Engineering Structures 92 (2015) 29–45

Contents lists available at ScienceDirect

Engineering Structures

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

Experimental and numerical study of a half-scaled reinforced concrete building equipped with thermal break components subjected to seismic loading up to severe damage state

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ARTICLE INFO

Article history:
Received 28 May 2014
Revised 20 February 2015
Accepted 4 March 2015
Available online 20 March 2015

Keywords:
Numerical modeling
Reinforced concrete
Cast3M
AZALEE
TAMARIS
Thermal break component
Shaking table

ABSTRACT

A half-scaled reinforced concrete (RC) structure designed with an irregular shape to exhibit coupling torsional/bending effects and equipped with thermal break components was subjected to seismic tests. The aim of the experimental campaign was to analyze the influence of the thermal break components on the overall behavior of the mock-up in order to close the gap between the thermal and the seismic requirements in case of strongly irregular RC structures. The analysis of the experimental results is supported by experimental/numerical comparisons using an homogenized constitutive law to describe the behavior of a representative volume element (RVE) of RC. The observations show that the thermal break components do not significantly modify the dynamic behavior of the RC structure and ensure almost the full load transfer between the shearwalls and the connected slabs.

1. Introduction

Reinforced concrete (RC) wall bearing structures are widely used as primary resisting lateral load system either for new or existing constructions. Sometimes, design engineers have to deal with buildings being irregular in the plane and regular in elevation. This structural geometry generally leads to some issues when dealing with the seismic assessment of such complex structures. For instance, specific nonlinear effects at localized positions may appear as well as coupling torsional/bending responses [1–9]. The thermal performance of such structures is becoming a requirement in European countries [10]. Consequently, many research works have been carried out to limit, ideally to erase, the sources of thermal dissipation between the building and the external environment [11–13]. Successful insulation techniques and dedicated components have been developed, leading to a drastic reduction of the thermal energy loss. Indeed, new structural components called *thermal break components* have been designed to improve the in-building thermal insulation. Despite the fact that such a technique of insulation appears as promising regarding the results coming from the thermal analysis, their effects on the overall mechanical response of the equipped structure have still to be addressed, especially when considering seismic loadings.

The issue of thermal and seismic compatibility rose in case of conventional buildings. Nevertheless, the work carried out so far to address this issue is mainly related to beam-column type structures. Although this structural configuration is recommended by design rules for conventional building for instance, it is not forbidden to consider wall based structures (even irregular) for conventional applications. One of the originalities of the research exposed in this paper resides in this key point. In addition, the fact of assessing the seismic response of a RC structure equipped with thermal break components that exhibits torsional effects is also a key point since the thermal break components have not been initially designed to withstand torsion. Within the framework of the European research project *Seismic Engineering Research Infrastructures for European Synergies* (SERIES) financially supported by the 7th frame research program, experimental and numerical studies of the seismic behavior of an asymmetric half-scaled mock-up equipped with thermal break components have been carried out. The objectives of this research project are (i) to

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http://dx.doi.org/10.1016/j.engstruct.2015.03.017
0141-0296/

assess the overall seismic behavior of such structures to provide quantitative pieces of knowledge and (ii) to analyze the local behavior of thermal break components under seismic conditions.

To reach these objectives, seismic tests have been carried out with the AZALEE shaking table of the TAMARIS experimental facility of the French Atomic Energy and Sustainable Energies Commission (CEA), operated by the Nuclear energy Division (DEN). The main advantage of the shaking table tests is their capability to represent inertial forces considering a physical time scale. A mock-up of a RC specimen designed according to the Eurocodes 2 (EC2) and 8 (EC8) has been built and then, equipped with thermal break components. Bi-directional seismic loadings, all gathered in a seismic testing sequence, with increasing peak ground accelerations (PGAs) have been applied to the specimen to assess its seismic behavior up to severe damage state. The input signals are synthetic, they have been generated using the design spectra defined in EC8. Local data acquisition systems were used to monitor the thermal break components behavior. In addition to the experimental investigations, a numerical study has also been carried out.

