Special semi-annual report to subcommittee, Lehigh University, (1950)

Fritz Lab

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TO: Members, Lehigh University Project Sub委员会, WRC

WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS

Progress Report I

Special Semi-Annual Report

March 8, 1950

Gentlemen:

GENERAL

This report has been prepared expressly for the forthcoming meeting of the subcommittee. A complete presentation of results is not intended. Reports for publication will shortly be commenced in at least two of the programs which will serve this purpose.

A number of reports have already been furnished to the committee.(1) Perhaps time should be allowed to receive your suggestions on the following items:

(a) what problems should be given emphasis in the future program?

(b) a criticism of work thus far (in July, 1950 we will have reached the end of our second year of the 5-year program).

(c) a criticism of measurements and instrumentation.

(1) Progress Reports B, C, D, F. See Appendix I.
A few test results are presented below. These summary reports have been prepared primarily by the research assistants. In the case of the connection program, in which a number of tests remain to be completed, typical and summary data have been presented so that criticisms may be made for the rest of the series.

Cambridge trip. Progress Report G has been distributed.

Time has not permitted the preparation of further reports on the trip. Rough notes, photographs, and sketches will be brought to the meeting for examination by subcommittee members if desired. Some of the items that could be reported on are:

(a) Photographs of some of the Cambridge test set-ups.
(b) Sketches of yielding in beams being tested for inelastic lateral buckling.
(c) Some results of column tests in which Lynn Beedle participated.
(d) Some suggestions made to Cambridge personnel for further column research on model scale.
(e) Chart of structural research including objectives, method of test, variables, sketches of test set-ups. This is an amplification of the projects listed in Progress Report G, and is partially complete.
(f) Details of fabrication of scale model sections.

A paper, "Columns in Tier Building Frames", emphasizing design requirements, is in preparation.
Reports. A complete list is presented in Appendix I for information. Two additional reports for publication are in preparation: Progress Report No. 3 on the program of beam tests, and No. 4 on the connection tests. The latter will be presented at the October meeting of the Welding Society.

We hope to present an outline of Progress Report No. 3 at the third Plasticity Symposium at Brown University in September.

Finances and general plans. No report is made other than to recommend that next year's AISI contribution be added to that of the AISC to support a full-time research associate and an expanded program in the column investigation. For the past two years this money has been devoted primarily to the connection and continuous beam investigations. In our next proposal to ONR a small sum will be included for column studies.*

With the funds remaining this year the outlined connection program will be completed, including control beam and coupon tests, two frames will be tested, and coupon studies for 14WF30 material and a few column tests will be completed.

Since the Navy is desirous of a fiscal year commencing Oct. 1 and since WRC operates on the same basis we plan to shift our financial operations to the same period. We believe this will not affect the contributions now received from our sponsors.

We have agreed to partial support (rail fare from New York + hotel accommodations) to have Dr. Heyman visit us for a discussion with personnel on this project. Would the committee agree that it is desirable to continue to support such contacts?

* ONR funds will be used primarily for connection and frame research.
Dr. Heyman, one of Professor Baker's team, is at Brown University this year.

**BEAMS**

(C. H. Yang, Research Assistant)

**Test program.** Table I contains the latest revision. No further tests (model B6 and B8) are planned under this year's budget, except to complete the coupon test work.

**Outline results.** The following table indicates the initial yield strength(1) and ultimate strength both observed and predicted (on the basis of coupon test data and the simple plastic theory).

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Initial Yield Strength W</th>
<th>Ultimate Strength W</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
<td>Predicted</td>
</tr>
<tr>
<td>B1</td>
<td>21.4</td>
<td>23.1</td>
</tr>
<tr>
<td>B2</td>
<td>27</td>
<td>34.7</td>
</tr>
<tr>
<td>B3</td>
<td>39</td>
<td>46.2</td>
</tr>
<tr>
<td>B4</td>
<td>29</td>
<td>34.7</td>
</tr>
<tr>
<td>B5</td>
<td>33</td>
<td>34.7</td>
</tr>
<tr>
<td>B7</td>
<td>39</td>
<td>44.5</td>
</tr>
</tbody>
</table>

(1) For observed values this is arbitrarily defined as the load at which the formation of yield lines in the specimen was accompanied by an obvious deviation from a straight line. Initial yield is a gradual process, and detection depends on sensitivity of gages and scale at which data is plotted.

