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Measurement of ground and nearby building vibration and noise induced by trains in a metro depot

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HIGHLIGHTS

- Land utilization problems make Chinese cities develop over-track buildings.
- Impact of train-induced vibration and noise in the metro depot was studied.
- Vibration and noise levels were higher than the allowable values of criteria.
- Predicted models were verified for assessment of newly built metro depots.
- Horizontal vibrations near the curved track were greater than vertical ones.

GRAPHICAL ABSTRACT

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ABSTRACT

Metro depots are where subway trains are parked and where maintenance is carried out. They usually occupy the largest ground areas in metro projects. Due to land utilization problems, Chinese cities have begun to develop over-track buildings above metro depots for people's life and work. The frequently moving trains, when going into and out of metro depots, can cause excessive vibration and noise to over-track buildings and adversely affect the living quality of the building occupants. Considering the current need of reliable experimental data for the construction of metro depots, field measurements of vibration and noise on the ground and inside a nearby 3-story building subjected to moving subway trains were conducted in a metro depot at Guangzhou, China. The amplitudes and frequency contents of velocity levels were quantified and compared. The composite A-weighted equivalent sound levels and maximum sound levels were captured. The predicted models for vibration and noise of metro depot were proposed based on existing models and verified. It was found that the vertical vibrations were significantly greater than the horizontal vibrations on the ground and inside the building near the testing line. While at the throat area, the horizontal vibrations near the curved track were remarkably greater than the vertical vibrations. The attenuation of the vibrations with frequencies above 50 Hz was larger than the ones below 50 Hz, and the frequencies of vibration transmitting to adjacent buildings were mainly within 10–50 Hz. The largest equivalent sound level generated in the throat area was smaller than the testing line one, but the instantaneous maximum sound level induced by wheels squeal, contact between wheels and rail joints as well as turnout was close to or even greater than the testing line one. The predicted models gave a first estimation for design and assessment of newly built metro depots.

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1. Introduction

China's economy has achieved rapid development in the last thirty years. This development has resulted in an enormous urban area expansion and higher intensive land use (Gong et al., 2014). Specifically, China's urbanization ratio has risen from just 18% in 1978 to above 50% in 2015 (Li et al., 2014). More and more densely populated metropolises, such as Beijing, Shanghai and Guangzhou, are competing against each other to become 'Asia's world city' and it has also led to growing scarcity of land resources and urban environmental problems (Derudder et al., 2013). Indeed, developing the underground space is a practicable approach. Urban transportation networks such as urban rapid transit system have been built in many cities to meet increasing population and traffic demand and reduce CO_2 emissions. For example, the metro network in Guangzhou has been progressively constructed since 1993. Nowadays, it has 9 lines with a total length of 259.84 km, 8 metro depots and 164 stations, serving approximately 6.23 million passengers on a daily basis (Chen et al., 2014). Before 2020, about 300 km subway line will be put into use and 20 metro depots and 359 stations will operate. Metro depots are where subway trains are parked and where maintenance is carried out. They usually occupy the largest ground areas in subway projects. Due to land utilization problems, many Chinese cities have begun to develop over-track buildings above metro depots for people's life and work over the last 5 years (see Fig. 1).

The over-track buildings are composed of shopping malls, apartments, hotels, office buildings and other public facilities. Different types of buildings are having mutual accessibility by escalators, stairs, bridges and air corridors, and connecting metro station directly. The characteristic of the high-density multi-purpose land use is that it not only reduces environmental pollution and energy consumption, but also improves the quality of people's lives and makes them enjoy entertainment, leisure, dining and other living and working convenience.

