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IN SITU EXPERIMENTS AND NUMERICAL ASSESSMENT OF ENVIRONMENTAL VIBRATION INDUCED BY URBAN VIADUCT RAIL TRANSIT IN SHANGHAI

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SUMMARY

In this paper, the realities, the mechanism and the propagation of the environmental vibration induced by the Mingzhu line are studied by both observational and theoretical method. In order to obtain the environmental vibration's characteristics of propagation and attenuation, a large number of measurements are carried out along typical zone of the Mingzhu Line. The ground response has been measured during the passage of trains at carriage speed about 60km/h. A statistic regression formula to evaluate the vibration level is suggested. Comparison of the formula with the observed datasets showed a satisfactory agreement. In the theoretical analysis, the total complicated system including train, bridge, concrete frame, pile foundation and soil, is divided into two substructures. The first one is train—bridge substructure, its dynamic analysis is made considering track irregularities. The frequency domain method is used to simulate the track irregularities. A special 2D analytical method has been developed. The second one is a 3D model of frame-pile-foundation-soil substructure adapted to analyze the dynamic responses of the ground along the line. The finite element model with viscous and elastic artificial boundary element is used to calculate the dynamic response. Combined the two above substructures, the environmental vibration induced by urban viaduct rail transit can be calculated. The observational results and the statistic regression formula are compared with the numerical prediction, and the results showed that the theoretical model proposed in this paper can be used to predict the environmental vibration induced by urban viaduct rail transit. Finally, by using the numerical model, the influence of train's speed and the number of passenger on the environmental vibration has been analyzed.

INTRODUCTION

The first urban viaduct rail transit in China，the Mingzhu Line，has been constructed and put into operation in Shanghai. Urban viaduct rail transit induced vibration is a new source of environmental nuisance as they may cause discomfort to citizen and malfunctioning of sensitive equipment.

The influence of urban viaduct rail transit induced vibration on the surrounding environment has been reviewed [1]. Theoretical model for urban viaduct rail transit induced vibration has been presented [2] for two-dimensional FEM model.

The objective of the present paper is to study the realities，the mechanism and the propagation of the environmental vibration caused by the Mingzhu Line by both experimental and numerical methods. The flowchart of the idea of present research is showed in Fig.1.