(2) Coupons not tested. SWF40 data used.
TABLE I

TABLE OF TESTS

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Size of Member</th>
<th>Loading (ft.)</th>
<th>Span (ft.)</th>
<th>Type of Test</th>
<th>Support Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>*B₁</td>
<td>8WF40</td>
<td>1/3 point</td>
<td>14</td>
<td>Simple Beam</td>
<td></td>
</tr>
<tr>
<td>*B₂</td>
<td>&quot;</td>
<td>&quot;(1)&quot;</td>
<td></td>
<td>Simulated Cont.</td>
<td>(a)</td>
</tr>
<tr>
<td>*B₃</td>
<td>&quot;</td>
<td>&quot;(2)&quot;</td>
<td></td>
<td>Simulated Frame</td>
<td>(a)</td>
</tr>
<tr>
<td>*B₄</td>
<td>&quot;</td>
<td>&quot;(1)&quot;</td>
<td></td>
<td>Simulated Cont.</td>
<td>(b)</td>
</tr>
<tr>
<td>*B₅</td>
<td>&quot;</td>
<td>&quot;(1)&quot;</td>
<td></td>
<td>Simulated Cont.</td>
<td>(d)</td>
</tr>
<tr>
<td>B₆</td>
<td>14WF30</td>
<td>&quot;</td>
<td></td>
<td>Simple Beam</td>
<td></td>
</tr>
<tr>
<td>*B₇</td>
<td>&quot;</td>
<td>&quot;(1)&quot;</td>
<td></td>
<td>Simulated Cont.</td>
<td>(b)</td>
</tr>
<tr>
<td>B₈</td>
<td>&quot;</td>
<td>&quot;(1)&quot;</td>
<td></td>
<td>Simulated Cont.</td>
<td>(d)</td>
</tr>
</tbody>
</table>

* Test completed.

(1) Force at end of overhanging sections regulated to keep beam level over support point.
(2) Cantilever load regulated to keep end in same horizontal plane as support points.

The results of tests B₁, 2, 3 and 8WF40 coupon data were presented in Progress Report B. The report for publication will summarize this plus the results of the remainder of the program.

Figures 1 and 2 from Test 7 are presented because they show behavior not observed on the 8WF40 series. (One of the objectives of the program was to show influence of section shape.) Further discussion is contained beneath the photographs.
Fig. 1. Test B7, 14WF30 section. This photograph, taken at collapse, shows how yielding on the compression and tension sides penetrated to about the same depth of section. In the top flange at the left can be observed evidence of both lateral and local buckling which combined to prevent the section from carrying additional load.
Shear yielding in this test differed from the 8WF40 tests in that it was localized at the supports. Note how the shear yielding pattern to the left stops abruptly.

Note also the local buckling of the lower (compression) flange on both sides of the support. Although there was some buckling on the 8WF40 it was not this severe.
Progress Report I, a discussion of Mr. Weiskopf's recent paper, has been furnished to you previously.

Additional Tests. Model B6 - a control test - is probably not necessary because the central span of the continuous beam B7 constitutes such a test.

A test of Model F (B8) is not considered urgent since the variable (effect of connection type) did not significantly influence behavior on the 8WF40 series.

The committee may wish to consider further study of local and lateral buckling producing inelastic instability. The 14WF30 test brought out such behavior and some similarities were noted in the connection program where section proportions are similar.

Quoting from the August 3, 1949 revision of proposal,

"An additional test should be made to continue the study of effect of varying end restraint, completing the series started by tests (A) and (B). From these tests, it appears that sufficient rotation at support points may prevent the "hinges" from developing before excessive deflections have occurred."

This could be accomplished with a single load applied at the center. Another method would be to increase the length of cantilever arms, but maintaining third-point loading.

