Journal of Materials and Engineering Structures

Research Paper

# A study of 3D modelling the vibrations induced from grab shock at the Metro Line 3 project in Hanoi

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ARTICLE INFO

*Article history:*

Received : 15 November 2022

Revised : 18 December 2022

Accepted : 19 December 2022

Keywords:

Vibration

D-wall

3D modelling

Metro line 3

ABSTRACT

The density of high-rise building is increasing over recent years in urban city. Construction activities, particularly piling processes, D-wall excavation, are paid attention due to ground borne vibrations. The impact of vibrations induced from construction activates on existing buildings is discussed in the past and so on. However, there is rarely study their vibrations in Vietname specially in construction activities such as grab shocking. Continuing the analytical and experimental studies of the grab shocking in the Metro Line 3 project in Hanoi, 3D modelling of vibrations induced from the grab shocking on the existing building is carried out by Plaxis software. The hardening soil model is used and the acceleration of the grabin the bentonite slurry is considered in the model. The comparison between the analytical solution and the 3D simulation is highlighted in the paper to show the accuracy and robustness of the 3D modeling. This study is applied to investigate the vibrations on existing building in the Metro Line 3 project and to control the grab drop length as well as the distance of existing building to the vibration source.

*F. ASMA & H. HAMMOUM (Eds.) special issue, 4th International Conference on Sustainability in Civil Engineering ICSCE 2022, Hanoi, Vietnam, J. Mater. Eng. Struct. 9(4) (2022)*

## 1 Introduction

The effect of some typical vibration construction activities including vibratory pile drivers, pile excavation, vibration compaction, impact pile drivers, blasting, drop balls on existing building has received attention in recent articles [1-4]. Although the vibration induced from construction activities have drawn particular attention in the past, their impact on sensitive existing building located close to the impacting source as such grab shock has been rarely discussed until 2020. The field measurements of the ground-borne vibrations induced by grab shocking at the Metro Line 3 project in Hanoi presented in Dang and Nguyen (2020) [5]. Based on the field test results, the analytical formulation was proposed for the soil profile in Hanoi and the grab shocking at Metro Line 3 project with the weight of grab and the height of grab drop are 14 tons and 1.0

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e-ISSN: 2170-127X, 

RESEARCH REVIEW of Sciences and Technologies

m, respectively (Figure2) [5]. Although the field measurements and analytical formulation are obtained, the many existing buildings are closed to the vibration source leading to more 3D modeling of vibration impact via Plaxis 3D software. The novelty of this paper is how to model grab shock in which the bentonite slurry and the shape of grab needs to be taken into account the model as well as the vibration impact of grab shock. The purpose of this paper shows the efficiency, as well as performance of the 3D numerical method on modelling vibration impact, and complete the potential effect of ground vibrations induced by grab shock on sensitive existing buildings at the Metro Line 3 project in Hanoi.

## 2 3D modelling of vibration impact

The kinetic energy of drop grab *F*, kN/m$^2$, can be model with time *t* in Plaxis as harmonic load [6], which is defined as Equation (1)

$$F = F'M'\sin(\omega t + \phi_0) \tag{1}$$

In which: *M'* is the amplitude multiplier (-); *F'* is the input value of the load (kN/m$^2$); $\omega=2\pi f$ with *f* is the frequency (Hz); $\varphi_0$ is the initial phase angle (degrees); *F'M'* is the amplitude of the dynamic load.

***Fig. 1 – The photo of the grab in Metro Line 3***

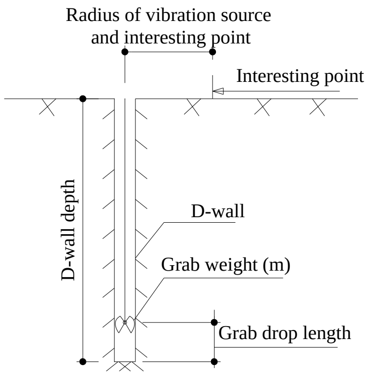


***Fig. 2 – Sketch of vertical section of grab shock at Metro Line 3 [5]***

The dynamic load from drop grab can be considered as single time step due to the long time between two times of dropping. In this case the frequency equal 0 Hz and the initial phase angle equal 90°. Giving the relation$F = F'M'$, the input value of the load, kN/m$^2$, can be estimated by Equation (2)

