1	21	0,2	40	(1)	375000
G2	20	0,2	37	(1)	175000
G3	19	0,25	34	(1)	90000
G4	19	0,3	32,5	4	70000
G5	19,5	0,3	30	6	50000

### 2.3 Input parameters of models - dynamic loading

The loading in the model is entered similarly as in the member [6], so it is continuous dynamic loading acting on a steel plate with the weight of the equipment itself. A VDR 22 reverse vibration plate compactor is the source of vibrations (Fig. 2), which is part of the equipment in the geotechnical laboratory at VŠB - TUO. The parameters of the reverse vibrating plate necessary for putting in the model result both from the characteristics given by the manufacturer [3] and from the executed

experimental measurement on the test stand in the premises of the FAST. The parameters set up in the model are presented in Table 4.



Fig. 2: VDR 22 reverse vibrating plate in experimental measurement

Tab. 4: Parameters of vibrating plate

Reverse vibrating plate VDR 22		
Weight	120	kg
Dimensions of the plate	400 × 630	mm
Frequency*	100 / 82	Hz
Centrifugal force	22	kN

\* Maximum frequency indicated by manufacturer / frequency achieved during experimental measurement

### 2.3 Input parameters of models - dynamic loading

The conventional geometrical boundary conditions are set up in the models to limit displacements in the appropriate direction and supplemented with absorption conditions at the lower and right vertical boundaries. By these absorption conditions, the absorption of increments of stress at the boundaries of the model caused by dynamic loading and which would otherwise be bounced back into the model, are achieved. The primary state of stress is generated by the software system automatically pursuant to the properties of soils under consideration and the depth. Furthermore, it is necessary to choose a correct size of calculation time steps. This will have an impact not only on the calculating time, but also on the volume of data and the accuracy of data themselves. The number of steps for the models was set up to 2000. For the calculation, it is also necessary to specify the period of time during which the dynamic loading is supposed to act. This period of time has an impact also on the calculating time and the volume of data. If the measurements are taken at longer distances (tens of metres), it is necessary to extend the period during which the loading acts. The dynamic loading acts on given models for 5 seconds. Surface points are further determined in the model in which calculation results were evaluated. 10 points are selected in the calculation module (limited by Plaxis) at the distances from the place of vibrating approx. 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 [m]. These points may be appropriately put in the result module.

### 3 RESULTS

The wave records in X-axis and Y-axis for selected surface points are the output of the mathematical models. Consequently, these waveform records are used for plotting the curves of amplitude velocity oscillation versus distance, also named as damping curves (hereinafter DCs only) [4]. The damping curves from the models are divided into four types according to soil types. These are damping curves of gravelly soils (Fig. 3 and Fig. 4), sandy soils (Fig. 5 and Fig. 6), argillaceous earths (Fig. 7 and Fig.8) and silty clays (Fig. 9 and Fig. 10).

