Inelastic dynamic response of 3D reinforced concrete infilled frames

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Abstract

An inelastic finite element model to simulate the behaviour of 3D reinforced concrete frames infilled with masonry panels subjected to static load and earthquake excitation has been presented. Under the loads the mortar may crack, causing sliding and separation at the interface between the frame and the infill. Furthermore, the infill may become cracked and/or crushed which then changes its structural behaviour. It may render the infill ineffective leaving the bare frame to take the entire load, which may lead to the failure of the framing system itself. In the present study, 3D reinforced concrete infilled frames have been analysed using the finite element method.
Keywords: infilled frames, inelastic, dynamic response, 3D reinforced concrete.

1 Introduction

Holmes [4] and Smith [12] proposed the concept of infill as an equivalent diagonal compression strut. Liauw and Kwan [6] examined the nonlinear behaviour of non-integral infilled frames using the finite element method. The nonlinearities of material, structural interface, effects of initial lack of fit and friction at the interface were taken into account. Papia [8] used the boundary element method to model the behaviour at the frame and the infill interface. Haddad [3] analysed cracked frames with masonry infill using the finite element method and fracture mechanics.

May and Naji [7] carried out nonlinear analysis of 2D infilled frames under monotonic and cyclic loadings using the finite element method. Choubey and

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Sinha [2] carried out an experimental investigation into the behaviour of 2D reinforced concrete frames infilled with brick masonry under lateral cyclic loading. Singh [10] and Singh et al [11] investigated the inelastic response of three dimensional reinforced concrete infilled frames subjected to earthquake excitation using the finite element method.

2 Finite element idealisation

The three dimensional skeleton frame, the panel and the interface between the frame and the panel have been modelled by a 3-noded frame element, an 8-noded isoparametric element and a 6-noded interface element respectively, as shown in Fig. 1.

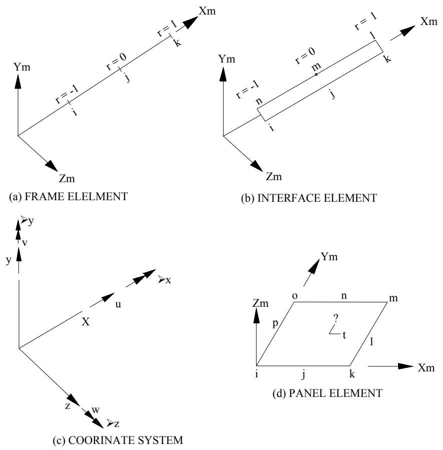

Figure 1: Different elements used for modelling the infilled frame.

2.1 Reinforced concrete frame element

A 3-noded beam-column element as shown in Fig. 1 has been used to model the skeletal frame [10, 11]. Inelastic behaviour of the element is governed by the interaction of the axial force, two flexural moments and a torsional moment.

2.2 Brick masonry infill

The eight-noded isoparametric element as shown in Fig. 1 has been used to model the masonry infill panels. In the present study only in-plane stiffness has been taken into consideration. The material has been assumed to be linearly elastic until failure. To predict the cracking and crushing type of failure, Von Mises failure criterion with a tension cut off has been adopted [11].

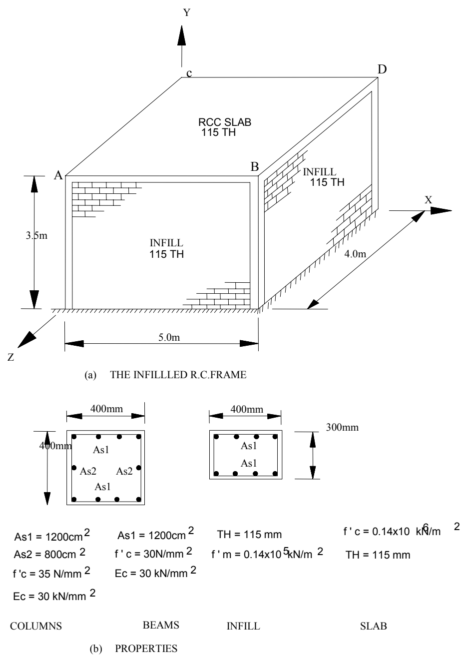

Figure 2: Geometry and X-sectional details for the infilled space.

