Attenuation Characteristics of Truck-induced Ground Vibrations Due to Different Truck Weights and Speeds

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Abstract. Knowledge of the attenuation characteristics of truck-induced ground vibrations has gained importance for micro-vibration mitigation of high-tech facilities. This study conducted an in-situ experimental study on the attenuation characteristics of truck-induced ground vibrations. The ground vibrations were generated by the passage of a truck on a low-cost road with different weights and speeds. Eight low frequency, one component, 941B vibration sensors were fastened on the ground surface to record the vertical velocity time histories of ground vibrations at eight measurement points with different distances. The vibration level was evaluated in terms of the vertical maximum displacement obtained by integrating the measured velocity time histories. The vibration level represented by the vertical maximum displacement decayed monotonically but nonlinearly with distance from the road. Ground vibrations at the measurement points that were close to the road decayed more rapidly than that at the measurement points far away. In general, the maximum displacement of ground vibrations induced by the 30-ton truck at a measurement point was smaller than that of ground vibrations induced by the 18-ton truck with the same speed.

1. Introduction

Analysis of the attenuation of ground vibrations generated by human activities is of great significance in solving environmental vibration problems for high-tech facilities in which vibration-sensitive equipment and instruments are housed [1, 2]. Because slight vibrations can disturb the equipment operation in a high-tech facility [3], environmental vibrations at a high-tech facility should be controlled at acceptable levels over long periods of time [4-6]. Recently, the road vehicle-induced vibrations have become a major environmental problem in urban areas because the distances between the high-tech facilities and the roads are decreasing due to space limitations [7]. For designing reliable measures to mitigate the road vehicle-induced vibrations at a high-tech facility, it is necessary to analyse the attenuation characteristics of vehicle-induced ground vibrations by taking account of vehicle weights and speeds.

Road vehicle-induced ground vibrations are in general generated by heavy vehicles moving on the roads with irregular surfaces [8]. Particularly, the vibration hazards to high-tech facilities are dominated by ground vibrations induced by heavy trucks. Various studies on the attenuation characteristics of road vehicle-induced ground vibrations have been conducted based on analytical prediction model [9, 10], numerical simulation [11, 12] and field measurement [13-15]. It was concluded that peak particle velocities of road vehicle-induced ground vibrations were strongly affected by the surface irregularities and speed of vehicles. The road vehicle-induced ground
vibrations are mainly due to the interaction between the wheels of heavy vehicles and the road surface. In addition to the surface irregularity and the vehicle speed, the interaction between the wheels and the roads is also affected by vehicle weight. Thus, analysis of the attenuation characteristics of vehicle-induced ground vibrations should take into account the vehicle weight.

Compared with analytical and numerical methods, field testing is believed to be a competitive method to obtain reliable information on the attenuation characteristics of ground vibrations. The objective of this study is to evaluate the effect of truck weight and truck speed on the attenuation characteristics of truck-induced ground vibrations via field measurements. First, the experimental program is briefly discussed. The ground vibrations at eight measurement points were measured during the passage of a truck with a weight of 18 ton or 30 ton on a low-cost road at speeds varying from 10 km/h to 30 km/h. Second, the measurement results are analysed and discussed. This study increases the knowledge in the field of truck-induced vibration attenuation, and provides a series of vibration data that researchers can use for further investigation.

2. Experimental Program

2.1. Site Characteristics
The experiment site is located in the northeast part of Beijing, see Figure 1. A rectangular experiment area of 300 m (north to south) by 200 m (east to west) was selected to conduct the in situ vibration measurement. The residential and commercial buildings are located far away from the experiment area. The nearest structure is a village building which is located in the north and is about 350 m away from the experiment area.

![Figure 1. Location of the experiment site.](image)

Many geotechnical investigations were carried out to establish the characteristic soil profile and to determine the geological conditions of the experiment site. Based on the geotechnical investigations, the experiment site is layered soil. Figure 2 illustrates the characteristic soil profile along with the setup of the in situ measurement. The soil profile consists of about 2.1 m artificial fill at the top. The natural soil beneath the artificial fill is sandy gravel which consists mainly of pebbles with medium sand. The thickness of the sandy gravel layer is approximately 21.5 m. Bedrock, which is made of granodiorite, was found at a depth of around 25 m from the ground surface. The geotechnical parameters of the experimental site are shown in Table 1.

| Layer             | Thickness (m) | Density (kg/m³) | Shear Velocity (m/s) | Poisson Ratio |
|-------------------|--------------|-----------------|----------------------|---------------|
| Artificial fill   | 2.1          | 1630–2010       | 172–193              | 0.43–0.46     |
| Sandy gravel      | 21.5         | 2000–2200       | 291–571              | 0.41–0.44     |
| Granodiorite      | —            | 2210–2630       | 684–1200             | 0.4–0.43      |
2.2. Dynamic Tests
A low-cost road was first constructed at the experiment site. The ground vibrations were generated by a truck moving on the low-cost road, as shown in Figure 3. The total truck weight was 18 ton or 30 ton. The speed of the 18-ton truck was 10 km/h, 20 km/h and 30 km/h. The speed of the 30-ton truck was 10 km/h and 20 km/h. The low-cost road had a width of 3.6 m and was composed of a compacted clay top layer and a sandy gravel subbase, see Figure 3.

