

Study on Vibration Bounce Area Caused by Metro -Based on the Pulse Impact Experiment

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Abstract. At present, there is no systematic research on the ground surface vibration bounce area induced by metro. The experiments of vibration attenuated on the ground surface were carried out in an underground laboratory at Beijing Jiaotong University to obtain the ground surface attenuation characteristics of vibration in 0~200Hz. The automatic falling weight device was designed for exciting a wide band vibration in the experiments. Vibration measurements were performed on the ground surface at distances varying from 0 to 60 m from the track at every 5m. Detailed results indicates that the attenuation of different single frequency acceleration peak value envelope decays wavy-type with peaks and valleys, and the attenuation of each single frequency is not the same. The ground surface vibration bounce positions depend on the main vibration frequency band of the vibration source and the propagation characteristics of the stratum.

Introduction

The vibration caused by metro spread from the rail system, tunnels, soil to the vibration body. Due to the presence of radiation damping and material damping, vibration attenuates in the soil. It is generally accepted that the ground surface vibration attenuates with distance is monotonically decreasing, Metro planning and design institute classified 20 meters away from the metro lines as the non-influence vibration scope caused by the metro. However, an increasing number of complaints showed that severe vibration issue happened 20 meters away outside the building. It is mainly because, after the vibration caused by the metro transmitting to the ground surface does not attenuate monotonically with the distance increased, but to a certain distance from the source there is a bounce area of a vibration, and the vibration of part of frequency band appears enlarged after incoming building.

The bounce area phenomenon are discussed by some scholars in their research. Through three-dimensional finite element simulation of the vibration caused by the metro, W.N. Liu, etc.[1] found the presence of vibration bounce area for the first time - surface vibration response is not monotonic decrease with distance. This distance depends on the depth of the tunnel and the stratum conditions, and presented that the buildings in the bounce area may be affected by the vibration caused by metro proactively. After that, H. Xia, etc.[2,3] found the vibration bounce area through urban rail transit test. He explained it follows a of Japanese scholars Fujikaka bedrock reflection theory that repeated reflection and refraction of S-wave while propagated in the soft soil between the surface and the bedrock caused the vibration local bounce with the distance increasing. By numerical calculation, F.C. WANG, etc.[4] found the ground vertical vibration caused by the metro is maximum at the tunnel center above, and subsequently gradually decay with increasing distance, and at approximately 60m there was the bounce area, but the amplitude is small. By ABAQUS software calculation[5], with the increase of the distance to the center line of metro the ground surface vertical vibration attenuation trend was monotonous, but in train vibration load frequency of 4Hz and 8Hz there was a local bounce areas 20~60m away from the center line of the metro. W.M. YAN research group of Beijing University of Technology takes a lot of urban rail transit field tests on metro induced

ground surface vibrations, and found the same vibration bounce area law. The literature [6] drawn that there is a vibration bounce area at a certain distance away from the metro line center, this distance depends on the depth of the tunnel and the stratum conditions. Measured vibration signal was processed at different frequency and proposed that significant contribution to the vibration bounce area was low-frequency signals below 20Hz, the contribution of high-frequency signal higher than 20Hz is small by the literature [7]. The literature [8] indicated that there was a metro induced vibrations (vertical) bounce area along the horizontal direction of the ground surface, and is mainly less than 10Hz vibration component. The horizontal distance is with relevant to the stratum conditions, tunnel depth and vibration source mechanism. Under the conditions of this article, this distance is 20~30m.

As the awareness level and research tools were limited, there are some limitations of the above conclusions, for further research on the mechanism of ground vibration bounce area and its position, conducted vibration propagation and attenuation experiments in the Lab of Track Vibration Abatement and Control (LTVAC) on Beijing Jiaotong University (BJTU) campus, the main objective of this paper was to describe the cause of vibration bounce area induced by metro and its position.

Experiments of vibration attenuation characteristics on the ground surface

The vibration attenuation characteristic measurements were obtained from the tunnel and the ground surface sites. The LTVAC is located in the southeastern part of the BJTU campus, and is surrounded by the Laboratory of All-optical Network and Modern Communications Network to the northeast, the Electrical and Mechanical Building to the northwest, and the Tunnel Center Building to the south. The Tunnel Center Building is a reinforced concrete frame structure supported by a strip foundation, and it consists of a laboratory and an office building. The part of the structure close to the LTVAC is a laboratory with a height of 6 m, and the rest is a four-floor 12-meter tall office building (Fig. 1).

