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NUMERICAL MODEL OF THE DYNAMIC LOAD RESPONSE IN THE REAL ROCK MASS USING LATIN HYPERCUBE SAMPLING METHOD

Abstract

This paper follows on previous paper "numerical model of the dynamic load response in the soil using Latin hypercube sampling method". In this paper the Latin Hypercube Sampling method (LHS) is used in order to evaluate the values of input parameters of real rock environment. The resulting values of the models were compared with the experimental in-site measurements. Twenty input values were generated for each input parameter. The peak oscillation velocities were calculated for 15 different surface points. The results were statistically analyzed in each distance (the basic statistical characteristics were evaluated). Based on this stochastic analysis the attenuation curve of the vibration velocity with the certain level of probability were determined.

Keywords

Dynamic loading, numerical model, stochastic parameter, Latin Hypercube Sampling method, peak oscillation velocity, experimental measurements.

1 INTRODUCTION

Objectivity and reliability of the input parameters is one of the most important factors of the mathematical models. One of the ways how we can take into account the variable nature of the geological environment is the use of stochastic simulation modeling. The application of the probabilistic approach to solving the seismic load response of geological environment and surrounding structures were solved in [1, 2, or 3]. These contributions mainly used the Latin hypercube sampling (LHS) for the selection of the sample values of the input parameters mathematical models. This paper focuses on the use of LHS method to take into account the stochastic character of the parameters of the geological environment, which was subjected to dynamic loads. The deformation modulus, the friction angle and cohesion were considered for random variable input parameters of the geological environment. The paper deals with the real geotechnics situation and complements the previous model study [4]. The results of stochastic models are compared with experimental measurements [5], which were carried out in the Faculty of Civil Engineering, VŠB – Technical university of Ostrava.

2 CHARACTERISTICS OF MODELS

The geological profile is taken from the final report, which was used in the article processed by Čajka R. et al. [6]. Geology in this area consists of 7 m layer of solid clay F6 (CI, CL) under which there is situated a of dense sand layer S3 (SF) with a thickness of approximately 3.0 m and

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below it is located about 5.0 m thick layer of dense sandy gravel G3 (GF). Under a layer of gravel continue the dense sandy layer S2 (SP). The geotechnical properties of soils are based on the indicative normative characteristics CSN 73 1001. The basic model is created with a simple geological profile. The water table is located on the ground at a depth of 16 m, in the model, however, the groundwater level is not considered. The geotechnical properties of soils are based on the indicative normative characteristics ČSN 73 1001 (This standard is no longer valid) and are shown in Table 1.

Table 1: Standard characteristics of soils ČSN 73 1001

Class	Poisson's ratio ν -	Unit weight γ $kN.m^{-3}$	Deformation modulus E_{def} MPa	Friction angle φ_{ef} °	Cohesion c_{ef} kPa
F6	0,40	21	3–6	17–21	8–16
S3	0,30	17,5	17–25	30–33	0
G3	0,25	19	90–100	33–38	0
S2	0,28	18,5	30–50	34–37	0

Soil strength parameters (cohesion c_{ef} and friction angle φ_{ef}) and deformation modulus E_{def} of soil are considered as stochastic parameters with a normal probability distribution (with the exception of cohesion in sandy and gravelly soils). The module GLHS for MS Excel application was used for the generation of stochastic input data. This module was worked out in the Department of Geotechnics and Underground Engineering, VŠB – Technical university of Ostrava. Generation was based on the selected probability distribution and the upper and lower limits, the mean and standard deviation of the stochastic parameters the geological environment. Overall, it was made out 20 variants of simulations. For each variant were determined by the respective distribution functions and their respective final values of the input parameters of the models (Table 2).

Table 2: Example of stochastic generated values from module GLHS

	modul F6		Soudržnost F6		Úhel tř. F6		Modul G3		Úhel tř. G3	
	DF	gen.hod.	DF	gen.hod.	DF	gen.hod.	DF	gen.hod.	DF	gen.hod.
1	0,275607	4,20203	0,175877	10,75842	0,475067	18,95831	0,524933	95,10423	0,275607	35,00338
2	0,824123	4,965595	0,026282	9,41537	0,524933	19,04169	0,674528	95,75408	0,724393	35,99662
3	0,624663	4,658875	0,375337	11,57633	0,076147	18,04568	0,824123	96,55198	0,375337	35,23521
4	0,026282	3,530762	0,724393	12,79459	0,175877	18,37921	0,275607	94,00677	0,973718	37,1154
5	0,375337	4,341125	0,923853	13,90863	0,425202	18,87427	0,126012	93,09092	0,076147	34,30711
6	0,873988	5,072723	0,475067	11,91662	0,375337	18,78817	0,923853	97,38579	0,774258	36,12745
7	0,325472	4,273775	0,325472	11,39673	0,674528	19,30163	0,724393	95,99323	0,225742	34,87255

