Soil Dynamics and Earthquake Engineering 96 (2017) 89–103

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

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

Safe distance of cultural and historical buildings from subway lines

Javad Sadeghi*, M. Hassan Esmaeili

Iran University of Science and Technology, Tehran, Iran

ARTICLE INFO

Keywords:
Monumental buildings
Safe distance
Vibration
Subway
Soil media

ABSTRACT

Construction and operation of subways (metros) closed to historical sites have been one of the main concerns of the world heritage protection bodies such as UNESCO. While metros alleviate condense traffic conditions and boost the tourism industry, the metro induced vibrations might damage cultural and historical structures (CHS). Although there have been various studies into the metros vibration characteristics and the CHS protection methods, there is still a lack of sufficient investigations into the measures by which a safe distance of the CHS to the metro can be derived. In response to this need, a thorough theoretical and experimental investigation was made in this research, aiming at developing a safe distance prediction graphs (SD). For this purpose, a finite element model of the track and the surrounding media was developed. The advantage of the model over the current ones is the consideration of the real (in situ) train loading conditions as an input. The model was validated by comparisons of its results with those of a comprehensive field measurement carried out in this research. New classifications of the CHSs and the track sub-structure form the aspect of metro-induced vibrations were developed in this research. Through parametric analyses of the model, the SD was developed for the first time as a function of metro characteristics, geo-mechanical properties of the media between the metro and the CHS, and the type of CHS. The effectiveness and practicability of the SD in construction of new subway lines were illustrated. It was shown that the SD graphs developed here can be taken as an effective tool for the design of subway lines in historical cities.

1. Introduction

One of the most important challenges in the construction and operation of urban railways (particularly subways) is the possibility of railway damages to the neighboring structures, in particular monumental buildings. A recent report released by the Iran Cultural Heritage, Handcraft and Tourism Organization (ICHTO), indicates that severity of the damages to the historical structures due to the construction and operation of metros has been one of the main problems in the preservation of monumental structures in the Iranian historical cities [1].

There are noticeable increases in construction of rail infrastructures in the cosmopolitan cities, particularly in the Asian and Meade-East countries where there are many cities with considerable number of residential and monumental structures [1,2]. Although a subway system is a safer, more economical and faster system of transportation (compared to the other systems) and in turn, boost the tourism industry [3,4], the Long-term metro induced vibrations might seriously damage historical structures due to low-intensity steady vibrations [5–7].

In the last three decades, considerable number of investigations have been conducted on the behavior of the CHS under the vibrations from various sources including explosion [8,9], road traffic [10–12] and construction machineries [13,14]. Results of investigations have been compared with various allowable vibration levels to evaluate the building safety [15]. It has been shown that the vibrations of small amplitude characterized by a high number of cycles may cause deterioration of mortar, its detachment from the bricks and consequently reduction of masonry strength [16–18].

However, less attention has been paid to the effects of metro vibrations on the CHS [19]. The only serious research have been made by Ma et al. who focused on evaluating train vibration impact on a historic bell tower above two metro lines in China [19]. The majority of related investigations on protection of CHS from railway vibrations are limited to the mitigation of the vibrations at the source. For instance, Federal Transportation Association (FTA) has used a hybrid semi-empirical approach to investigate the railway vibration received by the surrounding structures and presented several mitigation measures for subway superstructure in the form of guidelines [20]. Vogiatzis and Kouroussis used the finite element modeling technique and in-situ measurements of floating slab tracks in the Athens Metro to evaluate the effectiveness of the floating slabs in reduction of the effects of the

* Corresponding author.
E-mail addresses: javad_sadeghi@iust.ac.ir (J. Sadeghi), m_h_esmaily@rail.iust.ac.ir (M.H. Esmaeili).

http://dx.doi.org/10.1016/j.soildyn.2017.02.008
Received 30 September 2016; Received in revised form 6 January 2017; Accepted 25 February 2017

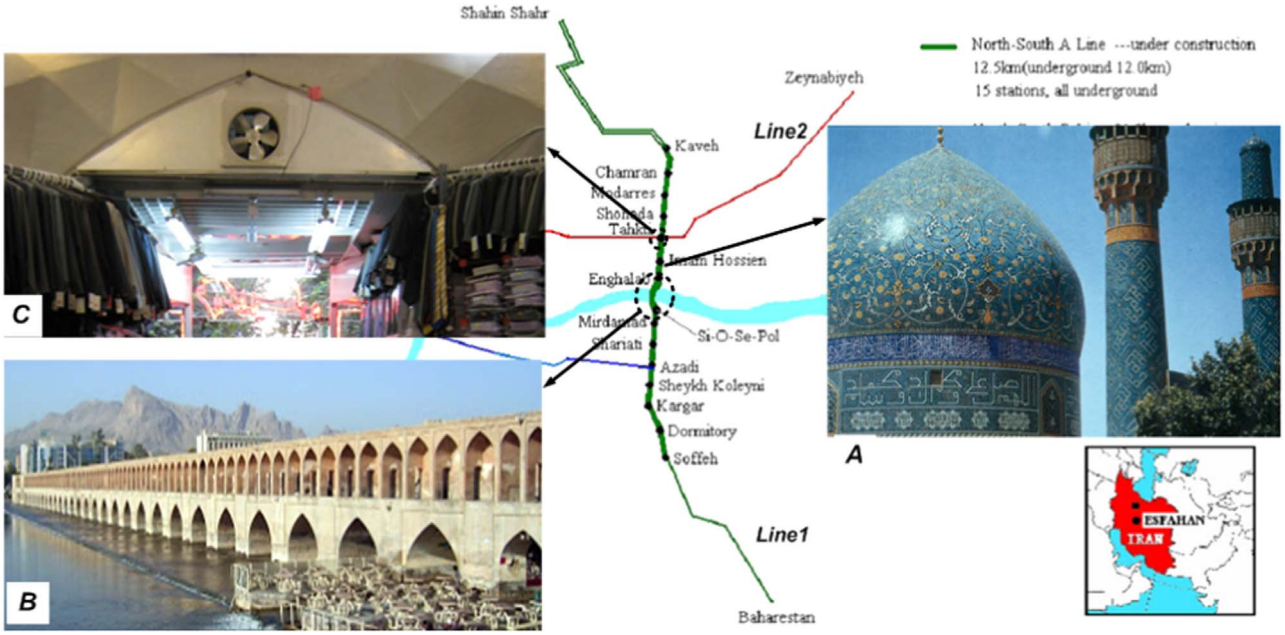

Fig. 1. Monumental buildings closed to line 1 of Isfahan subway, A) MCC; B) SSP and C) SKH.

Fig. 2. Instrumented monumental buildings to measure vibration received by historical structures using FTA method, A: MCH, B: SSP.

environmental induced vibrations on various high cultural value buildings along the given Athens Metro Extensions [21,22]. Cox and Wang made experimental studies to examine the effectiveness of different fastening and slab-track systems on the reduction of track vibration levels [23]. However, there is a need for a measure by which the safety of the CHS can be evaluated and in turn, the safe Metro-CHS distance for each type of subway superstructure, soil media properties, and various CHS categories can be derived/predicted. A review of the available literature indicates that there isn't any regulation or guideline for the safe Metro-CHS distance [19,24].

In response to this need, a comprehensive theoretical and experimental investigation was made in this research, leading to develop a