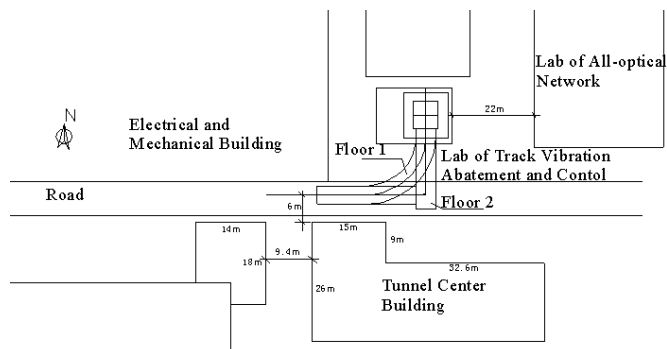


Fig. 1 Measurement sites

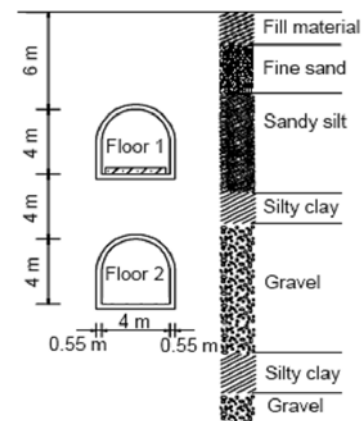


Fig. 2 Soil characteristics

Characteristics of the laboratory

The LTVAC has two floors (Fig. 2). Floor 1 is a curved tunnel with a small radius of 12.5 m, embedded in sandy silt to a depth of 6 m below ground. Floor 2 is an L-type tunnel, inserted in gravel to a depth of 14 m, a substrate similar to that of the underground railway in Beijing. Both tunnels have the same type of upright-wall concrete lining with a thickness of 0.55 m. The clear width and height of each tunnel are both 4 m.

Underground tunnel floor 1 laying Rheda 2000 track which was on-site pouring 1:1 model, the length and breadth of the track are 7000mm, 3500mm, and 400mm, the rail density is 60kg/m with the VOLOH 300 fasteners, the stiffness of fastener is 22.5kN/mm, fasteners spacing is 650mm.

Automatic falling weight device

To obtain a suitable and wind band excitation in the tunnel as the vibration source, an automatic falling weight device (AFWE) was developed, with a total mass blocks 193kg, and total height 2.29m, patent No. is ZL 2010 20196570.X (Fig. 3). Greater energy vibration is excited in the tunnel by the AFWE, so that the vibration response on the ground surface can be clearly measured. The effective

frequency band of the impact force and the vibration response are wide. To satisfy the requirement of the laboratory and field measurements, the device is easy to install. The amplitude of the impact force is controllable, and the force time history is measurable.

Experiment design

The hammer test (multiple trigger) was taken in the experiment, the trigger number was 4. The concerned frequency band is 0~200Hz, and the sample frequency is 512Hz. Automatic falling weight device was used to impact the Rheda 2000 track in floor 1 of LTVAC to excite underground vibration source.

Experiment equipments and setup

The vibration signals were recorded using INV 3018C data acquisition with 8 channels at a sampling frequency of 512 Hz, including data acquisition software DASP V10. The type of acceleration sensors are LC0130T, sensitivity are 40V/g, signal range are 0.12 g, sample frequency are 0.2~600 Hz.

A right-handed Cartesian frame of reference was defined with the origin at the tunnel invert on the middle cross section, the x-axis perpendicular to the tunnel centerline, the y-axis in the direction of the tunnel centerline, and the z-axis pointing upwards. To obtain the vibration propagation and attenuation characteristics in stratum, the z direction acceleration data of tunnel wall and ground surface was measured. The accelerometers were glued on the ground surface at distances varying from 0 to 60m from the track above at every 5 m (Fig. 3). Record each impact force data to ensure that the experiment impact forces were equal.

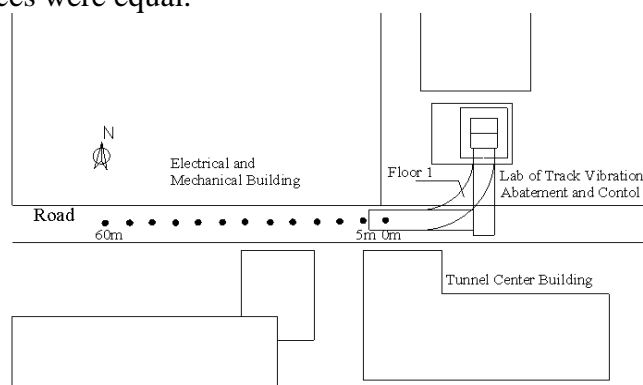


Fig. 3 Ground surface measuring points layout

Experiment results

Based on the vibration acceleration data of the measuring points, the vibration propagation and attenuation characteristics in stratum were analyzed in terms of time history, spectrum frequency, acceleration level, 1/3 octave band acceleration level, transmission loss, and transfer function of measurements data.

