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EVALUATING THE IMPACT OF CONSTRUCTION-INDUCED VIBRATION ON NEARBY STRUCTURES WHEN BUILDING ROAD EMBANKMENT IN HANOI

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Abstract. Vietnam is currently undertaking numerous transportation and infrastructure projects in urban areas, particularly in densely populated cities such as Hanoi and Ho Chi Minh City. These cities have high traffic density and frequent traffic congestion, which necessitates the use of construction equipment such as vibratory rollers and pile drivers. However, these machines can cause vibrations that affect the surrounding structures. This study investigates the impact of roller compaction-induced vibration on the building structure of Ring road No.2 in Hanoi, Vietnam. The finite element method (Plaxis 2D) was applied to evaluate the impact of vibration on surrounding structures. The maximum measured velocity is similar to the values derived from numerical analysis. The Finite element method (FEM) results exhibited a high degree of correlation with the actual velocity measurement and frequency dominant structure responses caused by ground-borne vibration induced by roller compaction within the frequency range of 5 Hz to 10 Hz.

Keywords: vibration, soil dynamic, Plaxis 2D, building structure, road embankment.

1. INTRODUCTION

Construction activities in civil engineering can cause significant ground vibrations that can disturb people and nearby structures, particularly when carried out near buildings [1- 6]. Such activities include soil excavation, traffic, pile driving, and compaction using vibratory equipment. Particle vibration velocity is the main parameter used to measure the impact of these vibrations on people and structures, and most standards and guidelines (DIN 4150, Swiss Association of Standardization) in this area set allowed vibration levels based on peak particle velocity (PPV) [7], [8].

The construction of Ring Road No.2 in Hanoi aims to solve the problem of congestion caused by the rapidly increasing volume of vehicles and to create favorable conditions for socio-economic development. However, during the construction of this project, construction machines can cause vibrations to buildings and historical sites.

Figure 1. Ring road no.2 during construction (The picture was taken on 10th April 2022 by authors)

Previous research has investigated the effects of vibration on buildings and structures in Vietnam. Nhung et al. (2020) discussed a method for accurately measuring the level of vibration caused by construction activities on the Hanoi pilot urban railway line 3, which passes through the busy Kim Ma Street in Hanoi [9]. The method involved using highly sensitive vibration accelerometers placed in lines from the vibration source. The study showed that it was possible to predict the impact of construction site vibrations on neighboring buildings. If the vibration level was high, appropriate measures can be taken to prevent damage caused by the construction of the Hanoi pilot urban railway line. Other research focused on the vibrations on an existing building in the Metro Line 3 project and controlling the grab drop length as well as the distance of the existing buildings to the vibration source. The results showed that the houses adjacent to the vibration source (grab drop) will be affected when the distance is less than 4m [6].

Numerical methods are commonly utilized to solve wave propagation such as the Finite Element Method (FEM) combined with non-reflecting boundaries [2], [3], [10]. Plaxis was used to predict the soil deformation around the pipeline [11]. The FEM model was calibrated against field data from two construction sites and was shown to capture the time-varying loading characteristics of the roller and the force–deflection behaviors of the underlying soil surface, but effect of roller compaction induced vibration on structure nearby was not considered [2].

There is limited research on roller compaction-induced vibration in Vietnam. Therefore, in this study, monitoring roller compaction-induced vibration was conducted for Ring Road No.2 in Hanoi for non-homogeneous soil layers. Then, numerical analysis (FEM) will be used for simulating the roller compaction-induced vibration for these monitoring points. The monitoring and FEM results can be used to evaluate the effect of roller compaction on nearby structures and provide a method to predict the effect of roller compaction-induced vibration on the house.