Dynamic load was characterized in the models as the reversible vibrating plate VDR 22. This vibrating plate was used for experimental measurement on the testing stand in VŠB – Technical university of Ostrava (see Fig. 1). The frequency of vibration during experimental measurement was 82 Hz [5]. Input parameters of the reversible vibrating plate (Table 3) were defined by the manufacturer brochures VDR 22 [7] and results of experimental measurement in-situ [5]. Duration of the dynamic load action in the model was 5 seconds.

Table 3: Input parameter of vibrating plate VDR 22

Reversible vibrating plate VDR 22		
Weight	120	kg
Dimension of the plate	400 × 630	mm
Frequency	82	Hz
Dynamic load	22	kN

Fig. 1: Experimental measurement in stand in Faculty of Civil Engineering

The basic mathematical model was created as an axially symmetric model of the size 100 × 50 m (W × H), which is bounded by classical geometric boundary conditions, and absorption conditions additionally (see Fig. 2). Input parameters of the geological environment were defined according to Table 1 (deterministic parameters of the geological environment) as well as according to Table 2 (stochastic parameters of the geological environment). In the software Plaxis material damping is involved by the Rayleigh damping parameters (α_R and β_R). In the model is finally considered $\alpha_R = 0.001$, $\beta_R = 0.0001$.

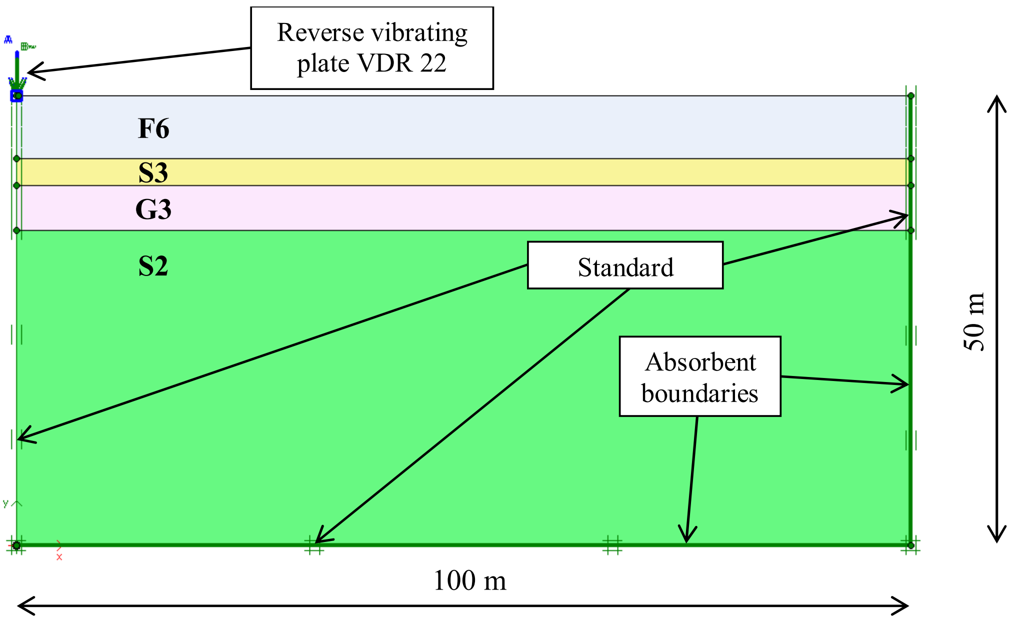

Fig. 2: The geometry of the model in software Plaxis (standard boundaries with total fixed points a), with horizontal fixed points b) and vertical fixed points c))

3 RESULTS OF MODELS

Based on the described input parameters (deterministic and stochastic) and the assumptions of the model there were evaluated for all 20 simulation variants the peak oscillation velocity in the horizontal and vertical axis corresponding to the 15 points located at different distance from the dynamic source (together 600 total value). These data are plotted in Fig. 3 and Fig. 4 and compared with the experimental measurements in situ.

