SEISMIC ANALYSIS OF INFILLED R/C FRAMES WITH IMPLEMENTATION OF A MASONRY PANEL MODELS

ELENA VASEVA
1113 Sofia str. Acad. G. Bonchev bl.3 CLSMEE - BAS
elvass@geophys.bas.bg

ABSTRACT. The influence of infill panels on the response of RC frames under seismic excitations has been subject of a lot of experimental and theoretical investigations in the last decade. Infill panels are widely used as interior partitions and external walls in buildings, but they are usually treated as non-structural elements and in a lot of cases not included in the design. The main reason that the infilled panels are not included in the design is due to the inherent uncertainty associated to the numerous parameters on which the behaviour of the infill panels depends. Important source of uncertainty is the type of interaction between the infill and the frame, which strongly influences the behaviour of the infilled frame by changing the load-resisting mechanisms of its individual components.

In this paper are shown the results from numerical nonlinear analysis of infilled frames with emphasis on the formulation of the infill panel model. Calculation and selection of the model parameters for the case study frames are given. The results from nonlinear analysis of the bare and infilled frames are compared and some conclusions are made in view of new EC8.

KEY WORDS: infill wall; strut model, interstory drifts

1. Introduction
The effect of infill panels on the response of R/C frames subjected to seismic action is widely recognised and has been subject of numerous experimental investigations, while several attempts to model it analytically have been reported. It is well known that the assessment of R/C frames with infilled walls is dependent on the material constituting the infills and the geometry of both frame and infill. The possible effects of infills on frames are the following:
(1) The presence of infills does not affect the structural response. This can be the case if the infills are very light and flexible, or completely isolated from the R/C frame, or so brittle that a total failure is expected even for a moderate ground acceleration.
E. Vaseva

(2) The infills are assessed to have a significant contribution on the response, and they are expected to remain in the elastic range. In this case a linear elastic analysis can be performed. The ductility capacity should be set to 1, unless inelastic structural wall behaviour can be expected, with columns acting as tension or compression boundary members, and the infill acting as a connecting shear element.

(3) The infills are assessed to have a significant contribution to the response, and they are expected to suffer significant damage during the seismic event. In this case the high probability of the formation of a soft storey has to be recognised and taken into account.

In order to decide whether the first case is applicable to a given situation, the following parameters should be examined: details of connections between infill and frame; ratio of the stiffness of the infilled wall and the stiffness of the bare frame; ratio of the shear strength of the infilled wall and the bare frame.

The decision as to whether cases (2) or (3) apply requires consideration of the likely infill failure mechanisms.

The parameters for quantifying the stiffness, strength and deformation capacities for infilled panels are given in this paper.

2. Discussion of the modeling of the infill wall

Recently a number of papers and documents have been published reporting on studies of the behaviour, design, and analysis of infilled frames. A recent NZSEE Bulletin article [1] provides a review of macro (equivalent strut) and micro models, and reports on some comparative studies between equivalent strut models and FEM (‘solid’ element) models. Among the conclusions were that single strut models can provide an adequate estimation of stiffness of the infilled frame, however multi-strut models are required to obtain realistic values of the bending moments and shear forces in the frames Fig.1. The equivalent strut approach could be adopted, considering a multi-strut modeling in order to receive a better representation of the effect of the masonry panel on the R/C frame by some researchers. The majority of reference sources model infill panels using concentric struts. However there appears to be some inconsistency in using a concentric strut model to determine actions on frame columns when testing and micro modeling indicate that a critical behaviour mode is column shear failure due to the eccentricity of the panel loading. The use of a concentric strut model alone does not accurately model the shear and curvature demand on frame members for ductile behaviour. A FEMA procedure [4] specifies that masonry infill panels shall be represented as equivalent diagonal struts. The struts may be placed concentrically across the diagonals, or eccentrically to directly evaluate the infill effects on the columns. This is illustrated in Fig. 2. FEMA-273 specifies strength requirements for column members adjacent to infill panels and recognizes the column shear mechanism, specifying that column shear may be evaluated by applying the expected panel forces eccentrically from the joint. This is
Seismic Analysis of Infilled R/C Frames

illustrated in Fig. 3. Shear force demand may however be limited by the moment capacities of the column of reduced length, \( l_{\text{eff}} \). However this would tend to be overly conservative in that it would not recognize the distribution of load between frame action and strut action. FEMA also appears to permit eccentric rather than concentric strut models to evaluate column action explicitly. FEMA-306 [5] recommends that infill panels may be modeled as equivalent struts in accordance with FEMA-273. Deformation capacity guidelines are given in the form of interstorey drift ratios. These vary from 1.5% for brick masonry to 2.5% for concrete block masonry. As diagonal cracking is initiated at drifts of 0.25% and essentially complete by about 0.5% this represents a high level of ductility in the panel system. For the concrete-frame components, shear demand is evaluated for short columns as specified in FEMA-273. FEMA-306 also provides an infilled frame component damage guide. Two topical behaviour modes are illustrated in Fig. 4. The bed joint sliding mode involves diagonal cracks from the corners intersecting horizontal cracks in centre of the panel and is associated with large displacements as may be found with flexible steel frame. The reinforced concrete column shear failure mode typically occurs near the frame joints and is associated with stiff and/or strong infills.

