

Conceptual Investigation of Short-Columns and Masonry Infill Frames Effect in the Earthquakes

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Abstract—This paper highlights the importance of the selection of the building's wall material, and the shortcomings of the most commonly used framed structures with masonry infills. The objective of this study is investigating the behavior of infill walls as structural components in existing structures. Structural infill walls are very important in structural behavior under earthquake effects. Structural capacity under the effect of earthquake, displacement and relative story displacement are affected by the structural irregularities. The presence of nonstructural masonry infill walls can modify extensively the global seismic behavior of framed buildings. The stability and integrity of reinforced concrete frames are enhanced by masonry infill walls. Masonry infill walls alter displacement and base shear of the frame as well. Short columns have great importance during earthquakes, because their failure may lead to additional structural failures and result in total building collapse. Consequently the effects of short columns are considered in this study.

Keywords—Short columns, Infill masonry wall, Buildings, Earthquake.

I. INTRODUCTION

DURING past earthquakes, reinforced concrete (RC) frame buildings that had columns of different heights within one storey were damaged more in the shorter columns, as compared to taller columns in the same storey. Poor behaviour of short columns is due to the fact that in an earthquake, a tall column and a short column of the same cross-section move horizontally in same amount. However, the short column is stiffer as compared to the tall column, and it attracts a larger earthquake force. Stiffness of a column means resistance to deformation - the larger is the stiffness, larger is the force required to deform it. If a short column is not adequately designed for such a large force, it can suffer significant damage during an earthquake. This behaviour is called Short Column Effect. The damage in these short

columns is often in the form of X-shaped cracking - this type of damage of columns is due to shear failure [1]. The shear failure of so-called «short columns» is a frequent cause of collapse during earthquakes. It concerns squat columns, i.e. columns that are relatively thick compared to their height, and are often fixed in strong beams or slabs. Slender columns can be turned into short columns by the addition of parapet infills in frame structures («unintentionally shortened columns»). Columns under horizontal actions in frame structures may be stressed up to their plastic moment capacity (plastification or failure moment). In the case of short columns with considerable bending capacity, an enormous moment gradient and thus a large shear force results. This often leads to a shear failure before reaching the plastic moment capacity. Short columns should therefore be avoided. An alternative is to design and detail the columns in accordance with the rules of capacity design, whereby the shear capacity must be increased to account for the overstrength of the vertical reinforcement [2].

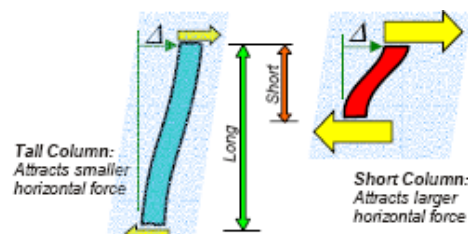


Fig.1. Short Column and Tall Column

II. SITUATIONS THAT OCCURS SHORT COLUMNS

Many situations with short column effect arise in buildings, such as:

a. When a building is rested on sloped ground, during earthquake shaking all columns move horizontally by the same amount along with the floor slab at a particular level (this is called rigid floor diaphragm action). If short and tall columns exist within the same storey level, then the short columns attract several times larger earthquake force and get damaged more compared to taller ones.

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b. The short column effect also occurs in columns that support mezzanine floors or loft slabs that are added in between two regular floors.

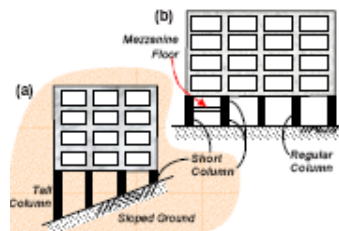


Fig. 2 Situations that Occure Short Columns

c. There is another special situation in buildings where the short-column effect occurs. Consider a wall (masonry or RC) of partial height built to fit a window over the remaining height. The adjacent columns behave as short columns due to presence of these walls. In many cases, other columns in the same storey are of regular height, as there are no walls adjoining them. When the floor slab moves horizontally during an earthquake, the upper ends of these columns undergo the same displacement. However, the stiff walls restrict the horizontal movement of the lower portion of a short column, and get deformed by the full amount over the short height adjacent to the window opening. On the other hand, regular columns get deformed over the full height. Since the effective height over which a short column can freely bend is small, it offers more resistance to horizontal motion and thereby attracts a larger force as compared to the regular column. As a result, the short column sustains more damage[1].

