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INFLUENCE OF INTERSTORY DRIFT ON CLADDING PANELS AND CONNECTIONS

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SUMMARY

Cladding panel response studies were performed using a localized response model to examine panel connection force levels and the influence of connections properties on cladding lateral stiffness. Recommended procedures for attaching precast concrete panels to exterior building frame for the purpose of isolating the brittle panels from potentially damaging interstory drift motions were found to be less than fully effective in accomplishing this ocjective.

INTRODUCTION

Recent studies (Ref.1,3,7) have shown that heavyweight cladding systems contribute to lateral stiffness and measurably alter dynamic properties of building structures. Therefore, their use as participating structural elements has also been suggested for control of lateral motions due to wind and earhquake loadings. Currently, designers attempt to prevent transfer of interstory forces into cladding panels and their connections by using slotted connections and oversized holes or ductile rods. However, present construction practice, lack of inspection, deterioration of connections with time, and initial friction in the connections may actually lead to structural participation of panels and their connections in spite of the design assumptions. Reports of cladding failure are, therefore, not surprising.

In a related study (Ref.2,5), the influence of cladding on overall structure frequencies and seismic response was investigated for a medium highrise office building. Frequency values were shown to increase with the introduction of cladding stiffness to the structure model. Overall structure response was either increased or decreased by adding cladding lateral stiffness depending upon the frequency content of the earthquake record applied. These findings suggest that failure to include cladding stiffness effects may be unconservative in some cases.

The present study which is reported on below is a continuation of this earlier work. However, the focus of attention is now on the localized response of cladding panels and connections. A rigid panel model was employed to investigate the localized response of a typical portion of the exterior curtain wall subjected to prescribed interstory drift motions. The principal objective was to determine the influence of panel support conditions on connection force levels and on the contribution of cladding to structure lateral stiffness. The effects of oversized holes and slots in the panel connection angles and initial friction at the panel connection interface were considered. Results are presented below following a description of the analytical model.

ANALYTICAL MODEL

Localized cladding response was investigated using the frame-panel model displayed in Fig. 1. The model represented steel framing members and two heavyweight cladding panels connected to the spandrels with clip angle connections. Framing members were idealized as one-dimensional finite elements. Clip angles were represented by linear elastic spring elements with stiffnesses Sx and Sy (connection rotational stiffness was assumed to be small and was neglected). The cladding panels were assumed to be flat and perfectly rigid. All panel-to-panel contact was neglected. Spandrel members with elastic connections at each end were used to support the panels. Columns were specified to be W10x49 and spandrel members W18x35 steel shapes (A36 steel) to represent a typical exterior bay in the prototype structure. The frame-panel model was used to compute forces in the cladding connections associated with interstory drift levels permitted by modern building codes (Ref.8). The lateral stiffness contribution of the cladding was determined by applying a unit lateral displacement at the top corner node.

RESPONSE STUDIES

Connection Stiffnesses. The stiffness properties of the clip angle connections supporting the cladding panels on the prototype structure were not known. Review of analytical and experimental studies of similar connections revealed that a broad range of stiffness values may be obtained depending largely on details of the particular connection. Items such as the tightness of connection bolts, length of welds connecting clip angles to spandrels, and degree of interaction of spandrel flanges with the clip angles were found to be significant variables in an accurate assessment of connection stiffness.

The lateral stiffness of the panel-frame system in Fig. 1 was determined by imposing a unit interstory lateral displacement to the frame at the uper level. Since actual stiffness values for the clip angle connections were not known, the initial assumption was made that each of the four connections for both panels had equal stiffness in both horizontal and vertical directions. A best match was obtained when connection stiffnesses were set at Sx = Sy = 374.2 kips/in (6.55 x 10^4 kN/m) (Ref.5).

PCI Support Condition Case. The effects of oversized holes and initial friction in connections on interstory shear stiffness and connection forces for a case which approximated the PCI (Ref.6) recommended support conditions shown in Fig. 2 are reported below. The figure shows that both top connections are free to slide vertically, while only the top right connection and the bottom right connection are free to slide horizontally. Horizontal sliding was accomplished by the use of a clip angle with a slotted bolt hole. The size of horizontal slots was taken to be 1.5 inches (3.8 cm) in these studies based on an inspection the prototype structure. In addition, the assumption was made that the initial location of the 0.75 inch (1.9 cm) bolt was in the center of the slot resulting in an open horizontal slot dimension of 0.375 inches (0.95 cm) on each side of the bolt. Vertical sliding, on the other hand, was due to the use of slotted panel inserts as recommended by PCI (Ref.6). Based on informatin for a typical top connection insert device, the open slot dimension above and below the bolt was taken as 0.825 inches (2.10 cm) in each location when the bolt was placed in the center of the slot. Very low connection-spring stiffness values were assigned to the interval in which free sliding was assumed in the model to simulate the sliding behavior.

