Prediction model of the building vibration caused by elevated rail traffic

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Abstract. A section of the subway viaduct is taken as the subject investigated, the acceleration of piers and ground are monitored when the train pass through. The vibration characteristics of elevated rail transit pier and adjacent ground are studied. Through the fitting of the monitoring data, the empirical formula of the building vibration is obtained in the vertical direction with different source distance under the standard working condition. The results show that the pier vibration caused by the operation of the elevated rail transit is mainly in the direction of the train operation. In the process of vibration propagation from the top to bottom of pier, vibration attenuation is larger due to the inlay effect of the foundation. The vertical vibration of the building decreases with the increasing of the distance from the pier due to the attenuation in the soil. Comparing the vibration prediction model with the home-abroad representative model, the curve of model is similar. The prediction model provides reference for the building vibration prediction near the elevated transit.

1. Introduction

In recent years, the rapid development of urban rail transit in our country has formed a three-dimensional intersecting space transportation system from underground to ground and into the air, which has gradually deepened into dense urban commercial areas, industrial areas and residential areas. It has become an important solution to solve the urban traffic congestion, at the same time, the issue of environmental vibration induced by the subway is also a problem that has generally been emphasized by all the countries in recent years. The vibration caused by traffic is an important part of the environmental vibration project. According to the statistics of the countries concerned, the environmental vibration caused by the traffic system is the most intense vibration pollution, which accounting for 14.2% of the total complaint rate, except for factories and construction. Takemiya H¹¹ et al established the numerical analysis model of ground vibration near the railway viaduct, and studied the influence of the soft soil layer thickness on the ground vibration of the viaduct. Lopes P² studied the conceptual simulation of dynamic substructure and the problem of train-track and building-ground interaction. The noise and vibration of the vibration of the rail transit are measured by Lakušić S³ et al. The environmental vibration caused by the elevated rail train was studied and tested by Xia H⁴ et al. Wei P B⁵ obtain the ground vibration prediction model by establishing the free site vibration analysis model caused by the ground track city rail train. Based on the vibration test data of Wuhan light rail line, Qiu J J⁶ proposed a related prediction formula for the viaduct line environment vibration. Jiang T⁷ et al studied the environmental vibration caused by the Shanghai Elevated Rail Transit based on field measurement and numerical simulation. Hong J Q⁸ studied the
response rule of surrounding environment induced by subway operation from the aspect of the load spectrum characteristics of the subway train and the soil type of the site. Sun X J[9] et al combined with practical engineering for the first time using two bit calibration method in the frequency domain to make a quantitative prediction study of the far field low frequency micro vibration. In this paper, a section of Beijing elevated rail traffic is taken as monitoring objects, monitoring the viaduct pier and ground acceleration, the prediction model is established by fitting curve of the ground vibration, which provides the reference for the elevated rail transit environment vibration prediction.

2. Field monitoring of elevated rail transit vibration
A section of subway viaduct is taken as the subject investigated, the acceleration of piers and ground are monitored. Due to the complex traffic conditions, the monitoring data is selected when the light on, in order to avoid the impact of road vehicles on the results. The monitoring position located in the middle of the two ground railway stations. The train in a state of high speed during the monitoring process (v=80 km/h), the vibration source caused by the running of the train, which meeting the monitoring requirements, the main field instruments as shown in figure 1.

Fig.1. Layout of field instruments

The type of network data acquisition instrument is Beijing wave spectrum WS-5921N, which the device is 16 port analog input, the single channel sampling rate up to 625 kS/s, 2 analog output (16 bit, 2.8 MS/S), 24 port digital input and output port.

Fig.2. The layout of spot measure point
As shown in figure 2, the monitoring points of 1 to 6 are placed in No.1 Pier which near the south side, the monitoring points of 7 to 12 are placed in No.2 Pier which near the north side. In order to judge the leading direction of the pier vibration due to the rail transit viaduct train, the points of 4 to 6
and 10 to 12 are arranged at the middle line of the pier’s long side, which distance from the ground are 0 m, 1 m, and 2 m, respectively, monitoring the bridge pier acceleration in the longitudinal direction. Similarly, the points of 1 to 3 and 7 to 9, monitoring the bridge pier acceleration in the transverse direction. The 13 and 14 points are arranged on the ground near the No.1 pier, and the 15 and 16 points are arranged on the ground near the No.2 pier, which the distance of points to the bridge are 3 m, 5 m, respectively, monitoring the ground vertical acceleration.

Combining with the Calman filtering method, the program of Matlab is used to filter the data, and the monitoring data were analysed in the time and frequency domain. Firstly, the time history data of each test point is extracted when the train passing through, and the data was compared and analysed in multiple directions.

As for the measuring point vibration of the same height in some pier, the measuring points 1 and 4 are taken as examples, as shown in figure 3. The peak value of the transverse vibration acceleration lower than the longitudinal vibration acceleration, which indicated that the pier vibration caused by the operation of the elevated rail transit is mainly along the direction of the train operation.

As for the different heights point acceleration on one pier in same direction, the point 1, 2 and 3 are taken as examples, as shown in figure 4. In the process of vibration propagation from the top to bottom of pier, the peak value of vibration acceleration decreases gradually. Due to the inlay effect of the foundation, vibration attenuation is larger at fixed position.
As for vertical vibration of the ground, the measuring points 13 and 14 are taken as examples, as shown in figure 5. Due to the attenuation of vibration during the propagation in the soil, the vibration of point 14 lower than point 13.