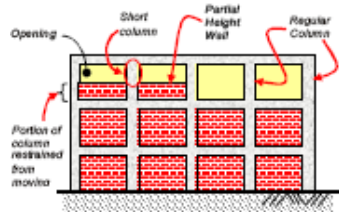


Fig. 3 Short Column Effect When Paetial Height Walls Adjoin Columns

d. The short-column situation, as shown in Fig.4, is created by large window openings.



Fig.4. large window openings AND SHORT COLUMN

e. Difference in levels can lead to short column.

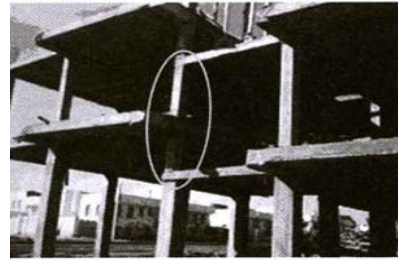


Fig. 5. Difference In Levels(Dublex)

f. another situation causing column failure by non-structural walls that will be illustrated later.

III. BEHAVIOR OF COLUMNS DURING EARTHQUAKES

The behavior of columns during earthquakes is very important since column failures may lead to additional structural failures and result in total building collapses. For example, in the Mexico City earthquake, the most frequent observed cause of structural failure was linked to inadequate beam-to-column and slab-to-column connections. Building configurations may cause columns to be over stressed. Columns of unequal length result in unequal load distribution and hence failure. Column construction and underlying soils also are factors in column failures. A column is a supporting pillar consisting of a base, a cylindrical shaft and a capital. These columns may be made of welded steel or reinforced concrete in which steel rods (rebar) are imbedded in the concrete. These steel rods may be tied together with metal strips at intervals (ties), or they may be wrapped spirally around the column with metal strips (spirally wrapped). All the metal reinforcing is embedded in the concrete. The Uniform Building Code requires that columns be confined by such spirals or ties. A spirally-confined column is basically more ductile than a tied column, but in lateral motion this ductility can only be achieved if ductility also exists at the column-to-beam connection at the top of the column. Shear is a condition caused by forces that tend to produce an opposite but parallel sliding motion of the body's planes. A shear wall is a wall in a building designed to absorb these forces. A soft story is a story in a building (often the first story) with few partitions and/or open exterior walls (such as garage doors, large windows, etc.). This openness makes it vulnerable to earthquake damage. Sometimes the configuration of the building causes the columns to be over stressed, and when they fail, the building fails. This was the case with the Olive View Hospital, which was severely damaged in the 1971 San Fernando California earthquake. The first two floors were soft stories in which the principal support for the floors above were columns. When earthquake shaking caused the upper floors to move as a unit as much as two and a half feet, the first and second floor columns could not accommodate such a large displacement, and they failed. The result was that the entire building had to be demolished. During the 1979 El Centro, California, earthquake, the building was destroyed due to column shortening by compression at the east end of the building. Short columns are often damaged in earthquakes. A

column twice as long is eight times more flexible. If the structure contains both short and long columns, the load will be concentrated in the shorter columns. The short columns are less subject to buckling and hence are capable of receiving high vertical loads. But under lateral loading (forces from the side), the short, stiff columns receive more than their share of the load, and fail. The condition may be avoided by equalizing the length and hence the stiffness of the columns. Columns and piers may be more resistant to failure in earthquakes if they are designed to be more shear-resistant. Extra column ties or spiral wraps should be provided in the end sections of all columns and in the beam-to-column connections.

