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FAILURES MODES FOR DIFFERENT STRUCTURAL TYPES DURING AN EARTHQUAKES

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ABSTRACT

The risks of earthquakes can not be avoided completely, but one can be reduce the damages and structure vulnerability. From the evidence of baste earthquakes, researchers put some guidelines for designing and construction of several structures. Herein, in this paper, steel structures, reinforced concrete and masonry constructions would be discussed briefly, and how each kind respond and performed during an earthquake.

KEYWORDS: Earthquake, Failure Mode, Structural

INTRODUCTION

Building codes have adopted a design philosophy intended to provide safety by avoiding earthquake- induced collapse in severe events, while permitting structural and nonstructural damage.

Herein, the Structures that would be studied (Each one responds differently from the other) are:

- Steel structure: Which is mainly constructed using steel sections, its resistance rely on the strength of steel skeleton against such loadings. Such structures used in tall buildings
- Reinforced concrete structures: Its performance depends on how RC sections resist forces. This type mainly used in moderate tall building
- Masonry Buildings: This type used in rural areas and it wildly used in development countries. Beginning a view about load path must be established and how does general frames behave during an earthquake.

LOAD PATH

The analysis of earthquake resistant buildings requires the transfer of vibration and the forces induced due to ground motion from different building members to ground.

These forces caused by earthquakes called “lateral forces” because its effect is often horizontal. Where these forces can be measured by sensors and special devices that measure the properties of the phenomena (wave length, frequency, etc…). Transformation of these forces and how do they be resist throw different building members is known as “load path”.

‘This path extends from the uppermost roof or parapet, through each element and connection, to the foundation. Load-path elements vary in scale from massive multi-story moment-resisting frames to individual nails connecting wood members’[4], see figure 1.

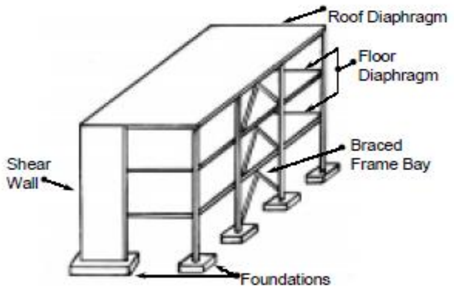


Figure 1: Load Path Elements

This path extends from the highest point in the ceiling or roof and all members and joints down to the foundation. Completeness and validity through the load path is fundamental for the analysis and design of facilities for earthquake resistance. There are two orientations of primary elements in the load path: those that are vertical, such as shear walls, braced frames, and moment frames, and those that are essentially horizontal, such as the roof, floors, and foundation. Figure 2 show how dose these different element resist and transfer load through it for more explanation about the load path, the reader may refer to "Earthquake and safety of building" [8].

