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## Highlights of tests of steel beam-to-column bolted connections, October 1974.

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Beam-to-Column Connections

HIGHLIGHTS OF TESTS OF STEEL  
BEAM-TO-COLUMN BOLTED CONNECTIONS  
(C6, C7, C8, C9)

by  
W. F. Chen  
K. F. Standig  
G. P. Rentschler

This work has been carried out as part of an investigation sponsored jointly by the American Iron and Steel Institute and the Welding Research Council.

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Bethlehem, Pennsylvania

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Highlights of Lehigh Connection Tests  
(C6, C7, C8, C9)

The test program consisting of twelve full-size moment-resisting beam-to-column connections conducted at Fritz Engineering Laboratory, Lehigh University has recently been completed. The overall objective of this study is to develop design procedures for safe, efficient, and economical beam-to-column connections. Primary attention was focused upon the strength (plastic limit load), deformation capacity, and over-all stiffness of the connections.

The tests result highlights presented herein are of the four bolted specimens tested in the twelve specimen program. They are connections C6, C7, C8 and C9. The experimental and reference loads along with a brief description of the joint and the failure mode are given in Table 1.

C6 and C7

Connections C6 and C7 are shown respectively in Fig. 1 and Fig. 2. Both connections were designed using A572 Grade 55 steel with a W10x60 column section and a W14x74 beam section.

Connection C6 is flange-bolted (8-1"φ A490 bolts in 1-1/16" round holes in each flange) utilizing 1-1/8"x10" flange connection plates with the beam shear carried by a stiffened seat plate. Connection C7 has the same bolting configuration, bolt diameter, and hole sizes in the flange as C6. The bolted parts of both specimens were designed as bearing type connections. However, in C7, the shear is

carried by means of a shear plate welded to the column flange and bolted to the beam web by 3-1"φ A490 bolts in 1-1/16" round holes.

The load versus deflection curves for C6 and C7 are given in Fig. 3. Also shown on the figure is a plot of C10 which is the control (fully welded) specimen using the same beam and column sections as C6 and C7. On this plot, as well as the plot of C8 and C9, the effects of slip are averaged by not plotting any of the horizontal slip plateaus. Note that the load-deflection plots for both C6 and C7 have three distinct phases (slopes).

#### C6

Photographs describing the failure of connection C6 are shown in Fig. 4 through Fig. 7. Figure 4 shows an overall view of C6 at failure depicting the extensive yielding in the beam web up to the end of the moment plates. Failure of this connection occurred at a load of 478.5 kips when the eight bolts connecting the tension flange sheared off simultaneously. Figure 5 presents a closer look at the beam on which the eight bolts failed.

Shown in Fig. 6 is a view of the column panel zone adjacent to the beam tension flanges. Figure 7 shows the shear failure of four of the bolts and the extensive deformation of the bolts at failure.

#### C7

Photographs detailing the failure of connection C7 are shown in Fig. 8 through Fig. 12. Figure 8 shows an overall view of C7 at

failure again depicting the extensive yielding in the beam web (Fig. 9) up to the end of the moment connection plates. Failure of this connection was due to the failure of five bolts in one of the tension flange connections. Two outside bolts in this flange failed at a load of 361 kips due to the prying action as shown in Fig. 10. Upon further loading three more bolts failed at the maximum load of 450 kips.

Shown in Fig. 11 is a view of the panel zone showing yielding and a view of the beam web connection plate and the relative rotation of the beam web and the web connection plate. Figure 12 presents a view of the five bolts which failed.

#### C8 and C9

Connections C8 and C9 are shown respectively in Fig. 13 and Fig. 14. Both connections were designed using ASTM A572 Grade 55 steel with a W14x136 column section and a W24x61 beam section.

Connection C8 is a flange-bolted (14-1"  $\phi$  A490 bolts in  $1\frac{1}{4}$ "  $\phi$  holes in each flange) and web-bolted (7-3/4"  $\phi$  A325 bolts in slotted holes). The flange connections were designed as friction connections using allowable bolt shearing stress values below those of a bearing type joint. The flange connection plates are 3/4"x11". The web connection was designed as a bearing joint using A325 bolts in slotted holes perpendicular to the direction of loading. Connection C9 is identical to C8 except the design of the bolted flange connection was based on treating the joint as a bearing connection. This led to a flange connection requiring 6-1"  $\phi$  A490 bolts in 1-1/16" round holes

and flange connection plates of 3/4"x11".

The load versus deflection curves for C8 and C9 are given in Fig. 15. Also shown on the figure is a plot of C11 which is the control (fully welded) specimen using the same beam and column sizes as C8 and C9.

### C8

Photographs detailing the failure of connection C8 are shown in Fig. 16 through Fig. 19. The maximum load reached on this connection was 516 kips. After reaching this level, the load dropped off due to column web buckling and the test was terminated for safety reasons. Figure 16 shows an overall view of C8 at the termination of test.

Shown in Fig. 17 is a view of one of the beams where it is connected to the column. On this view the appearance of slip on the tension flange (top) can be detected by the relative movement of the vertical lines. Slip in the compression flange (bottom) was much less. Figure 18 shows the extensive yielding which occurred in the column panel zone and Fig. 19 shows the extent of the buckling of the column web in the compression region.

### C9

Photographs showing the failure of connection C9 are given in Fig. 20 through Fig. 22. The maximum load on this connection was 402 kips. Failure occurred when the six bolts on one of the tension flange connections and one of the web bolts sheared off simultaneously.

This can be seen clearly in Fig. 22.

Shown in Fig. 20 is an overall view of the connection at failure. Figure 21 presents a closer view of the column panel zone and beam ends showing the yield pattern.

TABLE 1 TEST RESULTS OF CONNECTIONS

Test	Joint Description	Failure Mode	Experimental $P_m$	Reference		$\frac{P_m}{P_p}$	$\frac{P_m}{P_{pr}}$
				$P_p$	$P_{pr}$	$P_p$	$P_{pr}$
C6	Flange-bolted (bearing) with seat (W10x60 col. W14x74 bm.)	Shearing failure of eight bolts on one tension flange connection	478.5	322	270	1.49	1.77
C7	Flange-bolted (bearing) web-bolted (W10x60 col. W14x74 bm.)	Failure of five bolts in one tension flange connection.	450	322	270	1.40	1.67
C8	Flange-bolted (friction) web-bolted (W14x136 col. W24x61 bm.)	Buckling of column web	516	315	199	1.63	2.59
C9	Flange-bolted (bearing) web-bolted (W14x136 col. W24x61 bm.)	Shear failure of six bolts on one of the tension flange connections	402	315	199	1.28	2.02