In this study, a comparison was made between the PCI case and a case which assumed the horizontal dimension of the top left vertically slotted hole to be larger than the diameter of the bolt, i.e., an oversized hole was specified in the horizontal direction. A gap was defined as the distance from the side of a centered bolt to the edge of the hole. Two gap sizes were considered for the top left connection:

1) No gap or the actual PCI case;
2) Gap of 0.125 inches (0.32 cm).

In addition to studying the influence of placing a vertical slot along with an oversized hole for horizontal movement in the top left connection, the influence of initial friction in connections (i.e., in both PCI recommended slots and the oversized hole) was also considered. Two levels of initial friction were studied:

1) No initial friction in connections (i.e., actual PCI case if no gap exists);
2) Initial friction of 3 kips (13.3 kN) based on a value from a panelized construction connection study (Ref.4).

The same connection stiffnesses were used here as for the uniform spring stiffness case, i. e., Sx = Sy = 374.2 kips/inch (6.55 x 10^4 kN/m). It was assumed in the present study that the initial stiffness at the initiation of loading was equal to the stiffness of the connection after slipping when the bolt was bearing against the side of the hole.

Fig. 3 shows the interstory shear stiffness versus relative interstory drift for the cases with and without initial friction, and with or without a horizontal gap. The stiffness for the "no horizontal gap, friction" case decreased as friction was overcome in the vertical direction of top connections and again slightly when horizontal friction was overcome in horizontally slotted connections. When the case labeled as "gap, friction" was considered, it coincided with the "no gap, friction" case initially, but the interstory shear stiffness of the frame-panel model was reduced as friction was overcome. Once the gap closed the stiffness increased again and remained at that level for all remaining drift values considered. Fig. 4 displays connection force versus drift for bottom connections. The reduction in connection forces was evident for the cases with gaps. The critical load bearing bottom connections were observed to exceed their PCI determined ultimate capacities at relatively low drift levels (Ref.8). Finally, it was noted that none of the slots recommended by PCI (Ref.6) were observed to close at the interstory displacement levels considered in this section. The fact that the slots remained open suggested that an alternate panel support scheme such as providing a horizontal slot in the top left connection would be beneficial in reducing excessive connection forces. This alternate scheme labeled as the slotted connection case will be considered in the following section.

Slotted Connection Case. The slotted connection case is a modification of the PCI recommended support conditions such that both top connections are free to slide both horizontally and vertically (Fig.2). The slotted connection panel support system was considered because it was felt to be a more effective way to keep connection forces at moderate levels. Three levels of initial friction were considered when the effects of initial connection friction on both interstory shear stiffness and forces in connections were studied:

1) No initial friction in connections;
2) Initial friction of 0.5 kips (2.2 kN).
3) Initial friction of 1.0 kip (4.4 kN).

The friction values above are lower than the value used in the previous section, however, preliminary parameter studies showed that these lower values permitted higher drift levels before ultimate shear capacities in connections were exceeded. Slot lengths and connection spring stiffness values were taken to be the same as used for the PCI support condition case discussed above.

The results of these parameter studies are shown in Figs. 5 and 6. Inspection of Fig. 5 revealed that consideration of initial friction resulted in an interstory shear stiffness of 63.19 kips/inch (11066 kN/m) initially, but that value decreased when initial friction in the vertical direction of top connections was overcome and the shear stiffness was again reduced as friction was overcome in the horizontal directions of the slotted connections. The interstory shear stiffness increased when the horizontal slots of top connections closed. Finally, the case with no initial friction started with a low initial stiffness which increased as horizontal slots of top connections closed. Comparison of Fig. 6 with the corresponding figure for the PCI case (see Fig. 4) showed that vertical bottom connection forces were effectively reduced at a given interstory drift due to the presence of the horizontal slot provided in the top left connection in the present panel support system.

