Earthquake Engineering, Tenth World Conference © *1992 Balkema, Rotterdam. ISBN 90 5410 060 5*

Nonlinear seismic response of infilled steel frames

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ABSTRACT: A numerical study is performed to study the effects of infill walls on the nonlinear seismic response of infilled steel frames. Three structures are analyzed: a one-story one-bay, a two-story three-bay, and a ten-story three-bay. The conclusions of the study are the following: a) The axial forces in the members of the bounding frame are significantly affected by the presence of infill walls, b) infill walls reduce the bending moments and shear forces of infilled structures, c) walls at the lower floors are damaged more extensively than the ones at the upper floors, d) the location of the damaged walls determines which members of the frame undergo plastic deformations, and e) infill walls reduce considerably the number of members that undergo plastification and the number of loading and unloading cycles of these plastic hinges.

1 INTRODUCTION

The behavior of infilled steel frames subjected to strong earthquake motion is studied by nonlinear dynamic numerical simulation. The steel structures selected for analysis are low and medium height. Infill walls are modelled by six compression-only strength- and stiffness-degrading inclined struts. Both material and geometric nonlinearities of the steel frame elements are modeled to obtain a realistic response of the structures. The time-step is adjusted automatically according to the formation of plastic hinges or path changes of infill walls.

In the first part of this paper the infill-wall model is described, and in the second the results of the analysis of example structures are presented. The responses between the infilled and bare frames are compared to obtain an understanding of the effects of infill walls on the transient dynamic behavior of steel frames subjected to strong earthquake motion.

2 INFILL WALL MODEL

The model proposed for idealizing infill walls consists of six compression-only inclined struts as shown in Figure 1. Three parallel struts are used in each direction, and the off-diagonal ones are positioned at critical locations along the frame members. At any point during the analysis only three of the six struts are active, shown in Figure 1 with solid lines. The struts are switched to the opposite direction whenever they reach zero forces. The parameter a represents a fraction of the length or height of a panel and is associated with the position of the formation of a plastic hinge in a beam or a column. Theoretical values for this parameter are given by Liauw (1983).

The hysteretic behavior of the six struts is defined by a hysteretic model which consists of two equations. The first equation defines the strength envelope of a structural element and the second defines its hysteretic behavior. The shape of the envelope and the hysteretic

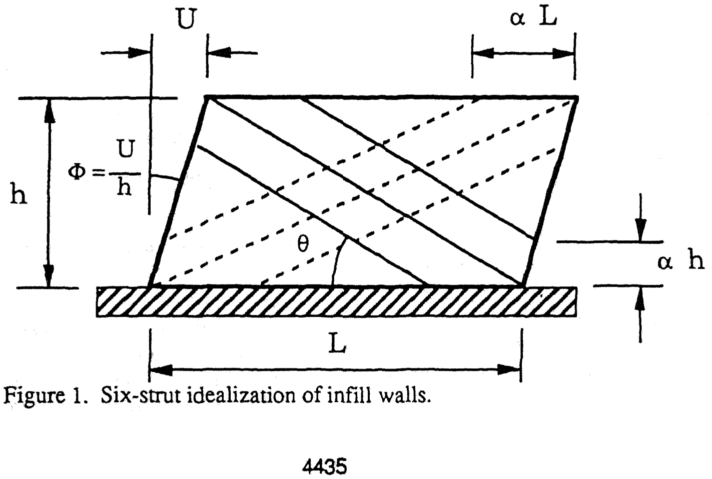

Figure 1. Six-strut idealization of infill walls.

loops (Figure 2 and Figure 3, respectively) is controlled by six parameters, all of which have physical meaning and can be obtained from experimental data. More details about the model are presented by Chrysostomou (1991).

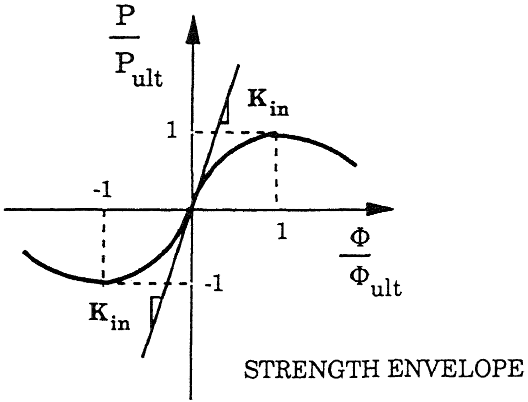

Figure 2. Strength envelope in normalized space.

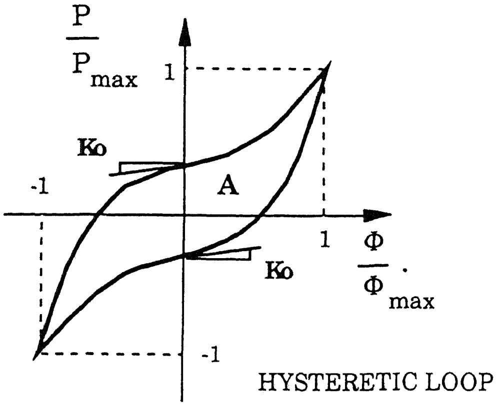

Figure 3. Hysteretic loops in normalized space.