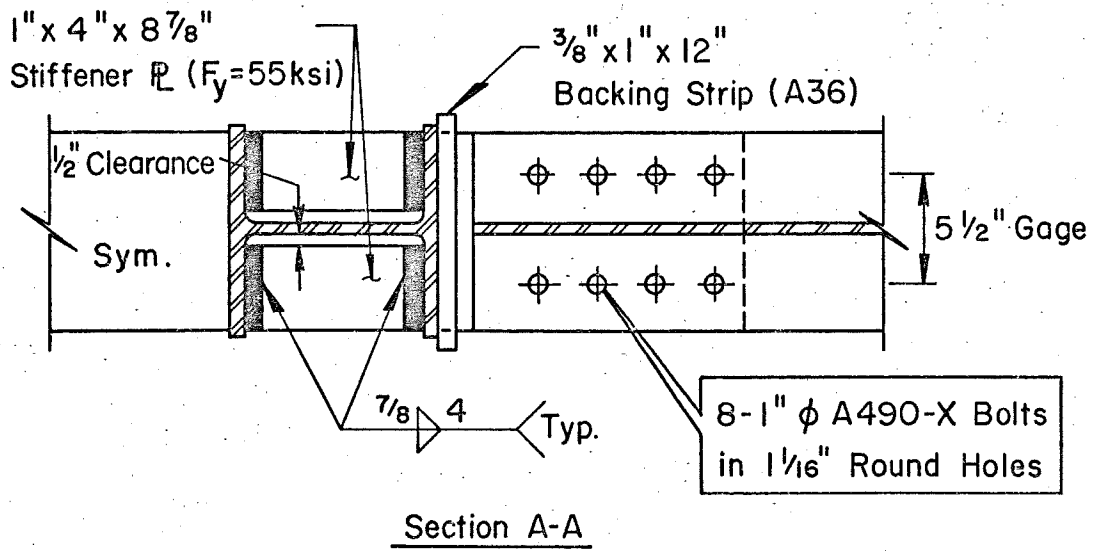
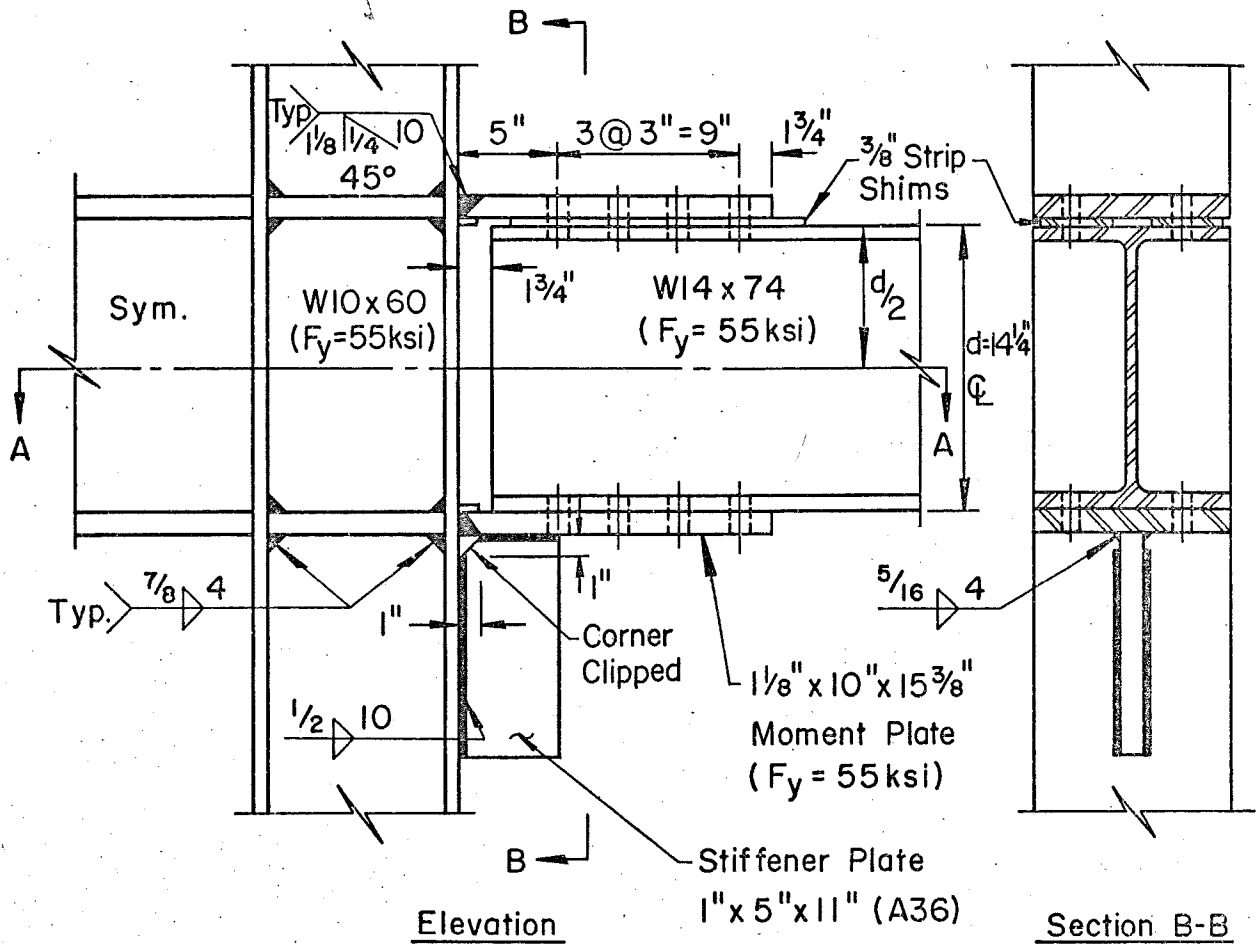
Symbols

$P_m$  = maximum load of connection under test

$P_p$  = plastic limit load

$P_{pr}$  = plastic limit load assuming the area of beam web is zero





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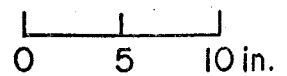
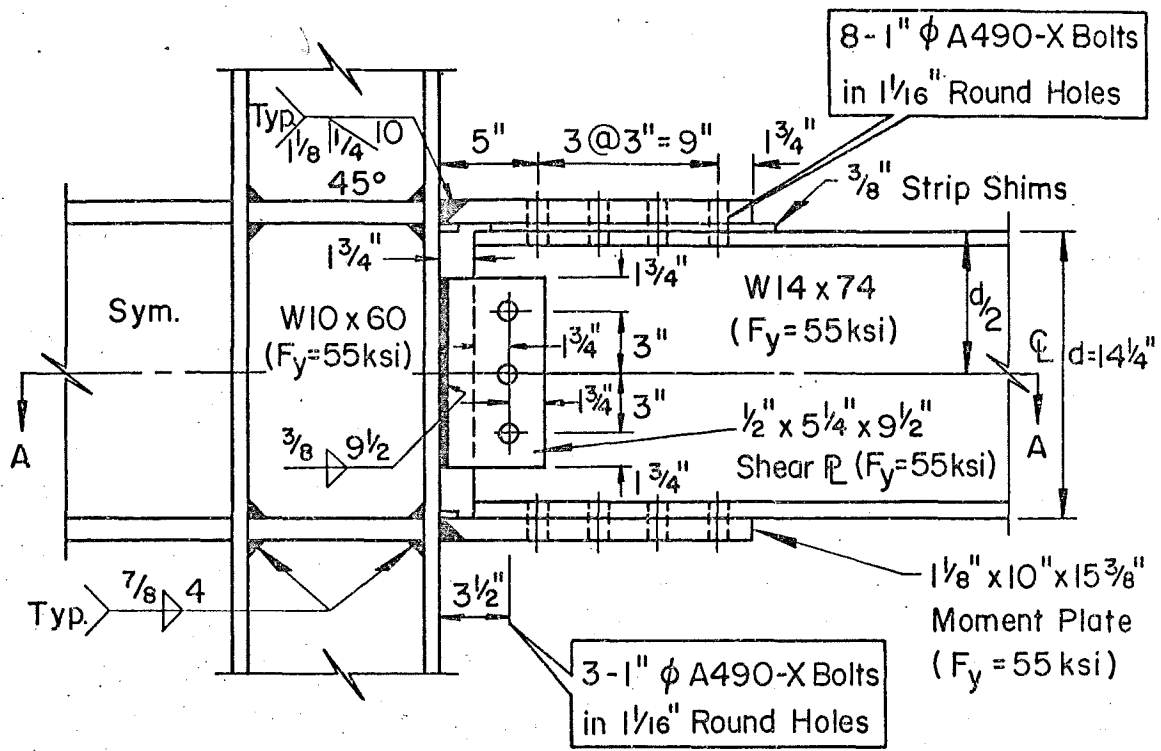
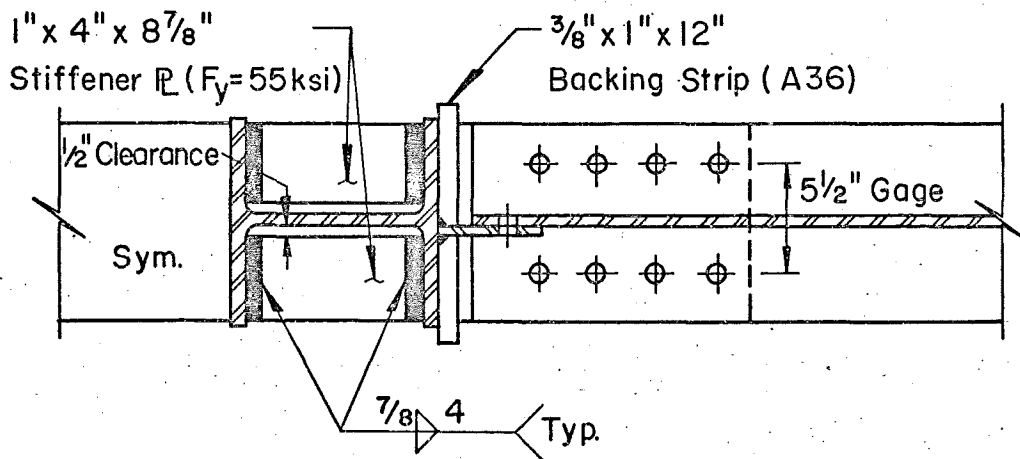


