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Seismic behaviour of reinforced concrete shear walls with regular and staggered openings after the strong earthquakes between 2009 and 2011

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ABSTRACT

The strong earthquakes recorded worldwide, between 2009 and 2011, have shown that the damages and the failure mechanisms of the reinforced concrete structural walls depend on a series of factors, such as: the shape in plan and elevation, the dimensions of the walls and openings, the reinforcement and the openings layout, the site conditions, the type of earthquake and the strain rates. Even if failure modes have been extensively researched, there are still certain failure modes we know little about. This is the case of the walls with staggered openings, whose rigidity, bearing capacity, high ductility were highlighted after the earthquakes of 1985 and 2010. Theoretical and experimental studies have been conducted on three types of walls with vertical staggered openings, one with regular openings and a solid wall. The models were loaded until failure and provided information on: the forces, the horizontal displacements, and the maximum stresses and strains recorded in the concrete and in the reinforcement. We compared the sequence of the yielding of the reinforcement and the crushing of the concrete, for models with the same amount of reinforcement and the same physical and mechanical properties of the concrete. The main aims of this study are the following: to present the failure mechanisms recorded after the earthquakes between 2009 and 2011, to explain their failure modes based on the latest recordings of seismic wave characteristics, to present the recordings made at the ground level and on the bearing elements of the constructions and to analyse the advantages of the reinforced concrete structural walls with staggered openings subjected to seismic loads function to the position of the openings.

1. Introduction

Earthquakes occur on all the continents. During the period between 2009 and 2011, there were recorded a series of strong earthquakes which caused a lot of deaths and significant damages. Thus, for example, in Europe: L'Aquila, Italy, earthquake, April 6, 2009, (6.3 magnitude) [1], in South America: earthquake in Chile, February 2, 2010, (8.8 magnitude) [2], Christchurch, New Zealand, February 22, 2011, strong quakes (6.3 magnitude) [3], Tohoku, Japan, March 11, (9.0 magnitude) [4], Ercis-Van, Turkey, October 23, (7.1 magnitude) [5].

Various buildings collapsed, among which we name: the Duca D'Abruzzi Hotel from L'Aquila (Fig. 1) [1], the Alto Rio residential building from Conception, Chile (Fig. 2) [2], the Pyne Gould Cooperation office building from Christchurch, New Zealand (Fig. 3) [3], the school from Gedikbulak, Van, Turkey (Fig. 4) [4].

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Fig. 1. Collapse of part of the Duca D'Abruzzi Hotel, L'Aquila, 2009 [1].

Fig. 2. Collapsed Alto Río tower, conception, Chile, 2010 [2].

Fig. 3. Collapsed Pyne Gould cooperation PGC building, Christchurch, New Zealand, 2011, [3].

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The buildings with reinforced concrete structural walls have recorded several failure modes of the walls after these earthquakes, which confirmed the results of the theoretical and experimental tests. The research based on the failure modes developed by the reinforced concrete buildings, after the strong earthquakes between 2009 and 2011, identified new factors which had led to the collapse and damage of the buildings.