Discussion Forum

Effect of brick masonry infill in seismic evaluation of an existing RC building

Dear Sir,

This has reference to the paper titled 'Effect of brick masonry infill in seismic evaluation of an existing RC building' by Vishal P. Jamnekar and D.J. Chaudhari, published in *The Indian Concrete Journal*, August 2013, Vol. 87, No. 8, pp. 46-52.

In the above paper, the authors have conducted nonlinear static push over analysis of a eight storey, five bay residential building and concludes that the masonry infills have a significant effect on the dynamic characteristics, stiffness, strength and seismic performance of buildings. They also suggest that the conservative formula given in IS 1893 (Part 1):2002 for calculating the time period has to be modified and encourage engineers to make economical designs by considering the effect of masonry infill.

Such studies on the beneficial effects of masonry infills are not new. The stiffening effect of brick wall was recognised as early as 1960s (see Stafford-Smith, 1962), and a good state-of-the-art review of the effect of infill frames was provided by Kaushik *et al* 2006. Surendran and Kaushik (2012) provide a review of in-plane lateral load behaviour and modeling approaches to masonry infilled RC frames with openings. In spite of all this research, most of the codes usually do not suggest to include the stiffness of infill brick walls into consideration in the analysis, unless they are reinforced. This may be due to the following reasons (Arun kumar, sefindia.org):

1. *Location and size of openings will affect the effect of the infill*: Most of the internal partition walls in multi-storey buildings are half-brick thick (115 mm thickness) walls. Even in the outer walls, which have 230 mm thickness, window and door openings, will weaken the walls, unless RC bands are provided. Even if the opening is properly modelled and incorporated, it is impossible to anticipate the changes that may occur during the life time of the structure. In fact, the openings in brick walls, if not properly placed, will even result in *short column effect* and affect the performance of RC columns during earthquakes (Subramanian, 2013).

2. *Dynamic load and inelastic behaviour*: It is well known that behaviour of the infill is brittle in nature and once it cracks, the frame stiffness will drop drastically. Also, during the first few cycles of earthquake, the infill brick wall will collapse completely (in fact many injuries are attributed to the flying debris of brick walls).

3. *Infills may result in non-ductile performance*: The increased stiffness of the building due to the presence of infills may reduce the ability of the frame to flex and deform. In ductile RC frames, masonry infills may prevent the primary frame elements (i.e., columns and beams) from responding in a ductile manner - instead, such structures may show a non-ductile (brittle) performance. This may culminate with a sudden and dramatic failure. (Murty *et al*, 2006)

4. *The stiffness of half brick walls is not reliable*: The half-brick walls, were found to collapse immediately during earthquakes. Long and slender walls are more susceptible to fail in dramatic fashion. During the 2001 Bhuj earthquake (Gujarat, India), even banded half brick walls collapsed and caused huge loss of lives in residential flats. A reliable method to strengthen these walls, so that they will perform better during earthquakes, has not

been found. Although resulting in increased cost, gunited ferrocement, on both sides of the wall, may prevent these walls from breaking up.

5. *Use of reduced R values:* In analysis and design, the actual earthquake load is not considered, as it will result in uneconomical structures. Hence we rely on the ductility and reduce the earthquake load by using the so called response reduction factor, R (Table 7 of IS 1893 (Part 1):2002. Detailed studies have to be conducted to suggest a suitable smaller value of R, so that the infill stiffness can be considered in the analysis.

6. *Infill material property variation* : There are many infill material available these days - clay bricks, flyash bricks, solid concrete blocks, hollow concrete blocks, Aerated Concrete (AAC) Blocks, Cellular Lightweight Concrete (CLC) blocks, Perforated Clay Blocks, Compressed Stabilized Earth blocks, etc. Each has different material properties. Considerable research is required to identify their behaviour under cyclic loading from earthquake and also the effects of openings in such walls.

7. *Quality of material and workmanship*: Some of the blocks such as AAC and CLC are manufactured in the factory and have better quality control than others like clay bricks and flyash bricks. Very poor quality bricks are found to be the cause of the failure of infilled walls on several occasions. Similarly, workmanship may also vary considerably, resulting in weak joints, susceptible for cracks and ultimate collapse.

8. *Wall removal*: When structures are built with columns and beams, the owners and interior decorators or architects assume that the structure transfers load through the RC members only. Hence, during the life of the building, they may remove certain walls for architectural or other reasons, thus jeopardising the safety of the structures during earthquakes.

9. *Richer mortar has to be used*: Richer cement-sand mortar of 1: 4 mixture (1 part cement by 4 parts of sand) makes the masonry stronger against earthquake shaking as compared with the usual 1:6 mortar used in such construction, by a factor of 2.5 to 3.0. Also 1:6 mortar is stronger than lime cinder or lime-*surkhi* mortar.