$$F' = \frac{ma}{S} \tag{2}$$

where: *m* is the mass of the grab (kg); *a* is the acceleration of the grab (m/s$^2$); *S* is contact area between head of grab and soil (m$^2$). The acceleration of grab drop is calculated by theory of movement in liquid environment [7] where the sketch of grab drop in bentonite slurry is taken a photo in the Figure 1. The acceleration of the grab is obtained by Equation (3) based on the Newton's theory

$$ma = mg - F_A - F_{mp} \tag{3}$$

where: *g* is the gravitational acceleration (m/s$^2$); $F_A$is the Archimedes' force (kN):$F_A=V\rho g$; *V* is the volume of grab (m$^3$);$\rho$isthe unit weight of bentonite (1100 kg/m$^3$); $F_{mp}$is the friction force is adopted by Stokes' formula [7], Equation (4)

$$F_{mp} = 6\pi R\mu v \tag{4}$$

where: *R* is the equivalent radius of the grab (m); $\mu$ is the dynamic viscosity of bentonite slurry (0.06 kPa.s); *v* is the speed of the grab (m/s)

### *2.1 Plaxis 3D model*

A 80 m x 40 m x 40 m soil strata was considered for modeling. Standard fixities and absorbent boundaries were applied to reduce wave reflection at the boundaries. The pressure of bentonite is modeled for keeping stability during excavation. The dynamic load is assigned at bottom of hole as harmonic load. To model the soil behavior, the Hardening soil (HS) model was used. The properties of different soil layers (Fill, GU3_4, GU1_s. GU5_a, GU5_b, GU7_8) are given in Table 1.

**Table 1 – Material properties of the soil layers**

| Layer | | Fill | GU3_4 | GU1_s | GU5_a | GU5_b | GU7_8 |
|---|---|---|---|---|---|---|---|
| Elevation (m) | | 0 | -1.9 | -7.88 | -14.38 | -29.38 | -31.88 |
| Model | | HS | HS | HS | HS | HS | HS |
| Unit weight γ (kN/m$^3$) | | 19 | 16 | 19 | 20 | 20.5 | 21 |
| Cohesion c' (kPa) | | 0 | 5 | 10 | 0 | 0 | 0 |
| Friction angle φ (degree) | | 25 | 20 | 25 | 34 | 35 | 40 |
| Poisson ratio ν | | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Hardening soil (HS) model | m | 1 | 1 | 1 | 0.8 | 0.8 | 0.5 |
| | $P_{ref}$ (kPa) | 100 | 100 | 100 | 100 | 100 | 400 |
| | $E_{50ref}$ (MPa) | 5.2 | 5.2 | 2.8 | 10 | 10 | 15 |
| | $E_{urref}$ (MPa) | 26 | 26 | 14 | 50 | 50 | 750 |
| | $E_{ode}$ (MPa) | 5.2 | 5.2 | 2.8 | 10 | 10 | 150 |

The calculation consists of four phases. The first phase is common for generating the initial stresses. The second phase is model the process of excavation D-wall. In this phase the pressure of bentonite should be active. A dynamic calculation type is chosen in third and fourth phase. In third phase the dynamic component of the surface load is activated and will be deactivated in latest phase. The detail of the model is showed on Figure3.

