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MASONRY INFILL WALLS IN AN EARTHQUAKE

PREFACE

The damaging potential of strong earthquakes is well known and accepted as an underlying premise by most design codes. The USA-California (SEAOC) Committee adopts the philosophy that structural damage is acceptable during a rare earthquake, but that collapse is not acceptable in any event for the protection of human life.

It is the responsibility of governments, engineers and architects to avoid incidents shown in the following photos.

Courtesy of http://www.eas.slu.edu/Earthquake_Center/TURKEY/

Courtesy of Reference No: 5

Building architectural planning must consider the following issues simultaneously to balance engineering and architectural requirements.

(i) Earthquake provisions must incorporate structural regularity.

(ii) Solar access and cross ventilation for energy efficiency and healthy building environments.

(iii) Economical yield for return of investments, e.g. number of units for residential developments.

(iv) Building's architectural design offering the most economical construction cost.

The above are planning/design requirements that are inseparable from each other for rewarding results for all stakeholders. The public and developer's expectations can only be satisfied if the co-operation of the ARCHITECT – ENGINEER starts at the selection of the development site phase.

ABSTRACT

The majority of human occupation is catered by residential and office buildings for our living and working quarters. The necessary urban consolidation requires multi-level buildings which are more vulnerable to the effects of earthquakes.

The most common structural system for both residential and office buildings consist of multi-level framed structures incorporating column-slab/beams which are the gravity and lateral load carrying elements.

The only difference between the finished residential and office buildings are the type of materials used for partitions and building perimeter wall enclosures. Residential buildings commonly use masonry infills both internally and externally. However, office buildings require as much open internal space as possible due to varying tenancy requirements. This necessitates the building system to consist of columns with lightweight, non-structural, easily removable internal partition walls, and the façade walls to consist of full or part glazing.

Despite having a similar structural frame, size and shape, office buildings exhibit much less loss of life, damage or collapse when compared to residential buildings of the same size.

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The reason for residential buildings having significantly more damage is because the masonry infills placed in framed structures, due to their stiffness, causes change in structural behaviour of such structures.

The observations and analysis results reveal that the use of masonry infill walls located in between the columns of reinforced concrete framed structures plays a major role in the damage and collapse of buildings during strong earthquakes.

The falling masonry walls are also the major factor for loss of life during earthquakes. The fall of masonry walls must be avoided without question.

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 irrespective of whether they are residential or office buildings.

INTRODUCTION

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 above are all known reasons for problems associated with buildings experiencing earthquake incidents. However, 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, including AS1170.4 – 2007 Australian Earthquake Code 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.

It is also important to state that observations have revealed that the majority of earthquake damage to residential buildings is occurring in buildings less than approximately eight (8) storeys in height with natural frequencies much closer to dominant ground motion frequencies and more potential for resonance conditions. These buildings with low height to buildings' width/depth ratios represent stiff framed structures. The addition of masonry infill walls further stiffens the overall structural frame behaviour significantly.

There is a common misconception that masonry infills in reinforced concrete or structural steel frames can only enhance their lateral load performance and must always be beneficial to the earthquake resistance (Reference 1) of the structure.

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.

Courtesy of www.leightongeo.com/taiwan.htm

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New Zealand practice (Reference 2) recommends the use of brick-veneer building claddings (brick outside, timber stud wall inside) to eliminate the problem of the stiffening effect of masonry infill walls on the reinforced concrete frames of the building structure. However, this does not solve the problem of masonry walls failing in the out-of-plane direction which, as stated before, can cause loss of lives of the building's occupants or even by-passers.

The above noted problems associated with masonry infill walls are extensively reported with references given in this article and by many others not mentioned. The recommendations for earthquake protection consist of the elimination of masonry infill walls. The irony is that the building codes for some unknown, but most possibly economical, reasons are yet to cover this very vital issue.

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.

STRUCTURAL RESPONSE OF FRAME STRUCTURES WITH MASONRY INFILLS

The addition of masonry infill panels to an originally bare moment resisting frame increases the lateral stiffness of the structure, thus shifting the natural period of vibration 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 columns that are in contact with the infill corners (Reference 1).

During an earthquake, these infill walls will increase the lateral earthquake load resistance significantly and often will be damaged prematurely, developing diagonal tension and compression failures or out-of-plane failures. The degree of lateral load resistance depends on the amount of masonry infill walls used. However, for the reasons explained above, masonry infills are commonly used in internal partitioning and external enclosure of buildings, increasing wall-to-floor area ratios. Therefore, in spite of the lower strength and expected brittleness of this type of masonry walls, the frames benefit from the extensive use of masonry walls until the threshold of elastic behaviour has been exceeded.

Beyond the premature failure of brittle masonry, the sudden loss of significant stiffness against lateral drift must be compensated by the slab/beam-column junction of the frame structure. This behaviour causes a high drift demand on the frame members, hence causing increased damage to the structure if there were no masonry infills.

The sudden loss of stiffness in the lateral load resistance mechanism causes a very high concentration of loading. This increased magnitude of loading causes significant damage or even the collapse of slab/beam-column joints. If one or two joints collapse others will follow, causing premature failure of the entire structure.

If the frame structure joints are asked to perform satisfactorily under the abovementioned behaviour, it will be extremely hard to satisfy the joint behaviour requirements without using significant sized beams in both directions at the top of the columns in lieu of flat slabs without beams.

The earthquake experience with frame structures and masonry infill shows much greater damage at the vicinity of the first and last column of the frame structures. This is the reason why earthquake prone countries use beams to increase joint resistance.