2. METHODS

2.1. Monitoring

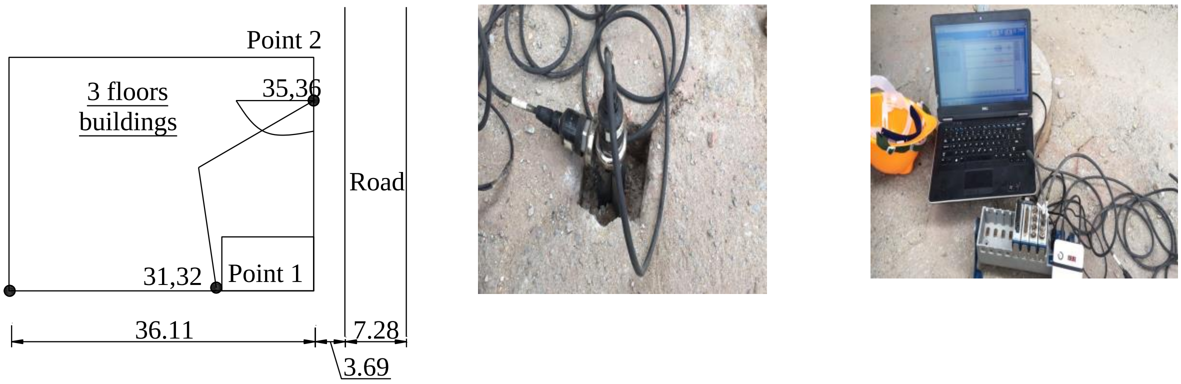
To measure the impact of vibration caused by construction activities on a plane that needs to be compacted by a vibrating roller, accelerometers can be used to measure vibration velocity (Peak Particle Velocity in mm/s).

In this project, roller compaction (HAMM 20T type) generates vibrations at a frequency ranging from 27 Hz to 30 Hz and exerts a centrifugal force of 250 kN to 330 kN. The substantial impact produced by the vibrating roller can displace and compress soil particles, leading to a decrease in soil porosity and resulting in ground vibrations that may impact nearby structures. To measure the magnitude of the impact due to vibration from the roller compaction, acceleration sensors placed on steel anchors are used to record the dynamic response of the ground during the construction process. Devices for vibration monitoring are shown in Fig.2.

a)  b) 

Figure 2. Devices for monitoring (a) Acceleration sensor. (b) Photos of data acquisition.

Vibration work was conducted along a road opposite Vinhomes Times City residence. The experiment aimed to measure ground vibration for a 3-story house that stands 9 meters above the ground. The vibration measuring device was attached to a steel pile, as shown in Fig. 3b. During the operation of the roller compactor, vibration measurements were taken (see Fig.3). The duration of the measurement and data collection process in the field was approximately 1 day. The data was processed using MATLAB, and the signals obtained from field measurements were evaluated.



a) Setup monitoring points b) Sensor at site c) Computer analysis data

Figure 3. Setup monitoring points for 3-storey house.

2.2. Geotechnical properties of soil layers

Geotechnical investigation was collected from the technical design reports. Among the boreholes, Borehole 1 is the closest to the testing building with a distance about 50 m. There are six layers in this monitoring area, which are named fill soil, layer 1, layer 2, layer 4, layer 5, layer 6, and layer 7. Based on the analysis results taken from field SPT tests and laboratory tests, the summary of physical and mechanical parameters of soil layers is shown in Table 1. In addition, the undrained shear strength of soil layers versus depth is shown in Fig.4.

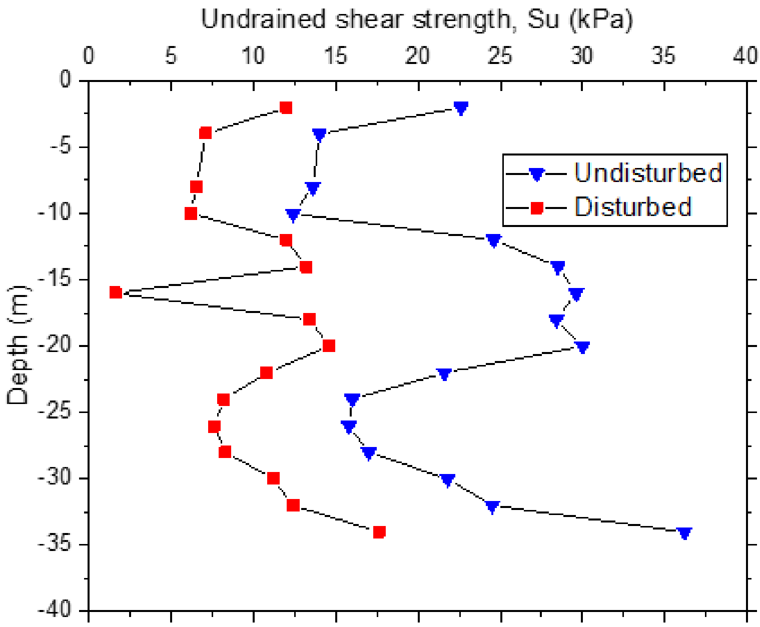


Figure 4. Undrained shear strength for soil layers in Borehole 1.