But the frequently moving subway trains that go into and out of the depots can transmit excessive vibration and noise to over-track buildings and adversely affect the living quality of the building occupants. To attempt to address ground-borne and building vibration and noise issues, field experiments and surveys were conducted in the United Kingdom (Thompson, 2009), the United State (Sanayei et al., 2013, 2014), Belgium (Connolly et al., 2015a; Kouroussis et al., 2013), Spain (Maffei et al., 2013; Torija et al., 2011; Galvín & Domínguez, 2009), Greece (Vogiatzis, 2012a), Germany (Degen et al., 2006; Elmenhorst et al., 2012) and China (Zhai et al., 2015; Ling et al., 2010). The different indicators like peak particle velocity (PPV), root-mean square value (a_w) (International Organization for Standardization, 1997, 2003), vibration velocity level (v_{dB}) (Federal Transit Administration (US), 2006) and weighted vibration severity KB_F (Deutsches Institut für Normung, 1999) were compared (Kouroussis et al., 2014c) and used to evaluate the influence of vibrations. The indicators, equivalent sound level L_{Aeq} and maximum sound level L_{Amax}, were calculated for assessing noise effect (Federal Transit Administration (US), 2006; GB 3096-2008, 2008). The propagation characteristics of vibration and noise near the tram, railway and subway in the tunnel or on the viaduct have been studied. The dominant frequencies during the trains pass-by have been observed. The effect of vehicle characteristics on ground and track borne-vibrations from railways has been summarized (Kouroussis et al., 2014b). Moreover, many researchers developed numerical models to predict vibration and noise impact and evaluate mitigation measures (Vogiatzis, 2010, 2012b; Kouroussis et al., 2015). An example regarding the 7.6 km extension of Athens Metro proposed a numerical model to access the environmental ground borne vibration and noise during metro operation at each section and each sensitive buildings (Vogiatzis, 2012a). The main contributions of railway-induced ground vibrations near the buildings and its radiated ground-borne noise by vibrating walls and floor in the Brussels Region were evaluated (Kouroussis et al., 2014a). An equation that enabled computation of L_{Amax} for the Tehran–Karaj commuter train was also developed to enable consideration of different scenarios for the optimal management of noise prevention and mitigation (Nassiri et al., 2007). An overview relating to railway vibrations reviewed holistic predicted measures of vibration from track to nearby buildings; vibration effects, modeling, mitigation and future trends were synthesized (Connolly et al., 2015b).

However, different from the common train-induced vibration and noise problems, the subway trains usually operate on the bottom floor of the metro depot and over-track buildings, and the vibration energy directly pass through vertical elements, such as columns and walls, to the upper floors (Zhou et al., 2013). These near-source induced waves usually contain high energy which may cause greater vibration and noise. In addition, considering the current needs of reliable experimental data for the construction of metro depots in China, it is urgent to fully understand the influence of train-induced vibration and noise in the metro depots and then develop safe and effective measures to mitigate the vibration and noise levels. In this study, measurements were carried out to study the influence of subway-induced vibration and noise on the ground and inside a 3-story building in a metro depot. The results may be useful in the plans and design of vibration and noise mitigation measures in the metro depots, and minimize vibration and noise levels in the over-track buildings within the criteria.

2. Main vibration and noise sources

The main buildings of a metro depot are composed of a maintenance building, a parking garage and office buildings. The roles of these buildings are for maintenance of trains, parking of trains and staff working, respectively. Moreover, the rail can be divided into three types in accordance with the characteristics of rails, as shown in Fig. 2 and Table 1.

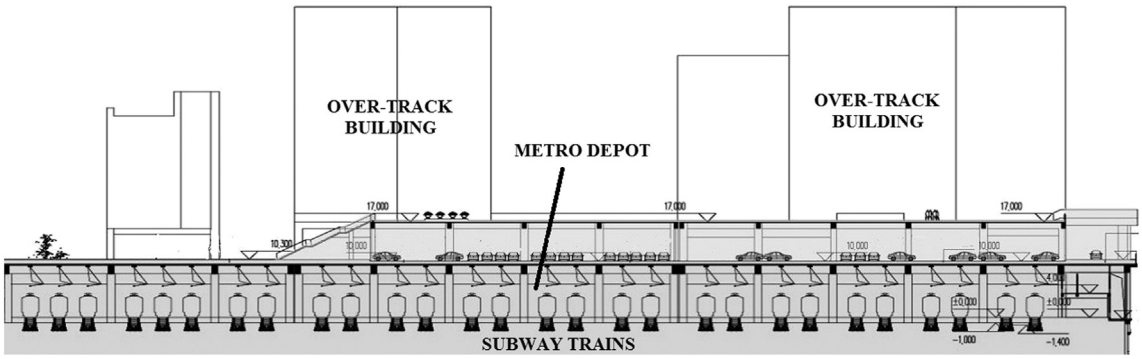

Fig. 1. Metro depot and over-track buildings.