In order to analyse the contribution of each frequency component in the ground vibration acceleration, the concept of Fourier principle and Fourier transform are introduced. Fourier principle shows that any continuous time sequence or signal can be expressed as an infinite superposition of sinusoidal signals with different frequencies. Based on the principle, the Fourier transform algorithm is used to calculate the frequency, amplitude and phase of different sine wave signals by accumulating the original signals directly. Therefore, the Fourier transform can be used to convert the time domain signal into the frequency domain signal. There are many kinds of software that can be used to Fourier transform, Matlab is selected as a tool to convert the time domain and frequency domain.

Fig.5. Vertical acceleration time history

(a) point13: Z direction     (b) point14: Z direction

Fig.6. Vertical vibration spectrum analysis

(a) No.1 pier point13: Z direction     (b) No.1 pier point14: Z direction

(c) No.2 pier point15: Z direction     (d) No.2 pier point16: Z direction
Figure 6 shows the ground vertical vibration spectrum curve. It can be seen that, near the bridge pier, the ground vibration of point 13 and point 15 focus on 8-25 Hz, the ground vibration of point 14 and point 16 which far from the bridge pier focus on 8-30 Hz. Chang L[10] monitored three direction vibration acceleration of a university stadium, which the distance far from the viaduct is 15 m, the monitoring point vibration focus on 5-25 Hz. Comparing the monitoring results with this paper, the main vibration frequency is similar approximately, which may due to the difference between the road traffic and the rail traffic.

3. Vibration prediction model for adjacent buildings caused by elevated rail transit

The finite element model of bridge pier-foundation-soil-building was established by the finite element software. Soil is emulated by tensile entity unit, the density is 1960 kg/m³, the modulus of elasticity is 20 MPa, the Poisson's ratio is 0.3, and the damping ratio is 0.1, size of soil is 200 m×200 m×60 m. The diameter of the pile foundation is 1 m, length is 30 m. The size of the cap is 6 m×4 m×2 m, and the type of concrete is C30. The pier is simplified as a cross section cantilever beam with a section size of 2.2 m×1.6 m. The building model is concrete frame structure with 6 layers. Under the influence of the vibration of rail traffic, the displacement between the pier-pile foundation and the soil is relatively small, so it can assume that there is no relative displacement and binding constraints between each other. Boundary conditions, the ground surface are free, the side of the model is horizontal constraint, and the bottom of the model is vertical constraint[8]. According to the actual monitoring environment, when the train running speed is 80 km/h, stress change cloud chart can be obtained. The longitudinal axis of the building is taken as the subject investigated, the vertical displacement cloud map of the whole pier foundation-soil-building under the vibration of viaduct train operation were obtained, as shown in figure 7. It can be seen that the large displacement occurs at pile in the depth of 20 m and first floor slab.

![Fig.7. Displacement cloud map](image)

The incidence of the train vibration on the surrounding environment is not more than 100 m[8]. Therefore, when other parameters under the standard condition, the distance of the bridge to the pier was changed, the distance are defined as 5 m, 10 m, 20 m, 30 m, 40 m, 50 m, 60 m,70 m, 80 m, 90 m and 100 m, respectively. The scatter plot of the vibration level with the distance is obtained by the index conversion. As for the prediction of the vibration level, the logarithmic form of $A+B\ln(d)$ is usually used, and the function relation between the ground vibration level and the source distance is obtained by regression fitting. The prediction formula can be defined as:

$$VL = 106.42 - 10.5 \ln(d + 0.67)$$

(1)

Where, $d$ is the distance of the calculation point to the centre of the pier.
In recent years, home-abroad scholars have also studied the vibration propagation of the viaduct system\cite{6}\cite{7}\cite{11}. Under the standard condition, train speed is 80 km/h, the vibration level curve of different models were obtained through substitution calculation, as shown in figure 8.

![Fig.8. Comparison of forecasting models of home-abroad](image)

Comparing the vibration prediction model with the home-abroad representative model, vibration attenuation trend of each model is similar with the increasing of distance, which verify the correctness of the model. The above formulas were simulated by the logarithmic model for the response of the vibration, when the vibration source distance more than 100 m, all the models are closer. The prediction model provides reference for the environment vibration prediction near the elevated transit.

4. Conclusions

1. As for the measuring point vibration on pier in same height, the peak value of the transverse vibration acceleration lower than the longitudinal vibration acceleration, the pier vibration caused by the elevated rail transit is mainly in the direction of the train operation. As for the different heights point acceleration on pier in same direction, vibration propagation from the top to bottom of pier, the peak value of vibration acceleration decreases gradually.

2. In the process of vibration propagation from the top to bottom of pier, vibration attenuation is larger due to the inlay effect of the foundation. The vertical vibration of the ground decreases with the increasing of distance due to the vibration attenuation in the soil.

3. Through the fitting of the monitoring data, the empirical formula of the building vibration in the vertical direction with different source distance was obtained under the standard working condition. Comparing the vibration prediction model with the home-abroad representative model, the curve trend of each model is similar, which confirm the correctness of the model. The prediction model provides reference for the environment vibration prediction near the elevated transit.

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