CONNECTIONS

(A. A. Topractsoglou, Research Assistant)

The following report presents more detail results than the other investigations since a number of tests remain to be completed. It was thought that the presentation of typical data might be of value to the committee at the present time.

* B2 and B3 in Table I.
At no cost to the project a graduate student, Mr. L. L. Schneider, made a significant contribution to the project by making an elastic analysis of the various connections. A number of methods were compared for the haunched type. Particularly in the case of built-up knees this was valuable since it permitted proper location of the line of load application. The information will be of further value in comparing results of tests with theoretical analysis.

**Purpose:** to study the behavior of welded joints in the elastic and plastic range, observe the mode of failure and the relative strength, stiffness and cost of fabrication.

Further, as indicated in the minutes of the previous sub-committee meeting, the purpose of the current series was to answer quickly and as economically as possible, questions relating to certain details of construction of connection types being considered.

**Suggestions.** In response to the proposal the following were some of the suggestions made by committee members:

1. to include more tests using curved inner flange connections in which radius would be kept constant, the flange thickness being varied. E or F and L or M might be omitted.

2. to use Bleich's method for curved knees for analysing knees with non-parallel flanges.

3. to use 8B13 section instead of 6WF15.1.

This was done.

**Specimens Tested.** Of the fourteen connections submitted in the proposal of September 9, 1949, and shown in Table II,
<table>
<thead>
<tr>
<th>Test</th>
<th>Type of Model</th>
<th>Number of Conn. Specimens</th>
<th>Sketch</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>1</td>
<td>![Sketch](see Fig. 3)</td>
</tr>
<tr>
<td>B</td>
<td>2B</td>
<td>1</td>
<td>![Sketch](see Fig. 4)</td>
</tr>
<tr>
<td>C</td>
<td>15</td>
<td>1</td>
<td>![Sketch](see Fig. 7)</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>3</td>
<td>![Sketch](see Fig. 5)</td>
</tr>
<tr>
<td>G</td>
<td>5A</td>
<td>4</td>
<td>![Sketch](see Fig. 9)</td>
</tr>
<tr>
<td>K</td>
<td>8B</td>
<td>3</td>
<td>![Sketch](see Fig. 6)</td>
</tr>
<tr>
<td>N</td>
<td>16</td>
<td>1</td>
<td>![Sketch](see Fig. 8)</td>
</tr>
</tbody>
</table>
eight have been tested. Tests have been completed on the following:

<table>
<thead>
<tr>
<th>Test</th>
<th>Model</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁</td>
<td>A</td>
<td>2</td>
</tr>
<tr>
<td>T₂</td>
<td>K</td>
<td>8B</td>
</tr>
<tr>
<td>T₃</td>
<td>M</td>
<td>8B</td>
</tr>
<tr>
<td>T₄</td>
<td>D</td>
<td>4</td>
</tr>
<tr>
<td>T₅</td>
<td>E</td>
<td>4</td>
</tr>
<tr>
<td>T₆</td>
<td>N</td>
<td>16</td>
</tr>
<tr>
<td>T₇</td>
<td>B</td>
<td>2B</td>
</tr>
<tr>
<td>T₈</td>
<td>C</td>
<td>15</td>
</tr>
</tbody>
</table>

All connections were tested in a 300,000 lb. Baldwin hydraulic machine as shown in Fig. 3 except Model B, T₇, which was tested in the 800,000 lb. Riehle screw-type machine.

In all cases lateral support was provided to prevent early lateral buckling. Approximate time for setting up the specimen in the machine and in completing a test has been 30 hours. The average cost of each test has been about $120.

DATA TAKEN

Rotations in the knee were measured with level bars which were supported on rods welded in the web adjacent to flange. Fig. 9 gives location of support rods while Fig. 3 shows level bars in place.

Deflections were measured with a deflection gage which can be seen in Fig. 3. Fig. 9 gives a typical location of gage.
Fig. 3. Picture showing test set-up. Note loading fixture, deflection gage, two level bars and strain indicator.
SR-4's are being used in certain localities:

1. to get the M-Ø curve for the rolled section.
2. to indicate the degree to which a uniform stress distribution is achieved along the compression flange of a haunch. This places the connection in a "worst loading" condition.
3. to compare experimental values to theoretical ones (see suggestion 2 mentioned above).
4. to observe stress concentration effects.

