INFILLED FRAME CONSTRUCTION IN SEISMIC REGIONS

by

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ABSTRACT

The behaviour of infilled frames subjected to combined loading, consisting of a vertical load, moment and the lateral load, applied at the joints is investigated. Two types of frames, with and without shear connectors, are considered. Finite element method has been used to determine theoretically the lateral stiffness of infilled frames under combined loading. Experiment results are based on a series of tests on models of steel frame and cement mortar infill panel. The study concludes that the lateral stiffness of infilled frames decreases with the increase of the vertical load and the moment acting simultaneously with the lateral load.

INTRODUCTION

There are two main advantages of using infilled frame construction of moderate height in seismic areas. Firstly, they increase the lateral stiffness of the enclosing frame system by providing lateral resistance to forces induced during an earthquake. Secondly, they absorb a considerable amount of energy during subsequent shocks by developing cracks inside and along the boundary edges of the infill panel, due to the occurrence of slip at the interface, and through the yielding of the material in the compression zone located at the ends of the compression diagonal.

It can be stated that such a composite structural system can resist initial earthquake shocks due to their high inplane stiffness and, subsequent shocks due to their large energy absorption or the damping capacity.(1) It is thus necessary to investigate the load deflection behaviour of such frames under the action of lateral loads and, to study their modes of failure.

The review of the existing literature(2,3,4) reveals that contribution of the infill panel towards the lateral stiffness and strength of a frame has been well recognised and, investigated during the last two decades. Design methods(5,6,7) based on an equivalent diagonal strut concept, and more rigorous methods(3) of analysis have already been developed to estimate the lateral stiffness of the composite frame. Owing to the high inplane stiffness of the infill panel, the lateral stiffness of the infilled frame is considerably increased provided the infill panel is a tight fit inside the frame. The analysis of this composite frame offers some problems due to the complicated nature of the interaction forces that develop at the

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interface. The interaction behaviour of the composite frame is further complicated due to (a) the development of boundary cracks and, the occurance of slip at the interface, and (b) the formation of cracks in the infill panel.

LOADING

Each storey segment of a multi-storeyed infilled frame building as shown in Fig. 1 is not only subjected to lateral loads during an earthquake but may also be acted upon by a combination of vertical load (or axial load) and moment at the joints due to the presence of upper storeyes (P - Δ effect). Also, if due to some reasons, the infill panel of any storey gives away or is removed, the frame of that storey will transfer moments to the joints of adjacent frames.

FRAME MECHANISM

An infilled frame with a tight fit panel developes separation cracks during lateral loading along the interface of the frame and the infill except over a certain length near the loaded corners which has been designated as the length of contact. Although, the widening of the separation cracks with the increasing lateral load does not decrease the lateral stiffness of the frame considerably till the yielding of the panel, yet the occurrence of such cracks is not desirable. So, the present author has also studied the behaviour of infilled frames with shear connectors in which the effect of any initial lack of fit in transferring the interaction forces between the bounding frame and the infill panel is taken care of. In addition, it is found that these shear connectors increase the lateral stiffness of infilled frames although the ultimate load carrying capacity almost remains the same. The total energy absorption capacity of the infilled frames with shear connectors is slightly decreased.

THEORETICAL ANAYSIS

Theoretical analysis of infilled frames, with and without shear connectors, has been carried out using the finite element method. The frame was divided into a number of beam elements and, the infill into a number of inplane bending rectangular elements. The stiffness matrix of the inplane bending element was derived by using Pian's hybrid(3) model in which an assumed stress pattern is made to conform to a specified boundary edge displacement pattern of the element through the minimisation requirement of the total compelmentary energy. Two types of plate elements have been employed. The first type of rectangular element was permitted two degrees freedom in terms of displacement u and v, at each of the corner node points. The edges of the plate element associated with these degrees of freedom displaced linearly. The second type of a plate element with four corner node poins was allowed three degree of freedom u, v and θ (inplane rotation) at a node point in contact with the joint of the rigid bounding frame, while the remaining three nodes were permitted two degrees of freedom, u and v, as shown in Fig 2(a). By introducing an inplane rotation component θ as a degree of freedom at one of the corner points, it was possible to maintain an angle of 90° at that corner which is consistent with the assumption of the rigidity of the frame. Further, when a beam element with two degrees of freedom, v and θ, deforms as shown in Fig. 2(b), the resulting configuration associated with each of these generalised displacement component is described by a cubic polynomial. For the displacement pattern of the beam elements meeting at the loaded corner and the adjacent infill element to be consistent in configuration, it was possible only if an inplane rotational degree of freedom, θ, was introduced at the corner node point in addition to the displacement components u and v as shown in Fig. 2(c). The stiffness matrix for the second type of inplane bending element is given in reference 8.

The procedure of finding the lateral stiffness of infilled frames without shear connectors using finite element has already been published(3). For computing the lateral stiffness of infilled frames with shear connectors, the following boundary conditions were used.

