Ground Vibrations Due to Moving Load in the Proposed Subway Tunnel Near Kamalapur

Tahmeed M. Al-Hussaini, Mahbubah Ahmed, and Sagar Barua

Abstract Mass Rapid Transit (MRT) Line 1 is planned for the eastern part of Dhaka city connecting the capital's International Airport Terminal at Kurmitola with the Main Train Station Terminal at Kamalapur. This line also has a second branch from Future Park to Purbachal. While a significant portion of the proposed MRT Line 1 will be above ground, three significant portions will be underground: (i) Khilkhet to Bhatara (ii) Bhatara to Bashundhara (iii) Mailbag to Kamalapur. Subway tunnel construction for metro rail involves many unique geotechnical design considerations such as the effects of fast-moving trains in an underground tunnel on adjacent property. The resulting vibrations can be the subject of legal complaints by owners of buildings in the immediate vicinity. The primary objective of this paper is to perform a numerical study to have an impression of the ground vibrations generated in the surrounding soils due to moving loads in an underground tunnel near the Kamalapur Railway Station. A numerical model is created using the finite element software PLAXIS 3D for moving load on rails in an embedded tunnel in an idealized soil profile. Numerical analysis is performed for a two-wagon train running on an underground tunnel at various depths.

Keywords Subway tunnel · Ground vibrations · Dynamic moving loads · FEM

1 Introduction

Underground railway technology being introduced in mid of the nineteenth century has become an integral part of the transportation system worldwide with the rapid development of urban modernization. But, along with bringing comfort and ease in public transport, on another side, the metro subway tunnel has become a significant concern regarding environmental issues. A wide range of studies has concluded that significant vibrations are induced by the passage of underground trains sometimes exceeding the tolerance level of residents living in adjacent buildings [1]. This kind of vibration has been listed as one of the seven significant environmental hazards in the

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world [2]. With the advancement of computer-based software, numerical analysis is commonly used to predict ground-borne vibrations due to fast-moving trains. Different numerical techniques have been adopted by various researchers for studying this three-dimensional problem of wave propagation, finite element method (FEM) is one of them. Singh and Seth [3] have shown that this kind of modeling can be effectively simulated in 3D FEM.

The Government of Bangladesh is implementing the Mass Rapid Transit (MRT) project as part of its transportation solutions for the capital city of Dhaka, which is overburdened by high population density and severe traffic congestions. The project consists of several MRT railway lines [4] consisting of both elevated and underground portions. This paper is concerned with the underground portion of MRT line 1 near Kamalapur Railway Station. A numerical study is conducted to study the wave propagation problem caused by underground railways using the finite element method software PLAXIS 3D. To the best of the authors' knowledge, this study is a first attempt to have an impression on the ground vibrations generated by proposed subway traffic in Dhaka city.

2 Site Parameters

2.1 Site Location

The 26.5 km long MRT line-1 has been planned to be constructed with three underground portions, represented by orange lines in Fig. 1. This line will connect Kamalapur Railway Station with the International Airport at Kurmitola and will also have another branch Bhatara to Purbachal. The three underground branches are: (i) Khilkhet to Bhatara, (ii) Bhatara to Bashundhara, and (iii) Mailbag to Kamalapur. This study is dealing with an area near Kamalapur Railway Station.

2.2 Soil Stratigraphy

Borehole data are obtained from the preliminary study report [5]. As part of the geotechnical investigations, a total of 41 borings have been drilled along the route of MRT Line-1. Borehole BH-01, drilled to a depth of 45 m, is near the Kamalapur railway station, as such soil data from BH-01 is considered in this study. The subsoil information shows that there is 7.5 m of grayish brown medium stiff to very stiff clay on top of 3 m sandy silt layer. Below the sandy silt layer, 13.5 m of silty sand overlies firm support ($N > 50$) consisting of very dense sand or hard clay. Shear wave velocities are estimated from SPT values of BH-01 using empirical relations given by the Japan Road Association [6]. For this study, the soil profile has been divided into 11 layers, the corresponding soil properties are shown in Table 1.