IV. SOFT STOREY

Many apartments and condos can collapse in earthquakes because they have parking on all or part of the first floor, or open commercial space on that first floor. These buildings typically have outside walls with large openings due to garage doors and display windows, as well as few internal walls, making this story "weak" or "soft" and likely to lean or fall over in earthquakes. Because of improvements in recent building codes for new construction, these soft-story buildings were likely built prior to 1990 and the most problematic buildings were built prior to 1980. They also are more likely to be a problem if they have wood-framing in the walls of the first floor (whether or not it is covered by stucco) [3].

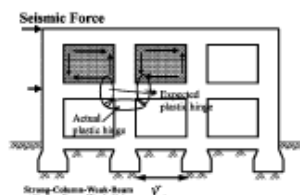


Fig. 6 Soft Storey Effect

V. EFFECT OF SOFT STOREY ON COLUMNS

The soft story effect will not only increase the total seismic horizontal load, which will induce huge moments in the columns, but also could increase the axial force in some columns. This situation will create very serious problems for columns. The first reason for this philosophy is that it is much easier to design a beam with high ductility, since the axial force in beams is very small and no $P-\Delta$ effect occurs in beams. The second reason is that the failures of beams would not create a catastrophic situation. However, we can conclude that the plastic hinge will occur at the column first, since the beams have been strengthened by the walls. This means the strong-column-weak-beam design breaks down and the actual structural behavior is strong-beam-weak-column. Also, another situation causing column failure by non-structural walls is the well-known short-column effect [4].

VI. SUGGESTIONS FOR ELIMINATING OR MINIMISING OF SHORT COLUMNS EFFECT

- In new buildings, short column effect should be avoided to the extent possible during architectural design stage itself. When it is not possible to avoid short columns, this effect must be addressed in structural design.
- The special confining reinforcement (i.e., closely spaced closed ties) must extend beyond the short column into the columns vertically above and below by a certain distance.

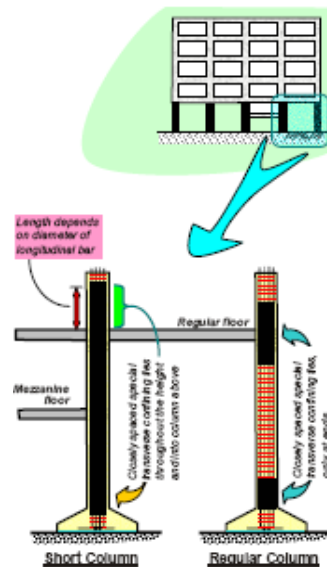


Fig. 7 Details Of Reinforcement In A Building With Short Column Effect

- In existing buildings with short columns, different retrofit solutions can be employed to avoid damage in future earthquakes.
- Where walls of partial height are present, the simplest solution is to close the openings by building a wall of full height – this will eliminate the short column effect. If that is not possible, short columns need to be strengthened using one of the well established retrofit techniques. The retrofit solution should be designed by a qualified structural engineer with requisite background [1].

VI. INFILL MASONRY WALLS

Masonry infill walls are found in most existing concrete frame building systems. This type of infill walls is common where seismicity has one of the prime importances. These masonry infill walls which are constructed after completion of concrete frames are considered as non-structural elements. Although they are designed to perform architectural functions, masonry infill walls do resist lateral forces with substantial structural action. In addition to this infill walls have a considerable strength and stiffness and they have significant effect on the seismic response of the structural system. There is a general agreement among of the researchers that infilled

frames have greater strength as compared to frames without infill walls. The presence of the infill walls increases the lateral stiffness considerably. Due to the change in stiffness and mass of the structural system, the dynamic characteristics change as well. Recent earthquakes showed that infill walls have an important effect on the resistance and stiffness of buildings. However, the effects of the infill walls on the building response under seismic loading are very complex and math intensive [5].