The node points along the horizontal boundary edge of the infill are connected to the node points of the girder of the frame in the direction of displacement v. The node points along the vertical boundaries of the panel are connected to the nodes of the adjacent frame elements to undergo the same displacement component u as shown in Fig. 2d. The effect of slip at the interface was taken into account theoretically using the iteration procedure discussed in reference 3.

It was observed from the laboratory tests that the behaviour of infilled frames with shear connectors can be assumed to be linear upto a load level which is approximately equal to two-third of the ultimate load. The experimental values of the stiffness of the composite frame are compared with the theoretical results of the linear analysis using the finite element method for a lateral load level of 300 kg as given in Table 1. There is a reasonably good agreement between the two.

Fig. 3 shows the energy absorption and energy capacity curves per half cycle loading of infilled frames with and without shear connectors. Curves A and C represent the energy capacity curves, and curves B and D represent the energy absorption capacity curves for frames without and with shear connectors(1).

EXPERIMENTAL STUDY

Effectively, the lateral stiffness of an infilled frame is a function of the flexural strength of the frame, the elastic properties of the material of the infill panel, and its length to height ratio and, the type of connection between the frame and the infill. As the main object of the present study was to investigate the effects of combined loading in the lateral stiffness and strength of the infilled frames, the above-mentioned parameters were kept constant within the acceptable limits. During each test, the vertical load, P and the associated moment, V.e, were assigned a specified value whereas the lateral load was increased gradually till the failure of the infill panel. e is the eccentricity of the vertical load V as shown in Fig. 4. Observations included the recording of lateral deflection or displacement with each increment of the lateral load, the first crack load, the final lateral load, and the mode of failure. The tests were carried out on infilled frames consisting of bounding steel frame and high alumina cement mortar infill panels with and without shear connectors. The frames were prepared in duplicate form and loaded in such a manner as to achieve rigid base condition along the central member as shown in Fig. 4. Vertical load V and the associated moment, V.e, at the joints were applied by pre-stressing a high tensile steel rod of 5 mm dia passing through the extended arm of the steel frame. The lateral load was applied gradually through a hydraulic jack. It may be mentioned that in practice, the vertical load and the moment at a joint are not related as described above. It was only due to an experimental convenience that M = V.e relationship was used.

CONCLUSIONS

1. Infilled frames without shear connectors.

    (a) These frames underwent initial lateral displacement when subjected to a combination of vertical load and moment alone.

    (b) The failure of the panel was mainly due to the crushing of one of the loaded corners along with separation cracks at the boundary junction.

2. Infilled frames with shear connectors..

    (a) These frames being relatively more stiff exhibited no appreciable lateral displacement with the application of vertical load and moment acting alone.

    (b) They bahaved linearly upto the first tension crack.

    (c) The mode of failure was due to the occurrence of the diagonal tension cracks eventually followed by a compression mode of failure. After the occurrence of the first crack load it was possible to increase the load further. In one case, the stiffness of infilled frame with shear connectors was less than that of without shear connectors in the vicinity of the failure load only. This decrease in the stiffness was due to the fact that the cracks developed all along the tips of the shear connectors thus yielding an infill panel with reduced dimension, and loosely fitted inside the frame.

3. General Comments:

    (a) Infilled frames with shear connectors were generally stiffer than the ones without shear connectors upto the failure load.

    (b) As the magnitude of the vertical load and the moment decreased, the stiffness of both types of frames increased.

Table 1 - Comparison of theoretical and experimental values of lateral deflection under combined loading

H = 300 kgms,   e = 15.24 cui   and   M = V.e

V kgms / Δ Lat mm	0	100	300	500	750
Experimental	0.14	0.15	0.16	0.19	0.25
Theoretical	0.10	0.12	0.17	0.22	0.30

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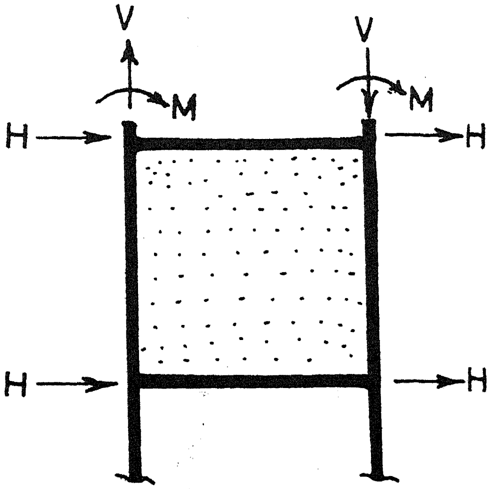


FIG.1 Infilled frame - storey segment of a multistorey building under combined loading

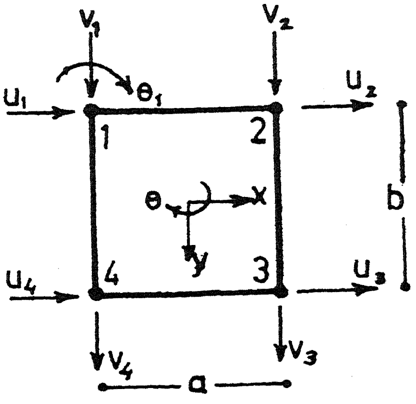
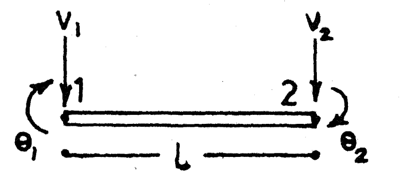


