Reducing hazards due to architectural elements in buildings subject to earthquakes

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Abstract

Architectural elements are an important part of the integrity of whole buildings. Most of them move or respond together within the main structure. In the past decade, different detail and material tests have been conducted to verify their seismic resisting capacities, and to minimize the impact of their response on the main structure. The objective is to reduce the loss of life and protect people from damaged elements as well as to minimize the damage to the structure. A good strategy to address these concerns is to place the elements in the correct locations, using or changing to proper materials, and incorporating good design practice in the planning process. Architects, engineers, and manufacturers need to make a proper evaluation and point out the priority issues arising from damage of architectural elements under earthquake forces. In this text, the authors address the issue of reducing the hazard of architectural elements during an earthquake. These suggestions offer guidelines to builders and occupants to assist in the decision making process.

1 Introduction

The extent of damage to architectural elements is associated with their seismic resisting capacities, their connections to the structure and the earthquake's magnitude. The effect of the damage depends on the importance of the building's function, its hazardous situation, and the injuries suffered by the people in or near the building. Villaverde [1] defined architectural elements, an article [2] described damage level of elements, and Bolt [3] defined earthquake magnitude. With these definitions, the author made a classification of each to analyze the main requirements. A basic requirement chart can easily be formed to show the relationship of earthquake magnitude and damage level in each category of element. Thus designers can easily identify the necessary capacity requirement of architectural elements. The preliminary judgement of
designing a new building or evaluating an old building is basically cleared. Second, the responsibility apportionment of professionals shall be made to classify their obligations and professions. Architects and structural engineers can not take care of all the elements. Product’s manufacturers and designers shall do their part of jobs. Even builders, investors, users and government shall pay more attentions on these issues. Architects and engineers have obligations to present certain design or planning materials to encourage the former people to change the budget, building code, element’s locations...etc. Some proper ways to achieve these reducing hazard issues will be clearly shown in the text.

1.1 Categories of architectural elements

In this paper, architectural elements have the same meaning as nonstructural elements. They can be classified into several categories according to their damage effects. When elements damaged can cause building to lose its major functions or jeopardize life safety are termed "critical". Such elements are stairways, elevators, exterior walls, escaping doors, electricity, heating and cooling systems. When elements damaged can cause secondary damages to threaten life safety are called "hazardous". Such elements are gas, water pipes, and tanks. All other elements are termed "regular". Such elements are ceilings, partitions, furniture, and equipment.

1.2 Damage level of elements

The damage levels are dependent on elements functional serviceability. There are 4 levels of damage conditions that reveal element’s functional requirement. (a) No damage or minor damage: Elements can keep major or most part of their functions. Damaged parts can be easily repaired and within a short period. There are no life safety concerns. (b) Moderate damage: Elements lose small part of their functions and their damages can be replaced or repaired to recover the functions. Life safety can be secured. (c) Severe damage: Life safety is generally protected. The elements are partly damaged and the repair is costly and time consuming (more than a year or so). (d) Near collapse: Many elements collapsed or lost most of their functions. At this level, main structures have severe damages and elements can’t be repaired or replaced.

1.3 Magnitude range of earthquakes

Earthquake can’t be predicted accurately and the magnitude varies each time. According to the probability and frequency of past experiences, the magnitude ranges are classified as followed: (a) Light earthquake: below 3 Richter scale. (b) Moderate earthquake: 4- 5 Richter scale. (c) Severe earthquake: 6- 7 Richter scale. (d) Deadly earthquake: above 8 Richter scale.
2 Damages of architectural elements to cause hazard

Past earthquake records showed different damage levels of elements and hazardous effects on people and buildings. Some account for these records is given in the following sections.

2.1 Results from past earthquakes (magnitude in Richter scale)

2.1.1 Sep., 21, 1999, Chi-Chi earthquake (Taiwan) [4] - magnitude 7.3
Partition or brick walls separated from structures. Building’s cladding fell off and damaged. Interior wall’s stone veneers fell off or broke. Ceiling’s frames were distorted and panel boards fell off. Light fixtures fell off and damaged. The damages of nonstructural elements in 4 hospitals [5] resulted in (1) Falling objects (2) Flooding (3) Loss of electricity. (4) Damage to medical equipment.

