Light Gage Steel Infill Panels in Multistory Steel Frames

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IN THE DESIGN of multistory structures, providing adequate lateral stiffness is often more difficult than satisfying strength requirements. For steel structures of 20 or more stories, deep or heavy beams are often required to maintain drift within acceptable limits. In many structures, vertical trusses, concrete shear walls, or a combination of these and rigid frames are used to achieve the required displacements. For very tall structures, various types of tube construction are often used.

The price paid for achieving stiffness in these ways is a decrease in the ductility of the structure, with important effects on its behavior under earthquake loading. The reason for this is that the increased total lateral base shear, required for stiffer systems by the Uniform Building Code, sometimes results in a change to a less ductile system. It is desirable to achieve an increase in stiffness without paying the penalty in decreased ductility. One attempt to do this is the slit concrete panel construction which the Japanese have developed.[2]

Normally, the strength and stiffness of infilling elements such as interior and exterior partitions are ignored in designing multistory frames, although such elements are acknowledged to make a substantial contribution to the lateral stiffness of the structure. A research program sponsored by the Committee of Structural Steel Producers and the Committee of Steel Plate Producers of the American Iron and Steel Institute was begun at Cornell University to assess the suitability of light gage steel infill panels for providing additional stiffness in multistory structures. The first portion of the research focused on developing the capability to analyze the infill-frame combination, making use of the finite element displacement method of analysis. The second portion, which is currently in progress, is an attempt to verify the analytical results experimentally and to assess the behavior of the panel-frame combinations at loads for which elastic analysis is not valid.

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DESCRIPTION OF PROPOSED CONSTRUCTION

The design approach taken in this project is to design the bare frame to resist the applied loads. The design can be carried out in the normal way, by either elastic or ultimate strength methods. Then the infill panels are added where necessary to reduce the drift of the frame to acceptable values. In this way, structural safety does not depend on the infill panels, although serviceability does. Using this approach, the sole structural function of the infill panels is to control drift; their ability to resist load is not counted on in the strength design of the structure. At some later stage, when the behavior of the panel-frame combination is better understood, the ability of the infills to resist load may be utilized to reduce the size of frame members.

The proposed construction is shown schematically in Fig. 1. The infill panel is made up of sheets of light gage steel having a trapezoidal cross section, such as are commonly used in floor or roof construction. The sheets are connected to the steel frame by means of a marginal member. The details of the connection between the frame member and the panel are such that loads in the plane of the infill and parallel to the frame member (shear) can be transferred from it to the sheet, but

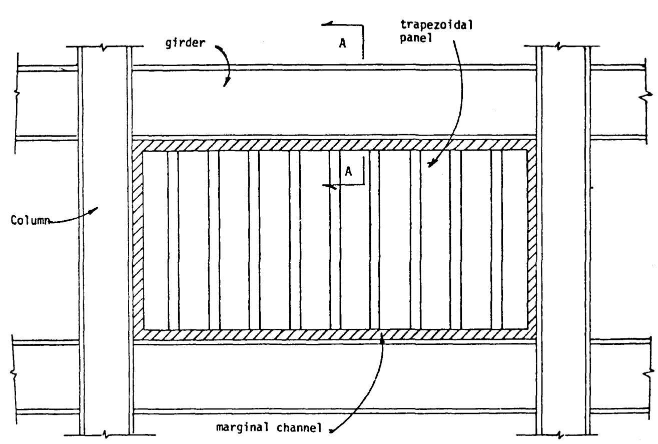

Fig. 1. Proposed construction for infilled frames (elevation)

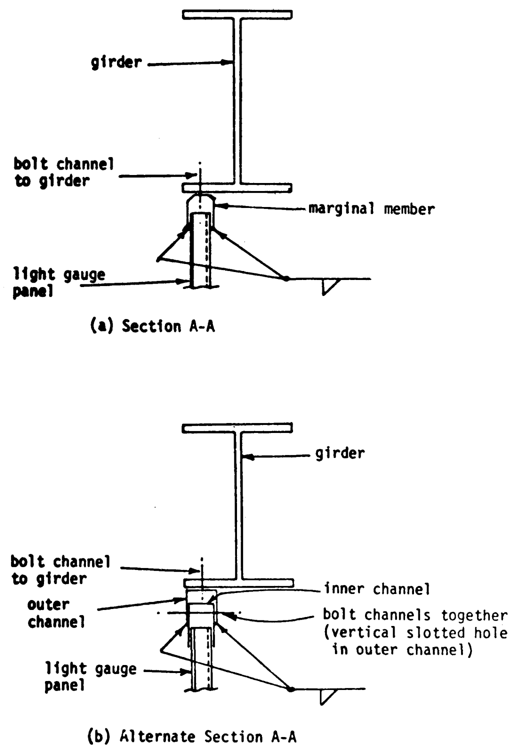

Fig. 2. Proposed construction for infilled frames (sections)

