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Failures of multi layered infill walls during seismic excitation

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Abstract:

Non-structural element damage or failure that trigger structural members' collapse are rarely investigated after the earthquakes. Multi-layered infills walls which is one of the non-structural element type are generally constructed with hollow brick as multi layered walls to increase the structural performance and provide heat and sound isolation at Reinforced Concrete (RC) buildings. Role of these type of infill walls have been investigated against to seismic response of RC framed buildings with field observations after the earthquakes, all over the world. This study focuses on main reasons of failures of multi-layered infill walls during the May 1, 2003 Bingöl (Mw=6.4) and October 23, 2011 (Mw=7.2); November 9, 2011 (Mw=5.7) Van earthquakes in Turkey. In this paper, in-plane, out-of-plane and combined failure mechanism of this type of walls were investigated and construction rules were suggested.

Key words: Multi-layered infill wall, earthquake, non-structural damages, field observation

1. Introduction

During the design phase of the reinforced concrete (RC) buildings, contribution to structural performance of all partitions and infills walls are neglected. Lateral loads are assumed to carried by RC structural elements (shear walls, columns and beams). Past earthquakes and experimental studies showed that if these non-structural elements are designed and constructed properly, they will provide substantial contribution to load carrying capacity of the buildings.
Many researchers proved that contributions of these non-structural elements cannot be neglected. Lourenço et al. (2016) implemented a series of experiments on three 1:1.5 scaled RC structure with different infill solution. These three-infill wall contains a few solutions to prevent out-of-plane failure. These are two leaf cavity walls, bed joint reinforcement and infill wall enclosed with wire mesh. Wire mesh and bed joint reinforcement increased the seismic performance of the infill walls exposed to artificial earthquake excitations on the laboratory [1]. However, two-leaf cavity wall showed brittle behavior on laboratory and then Onat et al. (2015, 2016) verified laboratory tests with FE models. In addition, Onat et al. (2015, 2016) compared two leaf cavity walls with single leaf infill walls to reveal the global contribution of two-leaf cavity wall type of infill wall solution to the structural system. Nonlinear static and nonlinear dynamic analyses proved that two leaf cavity walls increase later capacity of the structure. But, two leaf cavity wall shows brittle collapse mechanism [2,3]. Mısır et al. (2015) implemented laboratory tests to see the behavior of infill walls in RC frames under bidirectional and combined lateral loads. Z-ties were used in double leaf sandwich panel infill wall. It was emphasized that the double leaf with Z-tying lead to increased energy dissipation capacity and to about a 50% increase of the ultimate strength [4,5]. Ismail and

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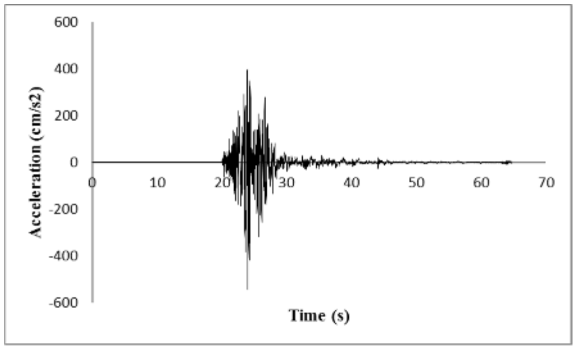
Ingham (2016) focused on in-plane and out-of-plane behavior of infill walls strengthened with two different polymer textile reinforced polymer. It was emphasized that this type of reinforcing technique leads to increase the in-plane capacity in the range of 130%. In addition, it was emphasized that out-of-plane strength was increased between 6 to 7 times [6]. Slab uplift and excitation differences between top and bottom have a strong influence on out-of-plane behavior during the earthquake. The reason of this is influence of kinematic and static boundary conditions. This reality is evaluated by Tondelli et al. (2016) on the out-of-plane behavior of infill walls. It was emphasized that it is strongly prevented from weak wall connections during the earthquake [7]. Maddaloni et al. (2016) implemented a series of experiment on T-shape tuff masonry. Monotonic and cyclic tests were performed and a strengthening technique was presented. Strengthening technique is composed of CFRP (Carbon Fiber-Reinforced Polymer) pultruded carbon bars wrapped with longitudinal and spiral stainless-steel fabrics. It was emphasized that this technique increased the out-of-plane failure capacity by 175% [8]. One more study related to the out-of-plane response was revealed by Furtado et al. (2016). Cyclic and monotonic tests were implemented on real scale reinforced concrete frame with infill walls. The effect of in-plane drift was investigated on out-of-plane response of infill wall. It was presented that out-of-plane test results with prior in-plane damage suffer a strength reduction and initial stiffness reduction [9].
In this study, failure of multi layered non-structural elements of RC buildings were classified and damage reasons were presented. Moreover, possible solutions were suggested on the base of field observation after May 1, 2003 Bingöl earthquake and October 23 and November 9, 2011 Van earthquakes in Turkey.

