Beam-to-Column Connections

PROGRAM OF PILOT TESTS ASSOCIATED WITH BEAM-TO-COLUMN WEB CONNECTION STUDIES

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1. INTRODUCTION

1.1 Background

The phase of beam-to-column connection research work currently being investigated under the guidance of the Welding Research Council Task Group on Beam-to-Column Connections is a study of unsymmetrical steel rigid web connections under monotonic loading. This work was initiated with the issuing of Ref. 1 at the June 1973 Task Group meeting.

At this meeting and the one a year later in June 1974, there was considerable discussion (Refs. 2 and 3) of the merit of conducting pilot tests to answer some questions concerning web connection behavior prior to testing full-scale specimens. A majority of the WRC Task Group members felt that a study of connection behavior under the simulated action of moment and shear separately would help in answering some of the questions concerning member sizes, connection geometry and stiffener requirements which arose out of planning the full-scale tests. The results of these pilot tests would then be incorporated in design of the full-scale specimens.

As a result of the June 1974 meeting and a discussion of Ref. 4, which raised many questions related to design of the full-scale tests, approval was given to proceed with the pilot tests.

When the pilot tests were first introduced at the Task Group meeting, both shear and moment pilot tests were discussed. The shear test would simulate the action of a shear force from the beam web acting on the column. The moment test would simulate the action of
flange forces from the beam, the flange forces being caused by a beam bending moment. Although there is considerable knowledge to be obtained from the shear pilot tests, the immediate needs of designing the full-scale tests centered on a study of the connections under simulated moment behavior. As a consequence, only the moment pilot tests have been planned in this text with the shear pilot tests being held in abeyance.

1.2 Objectives

The overall objective of the use of pilot tests is to obtain sufficient information to adequately design the full-scale specimens for study.

When considering the beam-to-column web connection assemblage shown in Fig. 1, obviously the maximum strength of this connection is based on the mechanism from simple plastic theory where plastic hinges form at A and B in the column, assuming the beam has sufficient plastic strength. For a column without axial load, this would occur when a moment of $M_p$ is reached at A and B ($M_{pc}$ for a column with axial load).

However, there exists the possibility that this maximum strength may not be achieved. First, if the beam flange is narrower than the distance between column fillets and the beam is welded directly to the column web, there is the chance for a yield line mechanism to form in the column web. Depending on the width of beam flange, depth of beam, and column web thickness, the maximum strength of the connection might be greatly curtailed by the formation of the yield line mechanism.
Secondly, even if the attachment of the beam to the column is such that the yield line mechanism will not form, the maximum load based on simple plastic theory might not be attained due to local buckling of the column compression flanges and web. Finally, an item which will not be dealt with in this study but which could also prevent the connection from reaching the maximum strength based on plastic theory is fracture.

If the loading of the beam is of such magnitude that strength beyond those values producing a yield line mechanism or local buckling, the concept of stiffening the column must be considered.

Thus, the objective of these pilot tests can be viewed as a study of maximum strength based on simple plastic theory, yield line mechanism, local buckling, and the related needs of stiffening should the maximum strength of the connection be required to carry the beam load.

More specifically, the overall objective of the moment pilot tests can be segmented into three components. They are:

1. A study of the ultimate strength of the column web under the action of flange forces representing the beam moment.
2. A study of the different methods of attaching the beam flanges to the column in web connections.
3. A study of the stiffener requirements on the side of the column opposite the beam.

1.3 Procedure

To realize these objectives, a series of eight tests will comprise the moment pilot tests. These tests will utilize two different
column sizes, one from a typical upper story and one from a typical lower story of a multi-story building. The two column sizes as well as the plates attached to them to simulate the moment forces, will be made of ASTM A572 Grade 50 steel, the same steel that is planned for the full-scale tests. With each column size being tested under four different geometries of attaching the moment plates to the column, a broad spectrum of knowledge will be obtained.
2. DEVELOPMENT OF THE MOMENT PILOT TESTS

2.1 General

Due to the many variables involved in setting up the moment pilot test program, namely all the different column sizes to choose from and different connection geometries, it was decided to concentrate on only two different column sections. The two sections chosen were a W14x184 and a W12x106. These particular sections were chosen because of their immediate availability. Also, the W14x184 section is just one size greater than the W14x176, which is the section used in design of the full-scale tests.

