Engineering Structures 100 (2015) 442–454

Contents lists available at ScienceDirect

Engineering Structures

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

Dynamic properties of typical consultation room medical components

L. Di Sarno [a,*], C. Petrone [b], G. Magliulo [b], G. Manfredi [b]

[a] University of Sannio, Department of Engineering, Piazza Roma 21, 82100 Benevento, Italy
[b] University of Naples Federico II, Department of Structures for Engineering and Architecture, via Claudio 21, 80125 Naples, Italy

ARTICLE INFO

Article history:
Received 6 November 2014
Revised 18 June 2015
Accepted 18 June 2015
Available online 30 June 2015

Keywords:
Nonstructural components
Shake table test
Dynamic identification
Natural frequency
Damping
Hospital building contents
Finite element model

ABSTRACT

The dynamic response of typical components of a consultation room in hospital buildings is investigated through full-scale shake table tests. Low-intensity random vibration tests were carried out on two free-standing medical cabinets and a desk. The natural frequency and the damping ratio of the components are evaluated via standardized methods.

Simplified finite element models of the tested components are implemented in order to assess whether simplified models can adequately describe the dynamic behavior of medical components. The outcomes of the numerical analyses fairly match the results obtained from the experimental tests. It is demonstrated that simple models are able to adequately simulate the dynamic properties of sample medical components and can be employed in the earthquake response analysis of healthcare facilities.

1. Introduction

The failure of nonstructural systems, especially hospital building contents and services, represents about 80% of the loss exposure of critical buildings to earthquakes (e.g. [1]). It is thus essential to include the response of nonstructural components when assessing the seismic risk of hospitals, building contents and services. The essential functions of the hospitals must remain fully operational for at least 72 h to provide emergency response when an earthquake occurs, because of the increase of patients to be assisted. Consequently, the damage to structural and nonstructural components and the failure of building contents should be prevented in hospitals. Numerous reconnaissance surveys carried out in the aftermath of major world-wide recent earthquakes demonstrated that large financial losses were caused to health care facilities, especially hospital buildings (e.g. [2–9], among others). For example, the common surveyed damage includes the overturning of bookshelves containing medical files with patient details. Hazardous contaminants may also be released when the bookshelves overturn; hence, there is a number of dangerous consequences caused by the lack of seismic protection, e.g. through restrainers and links to the walls. The connections between the surgery lamps and the slab may be severely damaged during a strong motion shaking. The medical lamps of the surgery rooms are heavy cantilever components, which are clamped to the slab. During the combined horizontal and vertical component of the earthquake ground motions such lamps may experience large oscillations, thus imposing large demands on the connections with the slab. The above connections may fail and, in turn, they impair the functionality of the surgery room.

There are sound procedures to evaluate the structural seismic performance of several building systems; such procedures are implemented in codes of practice (see, for example, [10–13]). However, there is a lack of reliable yet simplified numerical models and adequate seismic analyses to either design or assess the earthquake performance of freestanding medical laboratory nonstructural components. The latter components generally consist of complex sub-assemblages made of either metallic or wooden frames and/or plates. The evaluation of their dynamic response is not straightforward as it exhibits high nonlinearities; it significantly depends on the friction coefficients of the equipment supports. The mechanical properties of the interface contact, between the heavy medical equipment and the laboratory floors, can be experimentally determined by conducting slow-pull tests on the equipment. Simplified idealizations of the interface contact include elasto-plastic and the classical Coulomb friction models, where static and kinetic friction coefficients are utilized [14]. The static friction coefficient remarkably depends on the type of the pull-force. The kinetic friction coefficient exhibits a pressure and

* Corresponding author. Tel.: +39 0824 305566; fax: +39 (0)824 325246.
E-mail addresses: ldisarno@unisannio.it (L. Di Sarno), crescenzo.petrone@unina.it (C. Petrone), gmagliul@unina.it (G. Magliulo), gamanfre@unina.it (G. Manfredi).

http://dx.doi.org/10.1016/j.engstruct.2015.06.036
0141-0296/

Table 1
Test program details.

Test group	Plan configuration	Cabinets contents
1000	1	Equivalent mass uniformly distributed along the height
2000	1	Equivalent mass non uniformly distributed along the height
3000	1	Typical glass contents uniformly distributed along the height
4000	2	Equivalent mass uniformly distributed along the height
5000	2	Equivalent mass non uniformly distributed along the height
6000	2	Typical glass contents uniformly distributed along the height

velocity dependence. Sliding, rocking and overturning are the most common failure modes that may affect the response of freestanding medical furniture (e.g. [14–17]). Several seismic codes [18] do not deal with the use of friction for nonstructural components. However, many medical equipment could be hardly used if they were rigidly connected to the floor. For instance, while a cabinet could be fixed to the wall, the desk should remain unrestrained on the floor. An inaccurate approach of the current building codes is therefore evidenced.

Few experimental and numerical studies have been carried out to assess the seismic vulnerability of typical medical equipment [14,19,20]. There is however an urgent need to provide an insight into the modal identification of the typical components of hospital buildings.