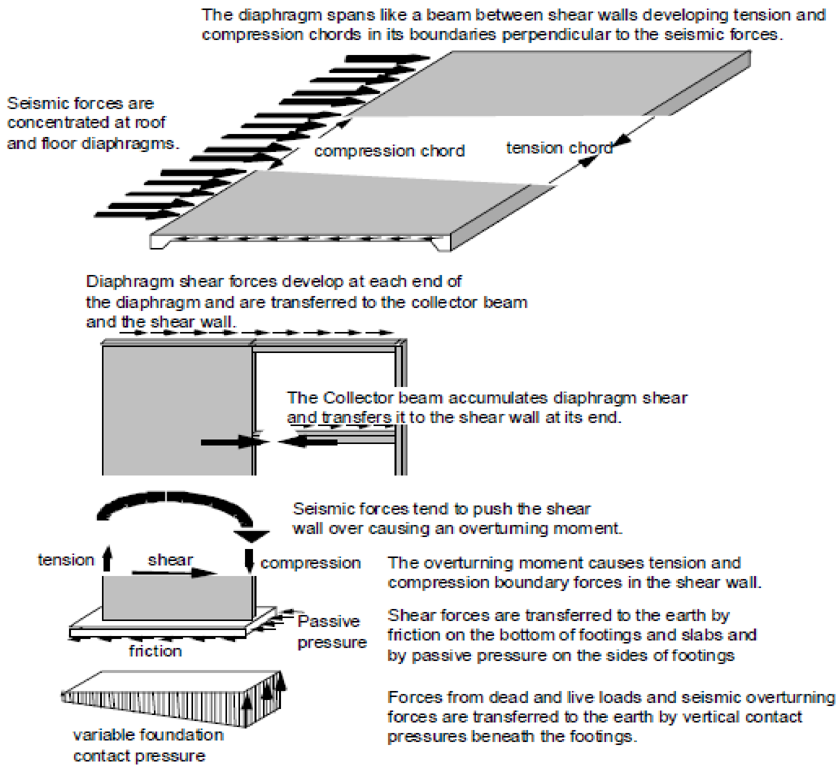


Figure 2: How the Load Path Resist and Transfer Loads

GENERAL BEHAVIOR OF STRUCTURES

Significant fatalities and property losses can be associated with poor earthquake performance of structural systems. Several researches have been published showing how do these different systems perform during an earthquake. In spit of the kind of the system, the over all configuration of the structural (architectural aspects) have an effective factors on the behavior of a building during an earthquake. These factors can be summarized as follows:

- Its shape is simple and symmetric.(simplicity and symetricity of constructed building) Buildings with simple geometry in plan typically perform better during strong earthquakes than buildings with re-entrant corners from plans with U, V, H and + shapes. This could be seen in figure 3.

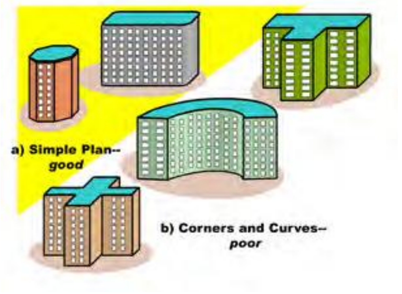


Figure 3: Different Planes that Effect on Structure Performance

This is because buildings with simple geometry offer smooth and direct load paths for the inertia forces induced during earthquake shaking to flow to the foundation.

- Vertical irregularities may have a negative effect on building performance during an earthquake. Buildings with vertical setbacks cause a sudden change in earthquake resistance at the level of discontinuity. Buildings that have fewer columns or walls in a particular story or with an unusually tall story, exhibit soft or weak story behavior and tend to incur damage or collapse that is initiated in the irregular story.

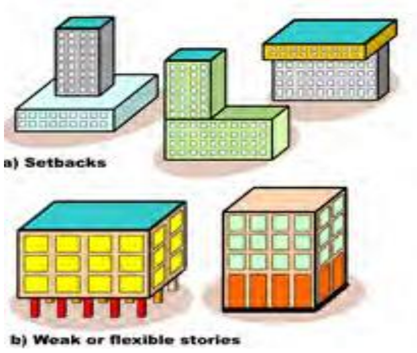


Figure 4: Vertical Irregularities

- Discontinuities in elements that are needed to transfer earthquake loads from the building to the ground are also of concern. For example, buildings are vulnerable if they have columns that hang or float on beams at an intermediate story and do not follow through all the way to the foundation

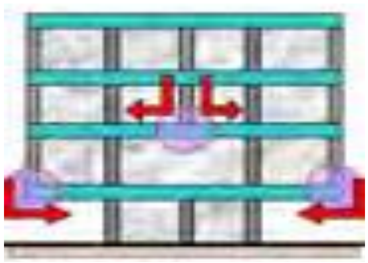


Figure 5: Discontinuity in Load Path

- Irregular shapes result in twisting under earthquake shaking. This can be avoid by ensuring that buildings have symmetry in plan (i.e., uniformly distributed mass and uniformly placed vertical members that resist horizontal earthquake loads). As a result of torsion, columns and walls on the side that moves more experience more extensive damage

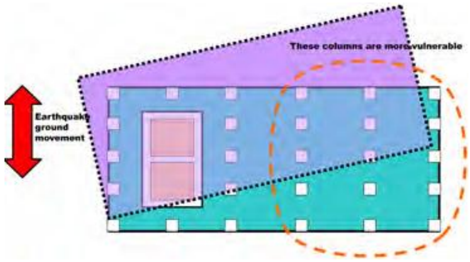


Figure 6: Inconsistency between Central Gravity of Structure in Plane and the Applied Force

STEEL MOMENT- RESISTING FRAMES

Steel moment- resisting frames have become a popular seismic load- resisting system because steel is a well-known ductile material with a high strength- to- mass ratio. And they demonstrate their superior performance versus other forms of construction in almost earthquake events. They experienced limited structural damage but did not collapse.