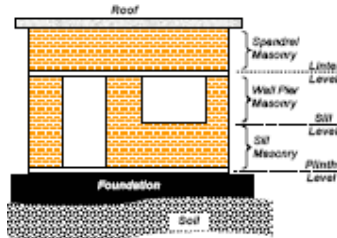


Fig. 8. Sub-Units In Masonry Building

VII. REASONS FOR USING MASONRY INFILLS

The masonry infills consist of unreinforced clay bricks or hollow masonry blocks. The locally available masonry infills are commonly used because:

- Cheaper materials with low cost labour availability make this material the preferred choice for under developed or developing countries. The use of these materials is rapidly diminishing in developing or developed countries because of high labour costs, diminishing availability of skilled labour and associated extended construction time.

- The people feel much more secure if the peripheries of their living quarters are built using solid walls. It is very important to have solid walls for the majority of people from different cultures.

- Masonry brick skins with cavities are an effective weather protection as long as cavities, flashings and weep holes are built properly. The face brick outer skin of cavity walls provides a hard wearing maintenance free façade finish provided proper articulation is adopted and cracking of brick walls is avoided. The cavity brick construction is very much unaffordable in many under developed and developing countries. Their infill masonry usually consists of single skin masonry brick with externally applied cement/gypsum-lime render and paint for weatherproofing.

earthquake observations reveal that the presence of masonry infills within the frame structure and their influence on structural behaviour is always overlooked in the design and construction practice. The falling of the masonry infill walls of frame structures causing loss of life is a well known fact and building codes requires that masonry infills must be secured to frame structures. And, it is now a recognised fact that the presence of masonry infill walls is one of the major reasons of causing the collapse or damage to building structures during an earthquake. The presence of masonry infills can result in higher stiffness; however sudden reduction of stiffness due to damage of infill walls can lead to the formation of a soft storey mechanism, which, due to the

introduction of joint damage, can occur at any floor level and independently of the distribution of the infills along the elevation[6].

VIII. EARTHQUAKE RESISTANCE OF INFILL MASONRY

In the event of an earthquake, apart from the existing gravity loads, horizontal racking loads are imposed on walls. However, the unreinforced masonry behaves as a brittle material. Hence if the stress state within the wall exceeds masonry strength, brittle failure occurs, followed by possible collapse of the wall and the building. Therefore unreinforced masonry walls are vulnerable to earthquakes, and should be confined and /or reinforced whenever possible. Nevertheless, low-rise residential plain masonry construction limited to the specifications provided in this document and including certain earthquake-resistant details can still be safe. Masonry walls resisting in-plane loads usually exhibit the following three modes of failure:

- Sliding shear- a wall with poor shear strength, loaded predominantly with horizontal forces can exhibit this failure mechanism. Aspect ratio for such walls is usually 1:1 or less (1:1.5)
- Shear- a wall loaded with significant vertical load as well as horizontal forces can fail in shear. This is the most common mode of failure. Aspect ratio for such walls is usually about 1:1. Shear failure can also occur for panels with bigger aspect ratio ie. 2:1, in cases of big vertical load.

Bending- this type of failure can occur if walls are with improved shear resistance. For bigger aspect ratios ie. 2:1 bending failure can occur due to small vertical loads, rather than high shear resistance. In this mode of failure the masonry panel can rock like a rigid body (in cases of low vertical loads)[7].

IX. EFFECTS OF MASONRY INFILLS ON THE SEISMIC RESPONSE OF FRAMES

Regardless of the extent of inherent weaknesses in the bare frame systems, the presence of infills (e.g. typically unreinforced masonry) and their interaction with the bare frame, can lead to unexpected and controversial effects (Crisafulli et al., 1997). The effects of infills still represent an open topic, with a critical need of further investigations for the seismic vulnerability assessment of extensive classes of existing buildings.