The results of the above studies showed that the slotted connection model, and not the PCI recommended support conditions, was best suited for use when connection forces were to be kept at low levels for static interstory drift motions. Additionally, it was observed that the case with no initial friction performed better than the cases of 0.5 kip (2.2 kN) and 1.0 kip (4.4 kN), since higher interstory drift levels could be accommodated. Subsequently, it was concluded that low initial friction levels were desirable for the frame-panel system being considered.

CONCLUSIONS

Connection forces and interstory shear stiffness values for the local cladding model were found to be affected significantly by the presence of oversized bolt holes, slots in connection angles and initial friction in cladding connection attachments. However, the load bearing bottom connections were observed to exceed their ultimate vertical shear capacity at relatively low interstory displacement levels in all cases except when both top panel connections were slotted horizontally. PCI recomended procedures for attaching precast concrete cladding panels to exterior building frame members for the purpose of isolating the brittle panels from potentially damaging interstory drift motions were found to be less than fully effective in accomplishing this objective. Ultimately, investigations of cladding performance are expected to lead to improvements in design of cladding for wind and earthquake loading.

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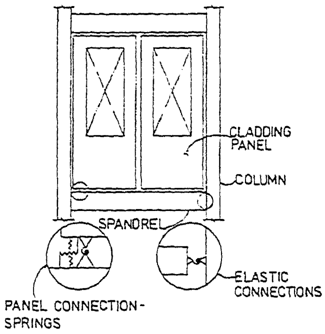

Fig. 1 - Analytical Model for Typical Portion of Cladding and Exterior Frame

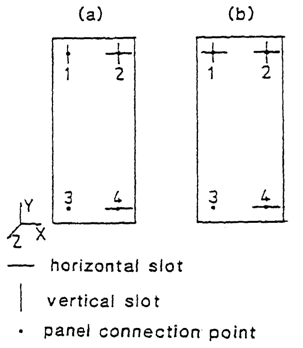

Fig. 2 - (a) PCI and (b) Slotted Connection Support Conditions for Heavy Cladding Panels

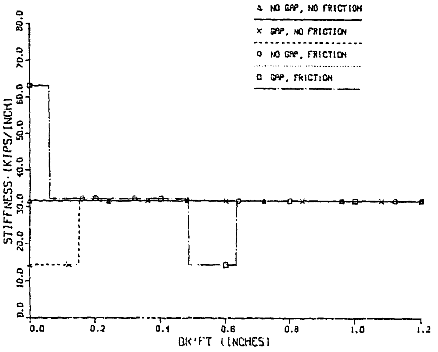

Fig. 3 - Interstory Drift versus Lateral Stiffness for the PCI Case

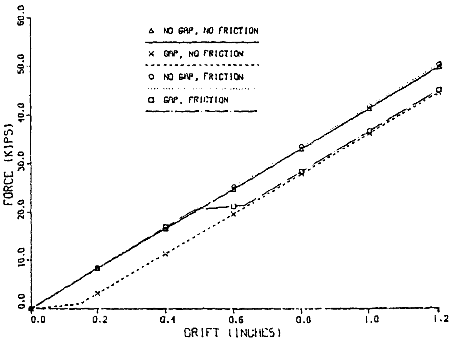

Fig. 4 - Interstory Drift versus Vertical Force in Bottom Connections for the PCI Case

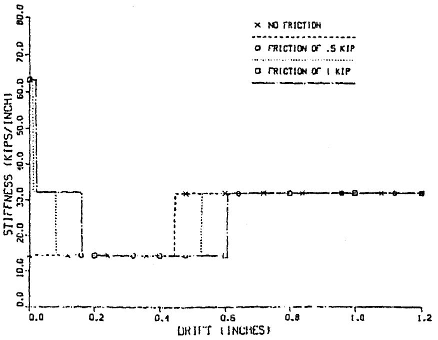

Fig. 5 - Interstory Drift versus Lateral Stiffness for the Slotted Connection Case

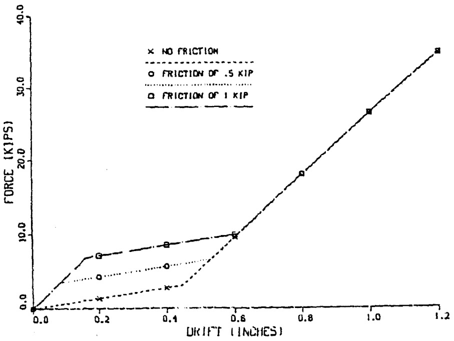

Fig. 6 - Interstory Drift versus Vertical Force in Bottom Connections for the Slotted Connection Case