3 CASE STUDIES

In this section the infill wall model is used to study the effects of infill walls on the nonlinear transient dynamic response of planar infilled steel frames. The change in the response of the frames when the infill stiffness and strength are accounted for is examined. Maximum accelerations and base shears, formation of hinges and their location, hysteretic behavior of walls and force histories for selected steel members are recorded.

The one-story structure was analyzed using the N-S component of El-Centro scaled to 0.67g while the other two structures were analyzed for the same earthquake component scaled to 0.5g.

3.1 *Response of a one-story one-bay planar frame*

A comparison between the behavior of the infilled and bare one-story one-bay structures is presented. Two analyses were performed: in the first analysis, the stiffness contribution of the infill was ignored but the mass included (bare frame), and in the second both the mass and stiffness of the infills were modelled (infilled frame).

Table 1 shows a comparison between the response of the two structures. Two results are reported in the Table concerning the plastic hinges. The first, which is the number of plastic hinge locations, is the number of frame member ends at which plastification occurred during the analysis; this can be used as a measure of the damage suffered by the frame. The second, which is the number of plastic hinges formed, indicates the number of loading/unloading cycles that these hinges have gone through; this can be used as a measure of the energy absorbed due to the hysteretic behavior of the steel members.

Table 1. Response of the one-story, one-bay structures.

		Bare	Infilled
Elastic period	(sec)	0.466	0.279
Max. recorded period	(sec)	1.017	0.421
No. of plastic hinge locations		8	0
No. of plastic hinges formed		36	0
Max. base shear	(KN)	810	-716
Max. top story accel.	(m/s^2)	14.7	-11.2

3.2 *Response of a two-story three-bay planar frame*

As in the previous case, the structure was analyzed as a bare frame and as an infilled frame. The infill was placed in the central bay of the structure. Table 2 shows a comparison between the responses obtained for the infilled and bare frames.

Table 2. Response of the 2-story, three-bay structures.

		Bare	Infilled
Elastic period	(sec)	0.867	0.375
Max. recorded period	(sec)	1.538	0.823
No. of plastic hinge locations		20	14
No. of plastic hinges formed		150	59
Max. base shear	(KN)	-1414	-1624
Max. top story accel.	(m/s^2)	-8.7	8.8

3.3 *Response of a ten-story three-bay planar frame*

The results of the analysis of the ten-story three-bay frame are summarized in Table 3. As for the other two structures, two analyses were performed; one for the bare frame and one for the infilled frame. The infill walls were placed in the central bay.

Table 3. Response of the ten-story, 3-bay structures.

		Bare	Infilled
Elastic period	(sec)	2.336	1.477
Max. recorded period	(sec)	3.261	2.133
No. of plastic hinge locations		90	31
No. of plastic hinges formed		430	61
Max. base shear	(KN)	-2380	2357
Max. top story accel.	(m/s^2)	8.9	-7.5

4 CONCLUSIONS

The research presented in this paper resulted in the following findings:

1. The maximum top story accelerations and maximum base shears are larger in the bare frames than in the infilled frames for the one-story one-bay and ten-story three-bay structures, and smaller in the bare frames than in the infilled frames for the two-story three-bay structure. These results are a function of the characteristics of the earthquake excitation and the energy absorption capacity of the infill walls.

2. The axial forces in the members of the bounding frame are significantly affected by the presence of infill walls. The axial forces in the columns of the infilled frame adjacent to the walls are considerably larger than the ones in the bare frame. For the top stories of the structures these forces are predominantly tensile. The axial forces in the exterior columns of the infilled frames, not adjacent to the infilled bays, are significantly smaller than the ones in the bare frames. Therefore, infill walls put a large demand for axial force resistance on the adjacent columns, and this is a potential place at which failure may occur during a strong earthquake.

3. Infill walls have a beneficial effect on the bending moments and shear forces of infilled structures by causing significant reductions in their magnitudes. The response pattern of the members depends on the floor at which they are located. Time histories of the response of members at the first floor follow the pattern of the base shear and acceleration time histories; for most of the time history, the magnitudes of the forces in the columns of the infilled frame members are less than those in the bare frame, although there are some fluctuations, and after the infill wall at that floor suffers considerable strength and stiffness degradation, the response of the members in the infilled and bare frames becomes the same. For members at the top floor both the bending moments and shear forces in the infilled frames are considerably smaller than those in the bare frames.

4. Walls at the lower floors are damaged more extensively than the ones at the upper floors. The greatest damage takes place at the first floor and there is a gradual decrease in damage along the height of the structure with the wall at the top floor being the least damaged one. However, this may not hold true for taller frames for which the whiplash effect may be significant.

5. The location of the damaged walls dictates the part of the frame which is subjected to plastic deformations. For the two- and ten-story structures hinges formed around walls which suffered considerable strength and stiffness deterioration, while the rest of the frame remained elastic. For the one-story structure no hinges formed, since the wall did not exceed its ultimate capacity.

6. Infill walls reduce considerably the number of members that undergo plastification. While in the bare frames the plastic hinges spread throughout most of the floors, in the infilled frames they form only around damaged walls. The number of loading and unloading cycles of these hinges is also considerably smaller for the infilled frames than for the bare frames.

ACKNOWLEDGMENTS

This research has been sponsored by the National Center for Earthquake Engineering Research (NCEER), SUNY Buffalo, Buffalo, NY (Projects 864011, 871008, 881005A, and 891201A). The Center is funded by NSF Grant No. ECE 8607591 and by a number of other sponsors including the State of New York.

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