2.1.2 Jan., 17, 1994, Northridge in Los Angeles [6] (USA) - magnitude 6.6
Northridge campus of California State University’s library- exterior glazing was damaged. Ceilings were more damaged near the top of the building. Contents of shelving fell to floor. Some storefront glazing damaged. Ceilings damage with HVAC diffusers and ducts falling. Sprinkle system failed to cause water damage.

2.1.3 Oct., 17, 1989 Loma Prieta earthquake [7] (USA) - magnitude 7.1
In Stanford University’s library, curtain wall, lighting fixtures and suspended ceiling were damaged and shelving on 2nd floor were fallen. An 11 story reinforced concrete building, all the fixed windows were broken.

Electrical generating plant in Moin, the equipment suffered damages like minor oil leaks and 1 diesel engine and 3 oil tanks suffered at their supports. Some damages in industrial facilities include anchor bolt problem, buckling of braces.

2.1.5 The 1971 San Fernando (Ayers and Sun), the 1978 Miyagi Prefecture (Schiff et al. 1980), the 1986 Carpathians (Segal et al. 1987), and the 1987 Whittier Narrows (Schniff 1988) earthquakes
These earthquakes have demonstrated the vulnerability of elevator system during earthquake [9]. A total of 674 counterweights were reported to have come out of their guide rails in San Fernando earthquake. About 25% elevator damages were in Miyagi Prefecture earthquake. The Whittier Narrows earthquake caused 91 counterweights to come out of their guide rail.

2.2 Damage situations

2.2.1 Deteriorating the functions of buildings
(a) Exterior walls are damaged, building can’t maintain necessary temperature, humidity and fresh air to people, machine or equipment to operate properly.
(b) Partitions are damaged, safety can be a problem when separations are gone. Debris blocks the path and circulation of functions.
Earthquake Resistant Engineering Structures III

(c) Pipes or ducts are damaged, electricity, water, gas, and air conditioning cannot support the demand. People can't work in these buildings.
(d) Light fixtures, equipment, furniture are damaged, these affect the efficiency of working.
(e) Elevators are damaged, all the vertical transportation systems are stopped.

2.2.2 Life safety inside or outside of the buildings
(a) Fall down to the people- Element's body like furniture or contains, ceilings, fixtures, pipes walls, glass, ...etc fall off to knock people. Debris, parts or surface material cut or hurt people.
(b) Block the way of escaping- Fallen material accumulated to block the path.

2.2.3 Secondary damages happen
(a) Gas pipes leak to cause fire and explosion. Smoke can hurt people badly.
(b) Water pipes leak or tank broken to cause flood. Fire system can't work.
(c) Blackout can make people feel panic to cause more damage. Electrical shock can hurt people and cause fire.
(d) Chemicals leak can contaminate the environment and hurt lives.

3 Relevant research and design

3.1 Laboratory tests

3.1.1 Exterior walls
In 1992 at University of Missouri-Rolla, a project was initiated to investigate the seismic performance of glazing systems [10]. Dynamic racking tests were performed at various frequencies in 1994 [11]. In 1996, Behr and Belarbi described the test consists of a continuous series of 4 sinusoidal cycles at 0.8Hz frequency ± 6 mm drift amplitude steps to test glass in curtain wall system [12].

3.1.2 Partitions [13]
In 1966, the Nevada Operations Office of U.S. Energy Research & Development Administration conducted a test program for the investigation of nonstructural wall panels subject to racking.

3.1.3 Elevators
Dynamic system models with structure and elevator's counterweight, the research was in 1996. [14]. In 1998, a dynamic study on elevator's counterweight to evaluate passive constrain [15].