Interaction between the wheels of the truck and the artificial unevenness of the low-cost road caused a dynamic excitation that generates vibrations that propagate in the soil. Eight low frequency, one component, 941B vibration sensors were used to simultaneously record the vibration velocities of the ground surface at 8 measurement points (P1~P8) at different distances from the center of the low-cost road: 10m, 20m, 30m, 40m, 50m, 60m, 80m and 100m, see figure 2.

3. Results and Discussion

3.1. Maximum Displacement versus truck speed
The vertical maximum displacements of ground vibrations at the eight measurement points were used to evaluate the vibration levels at different distances from the low-cost road. The relationship between the distance and the vertical maximum displacements generated by the 18-ton truck is plotted in Figure 4(a). The relationship between the distance and the vertical maximum displacements generated
by the 30-ton truck is plotted in Figure 4(b). The vertical maximum displacements were obtained from the integral of the vertical velocity time histories as:

\[ D_{\text{max}} = \max \left| \int v(t) \, dt \right| \]

where \( v(t) \) is the vertical velocity time histories of ground vibrations. \( \int() \) means to perform integral.

It is clearly shown in Figure 4 that the maximum displacement was a function of the distance to the low-cost road. The ground vibration level was decayed due to the material damping and geometric damping of soil [16, 17]. Material damping converts the vibration energy to internal energy as soil particles are moved by the propagating vibrations, and as the vibration energy is converted and “lost” the vibration level decreases [17-19]. Geometric damping attenuates the vibration level because the same vibration energy spreads over an increasingly larger volume of soil [17-19].

The slope of a maximum displacement-distance curve nearby the vibration source was steeper than that far away. In other words, ground vibrations in the zone close to the low-cost road decayed more rapidly than that in the zone far away. In addition, the maximum displacements of ground vibrations generated by both the 18-ton truck and the 30-ton truck at the eight measurement points increased with truck speed. However, the increment in the maximum displacement decreased with distance because the difference in the maximum displacements corresponding to different truck speeds at the same measurement point decreased with distance. Moreover, the increment in the maximum displacement decreased with truck weight because the difference in the maximum displacements corresponding to different truck speeds at the same measurement point decreased with truck weight.

3.2. Maximum Displacement versus truck weight
For the purpose of analysing and comparing the attenuation characteristics of ground vibrations generated by trucks with different weights, the vertical maximum displacements generated by the 18-ton truck and the 30-ton truck with the same speed at the eight measurement points were compared and are plotted in Figure 5.
(a) 10 km/h  
(b) 20 km/h

Figure 5. Comparison of vertical maximum displacements due to different truck weights.

Figure 5(a) shows that the maximum displacement of ground vibrations induced by the 30-ton truck with a speed of 10 km/h at the first measurement point was larger than that of ground vibrations induced by the 18-ton truck with the same speed. However, as shown in Figure 5(a), the maximum displacements of ground vibrations induced by the 30-ton truck with a speed of 10 km/h at the other seven measurement points were smaller than that of ground vibrations induced by the 18-ton truck with the same speed. In addition, as shown in Figure 5(b), the maximum displacements of ground vibrations induced by the 30-ton truck with a speed of 20 km/h at the eight measurement points were smaller than that of ground vibrations induced by the 18-ton truck with the same speed. That is to say, the maximum displacement of ground vibrations induced by the 30-ton truck at a measurement point in general was smaller than that of ground vibrations induced by the 18-ton truck with the same speed. This is because the restriction effect of the 30-ton truck on the dynamic interaction between the wheels and the low-cost road was stronger than that of the 18-ton truck.

4. Conclusions
Using the dynamic loadings generated by the moving of a truck with different weights and speeds on a low-cost road, field measurements were conducted to study the attenuation characteristics of ground vibrations in this study. It can be concluded that:

1) For each truck speed and each truck weight, the vibration level represented by the vertical maximum displacement decayed monotonically but nonlinearly with distance from the road.

2) For each truck speed and each truck weight, ground vibrations at the measurement points that were close to the road decayed more rapidly than that at the measurement points far away.

3) In general, the maximum displacement of ground vibrations induced by the 30-ton truck at a measurement point was smaller than that of ground vibrations induced by the 18-ton truck with the same speed.

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