The presence of infills can allow higher stiffness and strength, reducing the inter-storey drift demand, while increasing the maximum floor accelerations. A further protective action of the infills can be recognized in the reduction of column interstorey shear contribution as well as in the possible delay of a soft-storey mechanism which might instead develop in a bare frame solution. However, the sudden reduction of storey stiffness due to the damage of the infills can still lead to the formation of a soft storey mechanism, which, due to the interaction with joint damage, can occur any

floor level and independently of the distribution of the infills along the elevation (Pampanin,2005).Furthermore,shear failure in the column,due but not limited to short column effects,can result.Similarly,when investigating the response of 3-D frames under either uni-directional or bi-directional earthquake input excitation,inelastic torsion mechanisms can occur due to the irregular distribution of damage to the infills. It has been noted (Pampanin et al., 2004),that not only the distribution along the elevation but also the geometrical and mechanical properties of the infills (i.e. one or two withes, solid clay or hollowed bricks of different sorts used as internal partitions, grout type) can have a major impact on the overall response[8].



Fig. 9.Observed effects of interaction between infills and bare frame
a)shear failure of column , b)exterior joint shear damage(Bonefro,Molise,2002) ,
c)global collapse for soft storey mechanism(Izmit,1999).

X. MASONRY WALLS AND COLUMNS

In many instances, the masonry walls in the ground storey were discontinued at the sill level instead of being raised to the full storey height. This created the short column effect,an additional abnormality that was also not accounted for in the design.An example of such a structure is the Panchayat Bhavan building at Nabagram,about 25 km south of Diglipur .The ground storey columns of this building suffered extensive damage in the 2002 earthquake.Many columns were severely cracked and damaged near beam-column joints and at mid-heights.



Fig. 10.a.Severe Cracking and Damage to soft first storey columns of Nabagram Panchayat Bhavan building primarily due to 'missing' ties in 2002 earthquake, b.more damage in 2004 earthquake to same columns which were 'retrofitted'[9].

There is strong evidence that masonry infills enhance the lateral strength of framed building structures under severe earthquake loads and have been successfully used to strengthen the existing moment-resisting frames. However, there is a common misconception that masonry infills in

reinforced concrete (R/C) or structural steel frames can only enhance their lateral load performance and must therefore always be beneficial to the earthquake resistance of the structure.As a matter of fact,there are numerous cases of seismic damage that can be attributed to modification of the dynamic response parameters of the basic structural frame by so-called nonstructural masonry infills or even partitions. The addition of masonry infill panels to an originally bare moment resisting frame increases the lateral stiffness of the structure, thus shifting the natural time period on the earthquake response spectrum in the direction of higher seismic base and storey shears, and attracting earthquake forces to parts of structures not designed to resist them. Furthermore, if the structure is designed to act as a moment resisting frame with a ductile response to the design level earthquakes, neglecting the contribution of infills,the stiffening effect of the infills may increase the column shears resulting in the development of plastic hinges at the top of the columns that are in contact with the infill corners.One of the lessons learnt from past experiences in earthquakes is that abrupt changes in stiffness along the height of a building due to irregular distribution of masonry infill panels over the elevation of the building frame can unfavourably and sometimes catastrophically affect the seismic performance of the frame [10].

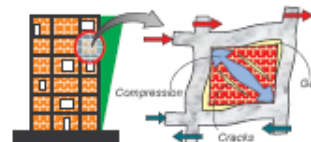


Fig. 11 Infill Walls move together with the columns under earthquake shaking

XI. SUGGESTIONS ABOUT MASONRY WALLS

- In flexible skeleton structures,it can be beneficial to separate non-structural partition walls from the structure by soft joints.This is particularly true for inplane stiff and brittle masonry walls.This way,damage occurring even for weak earthquakes can be prevented[2].

- Omit masonry partitions/facade walls and use light weight partitions with reinforced concrete frame structures. In this way,the presence of metal/timber stud walls does not alter the frame's performance.However, this will not be considered viable by many because of weatherproofing , longevity ,maintenance costs and more importantly the market's perception of where we like to feel secure within our living quarters because of the presence of solid walling barriers[6].

- All masonry walls must be laterally anchored to the structural backup.Corrugated ties, adjustable anchors, and horizontal joint reinforcement are all examples of anchoring devices. Building codes require the architect to indicate specified type, size and spacing of all ties and anchors on the project drawings. Since the architect is responsible for the design of the anchorage strategy [11].

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