10. *Affecting load path:* Infill walls, if considered to provide earthquake resistance, must be uniformly distributed in the building and should not be discontinued at any intermediate storey or the ground storey level, since such deviations causes undesirable effect on load paths.

However, although codes suggest to consider infill walls as non-structural elements, they do offer some relaxation in the case of frames with infilled walls by allowing the use of different formula to calculate natural period of vibration (see clause 7.6.2 of IS 1893).

Some more additional queries on the paper are:

1. In page 47, under the 'Methodology' section, the authors have stated that "rigid offsets were provided from the nodes to the face of columns or beams" why were such rigid offsets provided? The frame analysed by them is a regular frame only.

2. In page 50, under the section 'Hinge formation at various levels', they have stated that the results are consistent with those of Madan and Hashmi. But they have cited Sattar and Liel. The reference of Madan and Hashmi is not found in the reference list.

3. Have they considered strong-column-weak-beam concept in their design?

4. In their analysis have they considered cracked column and beam section properties, which will affect the results considerably (see Section 10.10.4 of ACI 318-11)?

5. Most of the references provided by them do not contain year/no./pages of publication.

In this connection, it is interesting to note that confined masonry construction, in which masonry walls are constructed first, and tie columns and bond beams cast around masonry walls, is more resistant to earthquakes. In this type of construction, the wall acts as a load bearing element and ductile detailing is not required in columns and beams (usually done empirically). The beams and columns are considered as confining elements acting in tension and hence will have smaller sections and fewer stirrups and use smaller bar diameters; However, quality workmanship and the connections to the tie columns and bond beams are critical. Such confined masonry constructions have been used in buildings up to 6 storey height (Brzev, 2007).

Another interesting application of 'dry-stone walls', called *ashlar* was found in the *Inca civilization* of Peru, where blocks of stone were cut to fit together tightly without any mortar. Peru is in highly seismic zone and for centuries the mortar-free construction proved to be apparently more earthquake-resistant than using mortar. The stones of the dry-stone walls built by the *Incas* could move slightly and resettle without the walls collapsing- a passive structural control technique employing both the principle of energy dissipation and that of suppressing resonant amplifications!

References

1. Stafford-Smith, B., "Lateral Stiffness of Infilled Frames", *Journal of the Structural Div., ASCE*, Vol. 88, No. ST6, June 1962, pp. 183-199.
2. Kaushik, H.B., Rai, D.C. , and Jain, S.K., "Code Approaches to Seismic Design of Masonry-infilled Reinforced Concrete Frames: A State-of- the-art Review", *Earthquake Spectra*, Vol. 22, No. 4, pp. 961-983, 2006.
3. Surendran, S., and Kaushik, H.B. "Masonry Infill RC Frames with Openings: Review of In-plane Lateral Load Behaviour and Modeling Approaches", *Construction and Building Technology Journal*, Vol. 6, (Suppl 1-M9), 2012, pp. 126-154
4. Arunkumar (http://www.sefindia.org/forum/viewtopic.php?p=61227#61227)
5. Subramanian, N., *Design of Reinforced Concrete Structures*, Oxford University Press, 2013, 872 pp.
6. Murty, C.V.R., Brzev, S., Faison, H., Comartin, C.D. and Irfanoglu, A., "*AT RISK: The Seismic Performance of Reinforced Concrete Frame Buildings with Masonry Infill Walls*", A Tutorial Developed by a committee of the World Housing Encyclopedia, Earthquake Engineering Research Institute, Oakland, California, Nov. 2006, 83 pp
7. Brzev, S., *Earthquake-Resistant Confined Masonry Construction*, National Information Center of Earthquake Engineering (NICEE), Indian Institute of Technology, Kanpur, Dec. 2007, 81 pp.

Dr. N. Subramanian,
Consulting Engineer,
Gaithersburg,
MD, USA

The author's reply

Dear Sir,

My replies to the reader's comments / queries (as far as I have understood them) are as follows.

Reader's comment: Such studies on the beneficial effects of masonry infills are not new
Author's reply: I would be like to know such research papers in which the 'detailed' work is carried out with respect to 'Modeling of Masonry Strut' using the ACT-306/ ACT-308/ ATC-40.

Comment: A good state-of-the-art review of the effect of infill frames was provided by Kaushik et al 2006
Reply: On the basis of the paper by Kaushik et al, further modeling and analysis is carried out in our research work. In our research work we have not presented the 'state-of-art' report.

Comment: Surendran and Kaushik (2012) provide a review of in-plane lateral load behaviour and modeling approaches to masonry infilled RC frames with openings.
Reply: In this research, an 'analysis' is carried out and not a review. Also in our research paper only 40% masonry infill is considered for analysis. (The detailed description regarding 40% infill was previously provided to ICJ during the manuscript review process before publication).