transfer of normal loads in the plane of frame is minimized. In this way, buckling of the light gage sheet due loads in its plane can be avoided. Two possible details to accomplish this are shown in Fig. 2. Utilizing this type of construction means that the transfer of gravity loads from their point of application to the foundation is accomplished in the same way whether or not the panels are present. This implies that members in symmetrical frames where design is controlled by the gravity load condition will be the same size for the infilled structure as for the bare frame. An additional advantage of the type of connection proposed is that deflection of the girders will not cause excessive local deformation of the panel connections.

The connection of the trapezoidal panels to the marginal member is by means of fillet welds at every flat on both sides of the channel (Fig. 2). In the work described here, the weld is assumed to restrain warping of the sheet profile at the ends, making it possible to utilize the full shear stiffness potential of the sheet.

The connections at the seams of the sheets are assumed to be of the type shown in Fig. 3a. This is a different type of connection than that commonly used in floor and roof diaphragms, which is shown in Fig. 3b. It is chosen because experimental results demonstrate that it is substantially stiffer and more reliable than the more common type. Since the infills are in a vertical plane, the type of weld shown in Fig. 3a can be made in the field.

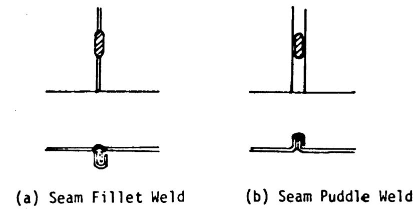

Fig. 3. Welded connections for light gage diaphragms

IDEALIZATION OF THE INFILL-FRAME COMBINATION FOR ANALYSIS

The analysis of the infilled frame is carried out using finite element methods. The light gage trapezoidal panels are assumed to be adequately represented by modelling them as equivalent orthotropic, flat membranes. The coordinate directions and the terminology for the sheets are shown in Fig. 4. The elastic modulus in the y-direction is taken as $E(l/s)$, where E is the elastic modulus for steel. The elastic modulus in the x-direction is taken as 500 ksi, based on experimental work done by Ammar.[3] This figure actually depends on flexural behavior of the sheet material, but is so low that an approximate value is appropriate. The Poisson's ratio in the x-direction, ν_{xy}, is taken equal to the Poisson's ratio for steel. The shear modulus G_{xy} is taken equal to $G(s/l)$ where G is the shear modulus of the base material. The shear modulus of an orthotropic membrane with properties equal to the actual trapezoidal panel is dependent on the conditions of restraint at the ends of the panel. If warping of the profile of the panel at the ends of the sheet is completely prevented, the above expression for the shear modulus will be true. With the construction details proposed above, it will be a close upper bound on the actual value, since the warping is not completely prevented.