2.3. FEM model

In this study, wave propagation from roller compaction was modeled by Plaxis dynamic finite element code. Soil conditions and shear wave velocity of these soils are included in the model. The horizontal length of the model is 70 m and the depth of the model is about 23m (Fig.5).

Table 1. Soil parameters in Plaxis 2D.

	Fill soil	**Layer 1 Sandy clay, soft**	**Layer 2 Sandy clay, Mixed with gravel**	**Layer 4 Fine sand, Dense**	**Layer 5 Sandy clay**	**Layer 6 Sandy clay**	**Layer 7 Sandy clay**
Elevation (m)	0	-1.2	-3.5	-5.6	-6.8	-10.5	-21.3
Type of Model	MC	MC	MC	MC	MC	MC	MC
γ (kN/m^3)	18	18.6	13.4	19	17.3	19.7	18
γ_{sat} (kN/m^3)	18.5	18.68	13.84	19.5	17.3	19.89	18.5
Cohesion, c' (kPa)	15	23	8.8	1	15.8	27.3	20
Friction angle, φ (degree)	20	12.91	8.18	28.23	18.5	15.76	20
ν	0.32	0.3	0.3	0.3	0.3	0.3	0.3
E_{oed} (MPa)	21.46	26.92	4.815	40.38	21.46	26	26.92
E (MPa)	15	20	3.0	30	15	26	20
V_s (m/s)	55.65	63.7	28.52	77.18	56.76	80.46	64.75
V_p (m/s)	108.2	119.2	59.37	144.4	110.3	113.8	121.1
R_{inter}	0.65	0.7	0.7	0.7	0.65	0.8	0.65

The Plaxis 2D has a calculation dynamic module that allows for solving dynamic problems using FEM. The elementary equation for calculating time-dependent deformation changes under dynamic loading is as follows:

$$F = F'M'\sin(\omega t+\varphi_0) \qquad (1)$$

In which: M' is the amplitude multiplier; F' is the input value of the load; $\omega = 2\pi f$ with f is the frequency in Hz; φ_0 is the initial phase angle in degrees; $F'M'$ is the amplitude of the dynamic load.

Plaxis allows for dynamic analysis of both single-source vibration and earthquake problems. The calculation consists of three phases. The first phase is common for generating the initial stresses. A plastic drained calculation type is chosen in phase two. The dynamic option should be selected in phase three to consider stress waves and vibrations in the soil. Simulation is performed using Mohr-Coulomb (MC) model because of the simplicity of formulation as well as the lesser data input determined by simple tests, has more applications than other models. This soil model is assumed of elastic and perfectly plastic and it requires five parameters. They are Young's modulus (E), Poisson's ratio (ν), friction angle (ϕ), cohesion (c), and dilatancy angle (ψ). The physical and mechanical properties of the soils were set up according to Table 1. The water table was set at 3m below the ground surface. The transversal and longitudinal velocities of propagation of seismic waves are automatically determined in the calculation software.