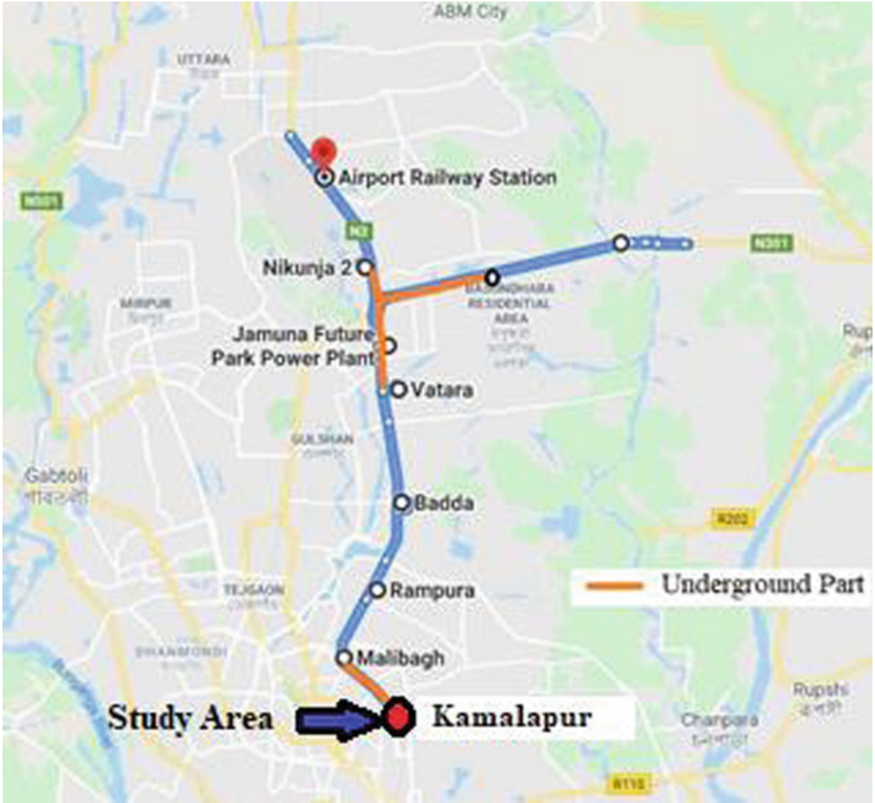

Fig. 1 Layout plan of MRT Line 1

Table 1 Soil parameters for different layers

Layer no	Depth (m)	Unit Weight (kN/m^3)	Poisson's ratio	Shear wave velocity (m/sec)
1	0–1.5	18.9	0.4	200
2	1.5–7.5	19.6	0.4	241
3	7.5–10.5	19.0	0.33	221
4	10.5–18	17.3	0.3	249
5	18–24	19.6	0.3	274
6	24–30	22.0	0.3	304
7	30–34	20.8	0.3	285
8	34–35	22.0	0.3	299
9	35–36	18.9	0.3	267
10	36–40.5	22.0	0.4	276
11	40.5–44	22.0	0.3	313

3 Numerical Analysis Under Moving Load

3.1 Numerical Model

A 30 m × 60 m × 44 m domain (Fig. 2) is considered in the numerical model for underground tunnel embedded in a layered soil medium with PLAXIS 3D. For the soil model, 1% hysteretic damping is considered. Dynamic load changing in time and location corresponding to two wagon train axle loads moving at speed 72 km/h is assigned on the rail track. The 7 m diameter tunnel is assumed to have a lining thickness of 0.3 m. High-strength concrete (fc' = 7000 psi) is considered for the tunnel lining. The rails used are UIC60A. Concrete sleepers are modeled with a base thickness of 250 mm and a height of 150 mm, with a length of 2.6 m. In this FEM model, the soil is modeled using 10-noded tetrahedral elements, the rails and sleepers are modeled using 3-noded beam elements, the tunnel is modeled with orthotropic 6-noded plate elements. The viscous boundary condition is applied at domain boundaries.

For introducing moving trainload, the X52 commuter train model [7] is considered, which consists of two wagons with a total length of 54 m and a load of 185 kN/axle. Figure 3 illustrates the configuration of axles and bogies of the train. Its speed is considered to be 72 km/hr. In terms of dynamics, a moving load changes its point of application with time compared to a static load, which is very different from a dynamic load that does not change its point of application. The dynamic load of

