Measurement 63 (2015) 87–99

Contents lists available at ScienceDirect

Measurement

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

Videogrammetric technique for three-dimensional structural progressive collapse measurement

Xianglei Liu [a,1], Xiaohua Tong [b,*], Xiaojing Yin [c], Xianglin Gu [c], Zhen Ye [b]

[a] Key Laboratory for Urban Geomatics of National Administration of Surveying, Mapping and Geoinformation, Beijing University of Civil Engineering and Architecture, 1 Zhanlanguan Road, Beijing 100044, PR China

[b] Department of Surveying and Geo-Informatics and Key Laboratory of Modern Engineering Surveying of State Bureau of Surveying and Mapping, Tongji University, 1239 Siping Road, Shanghai 200092, PR China

[c] Department of Architectural Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, PR China

ARTICLE INFO

Article history:
Received 10 September 2014
Received in revised form 27 October 2014
Accepted 26 November 2014
Available online 8 December 2014

Keywords:
Videogrammetry
Structural progressive collapse
High-speed CMOS camera
Displacement
Acceleration

ABSTRACT

In order to solve the shortcomings of the traditional transducers for monitoring the structural progressive collapse, this paper proposes to adopt the high-speed videogrammetric measurement technique to monitor the structural progressive collapse. First, the videogrammetric hardware components are presented. Second, three key issues about the stereo videogrammetric technique are studied in the paper, including camera calibration and placement, movable network control and tracking targets layout and image sequences processing. At last, three different kinds structural progressive collapse of five-story reinforced concrete frame-wall are performed, and the absolute accuracy of 0.43 mm, 0.87 mm and 0.65 mm and the relative accuracy of 0.61 mm, 0.29 mm and 0.62 mm are achieved in the *X*, *Y* and *Z* direction. The results show that the non-contacted videogrammetry is an alternative technique to monitor the structural progressive collapse.

1. Introduction

According to ASCE/SEI [1], the structural progressive collapse is defined as the spread of an initial local failure from element to element, which eventually leads to the collapse of an entire structure or a disproportionately large part of it. Generally, there are two main causes resulting in the structural progressive collapse. The first one is the manmade mistakes during the process of designing and construction of the structure, and the second is the accidental loading such as gas explosion, bomb attacks, vehicle collision and fire. However, no matter what kind of causes, the occurrence of structural progressive collapses inevitably leads to a serious loss of the lives and properties, and furthermore to a negative social impact.

Since the collapse of Ronan Point apartments in the United Kingdom in 1968, great efforts have been made for determining the dynamic behavior of the progressive collapse of structures [2]. For this purpose, the most frequently employed technique is the progressive collapse experiments based on the structure models. In the experiment, following a sudden removal of the primary structural component(s), the behavior of the progressive collapse of structure models can be observed by the use of spatial sensors. Traditional contacted transducers that have been widely used to collect dynamic data of the structural progressive collapse include the linearity variable differential transducers (LVDTs) [3–5], displacement gauges [6–9], accelerometers [7,10] and linear potentiometers [11,12]. However, there are essentially three major disadvantages of these contacted instruments with respect to

* Corresponding author. Tel.: +86 21 65988851; fax: +86 21 65981085.
E-mail addresses: liuxianglei@bucea.edu.cn (X. Liu), xhtong@tongji.edu.cn (X. Tong).
[1] Tel.: +86 10 683454204.

http://dx.doi.org/10.1016/j.measurement.2014.11.023
0263-2241/

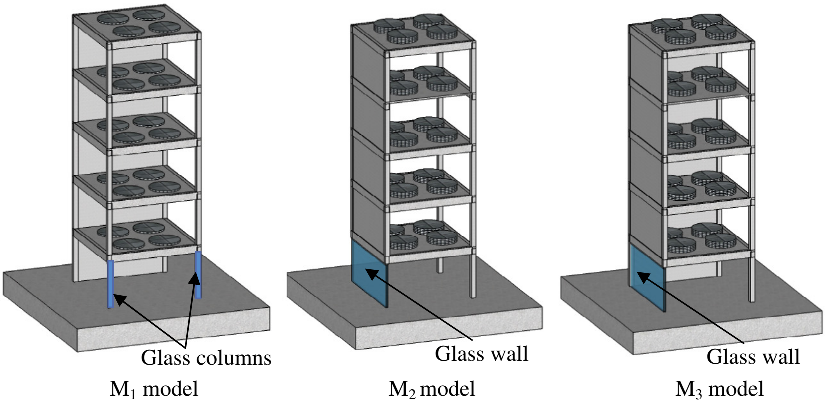

Fig. 1. Three structure models used in the experiment.

