MICROTREMOR VIBRATIONS IN THE SOIL EXPERIMENTAL INVESTIGATION AND FEM SIMULATION

Vibration problems of the building structures caused by technical seismicity are becoming increasingly topical. The aim of this paper is to show FEM simulation of the spreading wave impact, which causes vibration system consisting of subsoil-structure interaction in microtremor. The results of the experiment together with this theoretical analysis and FEM simulation appear to be effective application for engineering experience. They are also used in assessing and predicting the vibration effects induced by technical seismicity due to traffic [1].

Keywords: FEM simulation, vibration, response, spectrum, soil, interaction.

1. Introduction

The FE simulations and experimental measurements are used for the purpose of designing and evaluating the structures. However, the experimental measurements are often economically challenging and time-consuming. In the area of structural dynamics, the assessment structure is based on the dynamic response of the structure due to dynamic loading. Each standard has criteria for evaluating the dynamic response. For these purposes appropriate methodology of the FEM simulation can be applied. Load of technical seismicity requires precise approach to creating a FEM model. During the FEM model creation it is necessary to consider the interactive dynamic area. This paper contains a case study of the FEM simulation of the dynamic response of the model due to the mechanical impact load. The analytical results are compared with the experimental measurement “in situ”. For the purpose of the case study a real single-family house was chosen. It is located close to the railway line, which produces dynamic effects due to technical seismicity. The house of this type was selected as the most frequent building located near the railway line in Slovakia.

2. Description of the analysed object and its locality

The analysed object is a real single-family house located in the city of Žilina, in the area of Strazov. Strazov is situated in the western part of Žilinská Lehota and Dolný Hricov. In the eastern side it is separated from Žilina by the Rajcanka river. In the south it borders on the urban parts of the gardening area. In the northern side of Strazov there is a reservoir called the Hricov dam, city part Povazsky Chlmec and a village named Divinka. The investigated object (Fig. 1) is the house (built in 1962) which has an irregular floor plan and the built-up area is 91.72 square meters.

Fig. 1 The views on the single-family house

Its layout is spread over two floors and the whole surface basement. The attic serves as a storage. Perimeter and interior load bearing walls (the thickness of 450 mm and 300 mm) are built of traditional baked bricks on lime-cement mortar. Non-
bearing interior walls are made of bricks. Ceilings are reinforced, thickness 200 mm, reinforcing wreaths are also reinforced concrete, monolithic concrete class C 20/25 and steel 10 505 (R). The building is covered with a saddle-shaped roof with a slope of 40°. The roof load bearing structure is created from a standing stool. The room flooring (ceramic tiles and wood floors) are distributed inside. Access to the ground floor and the basement is provided with a wooden staircase (Fig. 2).

3. Soil dynamic diagnostics and experimental investigation

The pursued objectives of the measurement were carried out in two phases. The impulse - seismic method (ISM) was applied in the first phase. The ISM is based on the surface wave propagation in the form of pulses from the impact source. The second phase was to carry out an experimental evaluation of the basic soil parameters. Experimental devices used during measurements are shown in Fig. 3.

Dynamic response of real environment (half-space) response loaded by impulse excitation was measured using a set of five accelerometers with a frequency range of 1 - 4000 Hz (Bruel-Kjaer). The accelerometers were placed in drilled ground holes and on the object (Fig. 4). The accelerometers measured response in the vertical direction. Dynamic response in the observed points were measured in the form of vibration velocities (m/s), in three orthogonal directions x, y, z. The measurement was performed using the “off - line” method. The recorded signals are simultaneously saved in two PCs - AMILO and PC FS (NI Compact DAQ software). Evaluation of the measured data was carried out in laboratory conditions of the Department of Structural Mechanics (DSM), Faculty of Civil Engineering (FCE), University of Zilina based on the evaluation of software lines DSM.

The measuring unit consisted of:

- piezoelectric accelerometers BK 8306 (Brue - Kjaer) - 5pcs,
- integration amplifier BK-2693-014 (Brüel-Kjaer),
- AD converters NI Compact DAQ (NI - National Instrument).

Mechanical movement in the measuring points was transformed by measuring line of accelerometers from an electrical signal after amplification and integration to the vibration acceleration - $a(t)$ and vibration velocity - $v(t)$. It was conducted by means of shielded cables to the measuring center near the object. Notebooks were calibrated with NI Compact DAQ AD converters. The analog signal was recorded and saved using NI Lab View software with the sampled frequency $f_s = 1000$ Hz (the required criteria for sampling signals is $Δt < 1/2 f_{max}$).

Impulse device location and the position of the measured points are schematically shown in Fig. 4. In this case, the experimental finding of soil environment vibration intensity due to impact excitation and its frequency transfer were performed. Excitation signals were propagated as a surface and shear wave from the source. These signals had the stochastic character with the variable performance in time and space. For further analysis the characteristics of an ideal the elastic half space can be used for the soil.
Velocities of Rayleigh surface waves were observed using an analysis of the correlation \[ R_{ik}(\tau) \] \[ \text{the sandy clays and gravels point B1 - B3 compact road subsoil and pavement from 0.0 to 4.0 m level below the surface (Impulses) } CR \approx 128 - 132 \text{ m/s}, \]

for clays and sandy clays point B3 - B4, subsoil at 1.0 to 5.0 m level below the surface (Impulses) \[ C_R \approx 92 - 98 \text{ m/s}. \]