The decision to work with only two different column sizes was made for three main reasons. First, from the point of view of the ease of getting material, it was felt that in concentrating on two sections, the material would be available sooner than having to wait for many different sections. This is an important consideration because of the relatively short time planned for these tests in order to move rapidly into the full-scale tests. Secondly, obtaining longer pieces of a few column sizes rather than shorter pieces of several column sizes yields somewhat of a saving economically. Finally, and of greatest importance, was the feeling that by concentrating on only two different sizes, any results obtained would not be clouded by the issue of variability of cross section.

2.2 Connecting Geometries

The four different connection geometries to be tested on each of the two column sizes are given in Fig. 2 and labelled as Tests A
Tests A and B represent the cases where the beam flange is narrow enough to fit between the flanges of the column (actually between the fillets of the column). As was stated previously the maximum strength of the web connection assemblage is based on the simple plastic theory of hinges forming in the column. However depending on the magnitude of the loading it is not always necessary to strive to reach the maximum connection strength. In some cases for light beam loading the strength developed in the formation of a yield line mechanism is sufficient.

Therefore the purpose of Test A is to obtain a yield line mechanism (Fig. 4) and observe its pattern and associated strength. These tests will provide some experimental evidence to go along with existing yield line theories (Refs. 5 and 6). Also, it will be attempted to assess what stiffening requirements are necessary so as to prevent formation of the yield line mechanism in order to get the maximum connection strength of the column hinge mechanism if such strength is required. Also, if the yield line mechanism provides sufficient strength to carry the beam load, column stiffening may also be required in order to be able to attain the yield line mechanism because of the interference of local buckling.

As the beam flange increases in width, but still remaining less the distance between column fillets, a point is reached at which the yield line mechanism no longer will form. Test B is such a case where the flange is so wide (fillet to fillet) that a yield line
mechanism will not form. It is the intent with this test to observe whether the column mechanism can be attained or whether local buckling intervenes prior to reaching this load. If local buckling is observed, stiffening criteria must be developed.

Tests C and D simulate the case of beam flange connection plates, cut to a width equal to the distance between column flanges, framing into the column. These test would represent, among others, the case where a beam flange is wider than the distance between column flanges, thus necessitating a narrowing flange connection plate, or the case of a bolted flange connection, again necessitating a flange connection plate.

The purpose of these two tests is similar to that of Test B. It is hoped to be able to attain the column mechanism load without local buckling occurring. If local buckling does occur, stiffening criteria again must be developed to enable these connections to reach their maximum strength. The use of the different welding geometries on the strength will also be studied.

2.3 Test Setup

The test setup to be used in the moment pilot tests is shown in Fig. 3. The column section is placed horizontally on two supports and loaded at two points by means of a spreader beam. With this setup, one test can be conducted on each end of the column. The reaction and the applied load at each end of the column provide the force couple needed to simulate the beam moment. In the pilot tests, no axial force
will be applied to the column. Merely by using \( M_{pc} \), the plastic moment under the influence of axial force, rather than \( M_p \) when discussing the plastic hinge mechanism in the column, the effects of axial force may be included.

There are several reasons for selecting this particular setup. First, all fabrication for the tests using this setup can be done in Fritz Laboratory, thereby saving time and cost. Secondly, two pilot tests, one on each end of the beam can be performed simultaneously. This setup was another reason why each pilot test was not conducted on a different column size.

The compression flange plates serving as supports will be stiffened by plates welded perpendicular to them to prevent buckling.

The distance between the tension and compression plate on each test was chosen to be 24 inches on the large column and 14 inches on the smaller column. These distances reflect a relative deep and a relatively shallow beam depth respectively.

With one test being performed at each end of the column section at one time, a distance between these tests of at least three times the distance \( d \) between flange plates was selected arbitrarily to avoid interference of the effects of one test on the other. The end distances of at least \( d \) were chosen to lessen the effects of the end of the column section on the results of the test.

When one pilot test on a setup has reached its useful limit, that particular pilot test will be stiffened in order that the other test may be completed.
Thus, in order to perform the eight pilot tests, four different test setups will be required, two setups each on the two different column sizes. For each column size, Tests A and B will be conducted on one setup and Tests C and D on another setup.
3. DESIGN OF SPECIMENS

3.1 General

In the design of the welds and the plates of the four tests (Tests A through D) for each of the two column sizes, two different modes of failure were assumed. For Test A, it was assumed that this test would reach its useful limit when a yield line pattern similar to the one in Fig. 4 formed (Ref. 6). With the results of this test it is hoped to be able to predict the load at which the yield line mechanism occurs in a given column for a given beam flange width and beam depth. For Tests B, C and D, the maximum strength was assumed to be achieved when plastic hinges formed in the column of the testing setup as shown in Fig. 5.