A Mirror Gage was used to obtain changes in moment arm. See Fig. 9.

Whitewash was used to obtain location of yield lines.

Results. Table III gives experimental and calculated results. In obtaining the calculated load for initial yielding of the haunched or bracketed connections the flexure formula, Bleich's method and the Wedge Theory (Osgood) were used and the lowest of these is the value presented.

Table IV gives the relative cost of fabrication. Note last column.

Connection Type 2B has been chosen as typical and test data are presented with brief discussion. Fig. 4 to 7 give the general appearance at collapse and the formation of yield lines. The fabrication details of the connection are given in Fig. 8. The Loading Fixture used in all tests and the location of strain gages, level bars, deflection gage and mirror gage on Test 7 are given in Fig. 9. Fig. 10 is the Load-Deflection curve as obtained by the deflection gage. The broken line parallel to the elastic part of the curve is drawn with an offset of 0.04" deflection. The point of intersection with the curve has been
### Table III

**Tabulated Results**

<table>
<thead>
<tr>
<th>Test</th>
<th>Model</th>
<th>Type</th>
<th>OBSERVED (kips)</th>
<th>OBSERVED (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T1</strong></td>
<td>A</td>
<td>2</td>
<td>6.5</td>
<td>12.5</td>
</tr>
<tr>
<td><strong>T2</strong></td>
<td>K</td>
<td>8B</td>
<td>10.0</td>
<td>10.5</td>
</tr>
<tr>
<td><strong>T3</strong></td>
<td>M</td>
<td>8B</td>
<td>9.0</td>
<td>9.0</td>
</tr>
<tr>
<td><strong>T4</strong></td>
<td>D</td>
<td>4</td>
<td>19.0</td>
<td>16.0</td>
</tr>
<tr>
<td><strong>T5</strong></td>
<td>E</td>
<td>4</td>
<td>14.5</td>
<td>20.0</td>
</tr>
<tr>
<td><strong>T6</strong></td>
<td>N</td>
<td>16</td>
<td>16.0</td>
<td>18.0</td>
</tr>
<tr>
<td><strong>T7</strong></td>
<td>B</td>
<td>2B</td>
<td>4.0</td>
<td>10.0</td>
</tr>
<tr>
<td><strong>T8</strong></td>
<td>C</td>
<td>15</td>
<td>6.0</td>
<td>11.3</td>
</tr>
</tbody>
</table>