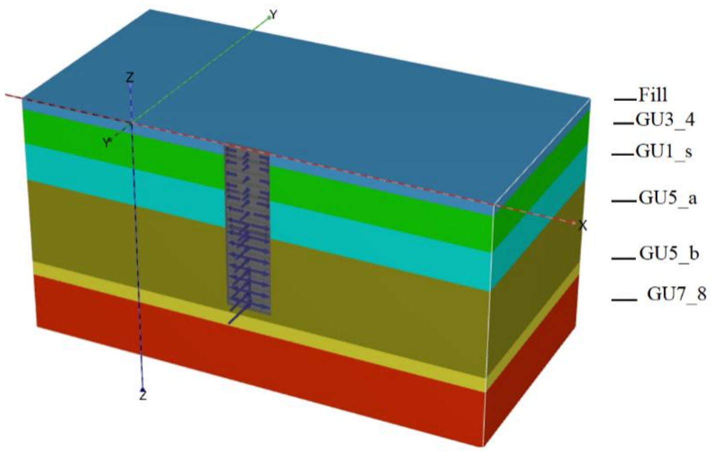


*Fig. 3 – Detail of the model*

### *2.2 Evaluation of 3D modelling*

The change of the horizontal and vertical velocity over time at a point with a distance of 0.5m from the source is shown in Figure4. The horizontal and vertical velocity reach their maximum values 35 mm/s and 20mm/s respectively after time t=0.5 s. The maximum of velocity with different distance from dynamic source illustrated in Figure5.

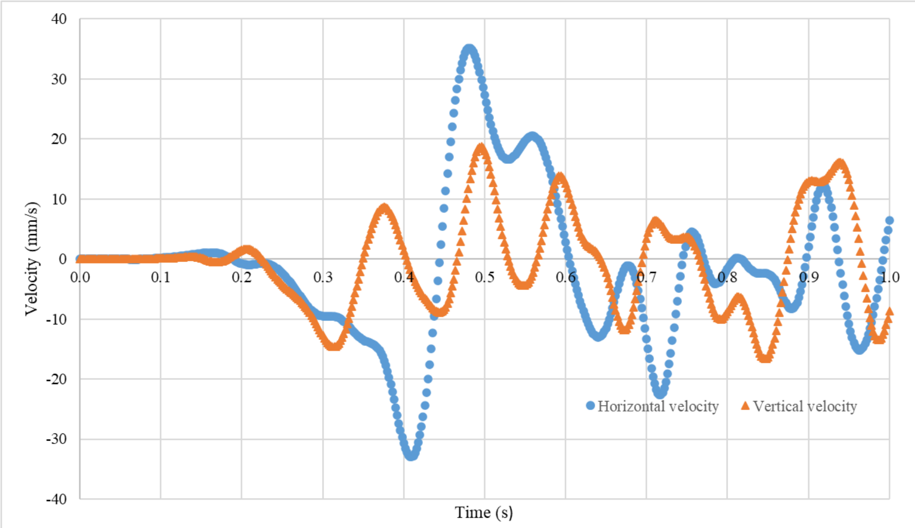


***Fig. 4 – The change of the velocity over time at a point***

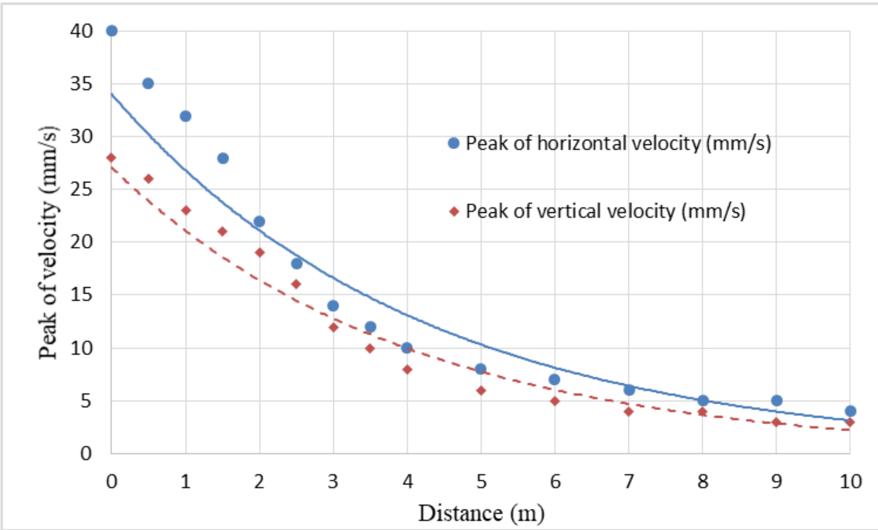


***Fig. 5 – Peak of particle velocity at different points***

## 3 Applications

### *3.1 Controlling the minimum distance between vibration source and existing buildings at S10 station*

This section studies the horizontal peak particle velocity (PPV) of other existing structures in case the distance between the other existing structures to the D-wall is from 20.0 m to 3.0 m. Figure6 presents results of horizontal PPV in case the grab level is 28m in two methods: numerical simulation and analytical solution. Note that the analytical solution was performed by [5]. From this figure, it can be seen that the proposed theoretical formula is similar to the results from the numerical model in Plaxis 3D. From the curves of numerical simulation and analytical formula, if the allowable of PPV is 10 mm/s [8], the horizontal distance from D-wall to the existing structure is recommended over 4m.