Toward this aim, a shake table test campaign is carried out to investigate the dynamic response of the most common components of a typical hospital consultation room. Low-intensity random vibration tests are performed on two freestanding cabinets, considering different mass configurations in the cabinets, and a desk. Both the natural frequency and the damping ratio of the components are investigated. Simple finite element models of the tested components are implemented and their dynamic properties are compared with the experimental outcomes. The aim of the paper is to demonstrate that simplified models can adequately simulate the dynamic behavior of medical components for practical use.

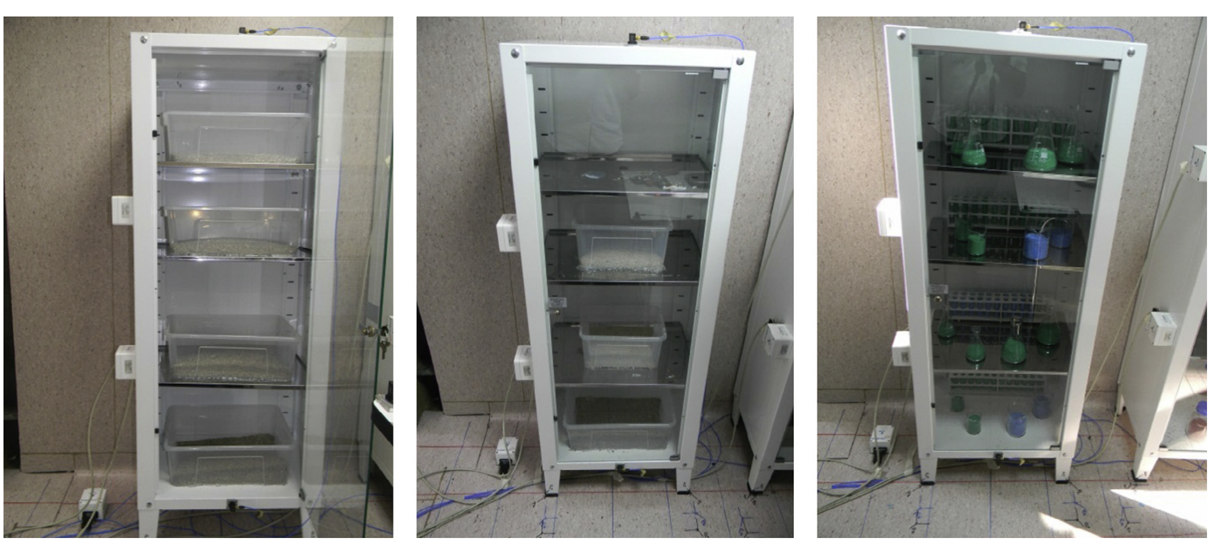
2. Experimental evaluation of modal response with shake table tests

The seismic tests on hospital building contents are carried out by the earthquake simulator system available at the laboratory of Structures for Engineering and Architecture Department of University of Naples Federico II, Italy. The system consists of two $3\ m \times 3\ m$ square shake tables. Each table is characterized by two degrees of freedom along the two horizontal directions.

A steel single-story framed system is designed with the purpose of simulating the seismic effects on the medical contents of a typical hospital room. The test frame is designed in order to simulate the effects of the earthquake ground motion at different floors on a hospital building; its large stiffness prevents the onset of the resonance. The effects of the interstorey drift were not considered, because they are not relevant for the problem at hand. The layout of the model consists of a $2.42\ m \times 2.71\ m \times 2.72\ m$ test fixture of S275 steel material with concentric V-bracings. Further details on the steel test setup are included in Magliulo et al. [21].

A typical hospital examination (out patients consultation) room background is reproduced within the sample steel frame. Plasterboard partitions and ceilings are mounted; linoleum sheets are also installed to cover both the floor and a large portion of the internal partitions. An overhead light and a ray film viewer are also installed in the room. The building contents used for the examination room include: (a) a hospital medicine cabinet made of cold formed sheet with dimension $75 \times 38 \times 165$ cm, having double moving glass doors with locker and four mobile shelves; (b) a hospital medicine cabinet made of cold formed sheet with dimension $53 \times 36 \times 139$ cm, having single moving glass door with locker and four mobile shelves; (c) a desktop computer (monitor, case, keyboard and mouse); (d) a desk made of a steel pipe frames and a wooden desktop. The mass of the two cabinets is respectively 15 kg for the single-window cabinet and 20 kg for the double-window cabinet; the mass of the desk is 31.6 kg. Cabinet contents with different slenderness, as flasks, test tubes, glass beakers and glass bottles, are placed in the cabinets to simulate the actual conditions of a typical hospital room. Different mass distributions are also selected to distribute such contents in the single- and double-window cabinets.

The present experimental research focuses on realistic medical components, i.e. cabinet with shelves loaded with different



(a) (b) (c)

Fig. 1. Single-window cabinet in (a) test groups 1000 and 4000, (b) test groups 2000 and 5000 and in (c) test groups 3000 and 6000.