2.3 Concrete mortar interface element

The behaviour of an infilled frame depends upon the interaction between the infill and the frame. There can be separation, closing of gap and slipping between the frame and the infill. A six noded interface element as shown in Fig. 1 has been used to model this behaviour between the frame element and the panel element. Two in-plane translational degrees of freedom per node have been considered [11].

3 Inelastic analysis

For the inelastic static analysis, an incremental iterative procedure has been adopted. For inelastic dynamic analysis predictor-corrector form of Newmark method [11] has been used.

4 Numerical examples

The effectiveness of the model for 2D infilled frames has been established by Singh [10, 11]. The proposed model is able to simulate the experimentally observed load deflection behaviour, separation of the infill from the frame, central strut width, failure mode and failure load. The inelastic algorithms are able to predict the sequence of formation of the plastic hinges in the frame members and the cracks in the infills. The model can predict the entire time history response of two dimensional infilled frame systems under earthquake excitation.

To study the behaviour of 3D reinforced concrete frames with masonry panels subjected to static and dynamic loads the analysis of the following structure has been presented.

4.1 An infilled space frame

A single storey one bay infilled reinforced concrete space frame shown in Fig. 2(a) has been studied for the inelastic behaviour under static and dynamic loads. The frame has a roof of reinforced concrete slab and all the other four sides have masonry infill. The properties and the cross-sectional details are shown in Fig. 2(b). For analysis, the roof slab has been assumed to have only the in-plane stiffness.

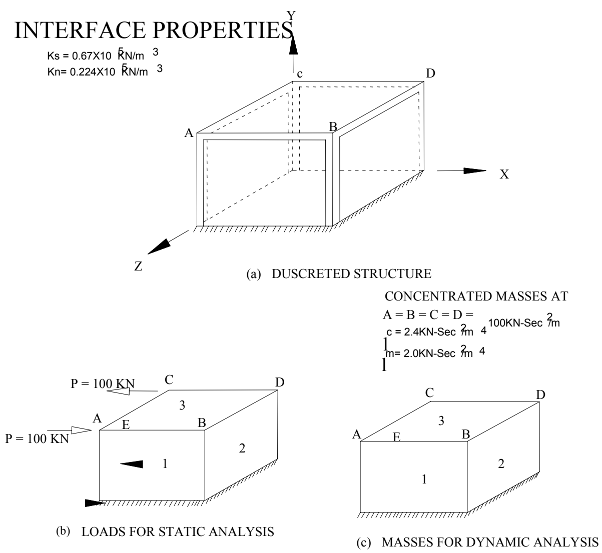

Figure 3: Discretization, loads and masses for the infilled space frame.

4.1.1 Static analysis

The infilled space frame of Fig. 2 is discretised as shown in Fig. 3(a). Two equal and opposite lateral loads are applied along the X-axis at points A and C to simulate the torsional loading as shown in Fig. 3(b). The inelastic response in terms of load-deflection curve in the X-direction at the point A is shown in Fig. 4. The sequence of formation of the plastic hinges in the frame and the cracks in the infill panel 1 are shown in Fig. 5 and listed in the Table 1. At the load factor (defined as the current load divided by the load at the first increment) of 16.0, cracks 1 and 2 appear in the panel 1. When the load factor reaches 22.0, two more cracks 3 and 4 appear in the panel 1. At a load factor of 28.0, eight plastic hinges form in the frame. The infilled frame loses most of its stiffness as the load factor reaches a value of 67.0. Beyond the load factor of 78.0, the solution is not possible even with a very small load increment.