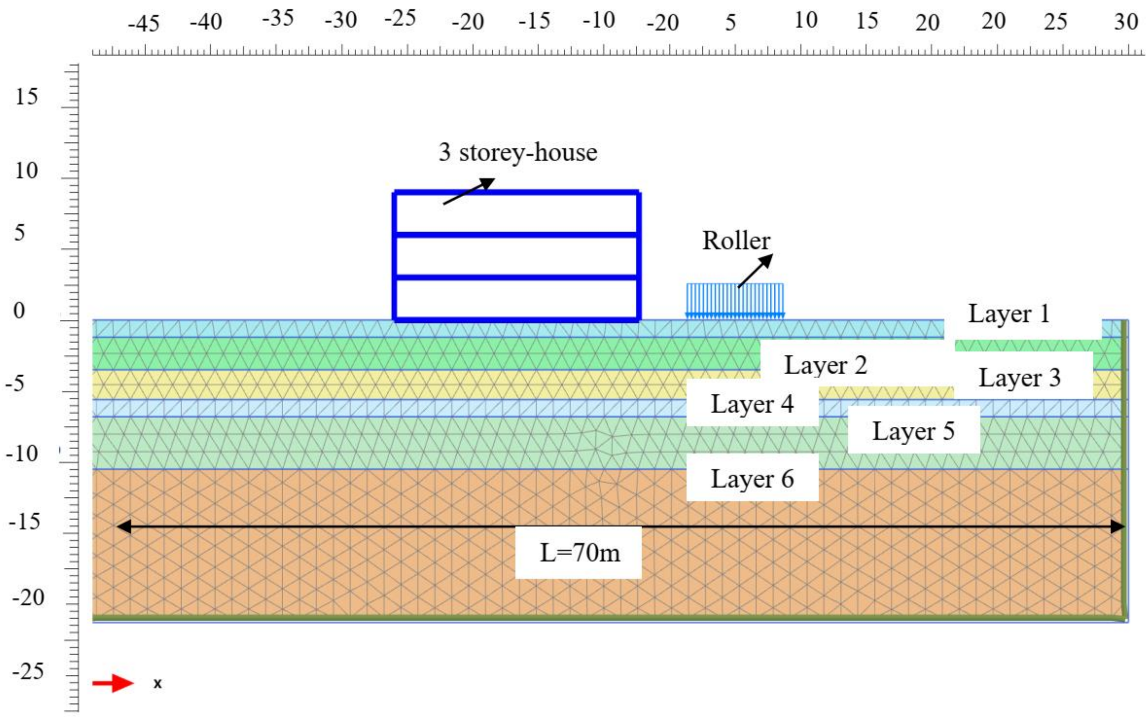


Figure 5. Plaxis model for 3 storey-house.

3. RESULT AND DISCUSSIONS

3.1. Monitoring result

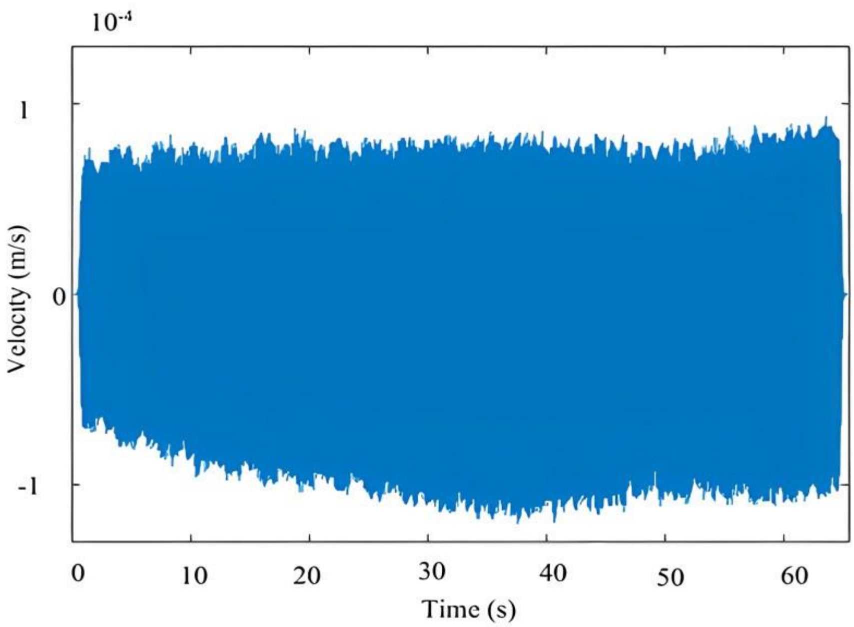


Figure 6. Vertical velocity versus dynamic time at point 35 for 3 storey-house.

The maximum of measured velocity is 0.85 mm/s.