2. Bingöl and Van Earthquakes Characteristics

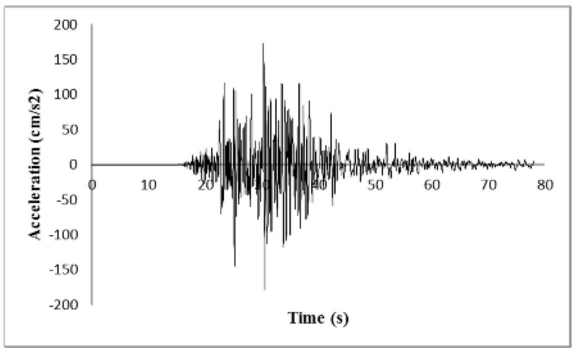
The acceleration records obtained from Republic of Turkey Prime Ministry Disaster and Emergency Management Agency (DEMA) [10] and characteristic parameters are presented in Table 1. Figure 1 shows the Peak Ground Acceleration values (PGA) of maximum components of these records. The acceleration response spectra of the maximum acceleration components of stations records are presented in Figure 2 for ξ=0, 2, 5, 7 and 10% damping ratios.

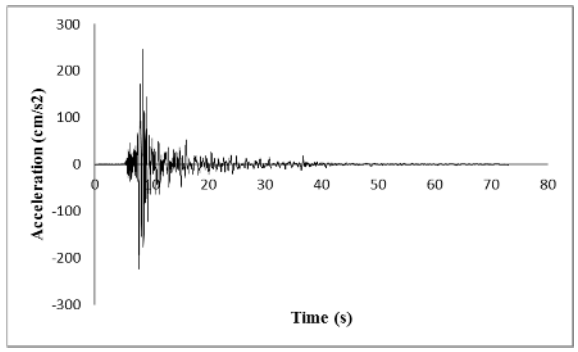
Table 1. Characteristic parameters of the earthquakes

Earthquake	Date	Station	Lat.	Long.	Depth (km)	M_w	M_L	PGA (cm/s^2)		
								N-S	E-W	U-D
Bingöl	May 1, 2003	Bingöl	38.998	40.463	10	6.3	6.6	545.53	276.83	472.26
Van	Oct. 23, 2011	Muradiye	38.689	43.465	19.02	7.0	6.7	178.50	169.50	79.50
Edremit	Nov. 9, 2011	Van	38.447	43.263	6.09		5.6	148.08	245.90	150.54



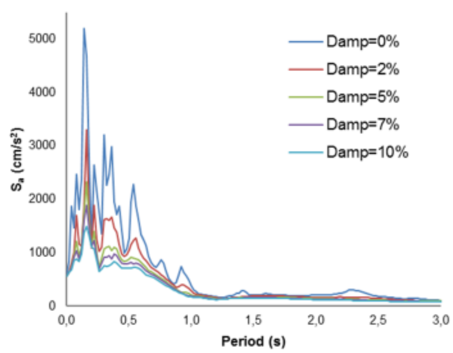
a) N-S component of May 1, 2003 Bingöl earthquake



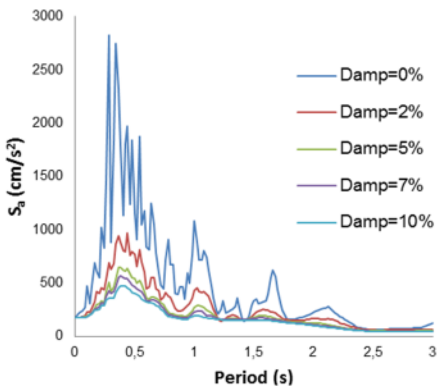


b) N-S component of October 23, 2011 Van earthquake c) E-W component of November 9, 2011 Van earthquake

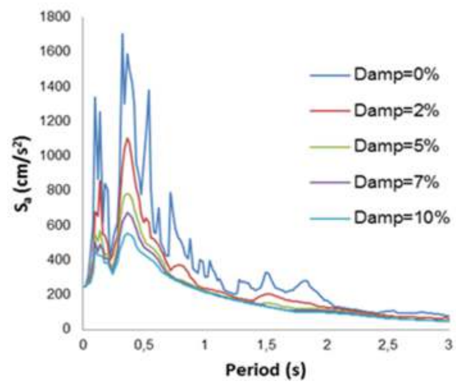
Figure 1. Peak Ground Accelerations of Bingöl and Van earthquakes



a) N-S component of May 1, 2003 Bingöl earthquake



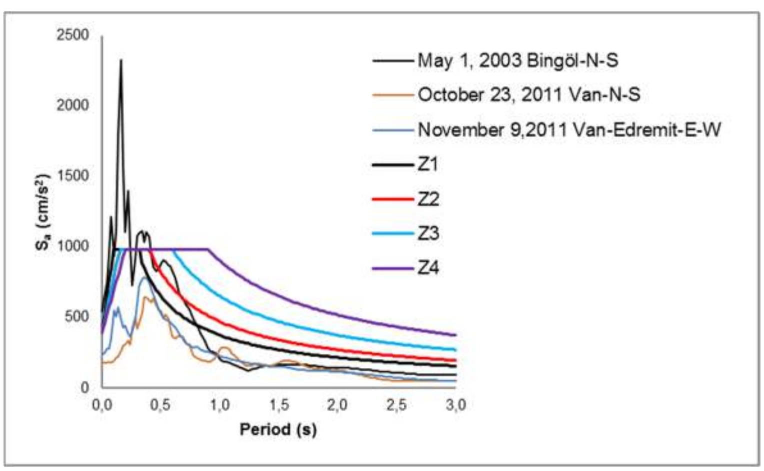
b) N-S component of October 23, 2011 Van earthquake