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DISCUSSIONS FOR OPTIONS

The following options may be considered:

1. **Continue to use infill masonry.** This will necessitate that the reinforced concrete frames have to be designed for increased capacity as reported in the attached references, which will most likely result in having significantly increased size of beam-column connections. The end result is loss of floor space because of the additional structure depths associated with beams. Or alternatively, the infill masonry walls can be detailed to accommodate building movement and earthquake induced sway by providing complex and expensive stability connections which are also most possibly subject to building's water ingress and condensation problems if the façade masonry walls consist of a single skin only. The joint sizes for earthquake sway against the structure will be significant, hence associated detailing for acoustics and fire will also be complex and expensive.

   Designers should note that Australian Fire requirements and associated provisions for fire safety significantly penalise the construction economics for buildings exceeding 25 metres in height above the emergency services entry level which is usually the public road level.

   The height of 25 metres (maximum) equates to 8 storey buildings in Australia. There is no economical incentive for the Australian developer to build higher buildings unless a minimum of 12 to 15 storeys in height is allowed by the authorities. The additional minimum 4 storey height of construction will compensate for the additional construction cost for fire provisions.

   However, even if the frames were designed for extra over strength, out-of-plane collapse of the masonry infill walls will still cause loss of lives. The building authorities require that all masonry walls be tied to the structure to avoid the fall of masonry brick walls during an earthquake event. The provision and functionality of masonry ties may not be possible as explained in **(Download – Earthquake Design and Brick Walls)**. Therefore, this cannot be a viable option.

2. **Omit masonry partitions/façade 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.

3. **Use load bearing concrete walls at facades, corridors and party walls. The internal partitions can be lightweight partitions.**

This option could be considered as **THE RECOMMENDED SYSTEM** because of the following reasons:

RECOMMENDED SYSTEM

Reinforced concrete frame systems deserve fundamental revisions. For new constructions, a less vulnerable option of unframed structures with planar concrete load bearing walls should be encouraged. The reasons for these are:

(1) RECOMMENDATIONS

All references mentioned in this document and many other literatures not mentioned also recommend using load bearing concrete walls in lieu of framed structures consisting of columns-beams-slabs and masonry infill.

(2) MATERIAL BEHAVIOUR

Concrete walls and floors of the same material will achieve total compatibility for material behaviour for structural, shrinkage and temperature purposes. Masonry clay bricks for walls and concrete floor behaviour are totally opposite to each other.

(3) SAFER STRUCTURAL BEHAVIOUR

The earthquake load stress concentration at each individual column-floor junction of a frame structure will be distributed along the length of the planar wall resulting in no load concentration and a much stronger lateral or vertical load carrying structure. There are no masonry infill walls to fail prematurely.

The extensive availability of concrete walls gives the opportunity to structural engineers many options to generate much stronger earthquake resistant structures. There is no reason or necessity for all available concrete walls to be reinforced to resist earthquake forces.
The stair and lift shafts in many instances are adequate to provide earthquake resistance structure. The earthquake regulations require the rest of the walls to be positively connected to floor slabs to avoid the fall of walls like a pack of cards.

(4) BUILDING PLANNING REQUIREMENT

The cross ventilation and solar access requirement of the building codes' plannings will compliment the structural system of multi-level buildings having parallel common party walls to each other.

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(5) CONSTRUCTION ECONOMICS

The suspended floor slabs of buildings with load bearing concrete walls results in 43% saving in comparison to column-beam-slab frame systems incorporating masonry infills. A 15% saving is also relevant for non-load bearing lightweight aerated concrete or dry walls used in lieu of masonry infills. The reason why load bearing concrete walls prior to Dincel-Walls are not considered is because of the construction cost of concrete walls. However, this is no longer an issue; the solution with Dincel-Walls offer unmatchable cost savings both in walls and floor slabs. (Download – FAQ, Answer No: 21 – System Advantage/ Construction) and (Download – Costing Analysis)

(6) EDUCATION

The developer should involve the structural engineer at the beginning of the project to assist architects; hence the structural system can be optimised to service earthquakes as well as wind loadings.

The regularity of the structure in multi-storey buildings for earthquakes and wind designs has to be maintained. The architects adopting this very basic principle will achieve the engineering purposes and in many instances will also eliminate the very costly transfer floor(s).

Not adopting the above principles will always force the boundaries of building affordability and in most cases the profitability margin of the developer which can be seriously compromised.

These principles can be incorporated into building designs by clever and creative architects without compromising the aesthetic values.

Therefore, in summary, load bearing concrete walls in lieu of conventional framed structures achieves significant additional structural safety and cost savings. Dincel-Walls being load bearing achieves further cost and time savings due to its speed of installation and elimination of critical paths in between the building trades. (Download – FAQ, Answer No: 3 – Faster/General) and (Download – Formworkers Benefits)

CONCLUSION

Worldwide experience clearly indicates that the masonry infill walls may have significant effect on the collapse of buildings and loss of life depending on the nature of the earthquake level, geology, building size, shape and irregularities.

The stability and integrity of reinforced concrete frames are disadvantaged with masonry infill walls. Presence of masonry infill wall also alters displacements and base shear of the frame. Irregular distributions of masonry infill walls in elevation can result in unacceptably elastic displacement in the soft storey frame or soft storeys can be formed due to premature failure of masonry infills at any level of framed structures.

According to reported earthquake damage studies, the reinforced concrete frames with masonry infills present a high level of damage. Under these conditions, the references quoted question the appropriate building authorities on why the reinforced concrete framed buildings with masonry infill walls are allowed and still continuing to be allowed in such a wide range.

Depleting resources, energy costs, increasing population, worldwide urbanisation and many other reasons require us to use multi-level buildings which increase seismic risks dramatically. Thus, it becomes the responsibility of all parties involved with the planning, design and construction process to advocate for safer buildings. Ultimately, the problem of reinforced concrete frame buildings with masonry infill walls is not just a building professional's (engineers/ architects) problem but also an important governmental issue.

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