Damage is expected to consist of yielding and local buckling but not brittle fracture of connection.

Formation of plastic hinges at beam-column joints and column bases is a feature of inelastic behavior for steel moment resisting frame these hinges form through flexural yielding of beams and shear yielding of penal zones.

That what have been showed in several experimental works[6] which the connection where applied to cyclic loading, and the failure modes were varied , but mainly exhibit a ductile behavior depending on several mechanisms characterized by bolt slip, yielding of steel, elongation of bolt holes, etc.

Failure Modes

There are a number of failure modes associated with frame behavior, as it have been given in NEHRP seismic design Technical Brief No.2[4],including the following criteria:

- **Beam Behavior**: it is expected that beams will undergo large in elastic rotations at targeted plastic hinges locations, at weakened portions of the beams, with reduced beam section designs, or within the beam span if large gravity moments are present. Failure modes can include excessive local buckling and lateral torsional buckling.
- **Beam- to- Column Connections**: because of the variety in the type of connection configurations, failure mode take different forms as follows
  - Fracture in or around welds
  - Fracture in highly strained fracture material
  - Fracture at weld access holes
  - Net section fractures at bolt holes, shearing and tensile failure of bolts, bolt bearing and block shear failures.
- **Joint Panel Zone Behavior:** failure modes associated with the direct transfer of forces from the beam flange to the column can include column flange bending, web crippling, and web buckling.
- **Column Behavior:** The intention is to keep inelastic deformations out of most columns to minimize detrimental effects of high axial loads on bending behavior and potential formation of single- story mechanisms, see figure 7. Regardless, many columns designed in accordance with the strong column/ week beam requirements in

AISC341,§9.6 might experience significant inelastic rotations in a major seismic event. Therefore, excessive local buckling and lateral torsional buckling are potential failure modes in addition to basic flexural buckling of column

- **Column Splices:** failure modes at column splices are similar to those for beam- to- column connections. Failure modes are similar to those for beam- to- column connections. Failure of column splices will not only reduces or eliminates bending and tension resistance, it will also reduce or eliminate of the column to transfer shear forces.
- **Column Bases:** failure modes depend on the connection between the column and the foundation. They include anchorage stretching or pull out, fracture in base plates or in column-to- base plate connections, and/ or excessive local and lateral torsional buckling if inelastic deformations are concentrated in the region above the base connection.
- **Structural P-Delta Effects**: amplification of internal forces and lateral displacements, known as the P-delta effect, occur when a structure is simultaneously subjected to gravity loads and lateral side sway. This effect reduces frame lateral tangent stiffness, might cause a negative effective lateral tangent stiffness once a mechanism has formed, and can lead to collapse.
- **Sidesway Collapse:** frame collapse can occur when the effective story shear due to inertial forces and P-delta effects exceeds the story shear resistance.

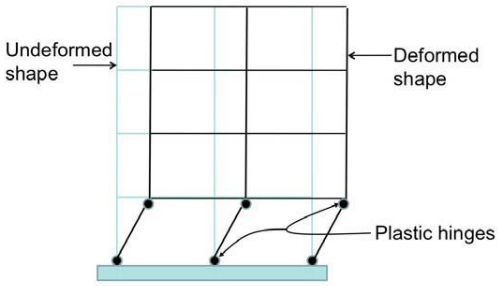


Figure 7: "Weak Story" Mechanism

The Special Truss Moment Frame (STMF) is a relative new type of steel structure system that is “implemented in buildings to help dissipate energy induced by earthquake ground motions The purpose of the STMF system is to give buildings a system that will help reduce damage and prevent collapse when earthquakes hit.