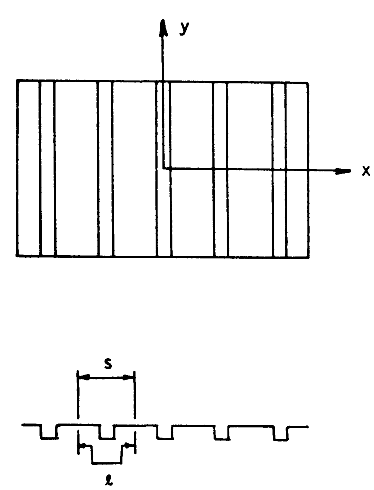

Fig. 4. Coordinate directions for sheet properties

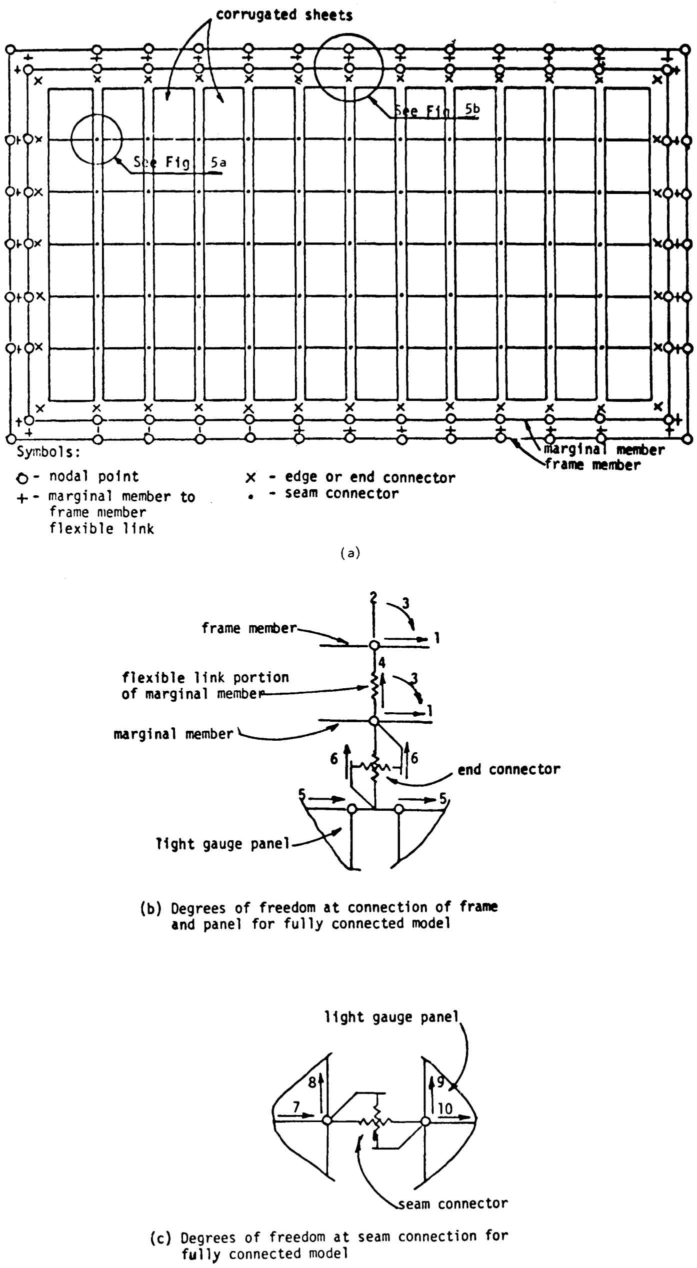

Fig. 5. Idealization of fully connected model

In order to model the equivalent orthotropic, flat membrane for the finite element model, rectangular plane stress elements based on an assumed linear edge displacement pattern are used. The derivation of the element stiffness matrix and the complete stiffness matrix are given in Appendix B of Ref. 4. The welds connecting the sheets to each other and to the marginal members are modelled as linear, elastic springs. The spring constants are obtained from the experimental work of Ammar.[3] The marginal members are represented by beam elements having horizontal, vertical, and rotational degrees of freedom at each end. The flexible portion of the connection between frame and sheet is also represented by a linear, elastic spring. The idealization used to analyze a single story, single bay infilled frame is shown in Fig. 5.

As is obvious from Fig. 5, a substantial number of degrees of freedom are inherent in a model of this type. The model shown has 440 degrees of freedom. Use of this representation directly in a multistory, multibay frame analysis would result in far too many degrees of freedom to be practical. As a first step in reducing the number of degrees of freedom, static condensation[5] can be used to eliminate those degrees of freedom in the interior of the panel, thus reducing the size of the problem by about 60%. This can be done with no further approximation.

The size of problem can be further reduced to the point where analysis of the infilled frame involves no more degrees of freedom than the bare frame. This is done by eliminating (for analysis purposes only) the connection between the frame and the marginal members except at the corners, as shown in Fig. 6. In order to obtain the same lateral displacement analytically with either model, the cross-sectional area of the marginal member must be made very large in the model connected to the frame at the corners only, to eliminate the effect of marginal member axial strain. Trial analyses using models for a number of combinations of panel thickness and frame size demonstrated that the corner-only model gives an adequate representation of the exact model for the range of sizes tested. Reference 4 contains the detailed results.

