Engineering Structures 57 (2013) 296–305

Contents lists available at ScienceDirect

Engineering Structures

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

Global vertical mode vibrations due to human group rhythmic movement in a 39 story building structure

Sang-Hyun Lee, Kyung-Koo Lee *, Sung-Sik Woo, Seung-Ho Cho

Department of Architectural Engineering, Dankook University, Republic of Korea

ARTICLE INFO

Article history:
Received 16 October 2012
Revised 13 September 2013
Accepted 18 September 2013

Keywords:
Vertical vibration
Measurement test
Resonance
Vibration control device

ABSTRACT

In this paper, the field vibration measurement tests have been conducted for investigating the exact causes of the abnormal vibration accident which occurred on last July 5, 2011 in TechnoMart, a 39 story steel building structure. The vertical accelerations of the building floors were measured under the 4D movie-theater operation and human rhythmic movements in a fitness center which were estimated as ones of the vibration sources. From field tests, it could be identified that the building has global vertical vibration mode of 2.7 Hz natural frequency and human group rhythmic movements having frequency component mainly close to 2.7 Hz in a fitness center caused the resonance of the vertical mode. Especially, the fact that the identified damping ratio of the vertical mode by observing the free vibration response after the human group excitation was just 0.3%, implies that response amplification could be so significant that only 23 people could excite the 39 story building having the total mass of 30 thousands of metric ton move globally up and down. Tuned mass damper (TMD) is being considered as a measure for keep this resonance by adding damping to the building. The TMD design results shows that the acceleration level resulting from the same human excitation can be reduced to one fourth of that of the building without TMD.

1. Introduction

On July 5th in 2011, people in TechnoMart, a 39-story building structure in Gwangjin-gu, Seoul, Republic of Korea, felt the building shake vertically for about 10 minutes. Because there was no sign of an earthquake or strong wind that could shake the building, the residents were fearful that the building might collapse, like the Sampoong department store which collapsed without any external extreme loads caused by an earthquake, typhoon or bomb. After two days of evacuation of the residents, and detailed investigation of vibration sources, an inspection committee tentatively concluded that the most likely cause of the shaking was from vibrations caused by “taebo,” an aerobic sport that is a mixture of taekwondo and boxing, which was carried out in a fitness center on the 12th floor of the building. Based on this tentative conclusion, Techno-Mart was reopened, but many people still have a feeling of insecurity, and wonder how human movement can shake such a large-scale building structure.

Many previous studies reported cases where human movement and mechanical vibration could affect the serviceability, and even safety, of a building structure. Allen showed that human movement resulting from aerobic dancing and pop concerts caused excessive vertical vibration in a slab with larger span and smaller mass and damping, by investigating various vibration accidents that occurred in the United States, Switzerland, and Canada [1]. Recently, the span and weight of a building structure have become larger and lighter, respectively, with the rapid development of construction materials and technologies. Also, there are increasing numbers of cases in which a building has complex usage, such as office, residence, fitness center, and theater. These facts indicate that the number of vibration sources has increased, while building structures have become more vulnerable to vibration sources [2–4]. Longinow and Hannen suggested a guideline for preventing floor vibration problems due to human excitation, based on the case studies of office buildings, hotels, banks, and hospitals [5]. The International organization for standardization (ISO) presented ISO 2631 in 1989 for the evaluation of human exposure to whole-body vibration, including that in the vertical direction [6,7]. The Research fund for Coal and Steel Human conducted the project “Human Induced Vibration of Steel Structures (HIVOSS)”, and presented a guideline for determining floor responses due to dynamic human-induced forces [8].

A tuned mass damper (TMD) has been considered an effective means of controlling the vertical vibration of a structure [9]. Generally, the TMD has been used for suppressing the lateral or floor vibration of a building structure under wind or human load [10]. Also, TMD has been applied to the suppression of the vertical

* Corresponding author. Tel.: +82 31 8005 3742; fax: +82 31 8005 4038.
E-mail address: kklee@dankook.ac.kr (K.-K. Lee).

0141-0296/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.engstruct.2013.09.035

Fig. 1. 39-story TechnoMart building structure.

vibration of a bridge structure under traffic and pedestrian loads. Caetano et al. investigated the dynamic behavior of a long-span pedestrian bridge in Portugal and showed effectiveness of a TMD on the mitigation of vertical and horizontal responses [11,12]. Setareh et al. presented a component mode synthesis method for obtaining the optimal design parameters of a TMD for reducing floor vibration caused by human movement [13]. Pourzeynali and Esteki proved that the TMD could reduce the peak vertical displacement of a suspension bridge under earthquake loads [14]. Zhang et al. numerically analyzed the vertical resonance phenomenon of a stadium corridor caused by human movements, and applied the TMD for controlling this resonance vibration [15]. Also, in the Millennium bridge in England, a TMD was installed to suppress the vertical vibration due to pedestrian loads [16].