REINFORCED CONCRETE MOMENT RESISTANCE FRAMES

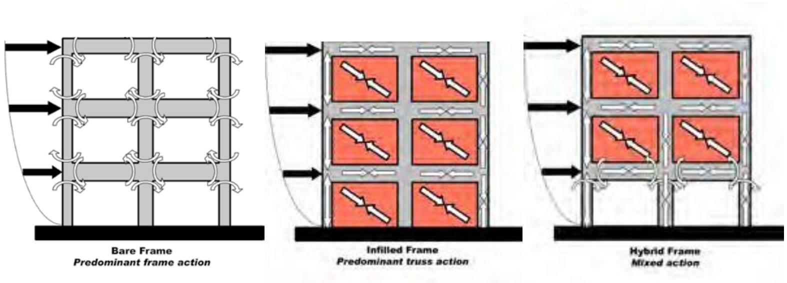
One of the challenges associated with the earthquake resistant design of reinforced concrete structures is to ensure that members behave in a ductile manner and that the damage occurs at predetermined locations. In addition, Earthquake resistant design aims to ensure that damage occurs at specific locations within a building, and RC buildings should possess ductility or the ability to sustain significant deformations under extreme loading conditions. There are many reasons contributing to structural damage and the collapse of buildings during earthquakes. These include inappropriate land use decisions, low quality concrete, inadequate engineering especially at floor-column junctions, incorrect construction techniques, poor detailing and inadequate construction supervision.The falling of the masonry infill walls of frame structures causing loss of life is a well known fact and building codes

Masonry Infill Walls

Walls in both the interior and exterior RC frames Performance of such buildings in past earthquakes has revealed that the presence of masonry infill walls is typically detrimental for the seismic performance of the building. Infill walls act as diagonal struts and increase the stiffness of RC frame building.

It can only be true if the building has been carefully designed by an engineer so the infill walls provide the bracing without failing the frame. A bare frame (without infills) must be able to resist the earthquake effects (see Figure 8a). Infill walls must be uniformly distributed in the building (see Figure 8b). Masonry infills should not be discontinued at any intermediate story or the ground story level; this would have an undesirable effect on the load path (see Figure 8c)[2].

When ductile RC frames are designed to withstand large displacements without collapse, masonry infills should be isolated from the frame by a sufficient gap. In this manner, masonry infill walls do not affect the frame performance and frame displacements are not restrained. Another advantage e of the isolated masonry infill is that the walls remain undamaged, thereby reducing post-earthquake repair costs.



8a 8b 8c

Figure 8: Performance of RC Frames with and Without Masonry Infill Walls [2]

CONFINED MASONRY BUILDINGS

Confined masonry construction has emerged as a building technology that offers an alternative to both unreinforced masonry and RC frame construction Confined masonry construction consists of masonry walls (made either of clay brick or concrete block units) and horizontal and vertical RC *confining members* built on all four sides of a masonry wall panel. Vertical members, called *tie-columns*, while horizontal elements, called *tie-beams.*

Confined masonry buildings have demonstrated satisfactory performance in past earthquakes. In general, buildings of this type do experience some damage in earthquakes, however when properly designed and constructed they are able to sustain earthquake effects without collapse. Poor performance is usually associated with tie-column omissions, discontinuous tie-beams, inadequate diaphragm connections, and inappropriate structural configuration.

Masonry walls act as diagonal struts subjected to compression, while reinforced concrete confining members act in tension and/or compression, depending on the direction of lateral earthquake forces. The studies that have been holding on the resistance of confined masonry wall to lateral load [10, 11], identify the following:

- Shear failure mode, and
- Flexural failure mode.

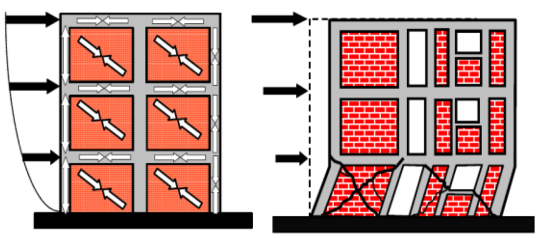


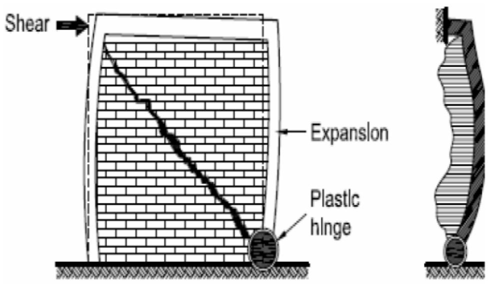
Figure 9: Confined Masonry Action

Note that, in confined masonry structures, shear failure mode develops due to in-plane seismic loads (acting along in the plane of the wall), whereas flexural failure mode may develop either due to in-plane or out-of-plane loads (acting perpendicular to the wall plane).