FIG.2a Inplane plate bending e
with three degrees of f
at the node 1 and two c
of freedom at the other



Beam element with two degree of freedom at each mode

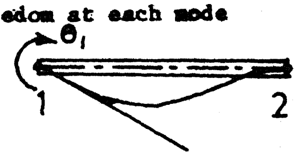


FIG.2b Deflection configuration associated with θ alone

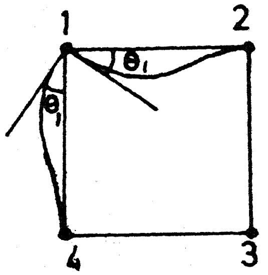


FIG.2c Deflection configurati
of plate element assoc
with θ at node 1 alone

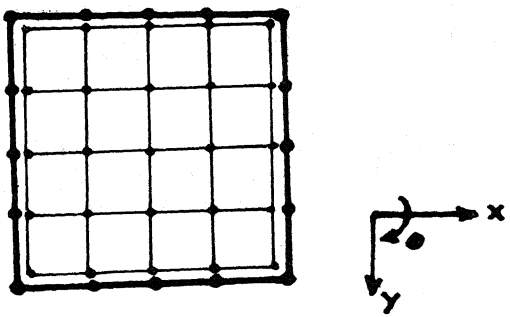


FIG 2d Finite element idealisation of frame and the infill panel

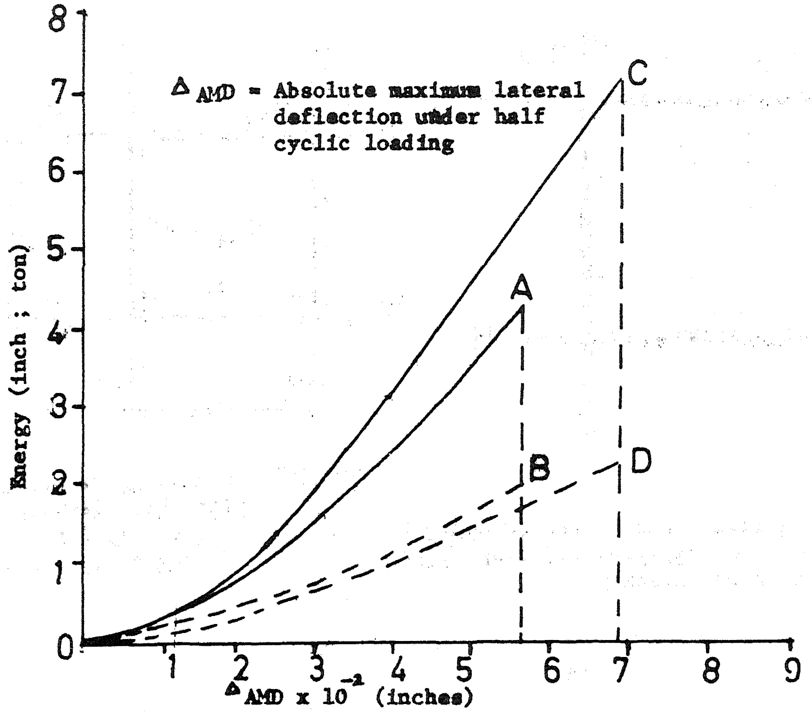


FIG.3 Energy absorption and energy capacity curges per half cycle loading

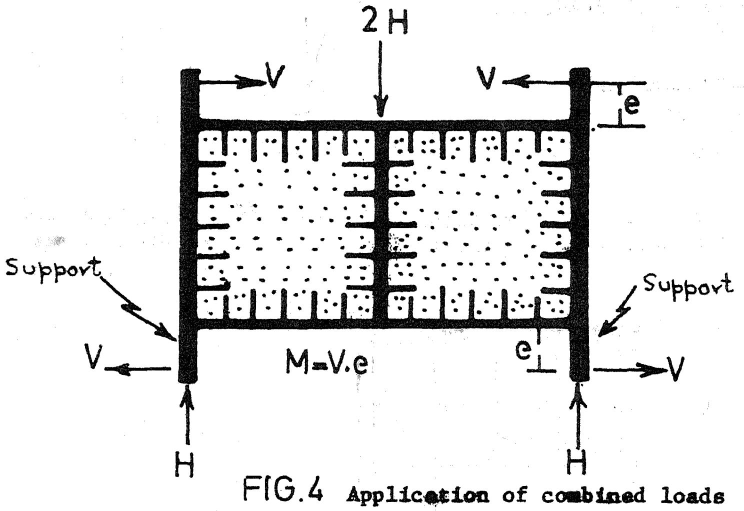


FIG.4 Application of combined loads at node points during the experiment