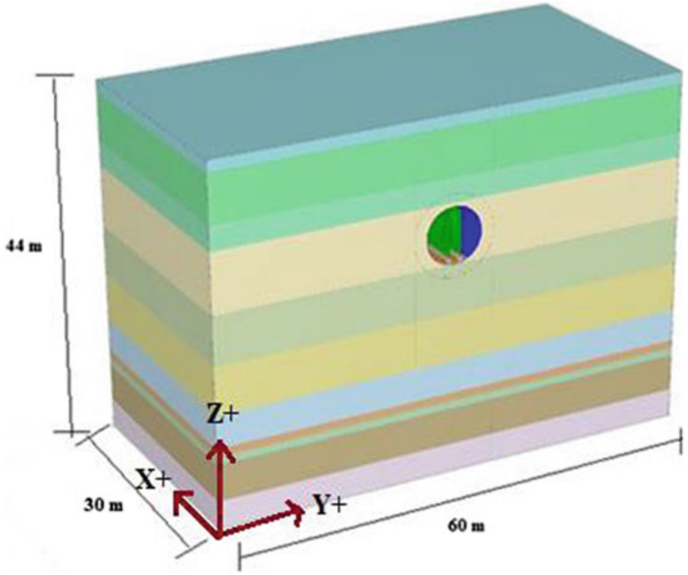

Fig. 2 PLAXIS 3D model of subway tunnel

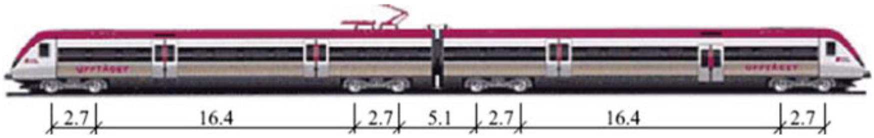

Fig. 3 X52 commuter train

this moving train is modelled using static point load and its corresponding dynamic multiplier. A pair of point loads, representing the wheels, together distribute the axle load. Rail spacing is 0.6 m. To simulate a train passage with 72 km/hr speed, the pairs of point loads are activated and deactivated in turn. Details of the numerical modeling are described by Ahmed [8].

3.2 *Validation of PLAXIS 3D Model*

To check the accuracy of the numerical model of moving train load developed with PLAXIS 3D, an example of a commuter train running at the ground surface is selected from the published literature. Comparison is done with field measurements [7] of track-bed acceleration over a buried culvert about 40 km north of Stockholm, Sweden. Figure 4 presents a comparison of numerical results computed by PLAXIS 3D with the field measurements. It is observed that there is a fair agreement between the field measurements and the FEM results of the time history of track-bed acceleration.

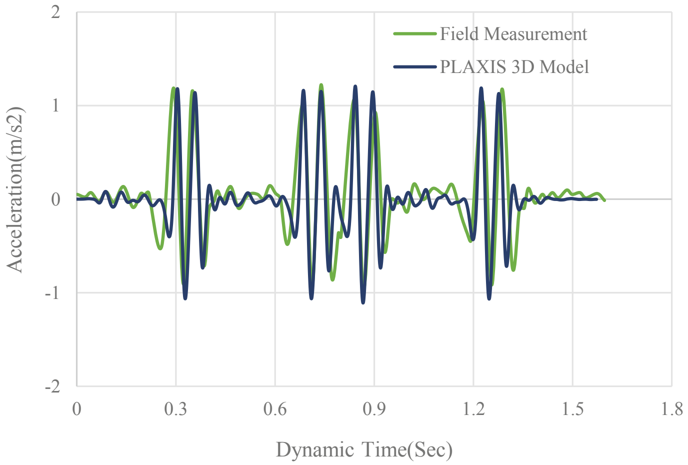

Fig. 4 Validation of PLAXIS 3D analysis for measured track-bed acceleration [7]

4 Numerical Results

Theoretically, ground vibration can be expressed either in terms of displacement, velocity, or acceleration. However, the response of humans, buildings, and equipment to vibrations can be more accurately described in terms of velocity or acceleration. As such, the ground-borne vibrations herein will be represented as acceleration on a logarithmic scale in decibels according to International Standard [9].

Figures 5, 6, and 7 present the free-field vibrations (at the ground surface) in X, Y, and Z directions (Fig. 2), respectively due to moving train (Sect. 3.1) in subway tunnel as a function of distance from the tunnel center line. Results are presented for three different depths of tunnel top (5, 8, and 11 m). The vibration level of the ground surface decreases with an increase in tunnel depth as expected. Wave Interference

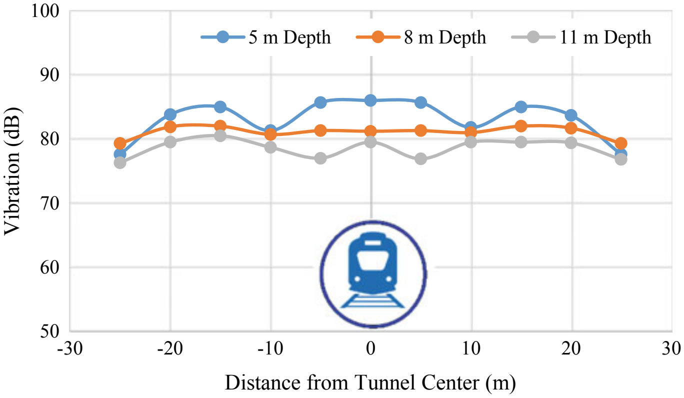

Fig. 5 Free-field horizontal vibration (in the direction of the tunnel) at various distances from tunnel centerline for subway train at three different depths