In this paper, the effects of the 4D movie-theater operation and human rhythmic movements, which were estimated as the likely vibration sources of the incident that occurred in TechnoMart, were evaluated through field vibration measurement tests. Human rhythmic movements were reenacted by the same number of people as was there at the time of the shaking on July 5, on the 12th floor of the fitness center of the building. Natural vibrating frequencies and damping ratios of the fundamental modes of the building structure were obtained by field tests. Finally, a TMD was proposed as a method for controlling this global vertical vibration of the TechnoMart, and the control effect was investigated by numerical analysis.

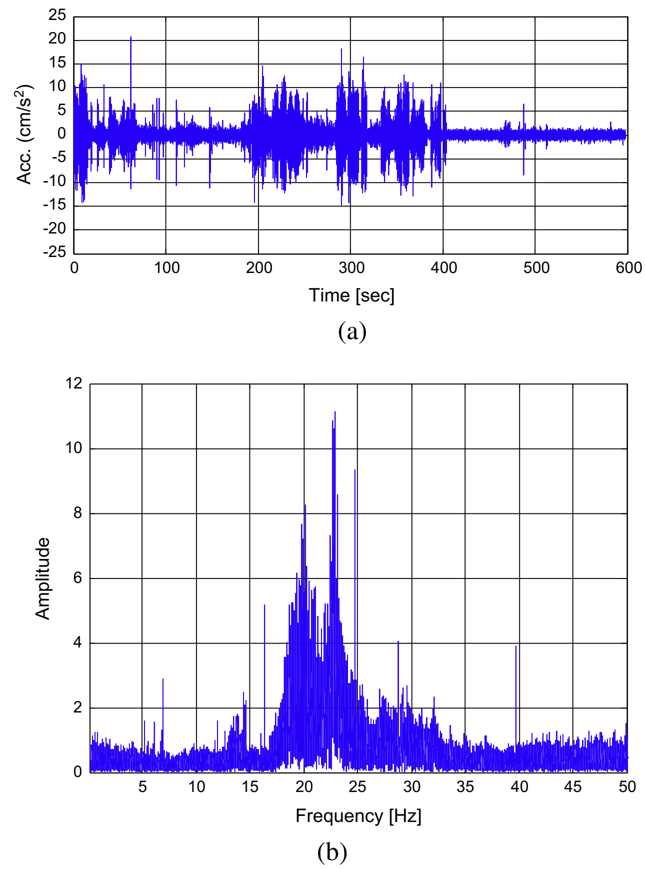

Fig. 3. Acceleration of the 4-D theater floor. (a) Time history. (b) FFT.

2. Outline of building structures

TechnoMart, shown in Fig. 1, is a 39 story building structure, with a height of 188.7 m, with 6 basement floors. The building was constructed in 1998, and it is composed of a 39 story high-rise part used as offices, and a 12 story low-rise part used as complex service facilities, such as shopping mall and theater. The people at the upper floors in the high-rise office building felt the building shake vertically. The office building has a rectangular plan of 69 m by 19 m, and was designed to resist wind and earthquake loads as a moment frame in longitudinal direction in plan, and as braced frame in the transverse direction. All columns and beams are made

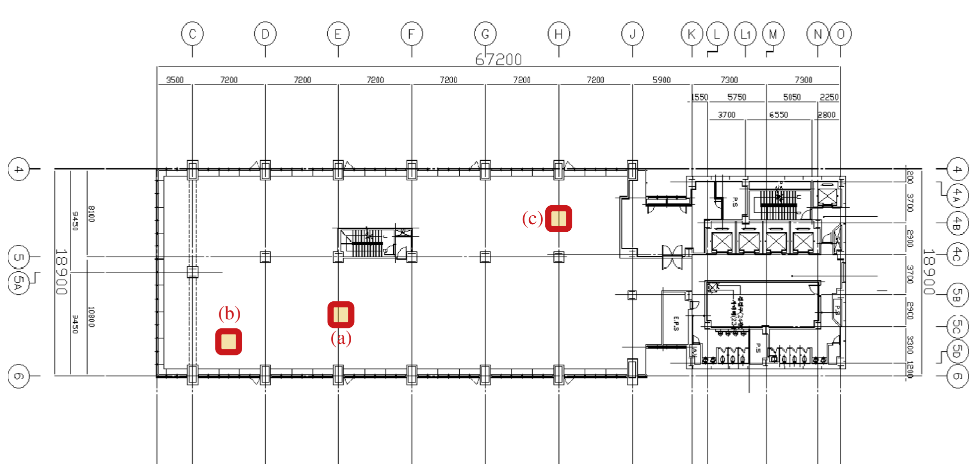

Fig. 2. Location of vibration sources and accelerometers. (a) G.X. room, (b) running on treadmills, and (c) stationary cycling.