Fig. 1 Connection C6



Elevation



Section A-A

Scale:

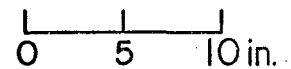


Fig. 2 Connection C7

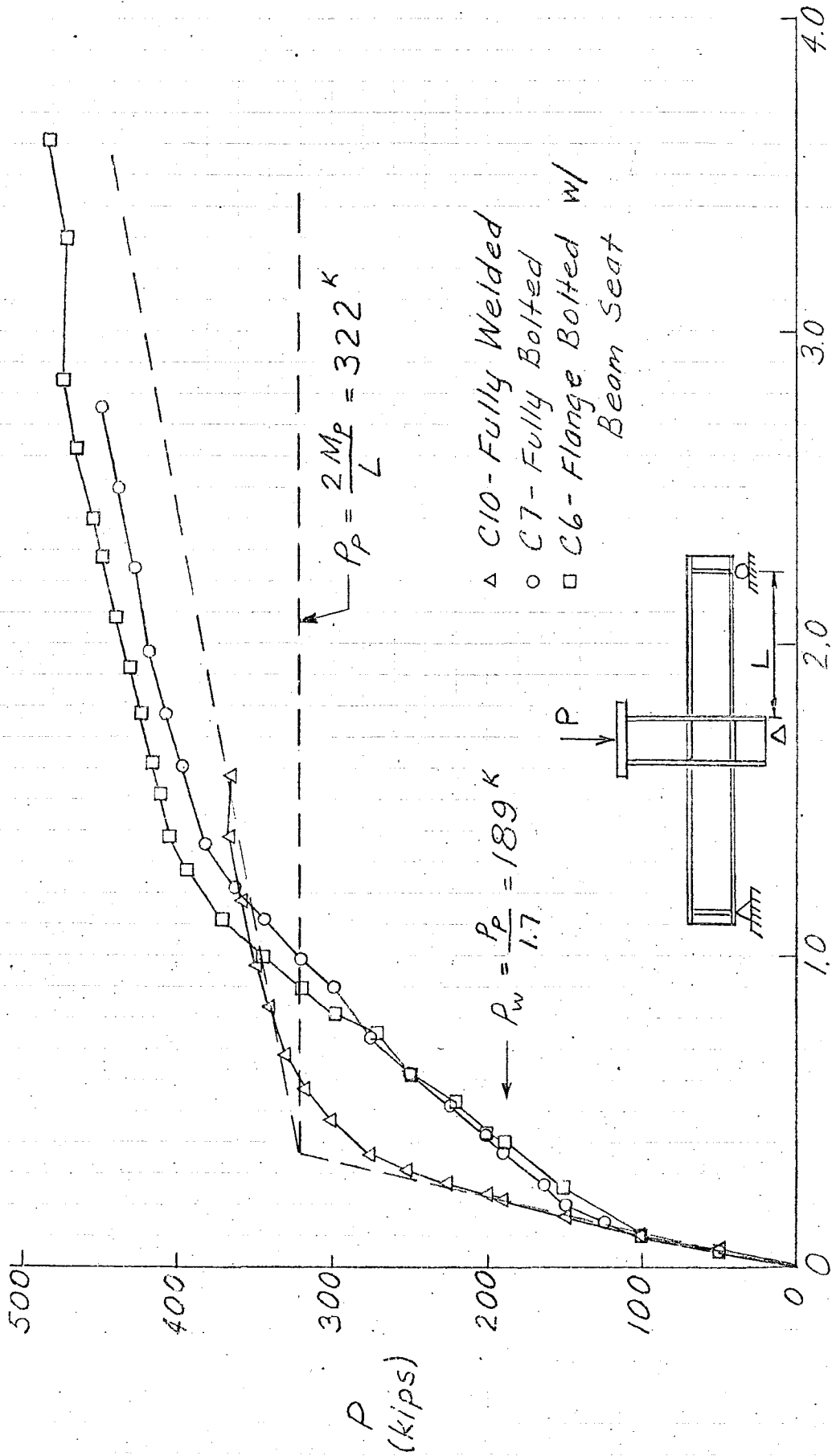


Fig. 3 Load vs Deflection of C6 and C7

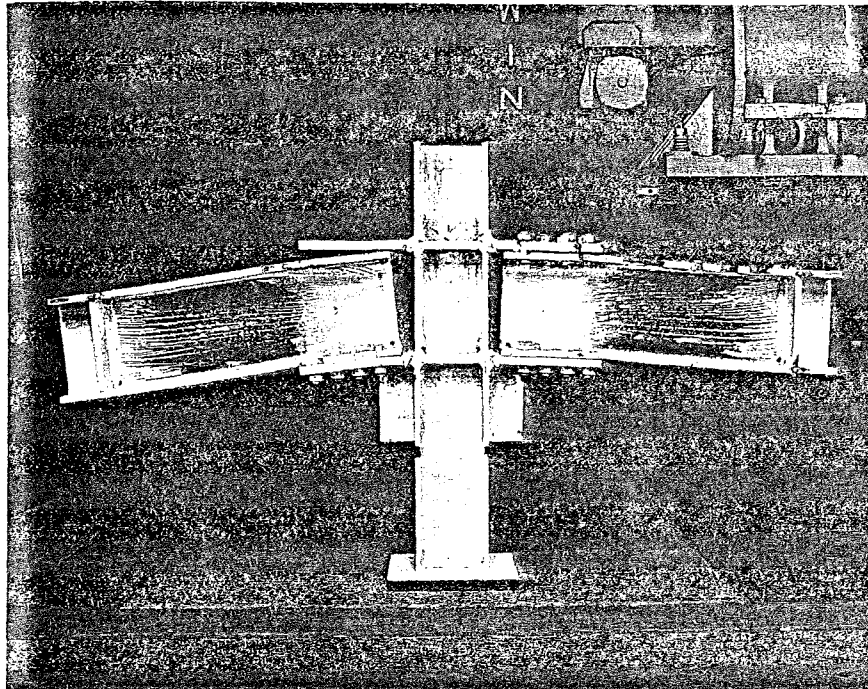


Fig. 4 Overall View of C6

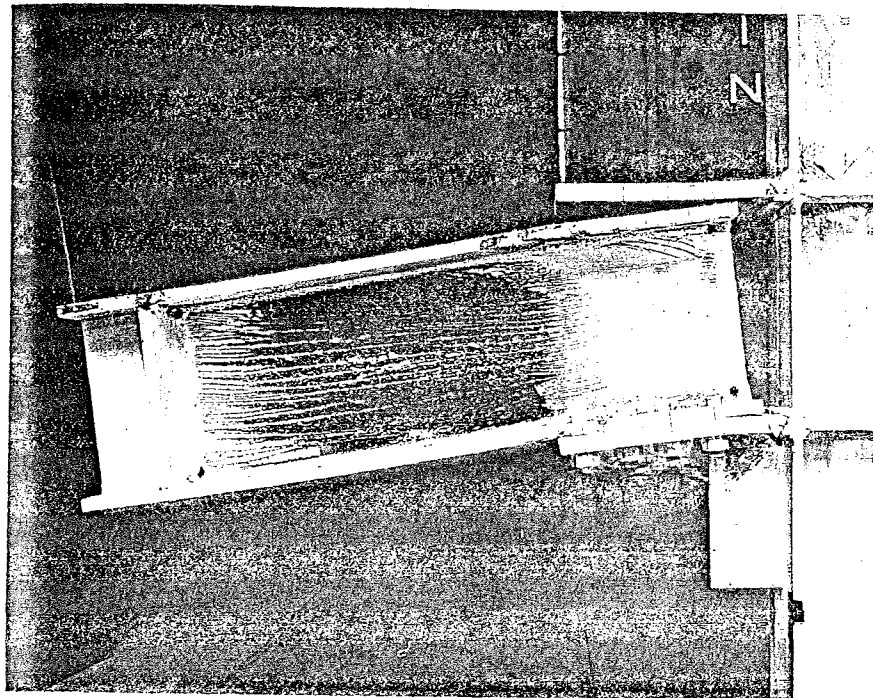