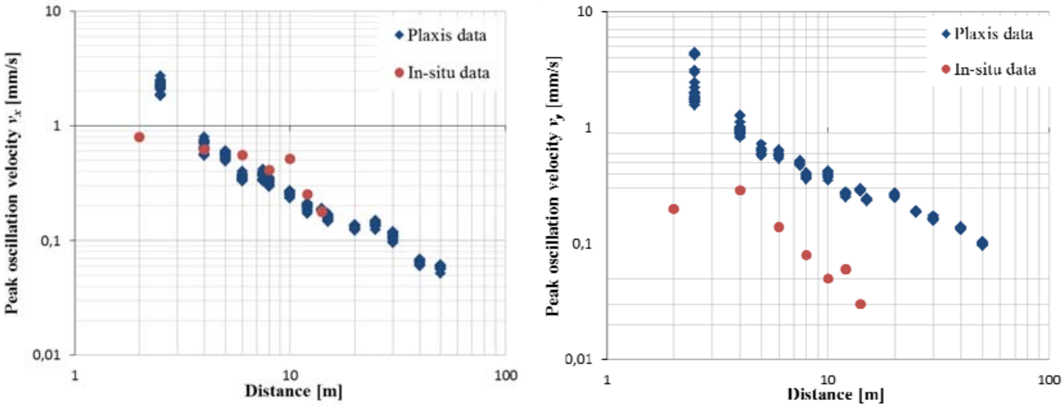

Fig. 3 and Fig. 4: Records of peak oscillation velocity from horizontal and vertical axis

These graphs show the influence of the geological environment to the peak oscillation velocity. The most significant influence corresponds to the distance between 8–10 meters from the vibrating plate in the horizontal axis and 10–12 m in the vertical axis. This increase peak oscillation velocity may be caused due to the reflection of seismic waves from the lower layers of the geological environment with different geotechnical properties. Another such phenomena is indicated at a distance of 20–22 meters (only in model). The peak oscillation velocities, obtained from the model, were analyzed in each distance statistically by using spreadsheet MS Excel. There were evaluated the basic statistical characteristics (Table 4) resulted from the obtained statistical response file.

Table 4: Basic statistical characteristic from spreadsheet MS Excel

Distance [m]	4	6	8	10	4	6	8	10
Axis	v_x [mm.s^{-1}]				v_y [mm.s^{-1}]			
Average (mean)	0.671	0.351	0.325	0.253	0.978	0.583	0.382	0.396
Median	0.672	0.349	0.326	0.255	0.951	0.582	0.381	0.399
Standard deviation	0.068	0.017	0.016	0.011	0.115	0.021	0.014	0.018
Quantile 0.05	0.561	0.329	0.299	0.233	0.859	0.559	0.363	0.359
Quantile 0.95	0.750	0.382	0.350	0.268	1.226	0.619	0.406	0.422

The results of the stochastic modeling of the dynamic response can then determine the range, in which the peak oscillation velocities with a certain probability were varied. For example, 6 meters away from the point of action of the vibrating plate the value of peak oscillation velocity lies with 90% probability within the range of from 0.329 to 0.382 mm.s^{-1} in the horizontal axis and within the range of from 0.559 to 0.619 mm.s^{-1} in the vertical axis. The data were processed in the box-graphs in Fig. 5 and Fig. 6.

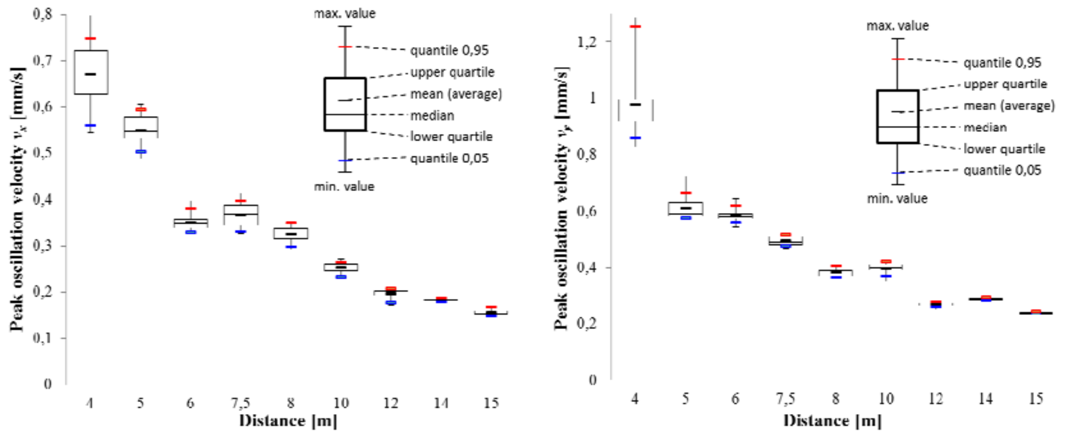

Fig. 5 and Fig. 6: Box-and-Whisker plots of peak oscillation velocity in horizontal and vertical axis