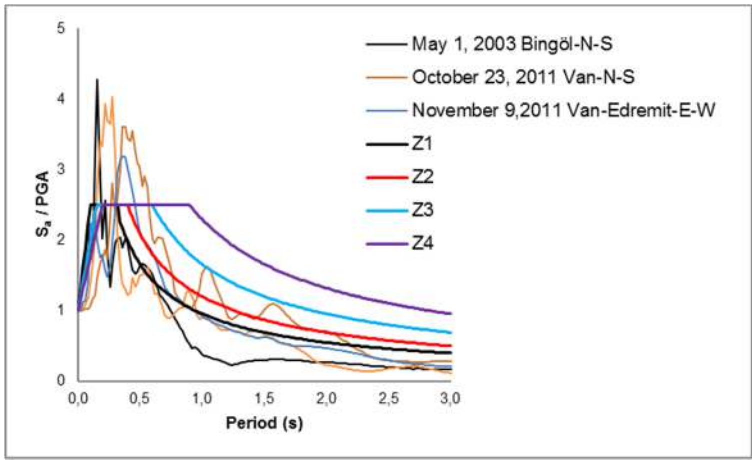
c) N-S component of October 23, 2011 Van-earthquake

Figure 2. Response spectra for various components of the earthquakes acceleration records

The acceleration response spectra of various components according to damping ratio of 5% are shown in Figure 3.a together with the design spectra of four soil classes defined in TSC-2007 [11]. In addition to this normalized with according to the maximum accelerations are presented in Figure 3.b. According to the TSC-2007, the stiffness of the soil class decreases from Z1 to Z4. The design spectra, which calculated for the first seismic zone according to all soil classes, are larger (except N-S components of Bingöl earthquake) than the response spectra of the earthquake records as seen in Figure 3.a. In addition to this the amplification factors of these normalized earthquake acceleration records exceed the limit (2.5) of the design code. This situation can be seen in the Figure 3.b. Though, the response spectra of the ground motions are quite low (except N-S component of Bingöl earthquake) compared to the design spectra, the occurred damages, loss of lives and properties evidently find out the structural deficiencies of the structure stock in affected regions.



a) Spectral curves



b) Normalized spectral curves

Figure 3. Comparison of response and design spectrums

3. Response of Multi Layered Infill Walls

In-plane and out-of-plane interaction is very complicated and should be analyzed well for this phenomenon. For low-rise and mid-rise Unreinforced Masonry (URM) infilled RC frames, ground story infill walls are expected to be damaged firstly. Because they are subjected to highest in-plane demands. However, under the effect of bidirectional loading, where the two components of a ground motion are equally significant, infill walls of the upper stories may fail under the combination of in-plane and out-of-plane effects. The in-plane demand reduces at the upper stories, while that of out-of-plane forces increases due to the increase of accelerations.

In many reinforced concrete buildings such as residential and office buildings, infill walls have been placed as two layers to increase the thermal insulation in Turkey. Insulation materials such as XPS foam and fiberglass are used between the internal and external layers of infill wall. The external layer is placed partially outside the frame, sometimes on a short-cantilevered slab as seen in Figure 4a, b.

a) b) c) d) e)

Figure 4. Failures of multi layers infill walls during the Van earthquakes

Furthermore, the external layers are constructed with separately between the storeys. In addition to this, connection of these two layers is not paid attention while designing and constructing. Production of these two layers in one frame poorly connected. This situation causes partially or totally damages. Even though, these type of design increases the seismic vulnerability of outer layer of infill wall, damages of inner layers remain lower level. This type of damages can be seen in Figure 4c-e and Figure 5 for both Van and Bingöl earthquakes, respectively.

a)

b)

c)

Figure 5. Failures of multi layers infill walls during the Bingöl earthquakes

Conclusions

In this paper, it is aimed to classify damage and failure of non-structural elements against to seismic behavior of RC framed buildings with field observations after the 2003 Bingöl and 2011 Van Turkey earthquakes. This study focuses failure mechanism of multi layered infill walls of reinforced concrete buildings. Findings obtained from field observations are listed below.

- This type of walls was poorly connected to the RC frame, especially the external wall. Then, under peak condition, the response of the wall shows similar behaviour as out-of-plane mechanism.
- For multi layered infill wall, outer layer shows lower performance than inner layer due to poor connection between layers and outer layers showed brittle behaviour.

This type of measures can be achieved by adopting suitable solutions for both in-plane and out-of-plane behaviour. For instance, placing light wire meshes anchored on outer layer of the infill wall. One another solution is using bed joint reinforcement between each two-brick layer.

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