Fig. 5 View of C6 Beam

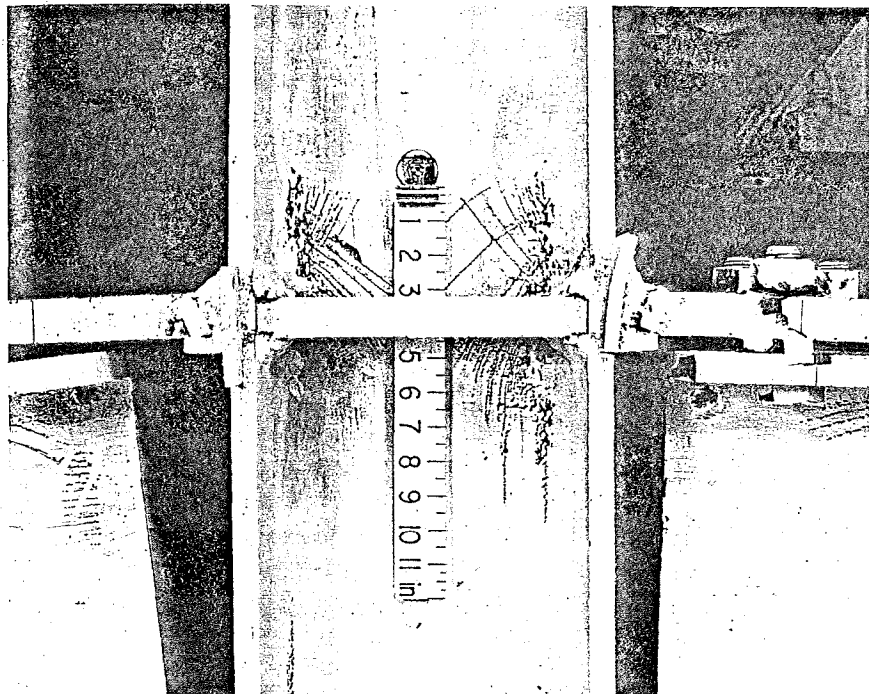


Fig. 6 Tension Panel Zone of C6

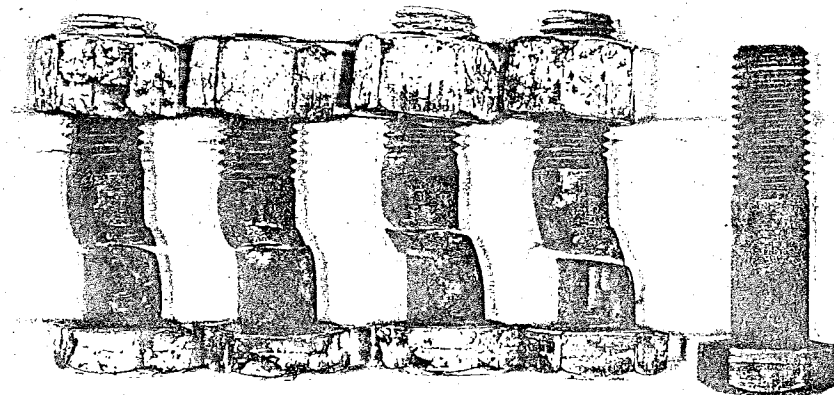


Fig. 7 Sheared Bolts of Connection C6

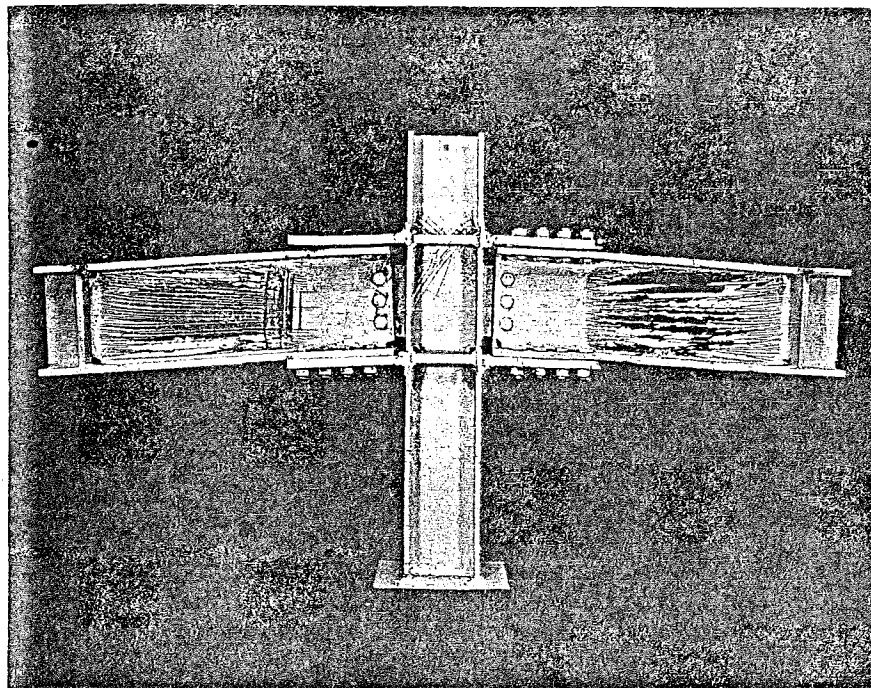


Fig. 8 Overall View of C7

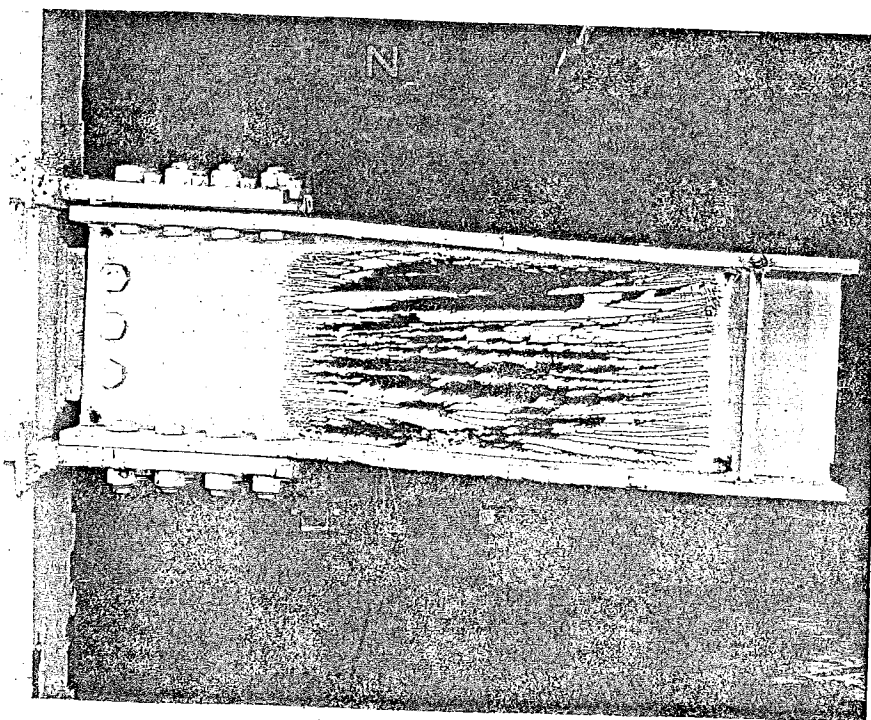


Fig. 9 View of C7 Beam