For investigated soil environment \( \nu \approx 0.33 \) the correlation between Rayleigh surface and shear wave velocity \[ 3 \] can be evaluated in the equation (1).

\[
C_{s} = \frac{C_{R}}{0.93} \quad \text{[m/s]} \tag{1}
\]

Seismic modulus of elasticity in shear strength-pressure is then calculated from the equation (2):

\[
G_{0} = C_{s} \rho, \quad E_{0} = 2G_{0} (1 + \nu) \quad \text{[MPa]}. \tag{2}
\]

Substituting the average value of wave velocity to (2) the elastic modulus parameter \[ 4 \] was calculated for:

In order to obtain the velocities time histories of vibration in the observed geological location due to impulse, it was necessary to establish the basic soil dynamic parameters. The impulse seismic method (ISM) was used in this case as a simple way to get the basic soil parameters. In the calculations of elastic modulus of the investigated natural environment the following mechanical characteristics were needed:

- \( \nu = 0.33 \) (Poisson ratio),
- unit weight \( \rho_{12} = 1760 \text{ kg/m}^3 \) (for sandy clays and gravels, point B1 - B3),
- unit weight \( \rho_{14} = 1600 \text{ kg/m}^3 \) (the sample weight, clays and sandy clays, point B3 - B4).

Velocity of surface waves \( (C_s) \) was measured between the points B1-B3 and B3-B4. The corresponding power spectra \( G_{ii}(f) \) and cross power spectra \( G_{ik}(f) \) together with the coherence function \( \gamma_{ik}^2(f) \) and transfer characteristic or gain factor \( H_{ik}(f) \) calculated from the vibration velocity time histories of pulse load in points \( v_1(t) - v_4(t) \) are shown in Fig. 6 as an analysis preview.

Fig. 3 Accelerometers installed in soil and on structure, ISM procedure

Fig. 4 Experimental measurement scheme

Fig. 5 Accelerometers installed in soil and on structure, ISM procedure

Fig. 6 Experimental measurement scheme
4. FEM simulation of the vibrations transmission in the soil

The finite element method as the most widely used numerical method for finding approximate solution is used for modelling the wave propagation in the elastic subgrade. This phenomenon is governed by the following equation

\[ M \ddot{U} + C \dot{U} + K U = R \]  

(3)

Solution of the equation is reached by the central difference method which assumed that the first derivative is

\[ \dot{U} = \frac{1}{2\Delta t} \left( e^{-\alpha \Delta t} U + e^{\alpha \Delta t} U \right) \]  

(4)

and second derivative is

\[ \ddot{U} = \frac{1}{\Delta t^2} \left( e^{-2\alpha \Delta t} U - 2\dot{U} + e^{2\alpha \Delta t} U \right) \]  

(5)

The governing equation is given in the following form

\[ \dot{U} = \frac{1}{\Delta t} \left( e^{-\alpha \Delta t} U + e^{\alpha \Delta t} U \right) \]

(6)
defined in a plane. It means that the spacious character of the wave propagation is neglected. The result is that the amount of equations is lower and there is no problem with solution of the simulation by using a common computer. The shape of a half-circle with a diameter of 50 meters is used to define the subgrade. The zero displacements are prescribed at the edge of the model (Fig. 6). This can be done because the width of the model is longer than the wave can pass during the time of the simulation. It means that the wave does not bounce back from the edge of the model.

The defined material characteristics of the subgrade are comparable with the values obtained from experimental analysis. The walls of the house are made as brick structures and the flooring plate is made of concrete. Results in the time domain for whole FE field in several time steps are shown in Fig. 7. (FE displacement)

Fig. 6 The model for numerical simulation with dynamic load

Fig. 7 Displacement magnitude in time t (sec)
5. Experiment and comparison of FEM results

FEM simulation was performed in the time domain. The measured power pulse was used as load. For dynamic load the pulse shape divided into time steps 0.001 sec. was considered in order to compare the results with experiment. The time duration of the pulse load 0.016 sec was determined experimentally. Force amplitude reached the value of 50 N. These values were statistically evaluated as the average parameters. The results of FEM simulation in time and frequency domains are shown in Fig. 8. The time histories from experimental measurements are in relatively good accordance with the time histories obtained from FEM simulation in points B1-B5. Time shifts between Rayleigh and shear waves propagation are identical. Particle velocities are not so identical due to inhomogeneity of the soil [5].

![Fig. 8 FE and experimental comparison in time and frequency domains (points B1-B5)](image-url)
6. Conclusions

Problems with the vibrations of civil structures due to technical seismicity resources are current. Soil-borne vibrations and their effects on civil structures can be solved theoretically (using \textit{FEM} simulations) and can also be detected experimentally \cite{6}. Experimentally obtained dynamic response of the structure is an objective basis for the structure evaluation loaded by technical seismicity effects. Measurements are not possible in the case of new buildings (designed near technical seismicity sources). In this case it is possible to measure the dynamic response in the reference points for future civil structure. These measured records can be used as a dynamic load for \textit{FE} model. In such simulation, however, the soil-structure interaction can not be considered. The case study shows the possibility of using complex modeling layered soil with structure interaction. The results obtained by \textit{FEM} simulation are in good accordance with the experiment. It is necessary to know the basic parameters of the soil for the complex computing model. These parameters can be easily detected using the ISM method. The most effective method to estimate the effects of the technical seismicity on structures can be the combination of theoretical - \textit{FEM} simulation and experimental measurements \cite{7}.

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