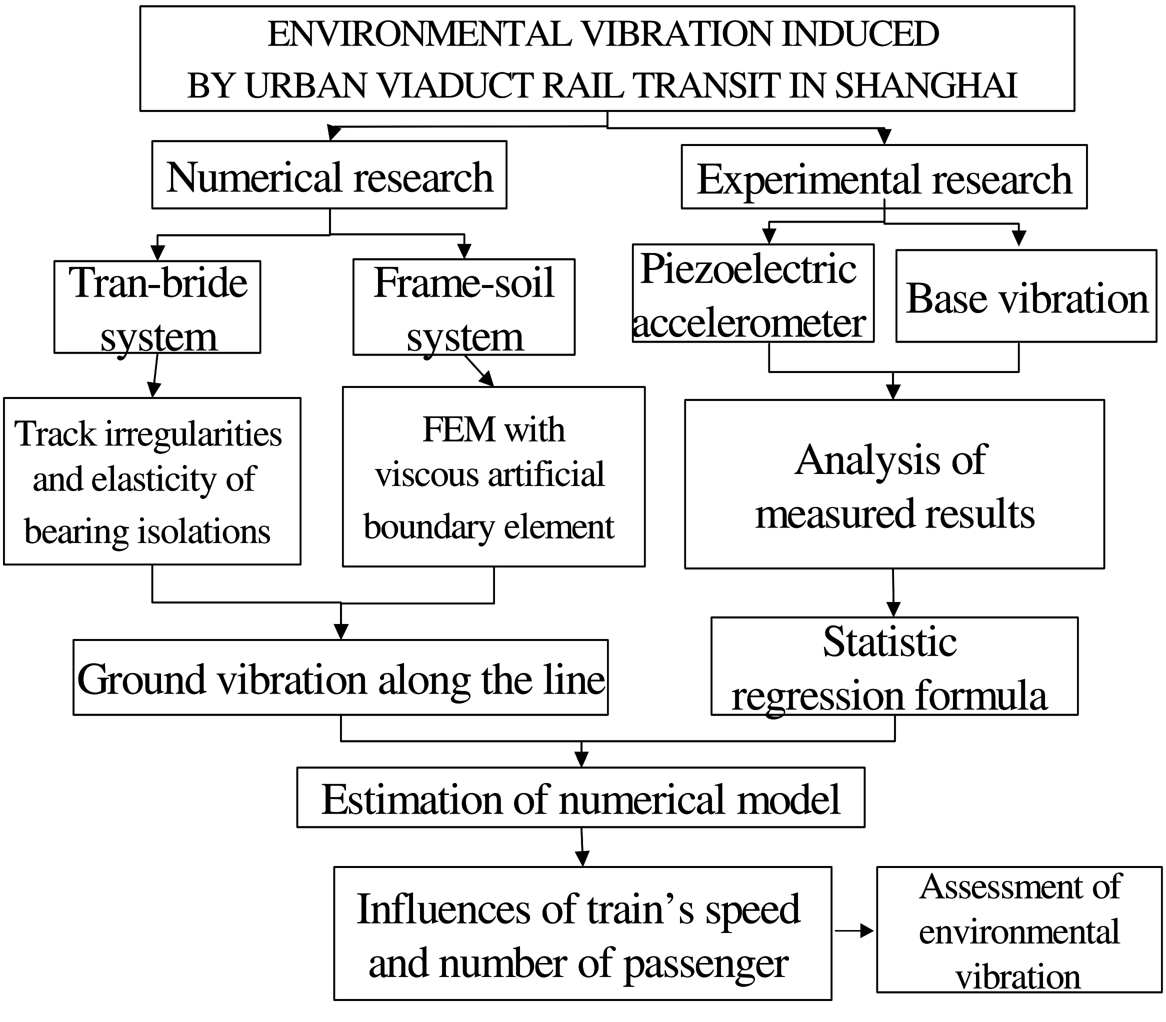


Fig.1 Flowchart of the present research

First, the experimental setup has been discussed. The response of the soil along the Mingzhu Line has been measured during the passage of a train at carriage speed about 60km/h. The background vibration of zones near the line is separated from the total environmental vibration and its characteristics have been studied. A statistic regression formula to evaluate the vibration level is suggested.

Second, the essential elements of the numerical analysis have been recapitulated. A 2D carriage-bridge model is used for calculating the dynamic loads acted on the support frames. Then the 3D model of frame-pile-foundation-soil substructure is adapted to analyze the dynamic responses of the surrounding soil. Finally the observational results and the statistic regression formula are compared with the numerical assessment.

Along the Mingzhu Line several places have been chosen as observation points. The soil responses have been measured during the passage of a train at carriage speed about 60km/h. The measurement line is designed perpendicular to the viaduct line. Vertical accelerations have been measured at several locations with piezoelectric accelerometer.

Response of the Soil along the Mingzhu Line

The map of Mingzhu Line and the measurement points are showed in Fig.1. The dashed line displayed the Mingzhu Line and the arrows displayed the measurement points. The length of the Line is about 20 Km and runs from north side to west-south side of Shanghai city.

The measured results of vibration along the Mingzhu Line are showed in Fig.3. Fig.3 (a) displays the typical time history of the vertical acceleration at distances of 0，6，10，16 and 20m from the center of the viaduct line. Fig.3 (b) shows the Fourier spectrum of the accelerations. Fig.3 (c) shows the vibration level (in decibels，VL) of the accelerations. The VL is based on ISO2631 [3] and defined as

$$VL = 20\log(\frac{a_r}{a_o}) \tag{1}$$

where: a_r is the effective value of the acceleration(RMS，m/s^2)

a_o is the reference acceleration level of $10^{-6} m/s^2$

The VL is corrected with frequency based on ISO2631.

From Fig.3 (a)， it can be observed that the wave propagation in the soil attenuates for increasing distance to the center of the viaduct line. It is also seen in Fig.3 (b) and (c) that the Fourier amplitude and the VL of 1/3-octave component attenuate with increase of distance. The behavior shows that the frequency is higher ，the attenuation is stronger. Fig.3 (c) also shows the effect of the base vibration generated by other vibration sources on the viaduct rail transit induced vibration. One can see that the effect of the base vibration is very small for the frequency band larger than 20Hz and in the distance less than 10m. In the distance from 10m to 20m the reduction about 0.5~3dB generated by other vibration sources should be considered when we evaluate viaduct rail transit induced vibration. Fig.4 displays the attenuation of VL with distance for individual frequency. The Fig.4 shows the same behavior with Fig.3 (c)，namely the value of VL decreases quickly with increasing frequency.