3.2. FEM result

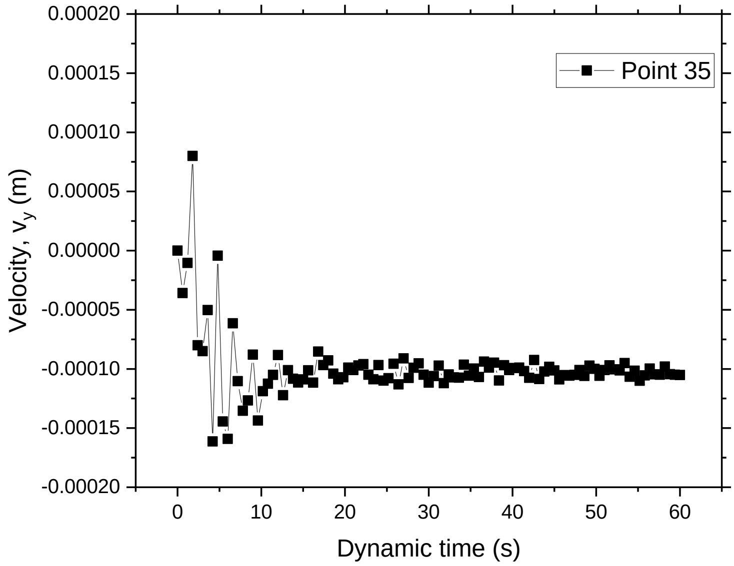


Figure 7. Vertical velocity from calculation of Plaxis.

The waveform records of vibration velocities (horizontal component v_x, vertical component v_y) were the outcome of the FEM model. Figure 7 shows the velocity values in the vertical direction (v_y) for point 35, the maximum velocity (v_y) is about 0.8mm/s. According to TCVN 7378-2004, which applies to buildings surrounding areas where activities from vibration machines with a frequency (f = 10 - 50 Hz) are taking place, the maximum vibration velocity limit Vmax is from 5 mm/s to 15 mm/s. The maximum velocity in this case is lower than the value of the TCVN 7378 2004 standard [12]. This finding is consistent with previous research [2], [9], [10], [13], [14]. It is observed that the maximum measured velocity (Figure 6) is similar to the derived values from numerical analysis (Figure 7).

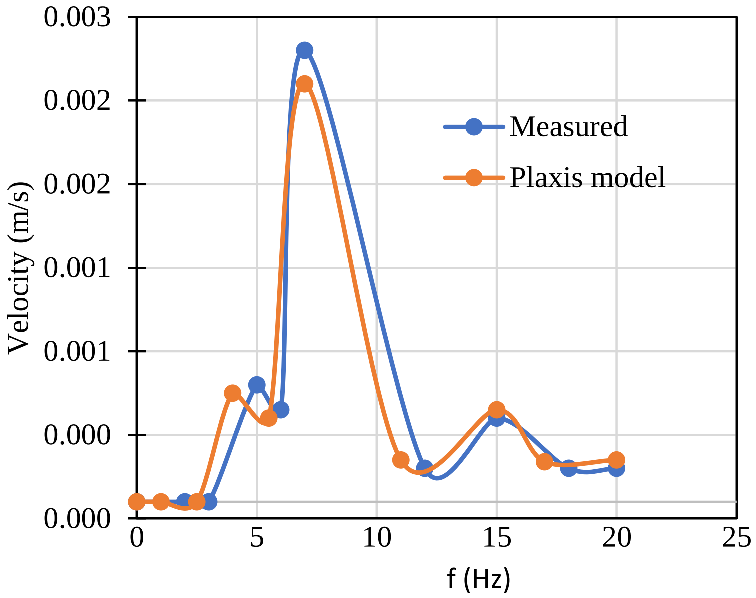


Figure 8. Comparison of measured data and Plaxis model.

In Fig.8, velocity-frequency plots for measurement value and FEM analysis are presented. FEM result is in good agreement with the actual velocity measurement in the frequency range considered.

4. CONCLUSION

Ground vibrations resulting from construction activities related to road infrastructure can have negative impacts on human health and cause damage to nearby buildings.

Experimental methods for evaluating the impact of urban construction on ground vibrations and nearby structures will provide accurate field measurement methods and assess safety issues for neighboring constructions during the construction of some urban elevated roads in Hanoi.

The FEM dynamic analysis of roller compaction-induced vibration based on the Hanoi condition was studied. The results show that the velocity decreases with the increase in distance from the roller. The peak vertical velocity is approximately 0.8mm/s. FEM results are in good agreement with the actual velocity measurement and frequency dominant structure responses due to ground-borne vibration induced by roller compaction between 5 Hz to 10 Hz.

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