Measurement 125 (2018) 394–405

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Measurement and analysis of vibrations in a residential building constructed on an elevated metro depot

Zhiliang Cao[a], Tong Guo[a,*], Zhiqiang Zhang[a], Aiqun Li[a,b]

[a] Key Laboratory of Concrete and Prestressed Concrete Structure, Ministry of Education, Southeast University, Nanjing 210096, PR China
[b] Beijing Advanced Innovation Center for Future Urban Design, Beijing University of Civil Engineering and Architecture, Beijing 100044, PR China

ARTICLE INFO

Keywords:
Train-induced vibration
Residential building
Metro depot
Vibration comfort
Theoretical analysis

ABSTRACT

As a place for trains to get maintenance, the metro depot often occupies a large amount of valuable urban lands. In recent years, the over-depot building is undergoing a rapid development, aiming at rational use of city space, while the train-induced vibration is one major concern. This paper presents the vibration tests in a seven-story residential building constructed on an elevated metro depot. Acceleration time-histories at different locations were measured and the corresponding frequency spectra were compared. The influence of track positions on vibration was investigated and the vibration serviceability was evaluated through two different indicators. Besides, a theoretical model of the residence structure was developed and validated through the test data. Parameter analysis was carried out based on the proposed model, so as to provide references to vibration control.

1. Introduction

The metro depot is a place for trains to get daily inspection and maintenance. When built on the ground, the depots often occupy a large amount of urban lands. Therefore, the over-depot buildings are undergoing a rapid development in recent years in China, aiming at rational use of city space. However, it has long been recognized that people living in the vicinity of the metro lines may suffer from excessive train-induced vibrations and structure-borne noise when high frequency of train operations. Both vibrations and noise are undesirable environmental issues and can cause discomfort of the occupants and impair the commercial value of the residences [1]. Considering that the over-depot buildings are directly above the metro, it is necessary to evaluate the train-induced vibrations in the design stage and develop effective ways to mitigate the vibrations for structural serviceability. So far a number of studies have been carried out with regards to the train-induced vibration, which are mainly focused on the following three aspects [2–4]: (1) dynamic properties of vibration source (i.e. the train-track system), (2) vibration propagation in soils and (3) vibration behavior of buildings.

Unlike the common case where the vibration waves induced by underground trains are mitigated in soils during propagation, the over-depot structures are directly subjected to the train-track dynamic forces, which contain high energy and may cause excessive floor vibrations even when the trains run at a rather low speed. Previously, Zhou et al. [5] performed a numerical study on an over-track building, and concluded that vibration serviceability of the first floor failed to meet the requirement and vibration control measures should be taken. Zou et al. [6] investigated the vibration transmission in the metro depot and the over-track building, where the vibrations of the depot platform (i.e. the 2nd floor) were amplified as compared with the ground vibrations; besides, they recommended that buildings within a horizontal distance of 40 m over the throat area, a place where multiple tracks from the depot extend to and gather together, should be examined for vibration comfort. Sanayei et al. [7] compared the vibrations on the foundation slabs inside six buildings induced by surface trains and subways respectively, and found that vertical vibrations were greater than horizontal ones by 10 dB. According to vibration tests and parameter analysis by Cao et al. [8], the distance between railway tracks and measure points had an obvious influence on the floor vibration response. Besides, Cao et al. showed that different from the conclusion drawn from Sanayei et al. [9], it was inefficient to control vibration by increasing the thickness of the bottom floor, and this phenomenon was partly attributed to the low slab-to-column impedance ratio [10].

In most existing studies, trains run on the ground floor of the metro depot [5,6,11], as shown in Fig. 1(a). However, the large throat area outside the depot may influence the ground traffic; therefore, a viaduct method has been put forward in recent years, so that the trains can run through viaducts into the depot at its 2nd or 3rd floor, as shown in Fig. 1(b). This paper presents the field measurement and vibration analysis on such a novel structure, which is located in Nanjing, China. In this case, sixteen seven-story residential buildings were built on the

* Corresponding author.
E-mail address: guotong@seu.edu.cn (T. Guo).

https://doi.org/10.1016/j.measurement.2018.05.010
Received 1 July 2017; Received in revised form 19 March 2018; Accepted 2 May 2018
Available online 06 May 2018

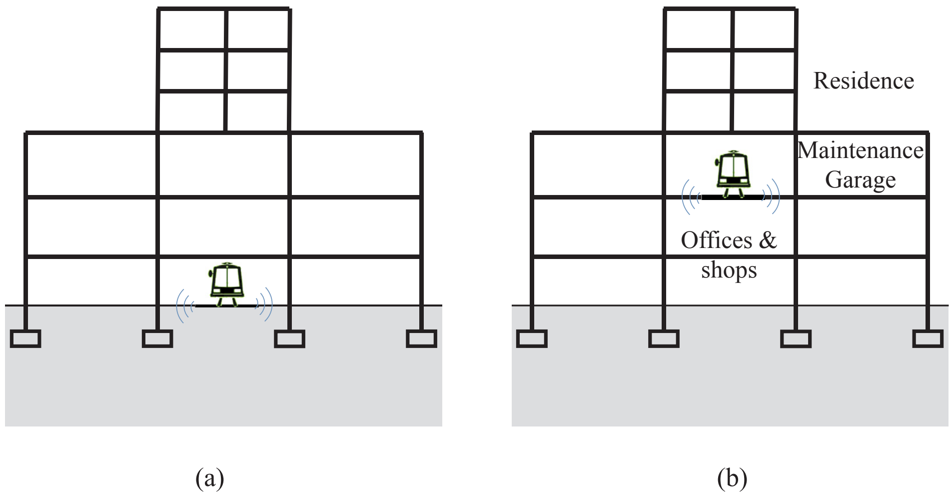

Fig. 1. Different locations of metro trains: (a) on the ground floor, (b) on the 2nd or 3rd floor (i.e. the viaduct method).