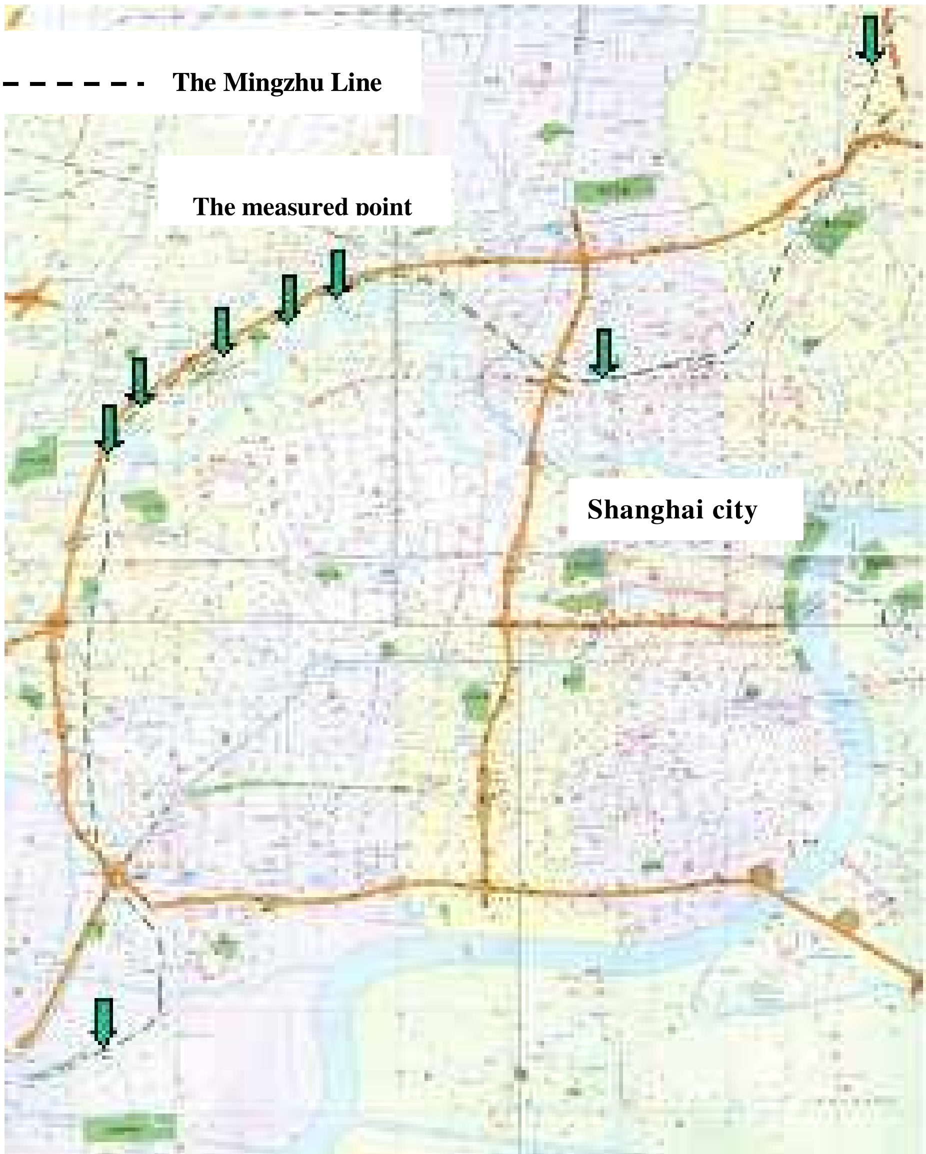
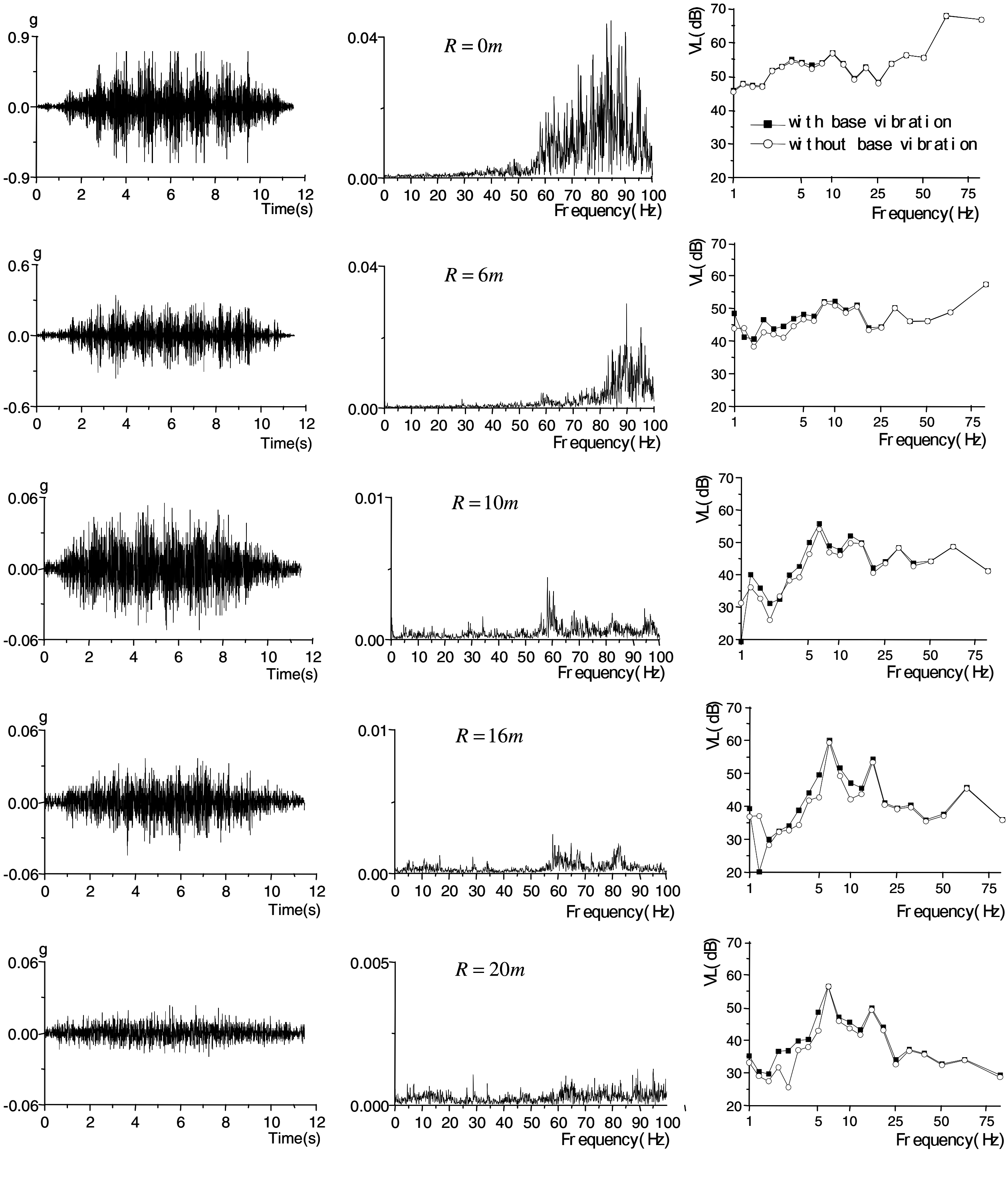