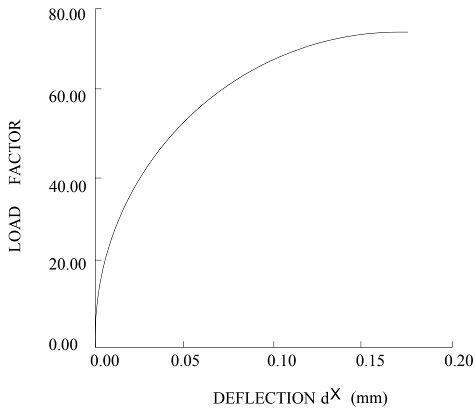

Figure 4: Inelastic response deflection at node A.

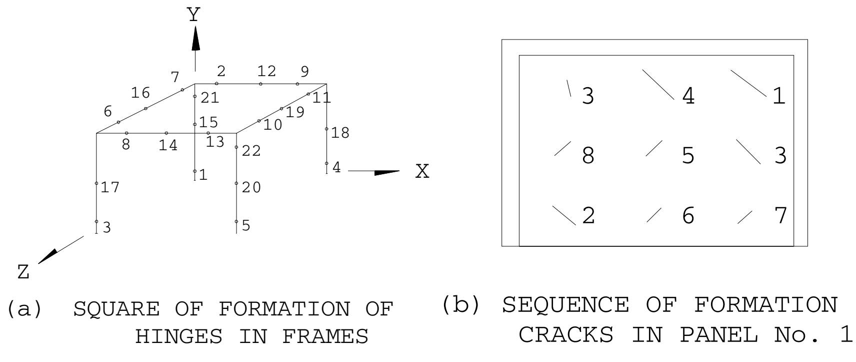

Figure 5: Sequence of formation of the cracks and the hinges in the infilled space frame.

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Table 1: The sequence of formation of the plastic hinges/cracks in the infilled space frame.

Load Factor	Sequence of Appearance of Cracks in Panel 1	Sequence of appearance of Hinges in Frame	Deflection at A δ_x (mm)
16.0	1 & 2	--	5.85
22.0	3 &4	--	8.84
28.0	--	1 to 8	18.08
34.0	5 &6	9 to 14	25.25
39.0	--	15 to 19	23.72
44.0	7 & 8	20	33.48
57.0	9	--	67.45
61.0	--	21	88.41
67.0	--	22	107.20

4.1.2 Dynamic analysis

For dynamic analysis, the frame is idealised as per the scheme shown in Fig. 3(a). The geometry, sectional details and the properties are shown in Fig. 2. In addition to the mass of the structure, four concentrated masses are attached at the points A, B, C and D as shown in Fig. 3(c). The S-0-E component of EL-Centro, Earthquake of 1940, 8sec duration has been applied in the X-direction of the frame. The earthquake had a peak acceleration of 3417mm/sec^2 in S-0-E direction at 2.14sec. A damping ratio of 0.05 has been assumed for the analysis.

The elastic and inelastic responses in terms of roof deflection at the point A have been plotted in Fig. 6. The elastic and inelastic acceleration responses at the roof level and the variation of the bending moment in the beam AB at the Gauss point near end A is shown in Fig. 7. The variation of bending moment at the section E has been presented in Fig. 8. The sequence of formation of the plastic hinges in the frame and that of cracks in the infill panel 1 are shown in Fig. 9.

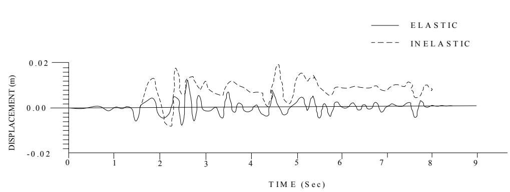


Figure 6: Elastic and inelastic responses: deflection at a point A of the infilled space frame.

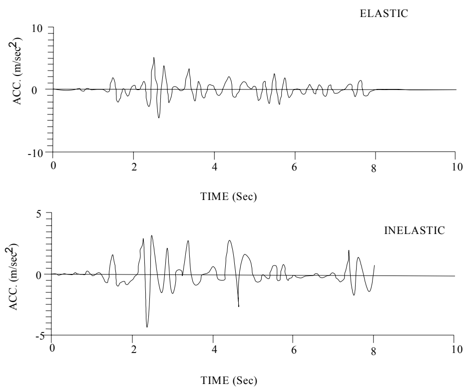


Figure 7: Elastic and inelastic responses: acceleration of the point A of the infilled space frame.