three-story depot, in which the 3rd floor is the maintenance garage and the other two stories are for commercial and official use. Since the vibration energy is transmitted to the upper residence directly through the vertical elements such as the columns and walls, and the train-induced vibration becomes a major concern of owners. Therefore, acceleration time-histories at different locations were measured and analyzed, based on which the vibration comfort was evaluated through two different indicators. In addition, a theoretical model of the residential building was developed and parameter analysis was carried out, so as to provide references to vibration control.

2. Field measurement

2.1. The metro depot and measure points

The metro depot under investigation is a reinforced concrete frame structure with large open space and infill walls. Most frame columns have the cross-section of 1.1 m × 1.1 m except for some inner columns with the cross sectional area of 0.8 m × 0.8 m. Slab thicknesses of the second and third floors are 120 mm and 150 mm, respectively, and the heights of the first, second and third stories are 5.9 m, 4.4 m and 9.2 m, respectively. The over-depot residential building is a seven-story concrete frame structure with masonry infill walls. Most frame columns have the cross-section of 0.6 m × 0.6 m except for some inner columns with the cross-section of 0.5 m × 0.6 m. Floor slabs have a uniform thickness of 150 mm, and story height of each floor is 3.1 m, as shown in Fig. 2(a). Note that the mid-row columns of the residential building, as shown in Fig. 2(a), are directly supported by the frame beams of the metro depot.

Considering the similarity in plan layout of the buildings, only one unit of the building was selected for measurement. There were a total of seven measure points, as illustrated in Fig. 2(a) and (b). Points 1 and 2 were set to compare the vibrations of the ground floor at column-slab joint and slab midspan. Point 3 was set for comparison with Point 1 to investigate the vibration transmission in columns. Points 4, 6 and 7, located in the middle of the slab of the living room, were set for comparison with Point 2 to study the vibration transmission in different stories. Besides, Point 5 was set in the middle of the slab of the bedroom, which is similar to Point 4 except that there are more infill walls in the bed room around Point 5. As a result, Points 4 and 5 were used for comparison to investigate the influence of nonstructural walls on vibrations. Note that in Fig. 2(b) the throat area is the place where multiple tracks from the depot extend to and gather together.

The influence of train position on vibrations was also investigated in this paper, and the locations of tracks are depicted in Fig. 2(c). The rails of the track system are rest on reinforced concrete columns with a longitudinal spacing of 1.4 m, and the columns had a height of 0.8 m to leave space for maintenance. The rails were fixed on the columns with elastic fasteners with the vertical stiffness of approximately 40kN/mm. The train is a standard vehicle consisting of two trailer cars and four driving motor cars, corresponding to a rolling stock of 119.88 m. To avoid excessive vibrations and noise in the depot, the train speeds were controlled below 5 km/h. Note that currently there is few investigations on structural vibrations induced by trains with such low-speeds.

2.2. Test instruments

The ADCRAS data acquisition & signal processing system with the AZ808 amplifier, as shown in Fig. 3(a), was used in the measurement. The type 941B ultra-low frequency accelerometers with the sensitivity of 0.3 $V/m/s^2$ and resolution of 5×10^{-6} m/s^2 were glued on floors to measure the vibrations, as shown in Fig. 3(b). Each accelerometer was connected to an amplifier, an anti-aliasing low-pass filter and a laptop in sequence, and all the accelerometers and the data acquisition system were calibrated before the measurement. The sampling frequency of accelerometers on floors was 256 Hz, corresponding to a meaningful spectrum below 100 Hz. For each measurement point, acceleration responses were obtained when trains ran on Tracks No. 3, 4, 6 and 8, respectively, as shown in Fig. 2(c). For each track, the measurement was repeated for seven times. Note that the vehicle length is 120 m and the train speed was measured roughly as 1.2–1.4 m/s, hence the duration of each record was no less than 100 s. In the following analysis, interferences due to walking people and occasional road traffic were neglected.

3. Measurement results and discussions

3.1. Vibration of the column-floor joints

Fig. 4 shows the vibration responses of the two joints with a moving train on Track No. 4, where Points 1 and 3 located on the first and second floors, respectively. The vibration lasted for about 120 s, and the peak accelerations of the two points were 121 mm/s^2 and 185 mm/s^2, respectively. The predominant frequencies of Point 1 was at 53 Hz, and the vibration energy was negligible below 20 Hz or above 80 Hz according to the 1/3 octave band root-mean-square (RMS) spectrum. As to Point 3, the spectrum peak value was observed around 52 Hz, while the energy contribution above 60 Hz increased as compared with Point 1.

Different from previous studies [8] where the column-floor joint