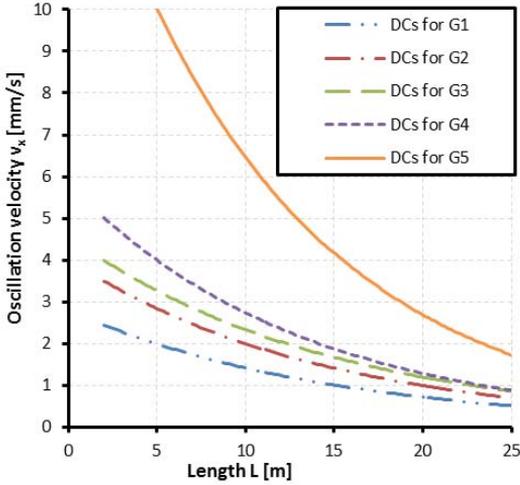


Fig. 3: DCs of gravelly soils in X-axis

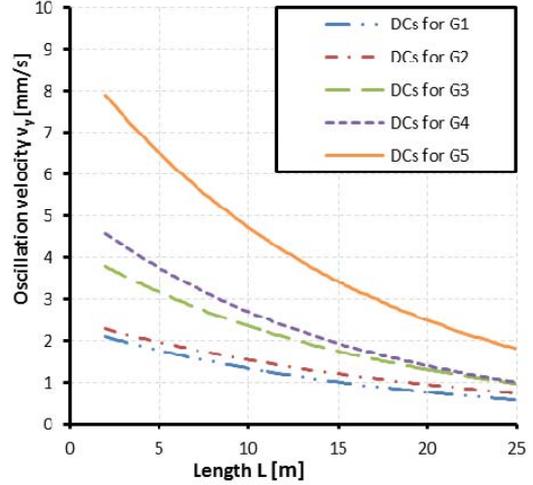


Fig. 4: DCs of gravelly soils in Y-axis

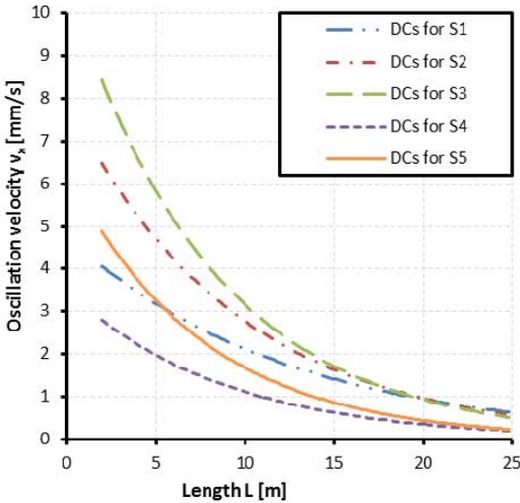


Fig. 5: DCs of sandy soils in X-axis

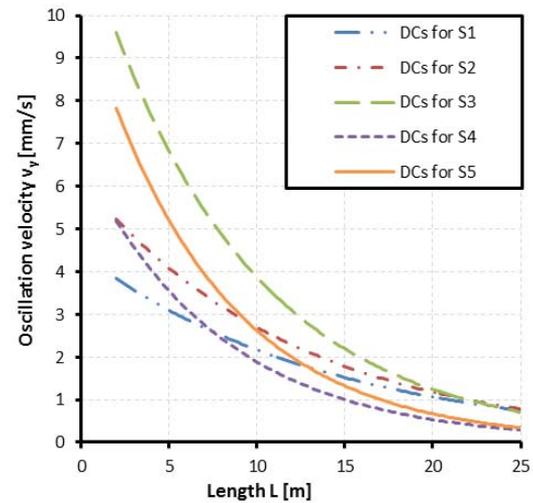


Fig. 6: DCs of sandy soils in Y-axis

As for gravelly soils, the lowest velocity oscillation amplitudes in both directions are achieved by well granulated gravel G1 – GW (see Fig. 3 and 4). On the contrary, the highest values are reached by clayey gravel G5 – GC. When looking at properties of gravelly soils in Table 3, it is evident that the deformation modulus of soils will have primarily the most significant influence. Also the deformation modulus similarly influences the velocity oscillation amplitudes in sandy soils (Fig. 5 and Fig. 6) at least in sands with lower contents of fine-grained soils (S1 – S3). However, also the

other properties show themselves considerably in sandy soils with higher contents of fine-grained soils (S4 and S5). Maybe that is why the lowest amplitudes are reached here by clayey sand S4 – SM.

The other properties show themselves considerably in argillaceous earths and silty clays where the differences in deformation modulus are minimal. It can be difficult to determine from graphs (obr. 7 – 10) which properties show themselves in attenuation curves and how much they influence them. But we can observe from the steepness of the attenuation curves that the fine-grained soils attenuate the velocity oscillation amplitude more significantly with increasing distance than in the case of sandy and gravelly soils.