Fig.2 The map of the Mingzhu Line and distribution of the measurement points



(a)Acceleration time history (b)Fourier spectrum (c) Vibration level

Fig.3 Typical measured acceleration verified with different distance

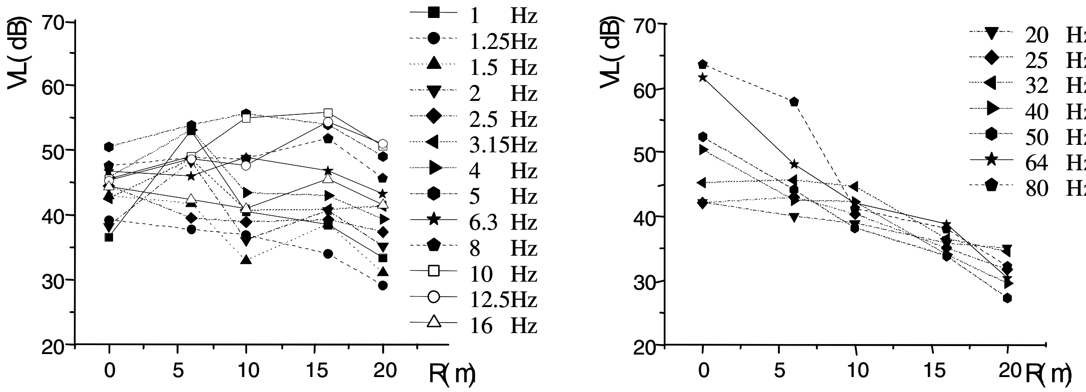


Fig.4 Attenuation of VL with distance for individual frequency

The Experimental Formula for Evaluating VL

According to the observational results obtained at several locations along the viaduct line the relation of VL versus logarithms distance from the viaduct line's center has been plotted in Fig.5. The Fig.5 shows that the VL is nearly in proportion to the logarithms distance from the viaduct line's center.