3.2 Test A

For the yield line pattern shown in Fig. 4 and assuming, (a) all lines in the assumed yield line pattern are stressed to $F_y$ of the column and (b) the web surface enclosed by lines (1) and (2) remains plane, the expression for internal work is

$$W_I = \frac{2F_y}{d} \left[ \frac{(bd - da)}{12} t + \frac{b^2}{2a} + \frac{d^2}{2a} + \frac{6t^3d}{a} \right] \Delta$$

(1)

where

$b =$ flange plate width

$d =$ distance between flanges

$a =$ one half of the distance between column fillets minus flange width

$t =$ thickness of column web

$\Delta =$ deflection under flange plate
The external work is

\[ W_{\text{EXT}} = 2 \, P_{\text{YL}} \, \Delta \]  

(2)

where \( P_{\text{YL}} \) = force in one flange required to cause the yield line mechanism.

Equating external with internal work

\[ P_{\text{YL}} = \frac{F_Y}{d} \left[ \left( \frac{bd}{12} + \frac{da}{6} \right) t + \left( \frac{b}{2} + \frac{d^2}{2a} \right) t^2 + \frac{6t^3 \, d}{a} \right] \]  

(3)

Once this value is calculated for assumed \( b \) and \( d \) values and for a particular column, the thickness of the flange can be calculated by

\[ t_{\text{flange}} = \frac{P_{\text{YL}}}{b \, F_Y} \]  

(4)

The possibility of the flange plates punching holes in the column web is also checked by comparing the shearing stress on an area equal to the perimeter of the flange times the column web thickness with the shear yield stress.

3.3 Tests B, C and D

Since for these tests, the maximum load is controlled by the formation of hinges at the loading points in the column section, the maximum load is easily obtained. Although the moment is uniform in the center of the column between the two separate pilot tests as shown in Fig. 5, the hinges will form at the load points due to the plastic strength of the column section being reduced from \( M_p \) to \( M_{ps} \) at the load points because of shear. For the magnitude of shear involved in the pilot tests, the reduction is about 0.5% and will be ignored for computational work. However, this amount is considered significant.
enough to tend to cause the hinges to form under the loads rather than anywhere else in the uniform moment region.

Also according to the current specification (Ref. 7), no local buckling will occur in the uniform moment region prior to the formation of hinges under the load.

From Fig. 5 the maximum load on each flange plate is therefore

$$P_{\text{hinge}} = \frac{M_p}{d}$$

where

- $P_{\text{hinge}}$ = force in one plate required to cause column hinge mechanism
- $M_p$ = weak axis plastic moment of column
- $d$ = distance between flange plates

The welds and flange plates of these three tests were designed to transmit the force $P_{\text{hinge}}$. In Tests C and D, shearing in the plate along the fillet welds and shear in the column flange adjacent to the fillet weld were checked. For Test D, the plate thickness was based on shearing of the plate along the welds. For Tests B and C, plate thickness was controlled by yielding of the plate due to normal stresses. The plates for all tests were designed based on using ASTM A572 Grade 50 steel.

Once $P_{\text{hinge}}$ was computed, the flange plate width in Test A was assumed to be small enough so that $P_{\text{YL}}$ for Test A was lower than $P_{\text{hinge}}$. This was done so that a definite yield line mechanism would form in Test A prior to hinge formation in the column.
Shown in Fig. 6 is a nondimensionalized plot of Eq. 3 versus flange width b for a constant distance between flange plates of 24 inches for the W14x184 column. $P_{YL}$ is nondimensionalized by dividing by $P_o$, the theoretical flange force as b approaches zero which corresponds to a point load. The beam flange width b is nondimensionalized by dividing by T, the distance between column fillets. As b approaches T, the value of $P_{YL}/P_o$ approaches infinity. The point where the vertical line marked Test A intersects the curve on the graph represents the value of $P_{YL}/P_o$ required to cause the yield line mechanism for Test A for the particular flange width used in this test (see Appendix A). The horizontal line represents the value of $P_{YL}/P_o$ needed to cause the hinge mechanism as shown in Fig. 5 for Tests B, C and D. This value of $P_{YL}/P_o$ is the nondimensionalized form of $P_{hinge}$ defined previously. Theoretically, for the test setup used, the portion of the curve above this upper line has no meaning. The distance between the two lines represents the margin of flange force which separates the failure of Test A from the failures of Tests B, C and D.