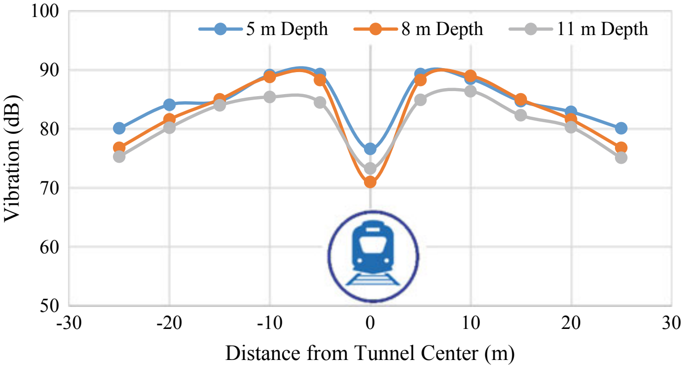

Fig. 6 Free-field horizontal vibration (perpendicular to the tunnel) at various distances from tunnel centerline for subway train at three different depths

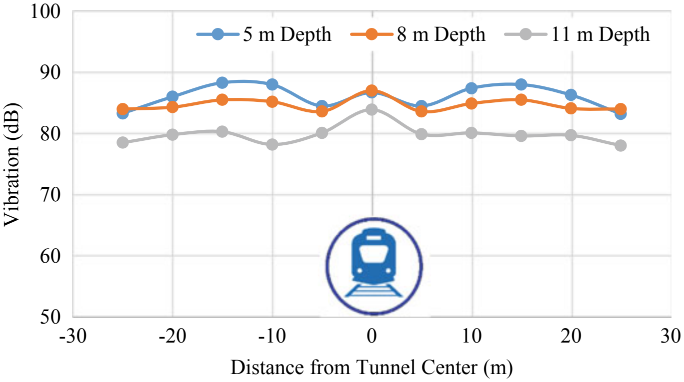

Fig. 7 Free field vertical vibration at various distances from tunnel centerline for subway train at three different depths

effects from waves generated from different points of the tunnel result in variation of vibration at ground level. Ground surface vibrations for different depths of tunnels can reach 70–90 dB. Even at distances of 25 m, vibrations may reach 75–85 dB, which is quite significant.

The maximum horizontal vibration (90 dB) is in a direction (Y dir) perpendicular to the tunnel length as shown in Fig. 6, which is in agreement with field measurements from published literature. This exceeds the safe vibration limit for human beings (85 dB) [10].

Figure 8 presents the vibration within the soil at points located at 2 and 4 m depth from the ground surface and 20 m distance from the tunnel center line. These are possible locations for shallow foundations or basement of nearby buildings. Vibrations at these locations range from 74 to 83 dB which can be significant enough to cause complaints.

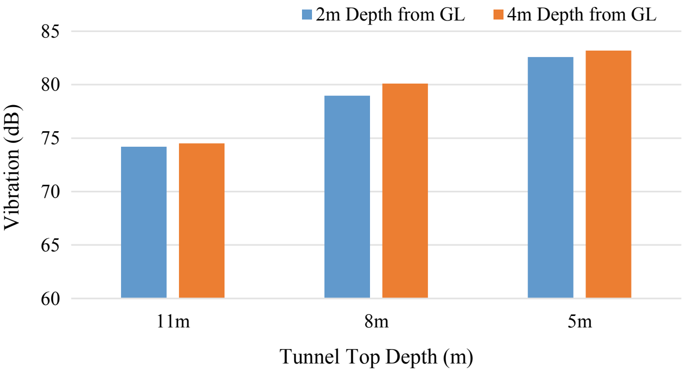

Fig. 8 Ground vibration at 2 and 4 m depths at a distance of 20 m from tunnel centerline due to subway train at three different depths

5 Conclusions

This paper presents preliminary results on ongoing research work for the prediction of ground vibrations caused by proposed underground metro Line 1 near the Kamalapur Railway Station in Dhaka city. Numerical analysis has been conducted using the three-dimensional FEM software PLAXIS 3D, simulating a two-wagon train moving at a speed of 72 kmph in a subway tunnel. Numerical results indicate that ground surface vibrations reduce with increased tunnel depth. Significant free field vibrations in the range of 70–90 dB can be caused by the train, exceeding the safe vibration limit for human beings (85 dB), and also exceeding tolerance limits for human discomfort. Significant vibrations are also induced at depths of 2 and 4 m which may affect adjacent structures at those depths.

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