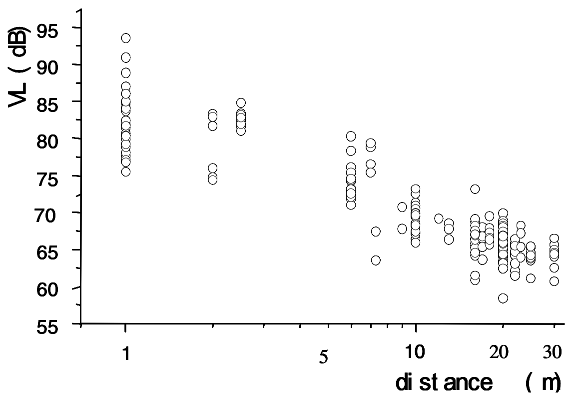


Fig.5 VL versus logarithms distance

A linear function has been picked up to simulate the relation of VL versus logarithms distance obtained by site measurement. Refer to the general formula [4] that expressed the relation of acceleration amplitude and the distance, by using the linear fitting theory, the statistic regression formula can be written as following

$$VL = 70 - 13.6 \cdot \log(\frac{r}{10}) \tag{2}$$

where: r is the distance from the viaduct line's center in m.

The average VL value at distance 10m is equal to 70dB. Fig.6 shows the comparison of the formula with the observation datasets， and a satisfactory agreement has been seen.

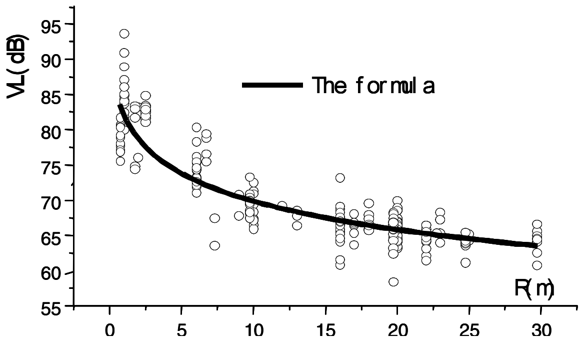


Fig.6 Comparison of statistic regress formula with measured datesets

ANALITICAL MODEL AND NUMERICAL RESULTS

The complicated system of environmental vibration, which is made up of train, bridge, frame, pile-foundation and soil, is divided into two substructures as shown in Fig.7. By analyzing the train—bridge system (substructure 1), the dynamic reaction from the top of the frame induced at the train passing can be calculated. Applying the dynamic reaction on the top of the frame and considering the soil-structure interaction, the frame-foundation-soil system (substructures 2) can be solved. Finally the ground vibration along the line induced by viaduct rail transit can be calculated.