* Based on plastic hinge of rolled section.
## TABLE IV
### TIME OF FABRICATION

<table>
<thead>
<tr>
<th>Model</th>
<th>Type</th>
<th>Cutting of Rolled section</th>
<th>Cutting stiffeners and butt plates</th>
<th>Bevelling</th>
<th>Welding</th>
<th>Total</th>
<th>Ratio based on Model A</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>2 00</td>
<td>1 52</td>
<td>1 08</td>
<td>12 53</td>
<td>17 53</td>
<td>1</td>
</tr>
<tr>
<td>K</td>
<td>8B</td>
<td>1 40</td>
<td>5 06</td>
<td>- -</td>
<td>15 11</td>
<td>21 57</td>
<td>1.23</td>
</tr>
<tr>
<td>M</td>
<td>8B</td>
<td>1 40</td>
<td>7 14</td>
<td>- -</td>
<td>16 45</td>
<td>25 39</td>
<td>1.43</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>1 40</td>
<td>9 41</td>
<td>1 08</td>
<td>31 08</td>
<td>43 37</td>
<td>2.44</td>
</tr>
<tr>
<td>E</td>
<td>4</td>
<td>1 40</td>
<td>8 33</td>
<td>1 08</td>
<td>25 58</td>
<td>37 19</td>
<td>2.08</td>
</tr>
<tr>
<td>N</td>
<td>16</td>
<td>1 40</td>
<td>29 45</td>
<td>0 34</td>
<td>51 58</td>
<td>83 57</td>
<td>4.70</td>
</tr>
<tr>
<td>B</td>
<td>2B</td>
<td>1 40</td>
<td>26 19</td>
<td>2 16</td>
<td>59 20</td>
<td>89 35</td>
<td>5.00</td>
</tr>
<tr>
<td>C</td>
<td>15</td>
<td>1 40</td>
<td>13 45</td>
<td>1 42</td>
<td>31 11</td>
<td>48 18</td>
<td>2.70</td>
</tr>
</tbody>
</table>
Fig. 3a. Test 7, Connection 2B.
View showing south side of connection when $P = 18,000$ lb.
Note lateral bracing, yield lines and deflection gage support at far left.
Fig. 4. Test No. 7, Connection type 2B. View from south showing yield lines at the completion of test. Note yielding at both compression and tension flanges, and local buckling.
Fig. 5. Test No. 7, Connection type 2B. View from N.E. Note lines in the tension flange of column and extensive yielding all over and especially near reentrant angle. There is no yielding in rolled section.
Fig. 6. Test No. 7, Connection type 2B. View from west showing amount of lateral buckling.
Fig. 7. Test No. 7, Connection 2B. View showing yielding in compression flange of knee.
chosen as the general yield point. This is an arbitrary criterion used for all connections. The rotation in the knee is given by the curve of Fig. 11. This curve is obtained from the rotations of Level Bar No. 1 and No. 2. It will be used for comparison with rotation of a beam of equivalent section.

Fig. 12 gives the increase in moment arm as obtained from mirror gage. The change in moment arm at maximum load is about $35/60$ inches, which is about $1\%$ increase in moment and has been neglected in calculations.

The agreement between theoretical line and experimental points of the $M-\phi$ curve at section A-A (see Fig. 9) as given in Fig. 13 shows satisfactory behavior of specimen and apparatus.

Welding Sequence. The following assembly and welding sequence was used on type 2B specimen.

1. Tack weld to the web the flange plates a to e in the alphabetical order given.

2. Start welding from middle of each plate, i.e. points $0$, $0'$ and $0''$.

3. Weld about 4" at a time. The sketch shows the general sequence followed. After all welds of one number are completed on one side the connection is turned and the same members are welded on the opposite side.

4. Weld the butt plates.

5. Weld diagonal stiffener on both sides of web.

6. Weld rolled sections.
NOTE
1) All thicknesses 1/4".
2) All welds 1/4".

Unless otherwise noted.

**TABLE**

<table>
<thead>
<tr>
<th>Wk No.</th>
<th>Section</th>
<th>Length</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>8 WF 13</td>
<td>1-4 3/4</td>
<td>Butt Plate</td>
</tr>
<tr>
<td>b</td>
<td>R 4-1/4</td>
<td>0-6 1/2</td>
<td>Stiffener</td>
</tr>
<tr>
<td>c</td>
<td>R 11/4</td>
<td>1-4 1/2</td>
<td>Lower Flange,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>bent as shown</td>
</tr>
<tr>
<td>d</td>
<td>R 4-1/4</td>
<td>2-7 1/2</td>
<td>Upper Flange</td>
</tr>
<tr>
<td>e</td>
<td>R 4-1/4</td>
<td>3-4 3/8</td>
<td>Web, cut properly</td>
</tr>
<tr>
<td>f</td>
<td>R 31/4</td>
<td>2-7 1/2</td>
<td></td>
</tr>
</tbody>
</table>

**CONNECTION B, TYPE 2B**

FL205C-36

9-28-1949

AAT

**FIG. 8 FABRICATION DETAILS**
LOAD-ROTATION of JOINT
CONNECTION 2B
MODEL 2B TEST 7

FIG. II
M-φ Curve at Section A-A Fig 9

FIG. 13
Prior report. 205.D was reviewed rather thoroughly at the last meeting. Unless there is further comment it may be passed over.

Further work. An expression of tentative opinion is sought from the committee on the suggestion to include more tests using curved inner flanges. The proposed connections have been fabricated but not tested.