3.2 Improving design

3.2.1 Walls
(a) Demountable or moveable partitions - The systems offer ideas of movement at joints can mitigate the interaction between wall and structures.
(b) The connections of wall panels to be used can accommodate the racking
3.2.2 Ceilings
(a) At the junction of ceilings and solid walls, wall angles or shadow mold units are provided with make-up tiles or infill members. The infill satisfies the variances caused by tolerance and provides space for building movements.
(b) To tie the ceilings diagonally to prevent buckling and uplifting.

3.2.3 Pipes and ducts
(a) Pipes and ducts are supported from structures with wire, rods and metal types. Tension straps must be used to prevent movement both 2 horizontal directions.
(b) Large pipes and ducts require hangers. Diagonal steel angle component is required in transverse and longitudinal direction.
(c) Flexibility is required in pipe-work to allow for building and equipment movements. These movements can be taken by using bends, offsets, or loops.

4 Building chart of different element’s category

To establish a chart of damages level with earthquake and listing different level of earthquake vs damages performance level of architectural elements as below

<table>
<thead>
<tr>
<th>Damage Level</th>
<th>No or Minor Damage</th>
<th>Moderate Damage</th>
<th>Severe Damage</th>
<th>Near Collapse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthquake</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Moderate</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Severe</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Deadly</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

4.2 Hazardous elements

4.3 Regular elements

<table>
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<tr>
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<td>*</td>
<td>*</td>
</tr>
<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Deadly</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* Basic quality  • Higher quality  + Superior quality  • Unnecessary to achieve
4.4 Suggestion to the chart

The preliminary judgement of designing a new building or evaluating an old building is basically cleared. Builders, investors, users can make their option to select the level of requirement for designing or using proper elements.

5 Planning and design concept as a tool to communication

5.1 Damage prediction to buildings

Architects or engineers can evaluate the element’s weak points, possible damage area and locations from predicting plans, sections and construction methods.

5.1.1 Plan

After evaluate an existing or new design building, architects and engineers can put possible damage locations and areas on building’s plan with illustrating text. Different marks can present different level of damage and hazard type to the building and people. These could encourage building owner, users, and investors to consider of changing elements or improving the damage levels.

5.1.2 Section

The sections can show the possible damage areas and cause hazardous area not only in the horizontal but vertical way. Material and detail of elements even the construction problems can be point out easily.

5.2 Avoiding or reducing damage method

5.2.1 Building code revise

(a) Building code shall give more concern to the architectural elements. The seismic force base shear, drift requirement need to be stipulated clearly.
(b) Give minimum requirement of outdoor rescuing area and rescuing path
(c) Flexible and brittle material application requirement.

5.2.2 Detail analysis

(a) Current seismic design details shall be check and classified
(b) Developing details are depended on architects, professional and designers
(c) Suggesting new details to each different damage level of requirement.

5.2.3 Escaping and rescuing route

(a) Providing a rescue place for ambulance and equipment to move in.
(b) Major entrance and escaping stair doors must be kept intact after shock.
(c) Offering a safety corridor on each floor with no threaten to people to escape.

5.2.4 Construction way

(a) To use light weight material- Falling damage can be minor.
(b) To use small size material- Brittle damage to the rigid material always caused
of unsuitable clearance space. Small size means small clearance needed.
(c) Do less or on lower position- Material and elements have alternative location
to be installed shall be constructed at lower position to reduce the risk of damage

5.3 Responsibility apportionment of professionals and checking list

Architects and engineers may be the major roles in designing building and
architectural elements. But some product manufacturers know how to improve
element's seismic resisting capacity and reduce the hazard. So responsibility
apportionment idea shall be built up to everyone who is concern to earthquake
hazard. Architects can offer a checking list of building to let resident or owner to
evaluate their building. From inside to outside and from top to bottom of the
building, each element shall be checked according to their capacities, locations,
connections, material properties,...etc.

6 Conclusion

Through a series of architectural capacity improvement, proper design elements
and apportionment responsibility of professionals, building code implement,
good planning arrangement, and all people join the preventing and reducing
damage work, we shall believe that reducing hazard issue can be achieved.

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