The corner-only model permits the analyst to determine the stiffness matrix for a unit consisting of the infill and the marginal members, using the fictitious increased area for the marginal members. Then all degrees of freedom except three at each corner can be

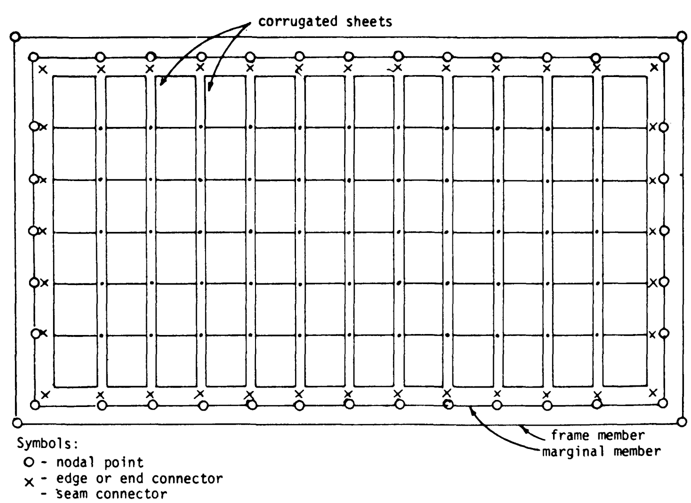

Fig. 6. Idealization of corner only model

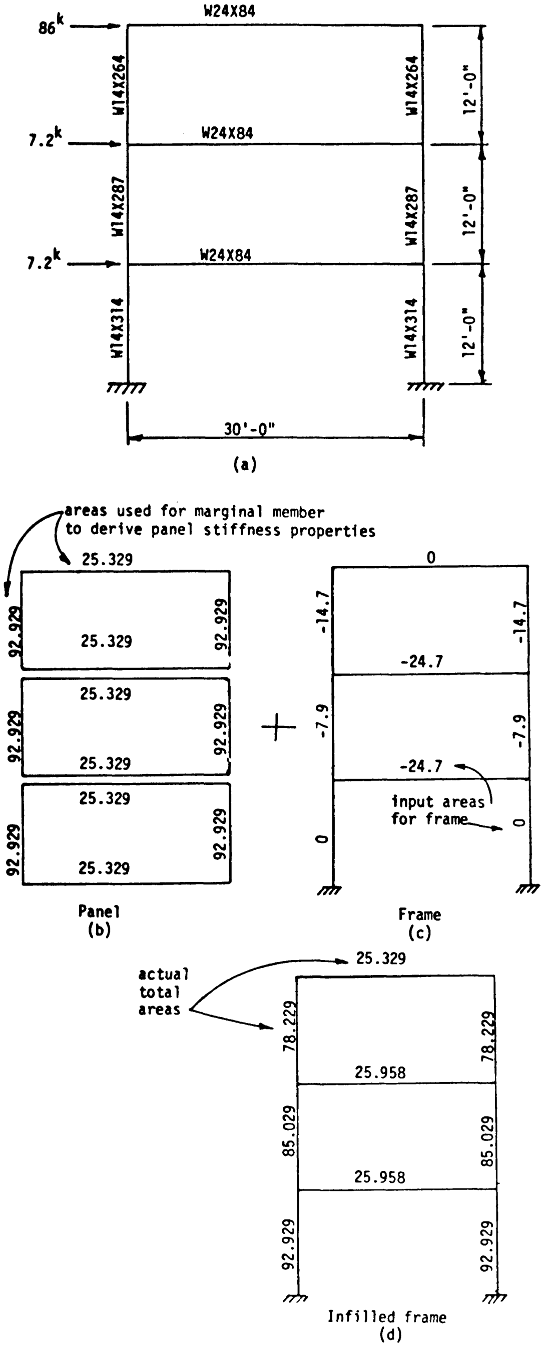

Fig. 7. 3-story frame example (areas in in.²)

eliminated by static condensation. The resulting 12 × 12 stiffness matrix can then be used for all panels of a given type in a structure. When used in a multistory frame, the area input for the frame members surrounding an infill is analytically decreased so that the total area input for frame and marginal members is maintained at the correct value. As an example, consider the frame shown in Fig. 7a. The areas used to derive the panel stiffness