As reported in the September 9, 1949 proposal, the 14WF30 section gave results in the initial test which might be typical for average rolled members of similar b/d ratio. Most type 7 connections fabricated of these sections would fail by shear in the knee web before reaching the yield point in bending. A test might be desirable using a rolled section in which bending failure would occur before shear yielding. The type 8 connection (no diagonal stiffener) should be similar in behavior to type 7 and would be suggested for such a test.

Specimens are being saved and after the program of "compression" testing is completed it is planned to load these in tension. Strength will be observed against overall deflection (measured by dial gage as shown in Fig. 9). Loading in compression will be more severe than in tension, but the latter is possible, hence the tests are suggested for discussion by the committee.

Numerous of the tests proposed as frames in the original proposal dated May 12, 1948 can probably be carried out as connection tests. Many were intended to study the influence of varying column and beam sections. Table IV in that proposal contains the tests suggested.

When considering type 2 connections the possibility of plate laminations is often mentioned. The influence could be evaluated
in beam tests as shown in the accompanying sketch using plates known to be laminated.

Tests and proposals thus far have been for the corner type. Consideration is now being given to tests of interior connections and will be presented in proposal form at a later date.

COLUMNS
(9an Ruzek, Research Assistant)

Current Program. Because of Lynn Beedle's trip to England a full-time series of tests was not planned for the year. The following tests have been completed since the previous report:

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Section</th>
<th>L</th>
<th>Test Conditions*</th>
<th>P/R</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>T6</td>
<td>4WF13</td>
<td>16'</td>
<td>b</td>
<td>.23</td>
<td>Note (1)</td>
</tr>
<tr>
<td>T7</td>
<td>&quot;</td>
<td>16'</td>
<td>b</td>
<td>.23</td>
<td>Notes (1), (2)</td>
</tr>
<tr>
<td>T8</td>
<td>8WF31</td>
<td>16'</td>
<td>c</td>
<td></td>
<td>comparison with Cambridge test</td>
</tr>
</tbody>
</table>

* "b": moment applied at one end, opposite end kept "fixed"
"c": equal moments of opposite sign applied at each end.

(1) The original plan was to duplicate the 8WF31 series of three tests completed last year except that 4 WF 13 sections would be used. Difficulties in testing T6 occurred and the column yielded, deforming laterally. Since the pilot test had been plastically deformed in the strong direction, it was decided to use both tests in a series to investigate influence of prior plastic deformation. T7 was tested in identical fashion but without previous plastic deformation.

(2) This test was conducted in accordance with the original plan and also furnished comparison with test 6 and the pilot test.
Lehigh-Cambridge comparison test. Appendix III outlines plans for test 8, noted in the above table. The chairman of the subcommittee was advised of the plan, Professor Baker agreed that the test proposed would be satisfactory, and the test was completed on March 5. It was a part of the regular program (refer to Table I of Progress Report 2, "Tests of Columns under Combined Bending and Thrust") although sequence of loading was different from that previously used at Lehigh.

The collapse load under nearly constant applied end moments is shown in Appendix III, Fig. 14. In subsequent test with zero end moments (pin-end condition), the column collapsed at a load about 2% below the equivalent collapse load of the Cambridge test.

There was no yielding of the "tension" flange. Suggestions for additional tests are contained under the heading, "Number of Tests" in Appendix III. This will also be discussed further with Professor Baker.

Reports. Progress Reports 2 and C were distributed to the committee at the time of the last meeting. As noted in the first part of this report, a study of design requirements of columns in tier buildings is in preparation.

Dissertation. A study by Mr. C. H. Chen of elastic lateral buckling of I-section columns is underway. Mr. Chen was research assistant on the project last year. The tentative outline of his dissertation is presented in Appendix II.

Future program. The two remaining 4/4 Fl3, 16-foot columns in the "original plan" will be completed. This will be followed by a study of all test data, on the basis of which a new proposal will be prepared.
Because of the smaller number of tests conducted, some "column" funds may remain at the end of the year. If so, these will be applied to next year's program. Cost of recent tests has been about $325.00 exclusive of salaries. The time to conduct a test has been from two to three days, not including time to set up or to make preliminary trial runs.

