Contents lists available at ScienceDirect





Automation in Construction

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

Automated seismic design of non-structural elements with building information modelling



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ARTICLE INFO

Keywords: Non-structural elements Automated seismic design Sprinkler piping system Building information modelling

ABSTRACT

The seismic performance of non-structural elements is nowadays recognized to be a key issue in performancebased earthquake engineering. The knowledge of construction details within a building is of paramount importance in order to reduce uncertainties and improve the quality of the analysis and design, particularly in regards to non-structural elements. The use of Building Information Modelling (BIM) could represent a new frontier in the seismic design of non-structural elements by increasing the reliability of the seismic design and/or assessment. This study discusses the effectiveness of using Building Information Models in seismic design of nonstructural building elements. A simple tool has been developed to perform automatically the seismic design of sway braces for pressurized fire suppressant sprinkler piping systems based on information extracted from a Building Information Models. The effectiveness of the proposed procedure was validated via a case study.

1. Introduction

Non-structural elements represent all the systems and elements attached to the floors and walls of a building that are not part of the loadbearing structural system [1]. Modern building codes worldwide generally classify non-structural elements into three main categories: 1) architectural elements, 2) mechanical and electrical equipment and 3) building contents. The architectural elements include suspended ceilings, partition walls, window systems and all those elements that form part of the buildings. Mechanical and electrical equipment are built-in non-structural elements that include electrical equipment, HVAC equipment, cooling towers, and piping systems. Finally, building contents belong to the occupants of a building and include computer and communication equipment, bookshelves and filing cabinets. Fig. 1a shows a three-dimensional view of a portion of a building with common non-structural elements along with typical structural components. According to Miranda and Taghavi [2], non-structural elements represent most of the total investments in typical buildings. In hospital buildings, for example, the structures make up approximately only 8% of the total monetary investments (Fig. 1b).

The damage induced in non-structural elements during recent earthquakes demonstrated their vulnerability to accelerations and displacements that arise from the structure's seismic response. A significant part of the observed earthquake related losses in recent earthquakes worldwide has been attributed to the damage to nonstructural elements. The non-structural elements without seismic design generally exhibit damage at low seismic intensities and can significantly affect the immediate functionality of buildings [4]. This issue is of paramount importance for strategic facilities, such as hospitals and schools that should remain operational in the post-earthquake emergency response [5]. During the recent 2010 Chile earthquake, the Santiago International Airport was closed for several days following the significant damage to the piping systems interacting with ceiling systems [6]. During the same earthquake, four hospitals completely lost their functionality and over 10 lost 75% of their functionality due to damage to fire sprinklers [6]. During the 2001 Nisqually earthquake in the Seattle region in the United States (US), considerable damage was observed to suspended ceiling systems and interior partition walls [7]. During the 2009 L'Aquila earthquake in Italy, one of the most common non-structural element failures was related to partition walls experiencing large in-plane inter-storey drifts [8,9]. Significant damage to non-structural elements has been also observed during the 2012 Emilia earthquake in Italy. In this seismic event, industrial facilities reported large economical losses often related to the failure of rack systems [10].

In the light of these considerations, the seismic performance of nonstructural elements is nowadays recognized to be a key issue in performance-based earthquake engineering (PBEE) in order to ensure a desired structural system performance for a given intensity of seismic excitation [11]. The most developed guidelines for the application of PBEE are those included in the FEMA P-58 document [12] developed

http://dx.doi.org/10.1016/j.autcon.2017.09.002 Received 29 December 2016; Received in revised form 12 June 2017; Accepted 5 September 2017 Available online 09 September 2017 0926-5805/ © 2017 Elsevier B.V. All rights reserved.

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Structural Non-structural







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Fig. 2. Overview of the four stages of PEER PBEE framework, after [13].

largely based on research conducted by the Pacific Earthquake Engineering Research Center (PEER). The FEMA P-58 procedure allows the probabilistic seismic assessment of the building performance through a multi-stage process based on PEER's PBEE framework. As illustrated in Fig. 2, the PEER's PBEE framework involves four stages: 1) hazard and facility definition analysis, 2) structural analysis, 3) damage analysis and 4) loss analysis.

Fig. 1. Typical non-structural elements and economical investments.

a) Typical non-structural elements, after [3].b) Relative investments in typical buildings, after [2].

The first two stages represent the conventional steps in earthquake engineering analysis. In the facility definition stage, the structural configuration and the seismic hazard at the facility location are evaluated. During the structural analysis stage, a structural model of the building is subjected to seismic excitations of various intensities in order to evaluate the maximum response in terms of displacements, forces and accelerations. The third stage of the performance evaluation consists in the damage analysis, which establishes the probability that a certain element (structural or non-structural) in the building will exceed a certain damage state for a given intensity level (using the structural analysis results together with the element fragility functions) [14]. Given the numerous types of structural and non-structural elements that can be found in a building, the availability of element fragility functions depends on extensive experimental investigations [15-16]. Finally, the last stage of the procedure includes the computation of decision variables such as monetary loss due to repair costs, loss of use of facility (downtime) or the likelihood of injuries and/or fatalities. For each damage states defined during the analysis, the consequences for all elements over the range of possible intensity levels are established.

The importance of non-structural elements in the PBEE framework is evident, considering the non-structural damage observed during past earthquakes. The losses and consequences related to the damage of nonstructural elements are much higher than those due to structural elements, in particular for low intensity seismic events. The knowledge of details within a building is of paramount importance in order to reduce uncertainties and improve the quality of the analysis results, particularly in regards to non-structural elements. With this in mind, the use of Building Information Modelling (BIM) could significantly increase the accuracy of a seismic assessment. Building Information modelling is defined by international standards as "a shared digital representation of physical and functional characteristics of any built object which forms a reliable basis for decision" [17]. BIM is a tool to manage accurate building information over the whole life cycle of a facility and is able to support data beyond the design and construction phases, such as the management, maintenance and deconstruction processes [18-19]. The detailing of all elements available in Building Information Models is essential in the PBEE assessment framework in order to properly attribute damage characteristics (fragility functions), define the quantities (for the estimation of repair costs) and evaluate the repair time. This paper discusses how the information available in Building Information Models could be used for the seismic design of non-structural elements in order to reduce the seismic risk of new and existing buildings. A case study is presented on the automatic seismic design of pressurized fire suppressant sprinkler piping systems using BIM.

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