Ground surface acceleration level analysis

Fig. 4 shows the attenuation law of ground surface acceleration level in three-direction with distance. Ground acceleration level attenuates with the increasing distance from the vibration source, however, in some regions there are obvious vibration bounce, which is mainly due to this regions are at the peak position of the wavy-attenuation of the predominant frequency acceleration. The acceleration bounce regions are 20~30m.

Ground surface acceleration frequency spectrum analysis

Fig.5 shows the three-dimensional and cloud graphs of ground acceleration spectrum amplitude attenuated with distance from the vibration source. The acceleration spectrum amplitude is greater at 0~10m in 20~140Hz, the peak frequency is around 100Hz and the acceleration spectrum amplitude bounces at 20~30m in 30~70Hz, which is the second peak value region except the source above. The attenuation of different frequency acceleration peak value envelope is not linear but wavy-type, and the attenuation of each frequency is not the same.

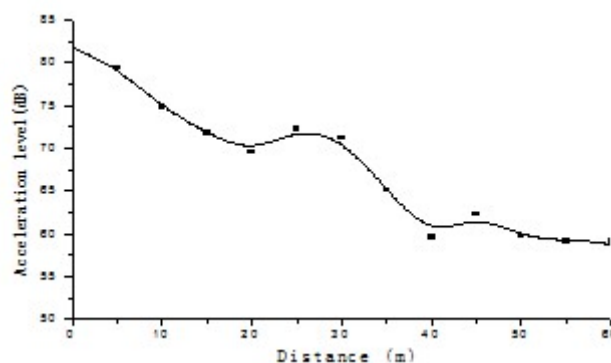


Fig. 4 Ground acceleration level attenuation curve

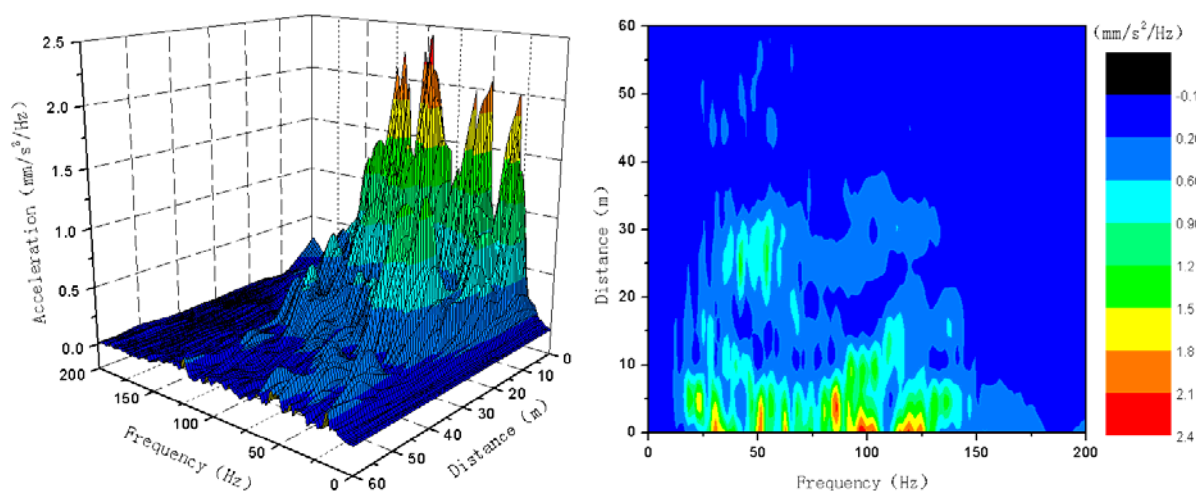


Fig.5 Acceleration spectrum of tunnel and ground surface

Conclusions

Making use of the 10m depth tunnel of LTVAC on BJTU campus, the experiments of vibration attenuation characteristic on the ground surface were carried out. The ground acceleration spectrum amplitude is greater at 0~15m, in 30~140Hz excited by AFWE. The acceleration spectrum amplitude bounces at 20~30m in 30~70Hz, which is the second peak value region except the source above. The experiments results indicated that the attenuation of different single frequency acceleration peak value envelope does not decay monotonically but wavy-type with peaks and valleys, and the attenuation of each single frequency is not the same. For different vibration sources (different tracks) and stratum conditions, the ground surface vibration bounce positions are not the same, it depends on the main vibration frequency band of the vibration source and the propagation characteristics of the stratum-in the LTVAC condition the ground surface vibration bounce area induced by the metro with DTVI2 fasteners is about 20~30m away from the track. To determine the precise location of ground surface vibration bounce area, we are focus on the transfer function of the stratum and the metro vibration source next.

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