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Research paper

Nonlinear analysis of a building surmounted by a reinforced concrete water tank under hydrostatic load

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ABSTRACT

This work presents a methodology for assessing the damage level of an existing structure under seismic action. First, the seismic demand is introduced by the response spectrum provided by the seismic code, and then the nonlinear static equivalent analysis is performed by structural finite element software to obtain the capacity curve. The evaluated performance point according to the pushover analysis is positioned in European macroseismic scale in order to deduce the damage domain of the structure. The effectiveness of this proposed method is tested successfully for a real case. As a practical application, we analyse a highly complex structure which is an apartment building in Algiers surmounted by a reinforced concrete water tank with a container capacity of 1000 m^3. It is complex in its design and analysis, and complex also by its behaviour under earthquake effect. Since being commissioned in 1962, this structure has been subjected to several earthquakes, but the one that hit Boumerdes town on 2003, was fatal for it. The proposed approach classifies the studied structure in the third domain; which describes a very important state of damage. This work fits into a practical environment of the engineering by combining analysis software with design codes and by the applicative character of the proposed approach.

1. Introduction

The phenomenon of earthquakes is not new or specific to Algeria. It appears cyclically from one region to another causing sometimes immeasurable damage that no other natural forces can cause. The recent earthquakes (Table 1) reveal the weakness of civil engineering structures comparing to the destructive power of these events [1].

The earthquake of May 21st 2003, with a magnitude of 6.7 on Richter scale that hit Boumerdes (located 40 Km East of Algiers) caused considerable loss of human lives (1391 victims) and significant property damage where more than 10,000 houses were completely destroyed. The damages were estimated at more than US $ 3 billion. According to the preliminary report of the experts' mission of AFPS (French Association for Earthquake Engineering) several vital public facilities such as bridges and water storage tanks were affected at least through cracks [2]. Among these structures, we find the building surmounted by a tank which is the subject of our study (Fig. 1).

The present study focuses on the seismic performance assessment of this complex structure (building surmounted by a tank) which belongs to the Algerian company of water distribution in Algiers. It is located in the municipality of Dar El Beida (Algiers), classified as a high seismicity zone by the Algerian seismic code (RPA2003) [3]. Initially, this structure has been the subject of a research undertaken by Hamitouche et al. [4]. A linear analysis was conducted by modelling the structure using the finite element technique with the structural finite element software Robot©. Thus, they were able to identify the damages causes on the central core of the structure caused by the earthquake of Boumerdes. One of the main results highlighted in this study is the map of cracks obtained by numerical simulation when the tank was full that agrees well with cracks found on the central core during the investigation. The study concluded that the tank was full at the moment of the earthquake.

A structure subjected to a violent earthquake is stressed beyond the elastic domain and has a nonlinear behaviour. Because of the elastoplastic behaviour of the reinforced concrete (RC), degradation appears gradually in various parts of the structure, causing plastic deformation or damage, from which follows a redistribution of forces. Therefore, the use of linear analysis and calculations to failure based on the principles of limit analysis are not sufficient. In order to address problems of safety to structures failure, it is necessary to know deformations that limit analysis could not provide. We deduce that the static linear analysis as the study conducted by Hamitouche et al. [4] becomes insufficient. After this first study, some questions remained without answers, such as the

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Table 1
Some previous earthquakes.

Epicentre	Country	Year	Magnitude
Kobe	Japan	1995	7,3
Izmit	Turkey	1999	7,6
Boumerdes	Algeria	2003	6,7
Kashmir	Pakistan	2005	7.6
Sichuan	China	2008	7,9
Haiti	Haiti	2010	7,0

Fig. 1. General view of the structure (building-tank).

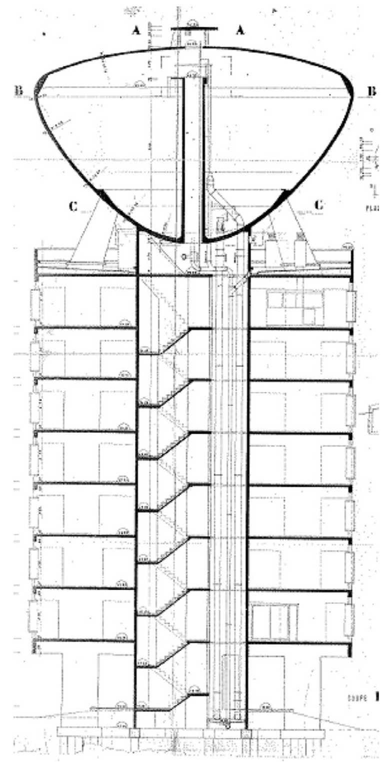

Fig. 2. Longitudinal cross section of the structure (building-tank) [12].

performance point, defining the working domain (elastic or plastic) of the structure, damage rate, and the penetration rate in the ductility for a given seismic intensity.

Consequently, the need to a better description of the structure performance to earthquake and a better assessment of its seismic vulnerability, require the use of nonlinear methods. The nonlinear static procedure is one of the four analysis methods (Lateral forces analysis method, modal analysis using a response spectrum, nonlinear static analysis and nonlinear temporal analysis) recommended by the new codes for paraseismic conception such as Eurocodes (EC8 in its part 3) [5].

The nonlinear static analysis called pushover analysis is used to evaluate the performance of a structure and its components for a given seismic action. Several nonlinear static analysis approaches have been developed, but the most known and the most used are the displacements method (FEMA) [6] and the capacity spectrum method (ATC40) [7] taken up in Eurocodes [8].

The FEMA 273 method developed in 1997 and published in the United States by the Federal Emergency Management Agency (FEMA) is presented as a technical guide. The capacity curve is constructed from an increasing load where the target displacement is located. Relative displacements on each floor of the building are evaluated and compared to the permissible relative displacement of FEMA273.

The ATC 40 method, designed for reinforced concrete constructions, published in the United States in 1996 by Applied Technology Council, is innovative compared to conventional approaches. By correlating the capacity curve of the displacement building with a maximum displacement caused by seismic motion of the given soil, determined by a proposed method in the document, a point called "performance point" is obtained.

In this paper already presented at the CC2015 [9], a new approach is proposed, combining the analysis software with design codes to assess damage level of the existing structure. The seismic performance of the structure is evaluated taking into account the hydrostatic effect using a static equivalent nonlinear analysis called pushover and exposed in the ATC40. The structural finite element software Etabs© [10] is used to perform the nonlinear analysis. The maximum displacement of the structure and the degree of its damage is estimated. The present paper extends the work of Hamitouche et al. [4] to provide an understanding of the structure behaviour. It is important to mention that in spite of the importance of this type of structure and the serious threat posed by possible failure, there are few published works or case studies on the subject.

2. Description of the building-tank

A detailed description of our structure (Fig. 2) is given in [11]. So we could read as follows: "*The building is a tower with a square form of 17 m of side, seven floors surmounted by a tank with a container capacity of 1000 m*^{3}*. This construction consists of a cylindrical central tower of 6 m of diameter, supporting the tank and around which are arranged in a star eight concrete walls forming the frame (Fig. 6). The bracing is provided by the floor. All is founded on 62 Franki piles of 13 m of depth through footings and great rigidity beams. Each floor consists of four apartments with three rooms, except the first which includes eight studios. The central tower includes the stairs, elevator, levels of access to the apartments, and the ducts through which pass tank pipes. The tank is constituted of a container in the paraboloid of revolution form connected to a spherical dome. The facades do not include bricks, at least externally, but largely use glass, plastic and aluminium. The ground floor is open and can be used partially as shelter to vehicles. The concreting of the tank was*

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