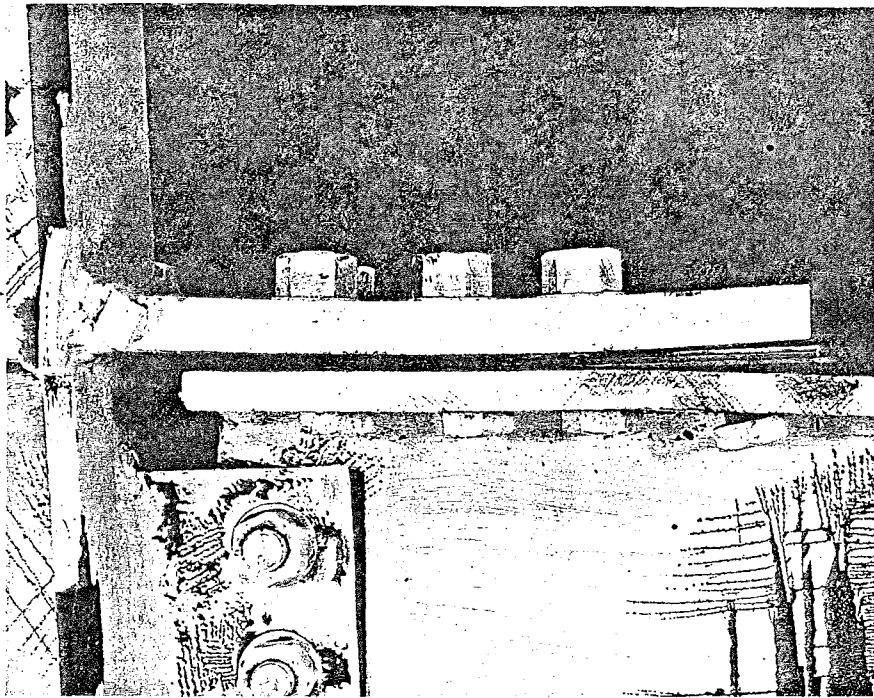


Fig. 10 Prying Action of C7 Flange Bolts

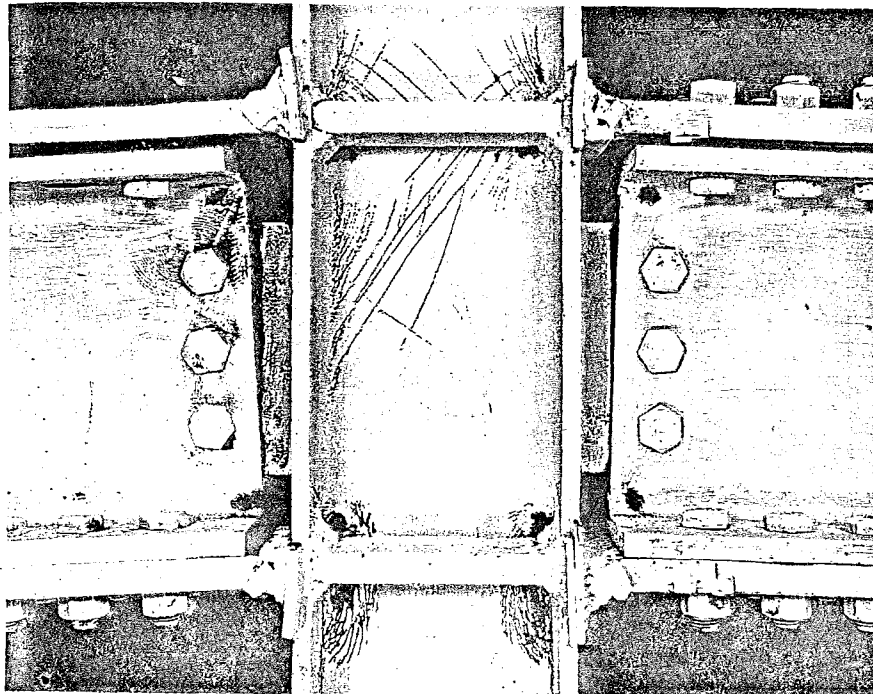


Fig. 11 Panel Zone of Connection C7

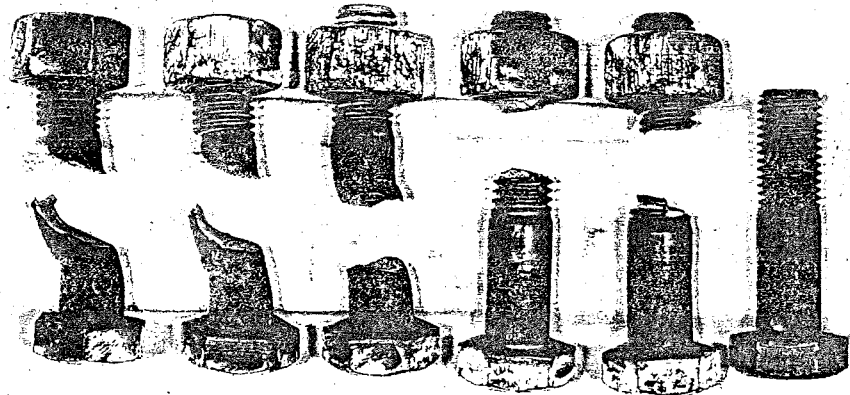
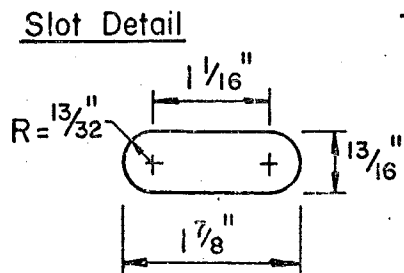
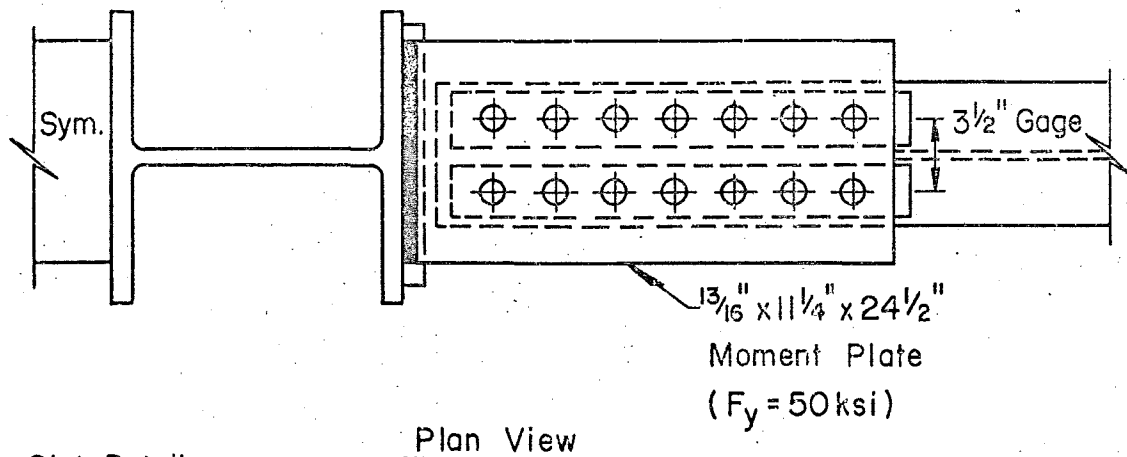
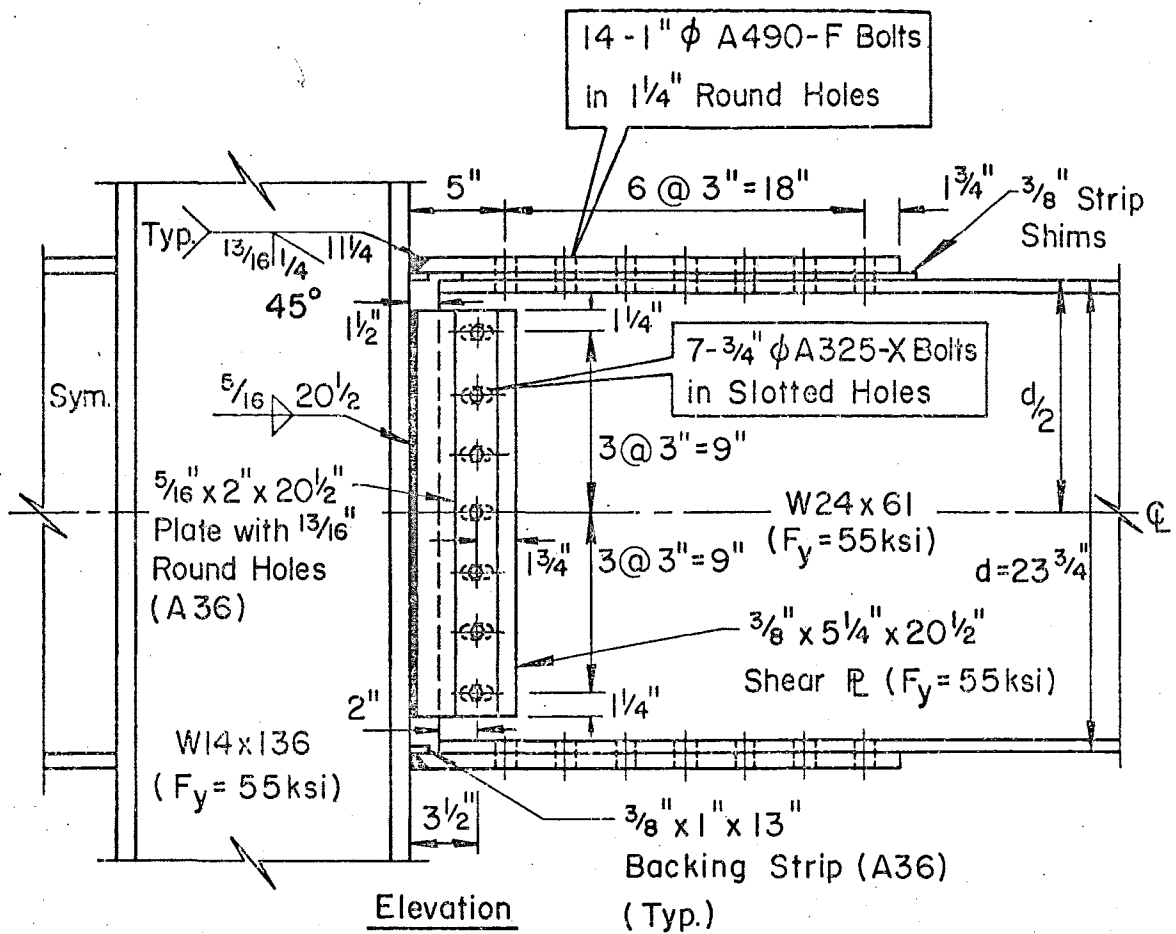