4 CONCLUSION

The application of stochastic modeling of geotechnical problems can significantly refine the idea of the expected behavior of the geological environment or structures and prevent poor or inefficient designs. It is known that the LHS is efficient stochastic method for taking into account the probabilistic character of the input parameters. This method reduces the number of required simulations while maintaining high accuracy of the results compared with standard Monte Carlo method. A disadvantage LHS method is that it does not add of any simulation to the already processed data set. Generally, the higher number of simulation is equal to the greater accuracy of the results. This is coupled with the increasing demands on the required space and time of calculations. It also increases the uncertainty associated with human error (e.g. rewriting data). At present there exist modifications LHS methods that allow to extend the default number of simulations (without having to repeat the previous simulation calculation), such as Hierarchical method Subset Latin Hypercube Sampling (HSLHS) [8]. Even if this method is used, the number of required simulations does not increase linearly (it would be necessary calculate an additional 40 simulations to the next level of the hierarchy in our case). We can get an idea to obtain a probabilistic range of values of peak oscillation velocities in the geological environment in the analyzed example. Then we can suggest another way of the construction process or other safety measure.

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REFERENCES

[1] RAJEEV, P. & TESFAMARIAM, S. Seismic fragilities of non-ductile reinforced concrete frames with consideration of soil structure interaction. *Soil Dynamics and Earthquake Engineering*. 2012, Vol. 40, pp. 78-86. ISSN 0267-7261.

[2] CELAREC, D. & DOLŠEK, M. The impact of modelling uncertainties on the seismic performance assessment of reinforced concrete frame buildings, *Engineering Structures*, Volume 52, July 2013, Pages 340-354, ISSN 0141-0296.

[3] HRUBEŠOVÁ, E. & LUŇÁČKOVÁ, B. Modelování dynamických vlivů odstřelu na napěťo-deformační stav svahového tělesa. *Sborník vědeckých prací Vysoké školy báňské – Technické univerzity Ostrava – Řada stavební*. 2006, roč. VI, č. 1, s. 65-71. ISSN 1213-1962.

[4] PETŘÍK, T.; MOHYLA, M. & HRUBEŠOVÁ, E. Numerický model odezvy dynamického zatížení v zemině s použitím metody latin hypercube sampling. *Sborník vědeckých prací Vysoké školy báňské – Technické univerzity Ostrava – Řada stavební*. 2013, roč. XIII, č. 1. ISSN 1213-1962 (v tisku).

[5] PINKA, M.; STOLÁRIK, M.; FOJTÍK, R. & PETŘÍK, T. Experimental Seismic Measurement on the Testing Construction and The Analyze. *Transactions of the VŠB - Technical University of Ostrava: Construction Series* [online]. Warsaw: Versita, 2012, Volume XII, Number 1 / 2012, s. 1-11 [cit. 2012-09-13]. DOI: 10.2478/v10160-012-0006-6.

[6] ČAJKA, R.; KŘIVÝ, V. & SEKANINA, D. Design and Development of a Testing Device for Experimental Measurements of Foundation Slabs on the Subsoil. *Transactions of the VŠB - Technical University of Ostrava: Construction Series* [online]. Warsaw: Versita, 2011, Volume XI, Number 1 / 2011, s. 1-5 [cit. 2012-09-13]. DOI: 10.2478/v10160-011-0002-2.

[7] NTC – Profesionální stavební technika [online]. [cit. 2012-09-13]. Oficiální stránky společnosti NTC stavební technika. Dostupné z: <http://www.ntc.cz/>

[8] VOŘECHOVSKÝ, M. Extension of sample size in Latin Hypercube Sampling with correlated variables. In EDITORS, Michael Beer. REC 2010, *Proc. of 4th International Workshop on Reliable Engineering Computing*, Singapore, March 3-5, 2010, pp. 353–368. ISBN 978-981-08-5118-7.

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