Presented in Appendix A is a complete calculation of plate dimensions and weld sizes for the four tests associated with the W14x184 column. Refer to Table 2 for a summary of plate and weld sizes.
4. **SUMMARY**

In order to obtain sufficient information to adequately design full-scale beam-to-column web connection specimens, a series of eight moment pilot tests have been planned. Although there is considerable knowledge to be gained from shear pilot tests, the immediate needs of designing the full-scale tests centered on a study of the connections under simulated moment behavior.

Of the eight tests, two will study the concept of yield line formation of buckling. The other six tests will attempt to reach the maximum strength of the column plastic hinge mechanism and investigate any local buckling which might prevent the tests from reaching this load. Also on these six tests, different geometries of welding the flange plates the column will be studied.

The eight tests planned consist of four different connection geometries applied to two different column sizes. The tests consist of applying flange forces through plates to the column section in a way analogous to the action of flange forces associated with an actual moment.

The two column sizes to be used are a W14x184 and a W12x106. Column sections and plates will be made of ASTM A572 Grade 50 steel, the same as planned for the full-scale tests. On the large column, the flange plates will simulate a 24-inch deep beam, and for the W12x106, the beam depth (or more specifically the distance between plates) is 14 inches.
5. APPENDIX

Design of Specimens Using W14x184 Column

TEST A

This test will be designed in such a way that the beam flange is less than the T distance (distance between fillets) of the column. The flange plate will be made narrow enough so that a yield line mechanism in the column web will definitely be obtained.

For W14x184 \( T = 11\frac{3}{4}' \), \( t_w = 0.84'' \)

Try \( b_f = 6.25 \) and \( d = 24'' \)

\[ a = \frac{11.25 - 6.25}{2} = 2.50 \]

Internal Work:

\[
W_I = \frac{2}{d} \left[ \frac{bt^2}{2} + \frac{bdt}{12} + \frac{t da}{6} + \frac{t^3 d}{2a} + \frac{6 t^3 d}{a} \right] \Delta \\
= \frac{2}{24} \left[ \frac{(6.25)(0.84)^3}{2} + \frac{(6.25)(24)(0.84)}{12} + \frac{(0.84)(24)(2.50)}{6} + \frac{(0.84)^3(24)^3}{2(2.50)} + \frac{(6)(0.84)(24)}{2.5} \right] \Delta \\
= 4.1667 \left[ 2.205 + 10.5 + 8.4 + 81.285 + 34.140 \right] \Delta \\
= 4.1667 \left[ 136.53 \right] \Delta \\
= 568.88 \Delta 
\]

External Work:

\[
W_{ext} = 2P \Delta 
\]

Equating Internal and External Work

\[
W_I = W_{EXT} \\
568.88 \Delta = 2P \Delta \\
P = 284.44k 
\]
thickness of flange required:

\[ t_f = \frac{284.44}{(6.25)(50)} = 0.910 \]

use 6\(\frac{1}{4}\)" x 1-1/16" H.'s 24" Apart

Check Pulling Out of Column Web by Flange

\[
6.25 + 2(\frac{3}{4})(.84) = 7.09
\]

\[
1.0625 + 2\frac{1}{2} (.84) = 1.9025
\]

Total Perimeter = \(2(7.09) + 2(1.9025) = 17.985"\)

\[
17.985 \frac{F}{\sqrt{3}} = 17.985 \frac{50}{1.732} = 519.20^k > 284.44^k \text{ OK}
\]
TESTS B, C & D

Since no yield line mechanism can form in these arrangements, the test will theoretically fail when a mechanism forms in the column, providing there is sufficient weld at the plate to column junction and providing the plate does not yield in shear along a line adjacent to these welds.

The test setup to be used is shown below.
\[
M = (7.83)(1.378)(3.915)(50)(4) + 2(12.624)(.42)(50)(.21) = 8559.71 \text{ k-in}
\]

\[
P = \frac{M}{24} = \frac{8559.71}{24} = 356.65 \text{k}
\]

Plate thickness for Test B:

\[
t = \frac{356.65}{(50)(11.25)} = 0.634
\]

Use 11\%"x3/4"H's 24" Apart

**TEST C**

Length of weld = 12.624 - 2.00 + 2(7.41 - 1.0)

= 10.624 + 12.82 = 23.444"

Weld Size

\[
356.65 = .707(t)(21)(23.444)(1.7)(2)
\]

\[
t = \frac{356.65}{.707(21)(23.444)(1.7)(2)}
\]

\[
t = 0.3014 \text{ use 3/8" (.375) fillet weld both sides of plate}
\]