Fig. 12 Bolts at Failure of C7





Scale:

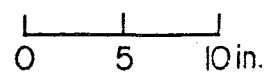
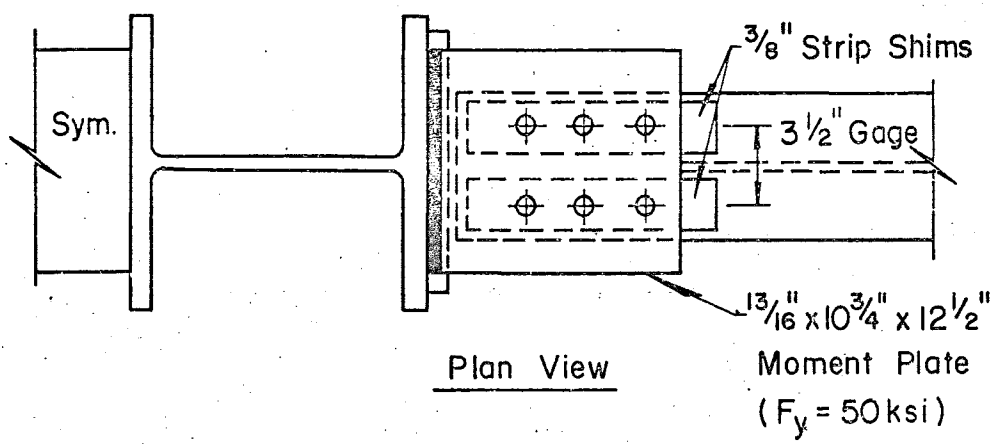
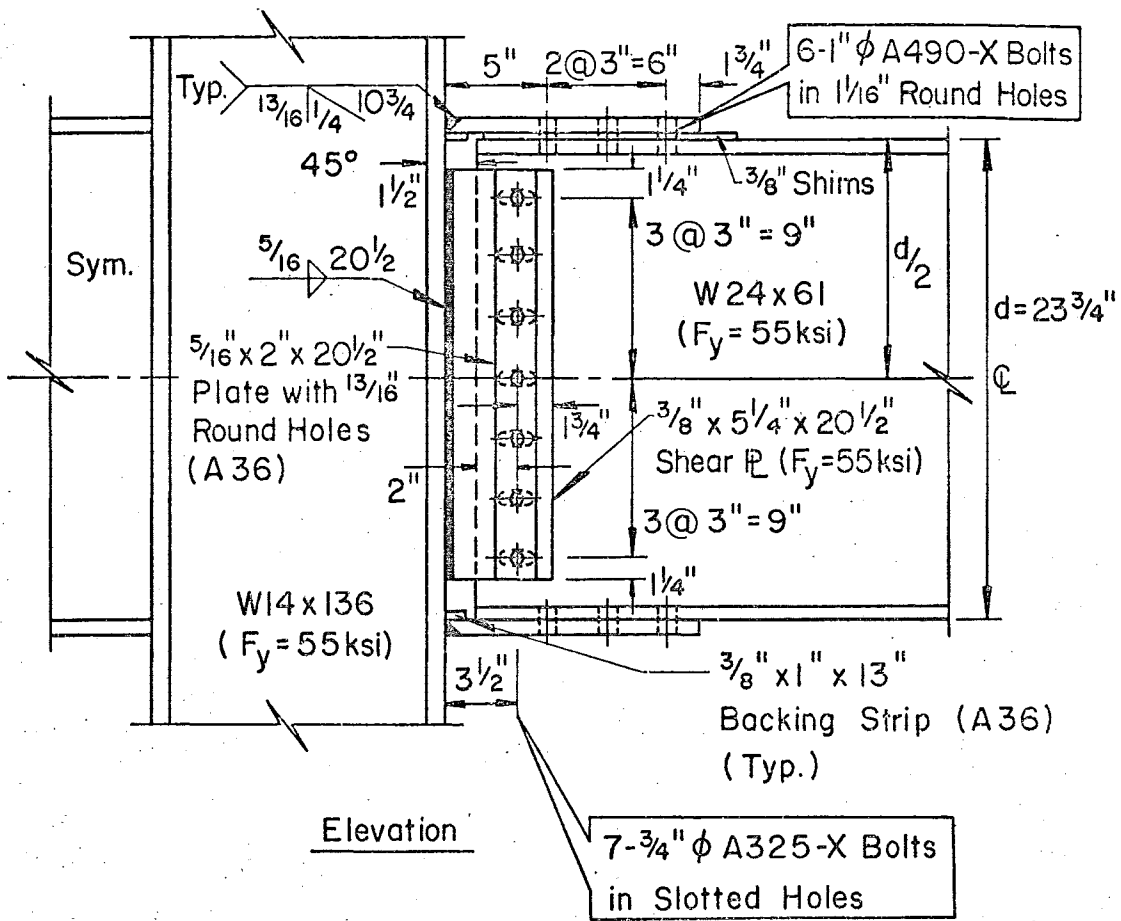


Fig. 13 Connection C8



Slot Detail

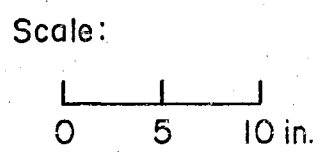
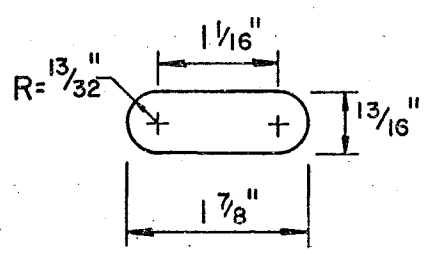