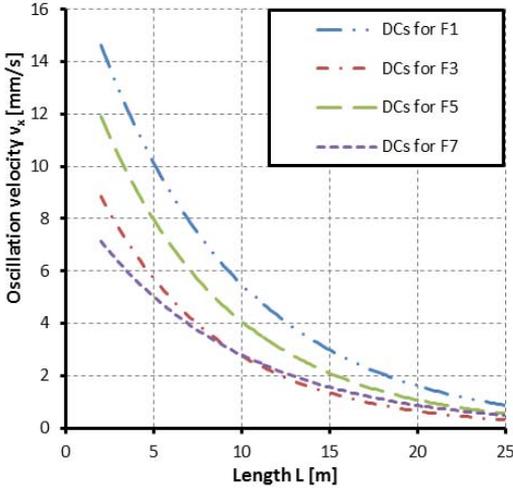


Fig. 7: DCs of argillaceous earths in X-axis

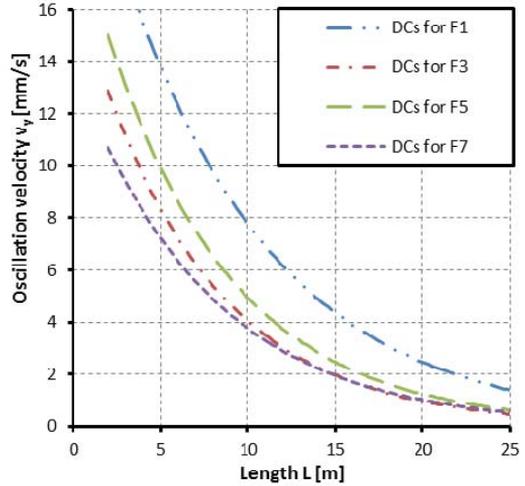


Fig. 8: DCs of argillaceous earths in Y-axis

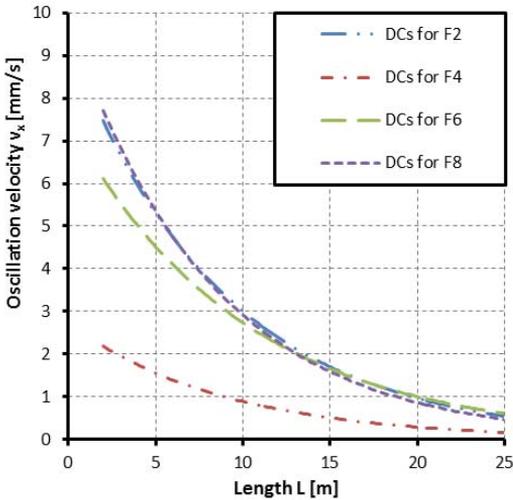


Fig. 9: DCs of silty clays in X-axis

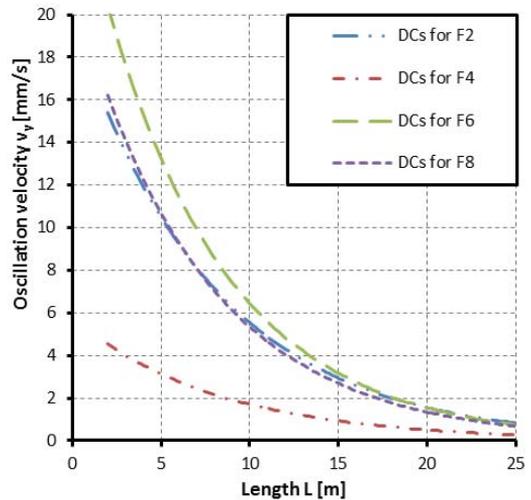


Fig. 10: DCs of silty clays in Y-axis

## 4 CONCLUSION

The dynamic module of Plaxis computer program turned up as a suitable means for implementation of parametric studies how effects of seismic oscillation depend on properties of soils. It was found out that the influence of change in properties of soil on the amplitude of oscillation velocity decreases with the increasing distance. It is evident from the graphs that dynamic loading is endured best by gravelly soils, primarily by the well granulated gravel (G1 – GW). It may be supposed from the above that significant influence on the amplitude of oscillation velocity is given by the deformation modulus which is higher in gravelly soils than in sandy soils and fine-grained soils. When looking at fine-grained soils, it is then evident that the deformation modulus will not be the only property of soils influencing the amplitude of oscillation velocity. Considering that we will have an environment with one variable property, in our case with the deformation modulus, and we utilized the equations for calculation of propagation velocity (3) and (4), the following can be stated: "The greater deformation modulus of environment, the higher velocity of propagation of seismic oscillations and the lower amplitude of oscillation velocity". For verification of primarily quantitative results of mathematical modeling it would be suitable to implement experimental monitoring measurements in-situ, which will not be easily taken in full range of the parametric study due to the nature of executed parametric calculations.

The objective of further parametric studies will be evaluation of the influence of individual physical and mechanical properties of soil, such as deformation modulus of soil, cohesion, internal friction angle, etc. The influence of individual properties of soils on seismic oscillation will be part of a dissertation thesis by Ing. Tomáš Petřík.

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