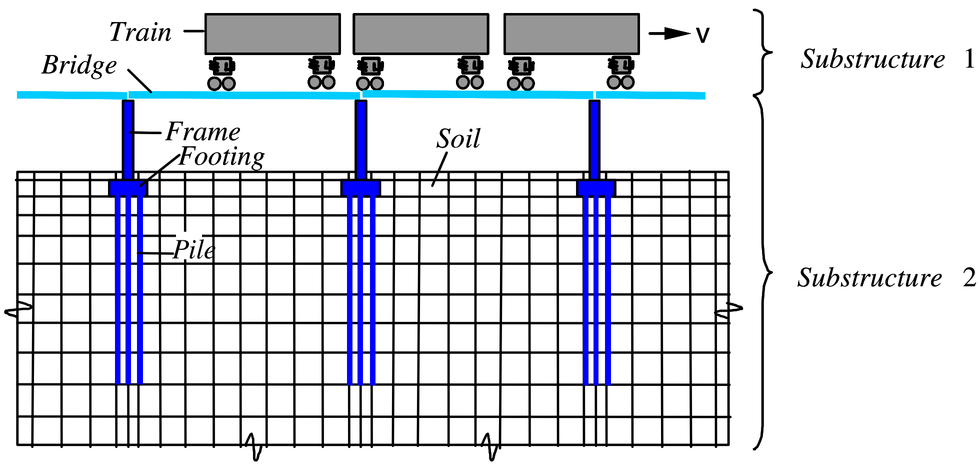


Fig.7 Total system and substructures

The Numerical Model of the Substructures

Dynamic analysis of the train—bridge substructure is made considering both the track irregularities and the bridge bearing isolation's elasticity. Fig.8 shows the model of the train—bridge substructure. A carriage has vertical and rotational freedoms Z and θ, and has simplified suspension system. The bridge is assumed as an Euler beam having elastic supports, whose spring constant is determined by considering the elasticity of the bearing isolations, the frame structures and the soil under the bridge. Let us consider a train having N carriages and moving at a speed V on an irregular track. The Frequency Domain Method (FDM) [5] is used to simulate the track irregularities. The results obtained by FDM fit well with the target Power Spectrum Density (PSD). The fitting results of FDM are rather better than the Trigonometric Series Method (TSM), which is the normal method to consider the track irregularities, as shown in Fig.9. By using the specially coded programs, a typical case of train—bridge system having five carriages and six spans is calculated.

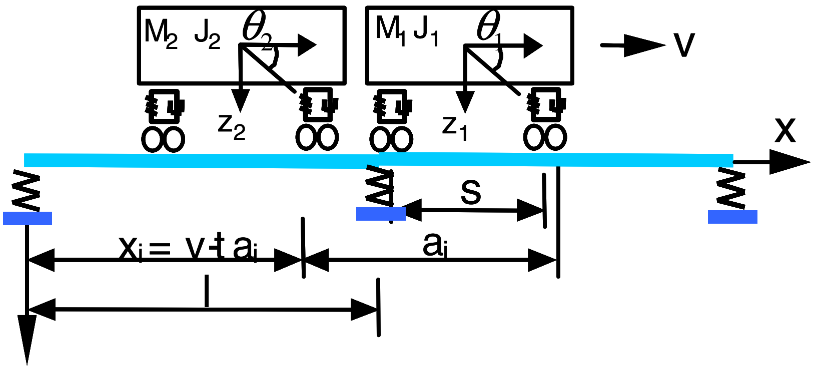


Fig.8 Train-bridge system Special computer programs have been coded.

As far as the analysis of the frame-foundation-soil substructure, the FEM is used considering viscous and elastic artificial element. The reliability of the viscous element has been checked by several classic problems of soil—structure dynamic interaction [6]. Furthermore, viscous and elastic artificial element is put forward to consider the elasticity of the soil outside of the FEM model.

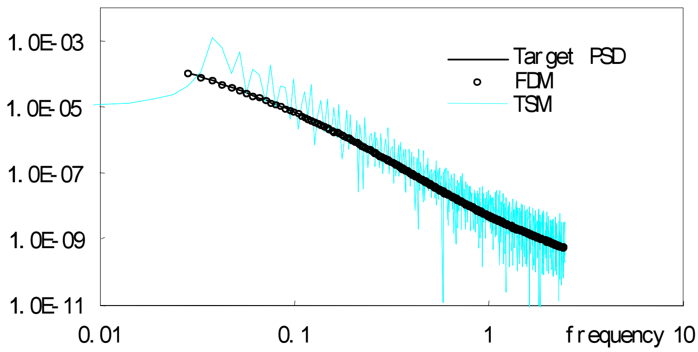


Fig.9 Simulation results of FDM and TSM

The Numerical Results

Combining the above two substructures ground vibration at several locations along the line induced by viaduct rail transit can be calculated. Fig.8 shows the total frame-foundation-soil model. Two models have been taken to compare the effect of the support frame's number. Fig.10 (a) shows element division of a single frame model (model 1). In the model the symmetry is used. The dynamic reaction P(t) caused by a train with five carriages at carriage speed 60km/h has been utilized. Fig.10 (b) shows element division of a three frames model (model 2). The dynamic responses $P_1(t)$, $P_2(t)$ and $P_3(t)$ under the same conditions having phase delay have been utilized.

Comparison of Numerical Results with Observational One

A comparison of VL attenuation with distance between calculating results and Eq.(2) has been made and displayed in Fig.11. Fig.11 (a) and (b) show that the calculating results of the model 2 approaches the values obtained by Eq.(2) better than the results of the model 1, because the model 2 involves the effects of wave propagation from the neighborhood frames and the VL is larger than that of the model 1. Fig.10 display the calculating results of VL attenuation with distance for individual frequency, Fig.12 (a) and (b) correspond model 1 and model 2 respectively. The figures also show that the VL for all frequency of the model 2 is larger than that of the model 1, especially in higher frequency band. The outline agreement of the numerical results with the observational results indicates that the analytical model and numerical method proposed in this paper can be used to assess the environmental vibration induced by viaduct rail transit satisfactorily.