Fig. 14 Connection C9

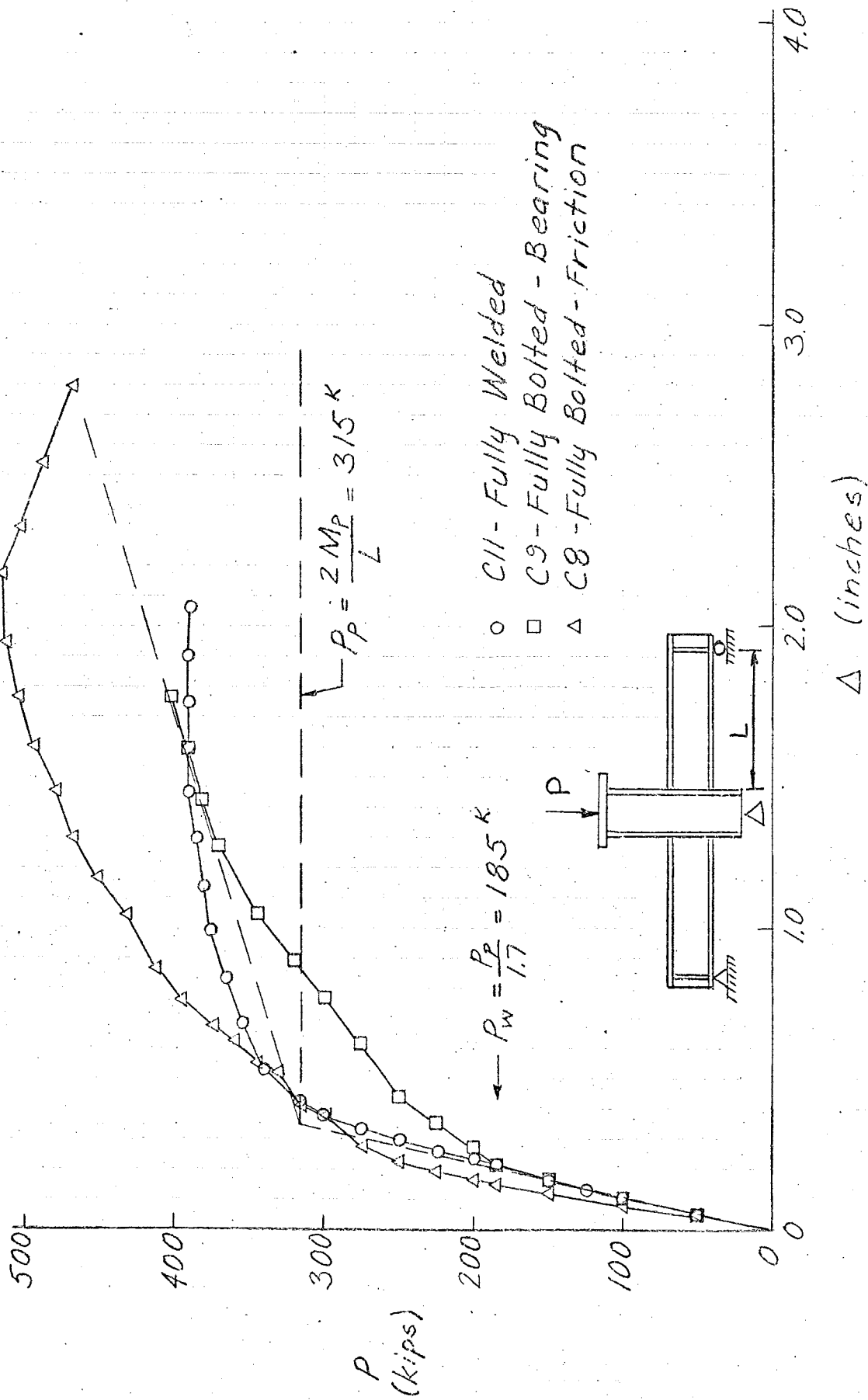


Fig. 15 Load vs. Deflection of C8 and C9

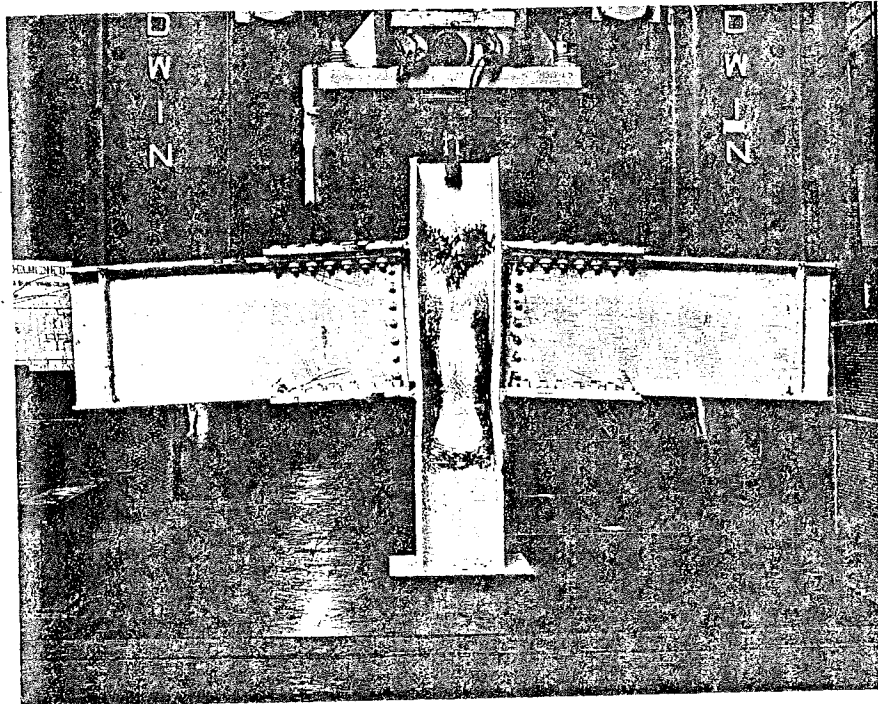


Fig. 16 Overall View of C8

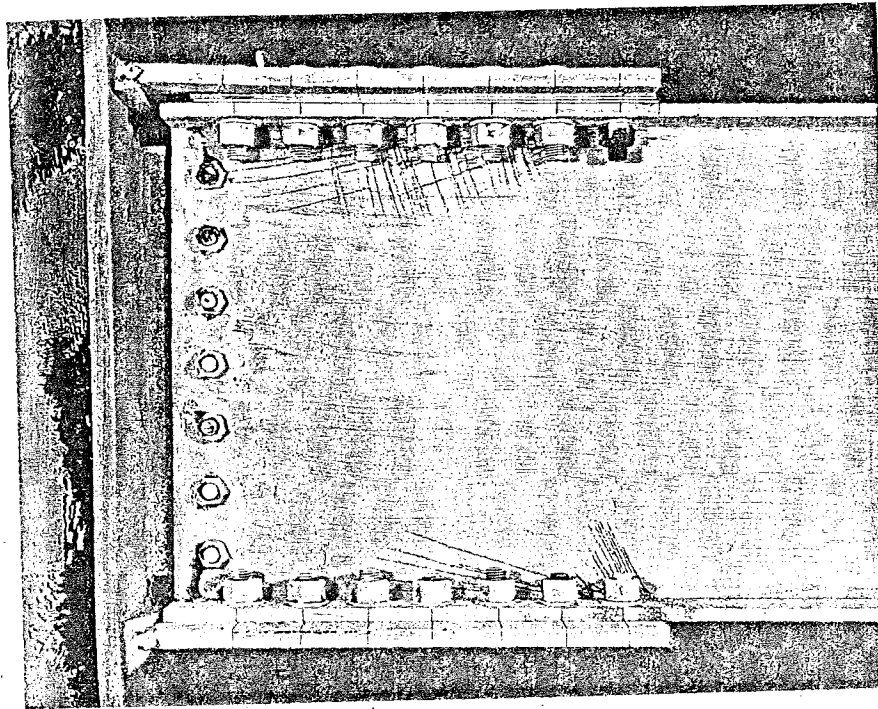


Fig. 17 View of C8 Beam

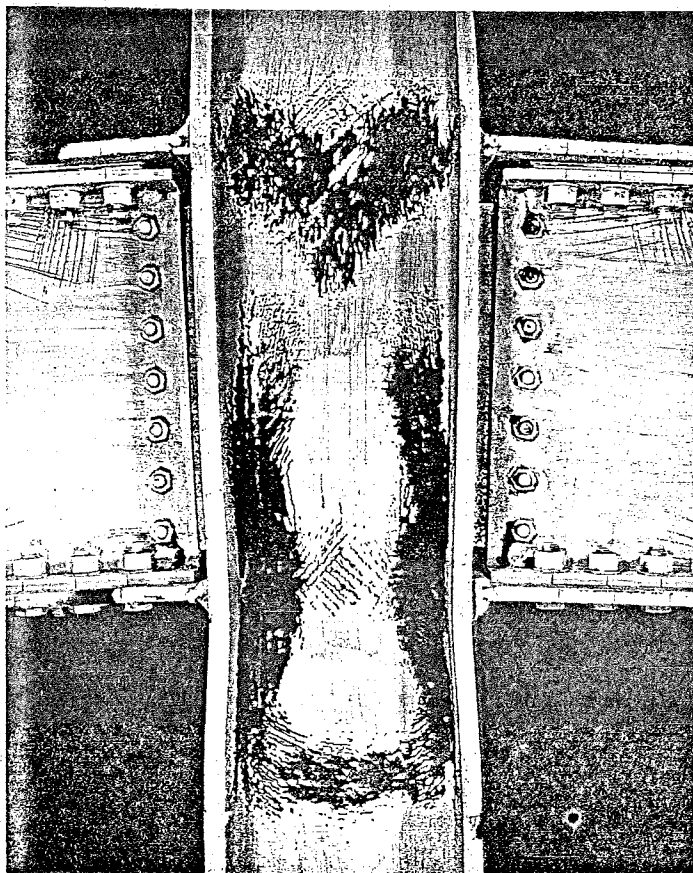


Fig. 18 Panel Zone of C8