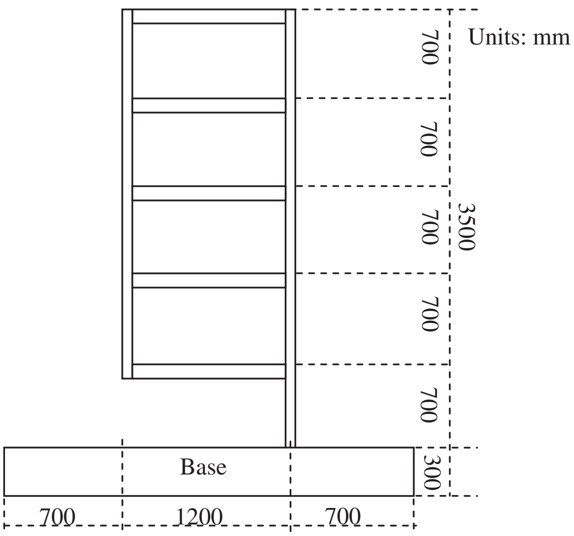

Fig. 2. Height size of the structure model M1.

the measurement of the structural progressive collapse: (1) each of the contacted transducers is positioned at some critical points on the structure surface, providing a local measurement rather than a full-range measurement of the structure; (2) each of the contacted transducers can only provide one-dimensional measurement rather than 3D (three-dimensional measurement) of the structure; and (3) each of the contacted transducers is likely to be damaged or failed during the collapse process as it is attached on the structure surface. At the same time, a large number of the traditional sensors would be required to position at critical points for monitoring the collapse process of large structures. As a result, the cost of using these traditional sensors would be rather high when the collapse experiment is supposed to be conducted many times. In addition, the use of piezoceramic-based smart aggregates was reported on the monitoring of the progressive collapse of the concrete frame [13], the evaluation of the impact of overheight truck-bridge collision on the concrete bridge girders [14], the damage detection of long reinforced concrete bridge bent-caps [15], as well as structural health monitoring of concrete columns subjected to shake table excitations [16]. The results showed that the smart aggregate is more sensitive in damage detection than the conventional transducers. However, it still has the same above-mentioned disadvantages as the conventional contacted transducers. Videogrammetry is an alternative technique for the full field 3D measurement of highly dynamic scenes using high-speed cameras at the image rates of several hundreds of frames per second (fps) and beyond. Compared with the conventional contacted sensors, videogrammetric technique has the following advantages: (1) videogrammetric technique is a non-contacted approach for providing the 3D measurement of dynamic objects, rather than providing the one-dimensional measurement at some critical points with the traditional ones; (2) videogrammetric technique is a wide-range measurement approach for providing the visual records of the entire change process of dynamic objects; and (3) videogrammetric technique is capable of repetitive measurements of dynamic objects. Since 1970s, videogrammetry has been widely used to track the positions of rigid as well as deforming flexible bodies as they move in diverse fields, such as Civil Engineering [17–19], Kinesiology [20], Environmental science [21,22] and Industrial inspection [23,24]. A number of studies have been reported on the applications of the videogrammetric technique to measure the dynamic characteristics of object vibration in the domain of civil engineering [25]. Maas and Hampel [25] reported an experiment showing the failure of a glass fibre roving for textile reinforcement of concrete parts based on a frame rate of 1000 HZ high-speed camera. Lin et al. [26] developed a monitoring system consisting of videogrammetry and terrestrial laser scanning for measuring displacement and deformation of as-built membrane roof structures. The result showed that an accuracy of better than 1 mm is achievable. Alemdar et al. [27] examined the surface deformations and rotations of a reinforced concrete bridge column under dynamic loading by videogrammetric system. Compared with the traditional instruments, an accuracy of approximate 1 mm is also achieved.

It should be noted that no significant literature can be found regarding the videogrammetric technique for