Comment: In spite of all this research, most of the codes usually do not suggest to include the stiffness of infill brick walls into consideration in the analysis, unless they are reinforced.
Reply: As per the referred papers from the standard journals / proceedings and IS codes we did not find 'Use of infill should not be considered' in analysis. But in spite of that, IS 1893: 2002 has given the provision for utilisation of infill effect in analysis and design.

Query: On page 47, under the 'Methodology' section, the authors have stated that "rigid offsets were provided from the nodes to the face of columns or beams". Why such rigid offsets were provided? The frame analysed by them is a regular frame only.
Reply: Part A: Rigid offsets were provided just to have in plane movement at all levels of slab so that the displacements of any joint at same level will not differ.

Part B: In this research work, frame (rectangular in plan) is being modeled. Such frames are not called as regular frames. Regular frames are those which had same

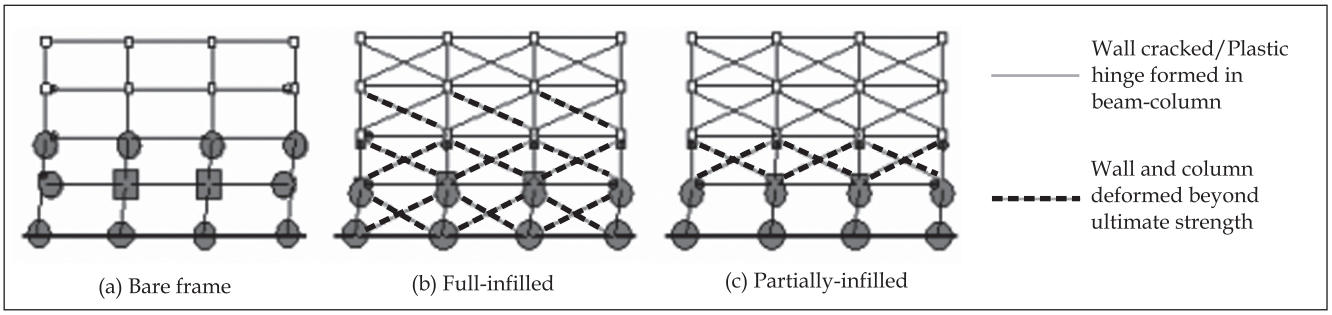

Figure 7. Typical failure modes observed for case study RC frames

dimensions in both directions (X and Y). In this research work we have analyised un-symmetrical building because we want to make it clear to everyone that the results obtained is for un-symmetrical building in plan and such analysis can be carried out on symmetrical/ unsymmetrical buildings. Also the results which were obtained from the analysis could be cross verified by manual calculations and hence to show the authentic research work we had selected such a building for analysis.

Query: On page 50, under the section 'Hinge formation at various levels', they have stated that the results are consistent with those of Madan and Hashmi. But they have cited Sattar and Liel. The reference of Madan and Hashmi is not found in the reference list.
Reply: In this research paper we have referred to 'Seismic performance of reinforced concrete frame structures with and without masonry infill walls' by Siamak Satter and Liel. As in our research paper, similar pattern of 'Hinge formation' is observed as provided by Satter and Liel (Ref. figure 7 below). But the original contribution for formation of such hinges was first reported by Madan and Hashmi. As we were unable to obtain the research of Madan and Hashmi, we had identified another approach to authenticate the work. The website to view the paper of Siamak Satter and Liel is www.learningace.com and link is : http://www.learningace.com/doc/1750649/fd0bd99f2dee72bc3ca1cbd1c283a159/sattar-liel-seismic-performance-of-infilled-rc-frames-final

Query: Have they considered strong-column-weak-beam concept in their design?
Reply: (As far as I have understood the question) Regarding our research work we have adopted the generalised dimensioning of beam and columns which is generally referred in most of the residential buildings in India, to have the effect of real behaviour of most of the common structures constructed in India.

Query: In their analysis have they considered cracked column and beam section properties, which will affect the results considerably (see Section 10.10.4 of ACI 318-11)?
Reply: (As far as I have understood the question) No. We have analyised the building as a 'Recently Constructed' structure. Hence, there is no question about the cracking of column or beam sections. The moment-curvature relationship is being considered for beam and columns as an inbuilt function in SAP 2000 v14.0 software.

Comment: Most of the references provided by them do not contain year / no. / pages of publication
Reply: The papers which we have referred are available on the web. In most of the research papers the authors / journals have not embossed about when that paper was published, page numbers, etc. Hence it was not possible to publish that information. [Regarding these, the detailed clarification was given to ICJ during the manuscript review process]

Vishal P. Jamnekar
Assistant Professor
Department of Civil Engineering
G.H. Raisoni College of Engineering and Management
Amravati