Check shear plane A-A in H.
Length = 6.41 \times (6.41)(.75) \frac{F}{\sqrt{3}} = 138.78 = \text{force required to cause yielding in shear}

Force in weld along A-A = (6.41)(.3014)(.707)(21)(1.7)(2) = 97.53^k

138.78^k > 97.53^k \quad \text{OK}

Check shear along a plane through column flange adjacent to weld (Sec. B-B)

\[
(1.378)(6.41)\left(\frac{F}{\sqrt{3}}\right) = 254.99^k = \text{capacity of flange in shear}
254.99^k > 97.53^k \quad \text{OK}
\]

\text{TEST D}

From the previous calculation it is apparent that the plate thickness will have to be increased from a shear point of view so that we will not get yielding along line A-A

Length of Weld = 2(6.41) = 12.82"

Weld Size:

\[
356.65 = .707(t)(21)(12.82)(1.7)(2)
\]

\[
t = \frac{356.65}{.707(21)(12.82)(1.7)(2)}
\]

\[
t = .551" \quad \text{use 5/8" fillet weld both sides of plate}
\]

Force in each weld = 356.65/2 = 178.33

Plate Thickness = \[
\frac{178.33}{(6.41)\left(\frac{50}{\sqrt{3}}\right)} = .9636" \quad \text{Use 1-1/16" HL}
\]

\[
178.33^k < 254.99^k \quad \text{so shearing along B-B is no problem}
\]
<table>
<thead>
<tr>
<th>TEST</th>
<th>PURPOSE</th>
<th>LIMITING CONDITION</th>
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<tbody>
<tr>
<td>A</td>
<td>Study Yield Line Mechanism and Local Buckling</td>
<td>Yield Line or Local Buckling</td>
</tr>
<tr>
<td>B</td>
<td>Study Column Hinge Mechanism and Local Buckling</td>
<td>M or Local Buckling</td>
</tr>
<tr>
<td>C</td>
<td>Study Column Hinge Mechanism, Local Buckling, and Welding Configuration</td>
<td>M or Local Buckling</td>
</tr>
<tr>
<td>D</td>
<td>Study Column Hinge Mechanism, Local Buckling, and Welding Configuration</td>
<td>M or Local Buckling</td>
</tr>
</tbody>
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### TABLE 2

Summary of Plate and Weld Sizes for Eight Pilot Tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Plate</th>
<th>Welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$6\frac{1}{4}&quot; \times 1-1/16&quot;$</td>
<td>Groove Welded to Column Web</td>
</tr>
<tr>
<td>B</td>
<td>$11\frac{1}{2}&quot; \times 3/4&quot;$</td>
<td>Groove Welded to Column Web</td>
</tr>
<tr>
<td>C</td>
<td>$12-5/8&quot; \times 3/4&quot;$</td>
<td>Fillet Welded (3/8&quot;) Both Sides of Plate to Column Web and Flanges</td>
</tr>
<tr>
<td>D</td>
<td>$12-5/8&quot; \times 1-1/16&quot;$</td>
<td>Fillet Welded (5/8&quot;) Both Sides of Plate to Column Flanges Only</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test</th>
<th>Plate</th>
<th>Welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$7&quot; \times 11/16&quot;$</td>
<td>Groove Welded to Column Web</td>
</tr>
<tr>
<td>B</td>
<td>$9\frac{1}{2}&quot; \times 11/16&quot;$</td>
<td>Groove Welded to Column Web</td>
</tr>
<tr>
<td>C</td>
<td>$10-15/16&quot; \times 11/16&quot;$</td>
<td>Fillet Welded (3/8&quot;) Both Sides of Plate to Column Web and Flanges</td>
</tr>
<tr>
<td>D</td>
<td>$10-15/16&quot; \times 1-1/16&quot;$</td>
<td>Fillet Welded (5/8&quot;) Both Sides of Plate to Column Flanges Only</td>
</tr>
</tbody>
</table>
Fig. 1 Web Connection Assemblage
Fig. 2 Four Tests Planned on Each Column Section
Fig. 3  Test Setup

d = 24" for test of W14 X 184

   d = 14" for test of W12 X 106
Fig. 4 Assumed Yield Line Pattern
Fig. 5 Moment and Shear Diagram of Test Setup
Fig. 6 Flange Force vs Connection Geometry

W14 x 184

$t_{web} = 0.84$
$T = 11.25$
$P_0 = 146.25$ Kips

Flange Width / Distance Between Column Fillets
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