Finally, by using the model 2, the influences of train's speed and number of passenger on the VL have been analyzed. Fig.13 shows attenuation of VL with distance for train's speeds V from 60km/h to 100km/h. The figure displayed that VL increases with the increasing train's speed for all distance from the viaduct line's center. The VL increases about 4dB for every speed increasing 20km/h.

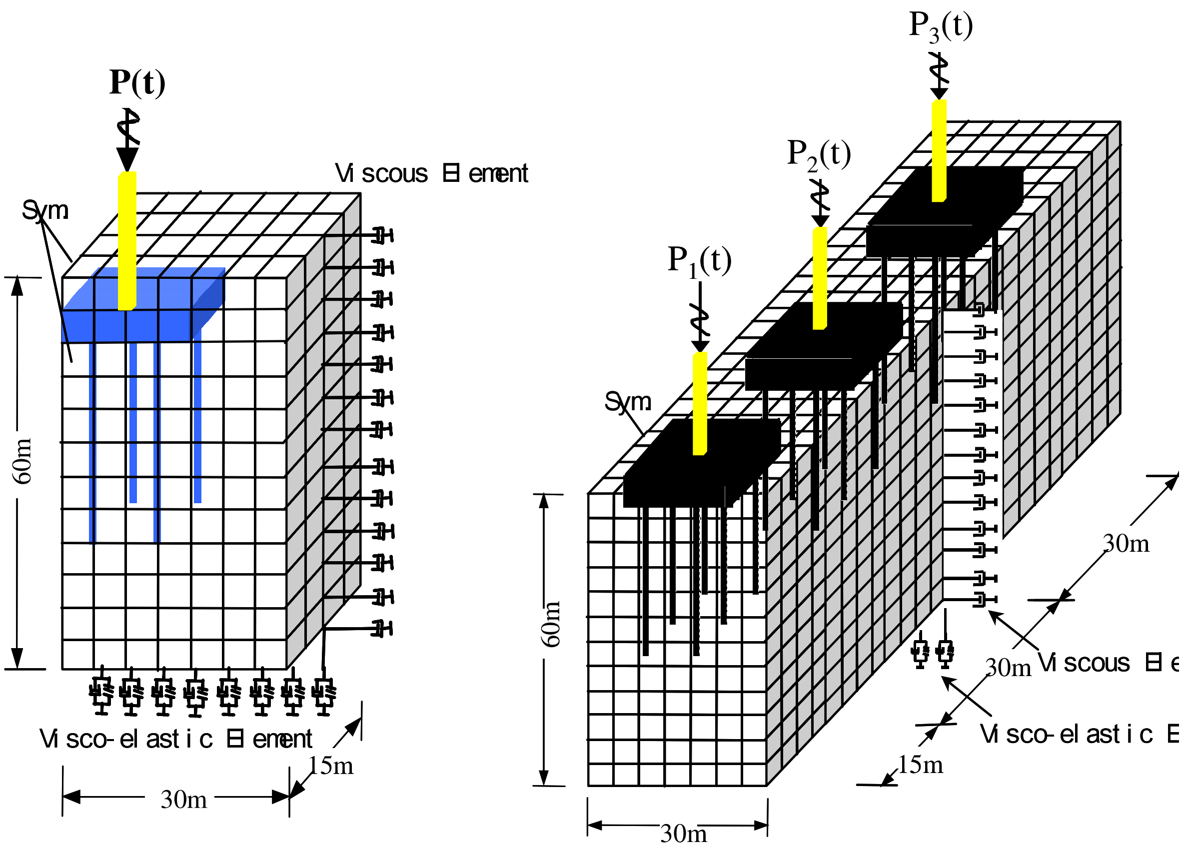
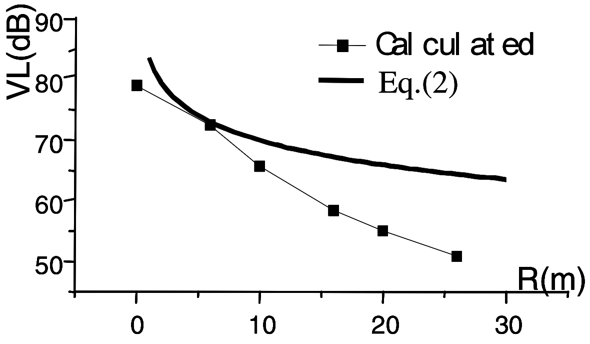
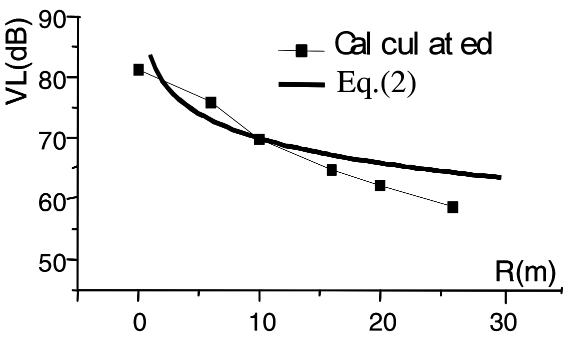