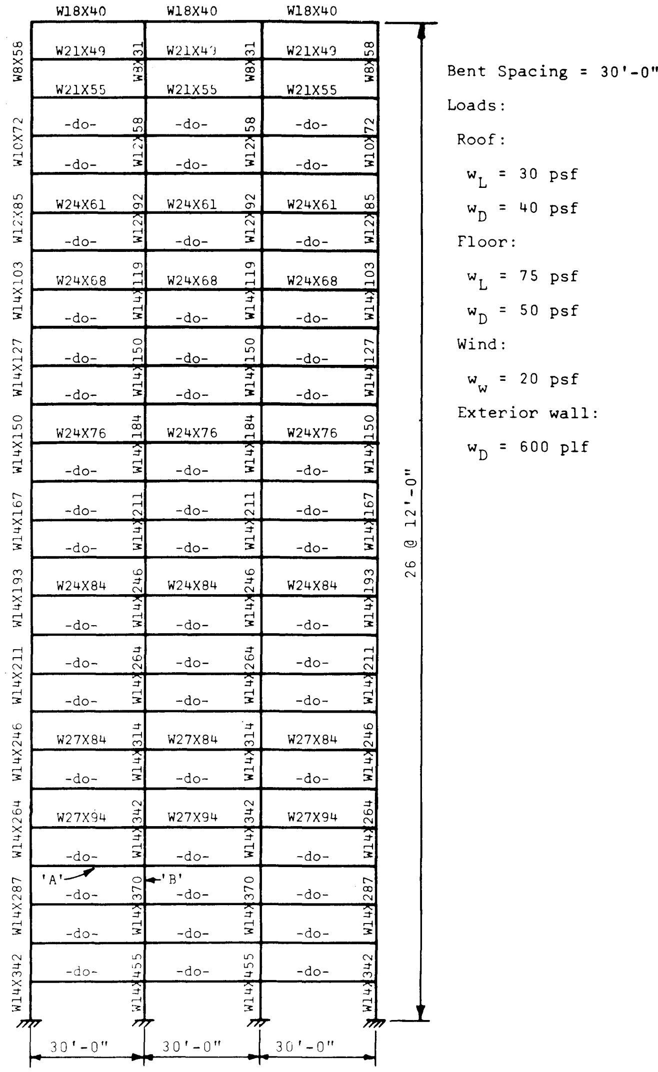

Fig. 8. 26-story frame

matrix are shown in Fig. 7b. The areas input for the frame members are shown in Fig. 7c. The sum adds up to the correct total area shown in Fig. 7d. The negative areas shown do not cause any trouble in the analysis.

ANALYSIS OF A 26-STORY FRAME

The 26-story frame shown in Fig. 8 has been analyzed three times with three different panels infilling the frame full height in the center bay, in order to demonstrate the usefulness of light gage steel panels in reducing deflections of the frame. The thickness of material used for the infills was 12, 16, and 20 ga. The dimensions of the sections used are shown in Fig. 9. The width of each piece of decking was assumed to be 2′-6′′. As Fig. 10 shows, addition of the light gage steel infills substantially reduces the deflection of the frame for a given input lateral load.

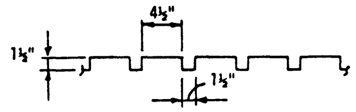

Fig. 9. Section used in infills

The distribution of shear between the frame and the infills is shown in Fig. 11 for the frame with 16 ga. infills. The percentage of the total shear carried by the panels remains relatively constant throughout the height of the structure. Utilizing the shear load on the panel, the possibility of shear buckling of the infill can be investigated. The work of Easley and McFarland[6] was used to calculate the load to cause shear buckling of the panel. The useful or allowable load on the panel is taken to be the buckling load divided by 1.5. For the 1½-in. deep, 16 ga. panel, the allowable load is 71.4 kips, the total shear load on one edge. Comparing that with the panel shears shown in Fig. 11, it can be seen that buckling is likely for the infills at the 2nd through 4th floors. Since the panel shears in the upper stories are well below the allowable values, it would be worthwhile to use lighter gage panels in those stories. The forces and stresses developed in the welds and in the sheets are well within allowable values for the shears carried by the panels.

The designer would like to have available some approximate method for determining the stiffness of panel required to reduce the drift of a given story to an acceptable value. Reference 4 contains a description of a simple, approximate method to do this.

CONCLUSIONS

The research described here demonstrates that light gate steel infill panels have potential use as drift control elements in multistory frames. The reduction in drift achieved with realistic panels in a realistic frame is quite substantial. The elastic analysis and design of an infilled frame can be made simple and quick enough to be practical in the design office. A computer program was developed to carry out the analyses.