Shear failure mode is characterized by distributed diagonal cracking in the wall. These cracks propagate into the tie-columns at higher load levels, as shown in Figure 8.

Initially, a masonry wall panel resists the effects of lateral earthquake loads by itself while the confining elements (tie-columns) do not play a significant role. However, once the cracking takes place, the wall pushes the tie-columns sideways. At that stage, vertical reinforcement in tie-columns becomes engaged in resisting tension and compression stresses. Damage in the tie-columns at the ultimate load level is concentrated at the top and the bottom of the panel. These locations, characterized by extensive crushing of concrete and yielding of steel reinforcement, are called *plastic hinges* (see Figure 10). Note that the term *plastic hinge* has a different meaning in the context of confined masonry components than that referred to in relation to RC beams and columns, where these hinges form due to flexure and axial loads. In confined masonry construction, tie-beams and tie-columns resist axial loads. Shear failure can lead to severe damage in the masonry wall and the top and bottom of the tie-columns.

Flexural Failure caused by in-plane lateral loads is characterized by horizontal cracking in the mortar bed joints on the tension side of the wall. Separation of tie-columns from the wall was observed in some cases (when toothed wall-to-column connection was absent). Extensive horizontal cracking, which usually takes place in tie columns, as well as shear cracking can be observed on Figure 11.



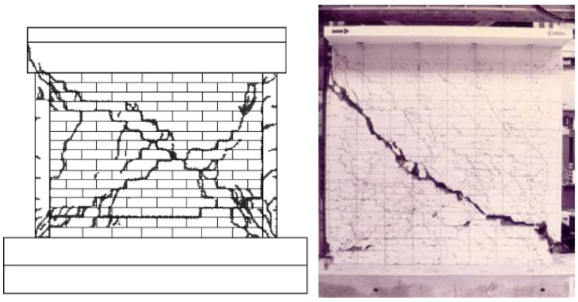


Figure 10: Development of Plastic Hinge **Figure 11: Shear Failure of Confined Masonry Walls**

The Factors and Requirements Affect the Performance of Confined Masonry Buildings

The factors that effect confined masonry building performance can be summarized as follows:

- Wall density is believed to be one of the key parameters influencing the seismic performance of confined masonry buildings. It can be determined as the transverse area of walls in each principal direction divided by the total floor area of the building.
- Strength of the masonry units and the mortar used.
- Effect of tie columns on increasing lateral resistance of confined masonry structures Tie-columns significantly influence the ductility and stability of cracked confined masonry walls.
- The provision of horizontal reinforcement placed continuously along the wall length and anchored into the tie-columns will enhanced the resistance of confined masonry wall

While the top 10 architectural design requirements related to confined masonry buildings are:

- Building plan should be regular.
- The building should not be excessively long relative to its width; ideally, the length-to-width ratio should not exceed 4.0.
- The walls should be built in a symmetrical manner.
- The walls should be continuous up the building height.
- Openings (doors and windows) should be placed in the same position up the building height.
- Tie-beams should be placed at every floor level at a vertical spacing not to exceed 3 m.
- Tie-columns should be placed at a maximum spacing of 4 m.
- At least two confined walls should be provided in each direction.
- Wall density of at least 2 % is required to ensure good earthquake performance of confined masonry construction.
- Confined masonry is suitable for low- to medium-rise building construction (one- to four-storey's high), depending on the seismic zone.

CONCLUSIONS

- The allover configuration of the building effect its performance against earthquake. As long as the building symmetricity (horizontally and vertically) increased, the resistance would be increased
- Presence of good integrity and the availability of a load path will enhance earthquake resistance.
- The resistance of a unit section depends on its material. Steel structures exhibit more ductile than RC and confined masonry structures.
- Mechanisms of failure depend on the type of structure and material of construction. For evidence, failure modes for steel structure take the form of ductile behavior; consist of yielding and local buckling. While RC structures behave a bit little from steel structure and it may behave in a ductile manner if "strong column week beam" approach has been adopted. Masonry walls are the weakest feature of construction, but by using steel bars (making confined masonry wall) this weakness would be upgraded.
- Failure mode can be defined as a form of energy dissipation. So, by using another energy dissipater like dampers, the damages will be reduced.

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