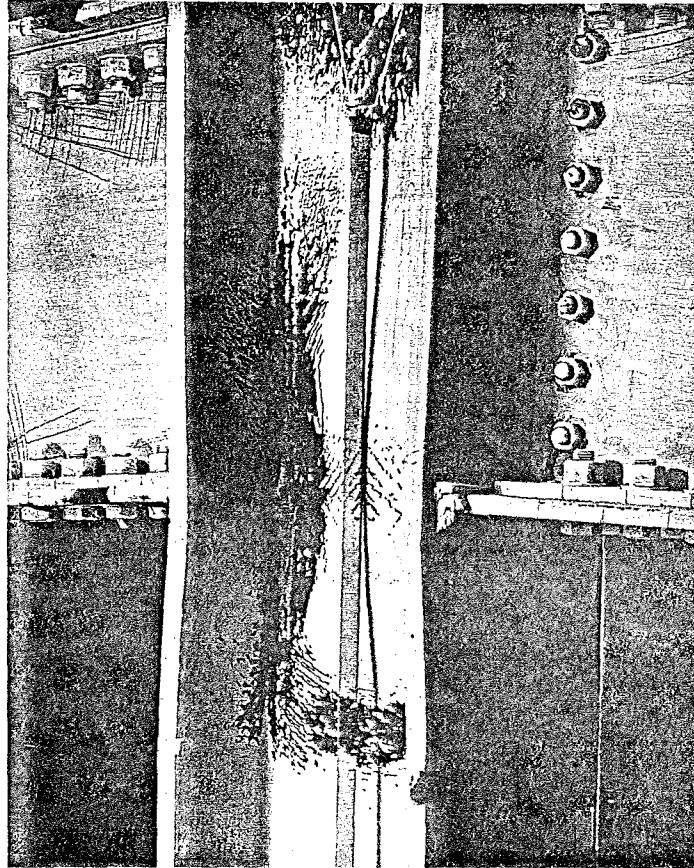


Fig. 19 View Showing Buckling of C8 Column Web

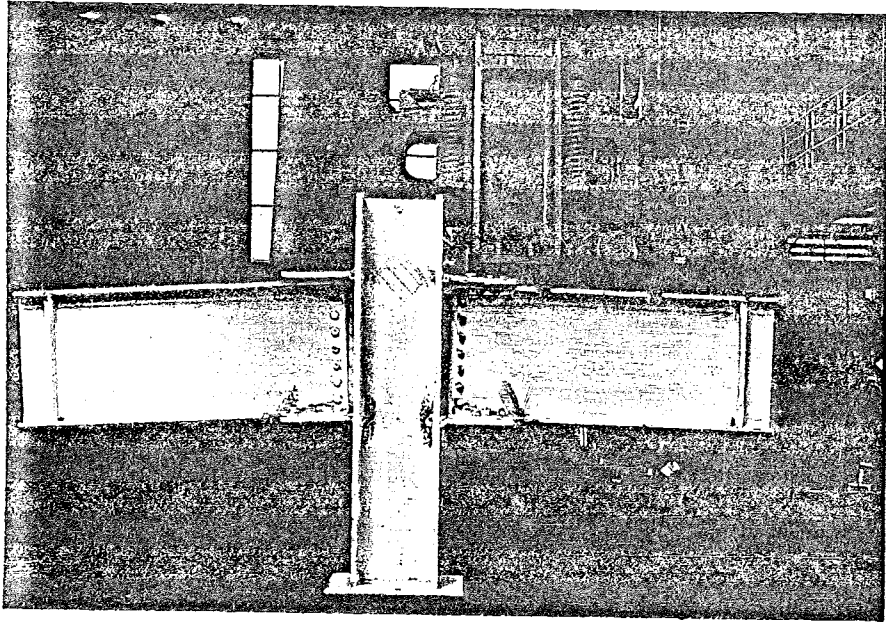


Fig. 20 Overall View of C9

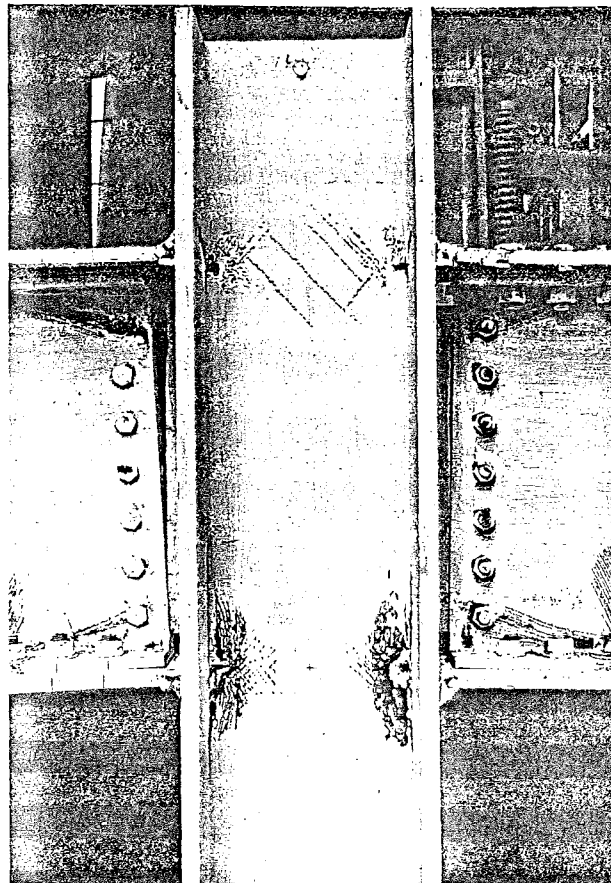


Fig. 21 Panel Zone of Connection C9

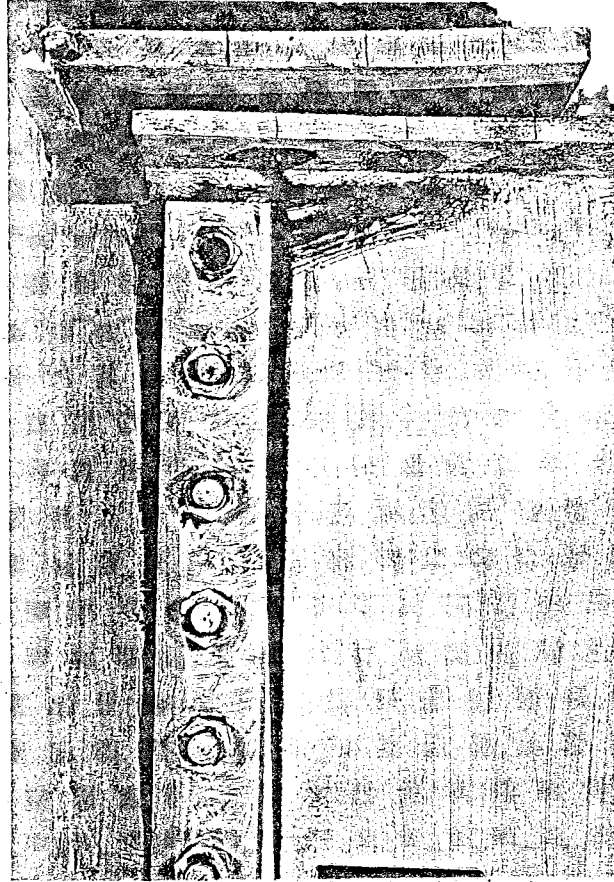


Fig. 22 View of C9 Beam at Connection