A lot of studies are carried out in Europe in support of EC8 [3,6]. Kappos and Ellul [7] carried out a study and conclude that EC8 is over conservative by disregarding the contribution to strength of the infills. It is proposed that design of frames be based on models which include infill elements using two different stiffness assumptions. Base shear should be calculated assuming the secant stiffness at peak load for the infill panels. Member actions should then be found assuming a lower stiffness of infills (approx. one third). Combescure and Pegon [2] carried out numerical studies and a testing programme on infilled frame structures. Both micro (panel element) and macro (strut element) models were considered. The modeling showed the validity of the diagonal strut model and highlighted the importance of identifying appropriate strut properties. The study found that an effective strut width...
of approximately 25% of the diagonal length was appropriate for the cracked stiffness and stiffness at maximum strength. Though a concentric strut was used, micro-modeling indicated a concentration of shear at the end of the columns, indicating that an eccentric strut model would be required for the detailed evaluation of member actions.

![Fig. 3. Estimating forces applied to columns (FEMA-273 1997)](image)

These conclusions are similar to the widely used reference text concerning the modeling panel stiffness, given in [9]. The recommendation is that masonry infill panels be modeled as equivalent concentric diagonal struts, based on an effective width of 0.25 times the diagonal length (a conservative estimate). It is recommended that where sliding or diagonal compression failure may occur, frames should be designed elastically due to the concentration of deformation in the first storey.

Eccentric strut models have been used in other studies [1] and recent New Zealand research indicates that they are required to obtain realistic values of the member actions in the frames. It appears that multi-strut models may be the best solution for infill frame evaluation. However there may need to be further research into the use of these models when panel damage occurs, so as to provide an adequate margin of safety against a column shear mechanism.

**3. Definition of the parameters for modeling of infill wall**

In the present paper the contribution of the masonry infill wall to the response of R/C frame is studied by replacing the infill wall by system of two diagonal masonry compression struts. The model of infill wall with struts consists of numerous parameters (mechanical, geometrical and empirical). The mechanical and geometrical parameters are required to define the behaviour of the masonry strut. The empirical parameters are necessary for the determination of the values, connected with hysterise behaviour.
Seismic Analysis of Infilled R/C Frames

The equivalent strut model for masonry infilled frame is used for estimating the control parameters for the rules used in the adopted hysteresis macro-model for the force-deformation behaviour of masonry infill walls. Details concerning the development of this macro-model are presented in the original reference [11]. The model is based on the well-known Bouc-Wen model for hysteretic behaviour taking into account hysteresis effects characteristic of masonry element subjected to repeat loading reversals such as stiffness degradation, strength deterioration and “pinching”. More information concerning the estimation of the envelope parameters of the strut are given in Vaseva [12].

4. Numerical example

Nonlinear structural analyses is used to determine the earthquake behavior of structures with infill walls. In the studies, reported here, IDARC2d-5.0, [11] have been used. The masonry panel model explained before was employed to reproduce the behaviour of the full-scale frame model used as a case study for the needs of this work. The full-scale, four-storey, two-bay reinforced concrete frame considered was pseudo-dynamically tested at the ELSA reaction-wall laboratory [8]. Two identical in geometry, construction and detailing frames were constructed and tested, one was bare and the other infilled. The case study frame was infilled with brick walls. More details concerning this frame are given in Vaseva [12].

With the model of infill panel explained before the nonlinear analysis are performed. When the frames have been subjected to earthquake with different intensity a type of vulnerability functions have been obtained. The different values of some parameters were estimated for a different multipliers for the reference accelerogram. These parameters are maximum beam and column rotations; maximum interstorey drifts and maximum top displacements. The vulnerability functions representing the relationships between these parameters and the intensity multipliers are given in Fig. 5,6.

For the uniformly infilled frame the vulnerability functions are similar to that of the bare frame – all the values of above mentioned parameters increase with a
E. Vaseva

small slope up to an scaling factor for intensity of 2.0. After this value of scaling factor the increasing is rapidly and the values for bare and infill frame similar for the scaling factor 2.5. A small slope in the vulnerability curves for damage parameters is a good sign, because small variation in the intensity taking into account the value assumed in the design correspond to a small variation in the coefficient of safety of structure under investigation.

4. Conclusions

1. With the application of the strut model it is possible to give good solution for infill frame evaluation.

2. The presence of masonry infill walls can affect the seismic behavior of framed building to large extent. These effects are generally positive: masonry infill walls can increase global stiffness and strength of the structure. The energy dissipation capacity of the frames with infill walls is higher than that of the bare frame.

REFERENCES

Seismic Analysis of Infilled R/C Frames