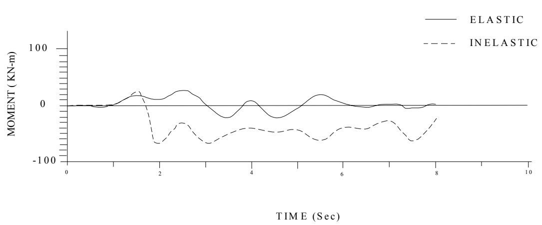
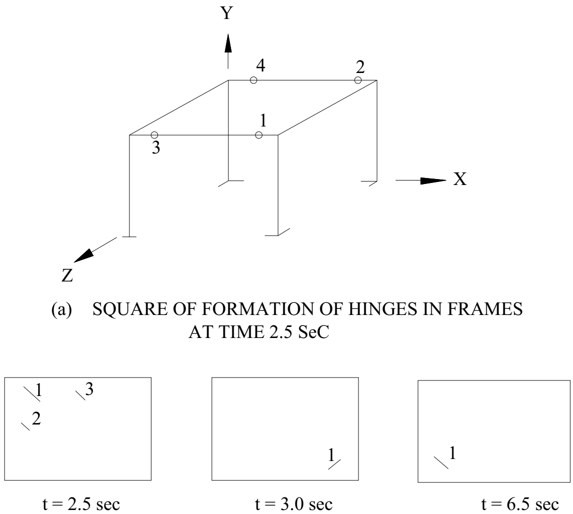


Figure 8: Elastic and inelastic responses: bending moment of section E of the infilled space frame.

The maximum inelastic deflection has been found to be 19.0mm at 4.27sec whereas the maximum elastic deflection is 14.0mm at 2.6sec, which is 26.3 per cent less than inelastic deflection. It has been noticed that after 2.6 sec, the deflection occurs only on one side of axis indicating a permanent deformation set. The maximum inelastic and elastic accelerations have been found to be 3.0 m/sec at 2.5 sec, and 5.9 m/sec at 3.5 sec, respectively. The former is 96.6 per cent higher than the latter. Maximum moments in frame at the section E have been observed to be 69.0 kNm at 2.0 sec and 27.0 kNm at 2.6 sec for the inelastic and elastic responses, respectively.

The infill panel 1 and the one opposite to it have shown cracks during the application of the earthquake load. Only the beams along AB and CD have shown plastic hinges at the Gauss points near the ends. The behaviour has been found to be symmetrical along the edges AB and CD. So the panel 1 and the beam AB have been studied. At time 2.5 sec, four plastic hinges are formed in the frame and three cracks appear in the panel 1. Little later at time of 3.0 sec, the cracks disappear (since the stresses are now within the yield surface limit, however the plastic strains continue to be present) and one new crack appears. At the time of 6.5 sec, one crack reappears in the panel 1, but the others vanish. After this stage all the cracks ‘disappear’.



(a) SQUARE OF FORMATION OF HINGES IN FRAMES AT TIME 2.5 SeC

(b) SEQUENCE OF FORMATION OF CRACKS IN PANEL No. 1

Figure 9: The sequence of formation of the cracks and the hinges in the infilled space frame at different times.

5 Conclusions

The proposed model is able to simulate the load deflection behaviour, the sequence of formation of the plastic hinges in the frame members and the cracks in the infills. The model can predict the entire time history response of three dimensional infilled frame systems under earthquake excitation. In the inelastic static analysis, the cracks in the infill are first to develop and subsequently with further increase of the load the infill looses its stiffness, which leads to the failure of the frame. With the formation of sufficient number of hinges or cracks, the structure looses most of its stiffness and very large deflections are produced. The plastic hinges and cracks 'disappear' on the reversal of loads and also on reduction of magnitude of exciting force.

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