Before the use of light gage infills can be considered for an actual structure, further research is needed. The first priority should be given to verifying experimentally the analytical work described here. Such experiments are underway at Cornell University. In addition, work

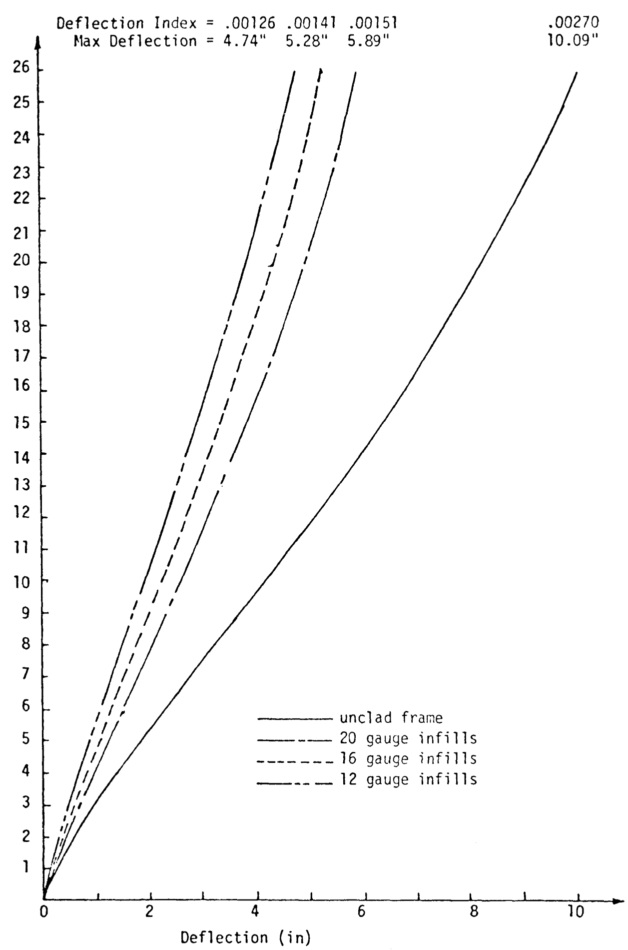

Fig. 10. Deflected shapes for 26-story frames

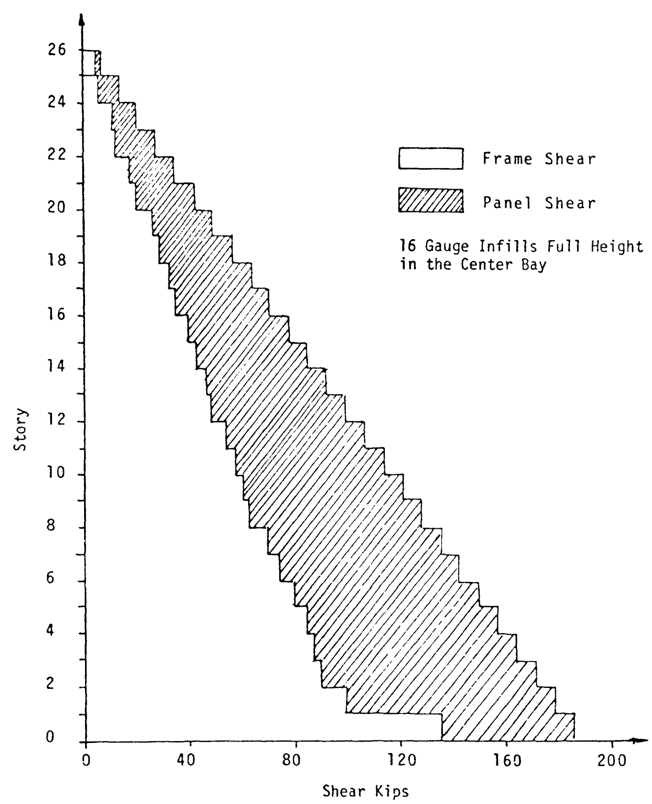

Fig. 11. Distribution of internal force between frame and panels in 25-story building

done at Lehigh University as part of the Project Instruct by researchers under Professor J. Hartley Daniels will provide additional experimental data.[7] The experiments at Cornell will provide some insight into the behavior of the panel-frame combination in the inelastic range. This will make possible a rough assessment of the potential of this construction system for use in earthquake areas.

The conclusions of this work are largely substantiated by the work of Oppenheim which is reported in Ref. 8. In Ref. 9, Oppenheim deals with some of the dynamic behavior problems associated with infilled frames.

ACKNOWLEDGMENTS

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