### *3.2 Controlling the height of grab drop*

The below calculation studies the horizontal PPV in case the horizontal distance from D-wall to the existing building is 3 m with the different grab drop (Table 2). It is recommended that the grab drop is reduced to 0.6 m if the allowable horizontal PPV is 10 m/s. The height of grab drop shall be controlled by painting marks on the cables. The crane operator can easily control the grab drop based on the marks.

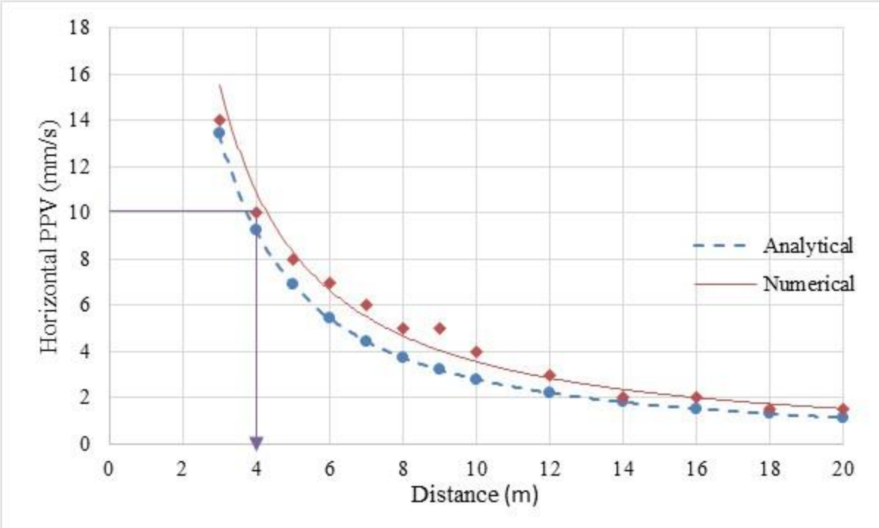


*Fig. 6 – The curve of the PPV versus horizontal distance*

**Table 2 – PPV value for grab at 3m in horizontal distance and 28m in vertical depth**

| Grab drop | Horizontal direction | | Vertical direction | |
|---|---|---|---|---|
| | Analytical | Numerical | Analytical | Numerical |
| (m) | (mm/s) | (mm/s) | (mm/s) | (mm/s) |
| 1 | 13.42 | 14.01 | 3.71 | 3.85 |
| 0.9 | 12.53 | 12.86 | 3.61 | 3.74 |
| 0.8 | 11.61 | 12.01 | 3.50 | 3.65 |
| 0.7 | 10.65 | 10.86 | 3.39 | 3.47 |
| 0.6 | 9.63 | 9.92 | 3.26 | 3.34 |
| 0.5 | 8.55 | 8.93 | 3.12 | 3.24 |
| 0.4 | 7.40 | 7.85 | 2.95 | 3.01 |
| 0.3 | 6.14 | 6.23 | 2.74 | 2.95 |
| 0.2 | 4.72 | 4.89 | 2.48 | 2.58 |

## 4 Conclusions

Continuing the field experience and analytical formula of construction-induce vibration was studied in the Metro Line 3 project, Hanoi, Vietnam, the 3D modelling by Plaxis 3D was implemented in order to verify again the analytical formula and control the construction procedure of the vibration construction. The use of this analytical formula is very fast and efficient with high accuracy compared to numerical methods but it is difficult to deal with different soil layers while it is easy in the 3D modelling by Plaxis 3D. The paper showed the minimum distance of 4m between vibration source to existing building and the grab drop height of 1m of grab shock for Metro Line 3 project. In additional case, if the distance of 3m between vibration source to existing building is considered, the grab drop height of grab shock needs to reduce to 0.6m.

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