Fig.10 Total numerical model

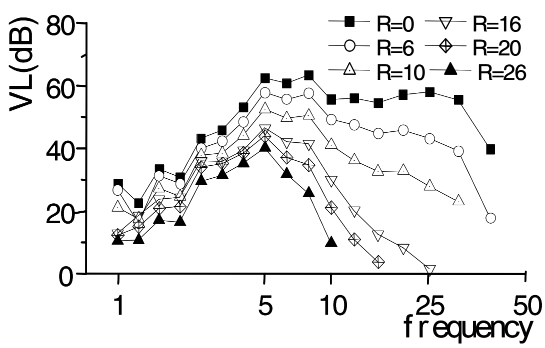


(a)Single Frame Model

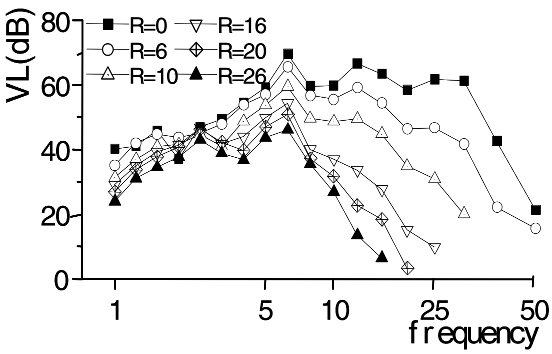


(b)Three Frames Model

Fig.11 Comparison of VL attenuation with distance between calculating results and Eq.(2)



(a)Single Fame Model



(b)Three Fames Model

Fig.12 Attenuation of VL with distance for individual frequency

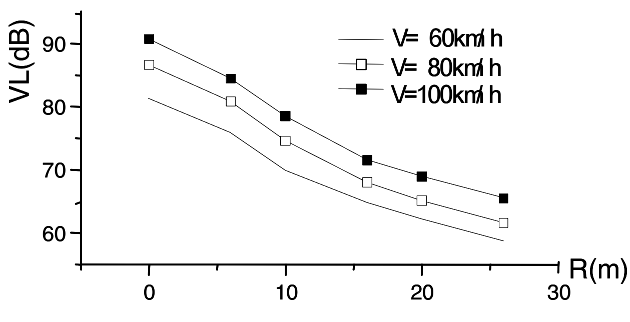


Fig.13 Attenuation of VL with Distance for Different Train's Speed

CONCLUSIONS

In This paper, the ground vibration of the soil along the Mingzhu Line, Shanghai, has been measured during passage of a train. The results show that the VL attenuates with increase of distance from the viaduct line's center. The value of VL at high frequency attenuates more strongly than that at low frequency.

A statistic regression formula to evaluate the VL induced by viaduct rail transit is suggested. Agreement of the formula and the measured datasets is quiet satisfactory.

A analytical model to predict the VL induced by viaduct rail transit is made up. The model is divided to two substructures. A 2D carriage-bridge model is used for calculating the dynamic loads acted on the support frames. Then the 3D model of frame-pile-foundation-soil substructure is adapted to analyze the dynamic responses of the surrounding ground soil.

Combining the above two substructures ground vibration at several locations along the line induced by viaduct rail transit can be calculated. A single and three frames models are calculated. The results of the three frames model approaches the values obtained by statistic regression formula better than that of the single model. The outline agreement of the numerical results with the observational results indicates that the numerical model presented in this paper can be used to assess the environmental vibration induced by viaduct rail transit.

ACKNOWLEDGEMENTS

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