This paper is outlined as follows. In Section 2, the experimental program is presented. The half-scaled mock-up design and its geometry are exposed. A specific attention is paid to present the thermal break components. Measured data regarding the mechanical characterization of the constitutive materials, not only for the RC mock-up but also for the thermal break components, are given. Then, the seismic sequence and the measurement points of interest are presented. Section 3 is dedicated to the dynamic identification of the RC structure. Hammer shock tests and white noise excitations are used to assess the initial dynamic properties and their evolution during the seismic sequences. In Section 4, the seismic response of the mock-up is presented and analyzed. A focus on the local behavior of the thermal break components is made so as to quantify their influence on the overall behavior. Section 5 is dedicated to the numerical analysis of three successive seismic loadings with PGAs equal to 0.2, 0.4 and 0.6 g. Structural and local results are presented and discussed in order to assess the relevancy of the modeling approach through experimental/numerical comparisons before drawing a few concluding remarks in Section 6.

2. Experimental program

2.1. Specimen design and geometry

The specimen represents a typical three storey conventional building. The shape of the specimen is inspired by the one considered within the framework of SMART 2008 project [14]. However, it is important to highlight that the specimen considered in this study is not devoted to nuclear applications as it is in case of SMART 2008 project. Therefore, the design practices followed are not the ones considered in the French nuclear industry but are the ones considered in case of civil engineering buildings. The following criteria have been considered in the definition of the full scale specimen:

- the design was realized according to EC8;
- the concrete and reinforcement grades were selected as C25/30 and Fe500-3, respectively;
- the structure was composed of uncoupled walls and thus according to EC8 it is considered in the DCM ductility class and classified as torsionally flexible system;
- the seismic parameters were chosen to represent a moderate seismic area like the Mediterranean seismic area: the design spectrum was represented by Type I spectrum with soil type C. The nominal acceleration value was assumed to be 0.3 g.

Due to the shaking table dimensions, the full scale structure could not be tested. A reduced scaled mock-up at the 1:2 scale had to be built for this reason. In order to ensure, as best as it could be done, the representativeness of the measurements carried out on the reduced scaled mock-up, a similitude rule had to be introduced. The similitude rule considered in this study is the Froude's rule [15] that was developed with the aim to keep unchanged the stress and the acceleration field through the scale change. To keep these quantities constant, the requirements lied in considering both (i) a time contraction and (ii) an increase of the mass density of the constitutive materials (both steel and concrete). In addition, the design spectrum of the RC mock-up is obtained by dividing the period of the design spectrum related to the full scale structure by the square root of the scale factor (equal to 2). The full scale structure should have its first three eigenfrequencies in the range 4–14 Hz (or 0.071–0.250 s if it is expressed in period). Due to the scale change, the reduced scaled mock-up should have its first three eigenfrequencies in the range 5.65–19.79 Hz (or 0.050–0.176 s if it is expressed in period). This requirement was considered to make compatible the frequency content of the loading and the natural frequencies of the tested system.

The condition (ii) could not be fulfilled accurately since it was not possible to act on the mass density from a practical point of view. Therefore, additional masses were put on the slabs, assuming most of the mass is concentrated on them. For this purpose, 6.45 tons were put down on each floor, leading to a total amount of additional mass equal to 19.35 tons. The total mass of the mock-up loaded with the additional masses is about 40.2 tons. This strategy has been defined to make the reduced scaled structure the most representative of the full scale one. If it is considered that the similitude rule is fulfilled, both the stress and the acceleration field are not modified. This strategy allows conserving the original materials for the construction of the specimen and using classical constitutive laws for numerical modeling purposes. A picture of the ENISTAT mock-up is shown in Fig. 1.

The structural frame is composed of various components: three shearwalls, one column, three beams, three slabs and one footing. The main dimensions of the formwork are given in Fig. 2. Some indications about the steel reinforcing bars arrangement are given in Table 1.

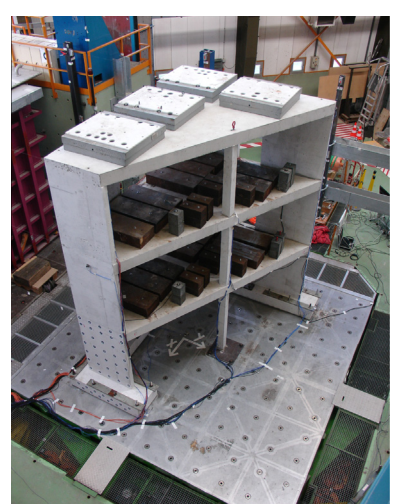

Fig. 1. Picture of the ENISTAT RC mock-up.