FRAMES

As has been noted in the previous progress reports, two frame tests are planned and will be tested during the summer. The specific details will be forwarded to the committee in proposal form prior to the test and following completion of the present connection tests. One will have a haunched or curved connection, the other to be a simple unstiffened knee such as type 2, 7, or 8.\(^{(1)}\)

Lynn S. Beadle  
Research Engineer

Bruce G. Johnston  
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CC: J.F. Baker  
W.J. ENey  
LaMotte Grover  
W. Spraragen  
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\(^{(1)}\) Refer to Table II for connection types.
Appendix I

LIST OF REPORTS
(The following are on file in the library.)

<table>
<thead>
<tr>
<th>TITLE</th>
<th>DATE</th>
<th>AUTHORS</th>
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<tr>
<td><strong>Reports for Publication</strong></td>
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<tr>
<td>203.1(1) The Plastic Behavior of Wide Flange Beams</td>
<td>8 Sept. '48</td>
<td>Luxion Johnston</td>
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<tr>
<td>(Welding Journal, Nov. '48)</td>
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<tr>
<td>205.2 Tests of Columns under Combined Bending &amp; Thrust (to be</td>
<td>20 May '49</td>
<td>Beedle Ready Johnston</td>
</tr>
<tr>
<td>published in SESA Vol. VIII, No. 1, June '50)</td>
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<td><strong>Reports to Lehigh Project Subcommittee</strong></td>
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<td>205.A Plans for Connection and Column Tests</td>
<td>26 Nov. '48</td>
<td>Beedle Ruzek Johnston</td>
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<td>205.B Plastic Behavior of Continuous Beams</td>
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<td>205.C Strength of Columns under Combined Bending and Compression</td>
<td>27 May '49</td>
<td>Chen</td>
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<td>205.D Test of a Rigid Frame Knee</td>
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<td>205.E Working Drawings for Three Connection Tests Proposal for</td>
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<td>205.F General Summary Report</td>
<td>19 July '49</td>
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<td>205.G Structural Research at Cambridge University</td>
<td>30 Jan. '50</td>
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<td>205.H Discussion of &quot;Flexure of I-Sections above Plastic Range&quot; by</td>
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<td>Beedle Yang</td>
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<tr>
<td>W.H. Weiskopf</td>
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(1) Indicates Progress Report "1" or "A" as the case may be.
Appendix II

Tentative Outline of Dissertation

Chin-huo Chen
Oct. 28, 1949

Columns of thin-walled open section possess extremely low torsional strength. Such a column loaded eccentrically in the plane of its maximum moment of inertia may buckle laterally, involving twisting and bending. The problem has been analyzed and discussed by H. Wagner, R. Kappus, S. Timoshenko, J. N. Goodier, H. N. Hill and B. G. Johnston and various solutions obtained for some cases. This dissertation is intended to make a thorough investigation of one or more of the following problems concerning the lateral buckling of I-section members:

1. To find the general solution of the critical lateral buckling load of a I-section member with axial load and end-moments applied in the plane of the web.---The problem of lateral buckling of a I-section column with equal end-moments has been discussed by B. G. Johnston.* In actual structures, generally, these moments are not equal. It seems that the investigation of the case of unequal end-moments would be of some practical significance.

2. To find the direct stress due to non-uniform torsion in a I-section column with end thrust in neither principal
plane of the section.---- In the 1946 A.R.E.A. Specifications, the allowable stress for compression member with the load applied with simultaneous eccentricity with respect to both principal axes is given by the following formula:

\[ p = \frac{\sqrt{\frac{1}{\left(1 + \left(\frac{E_t c}{I_t} + 0.25\right) \sec \frac{k}{\bar{r}} \sqrt{\frac{F}{E}} + \left(\frac{E_t c}{I_t} + 0.25\right) \sec \frac{k}{\bar{r}} \sqrt{\frac{F}{E}}\right)^2}}}}{\sqrt{\frac{1}{\left(1 + \left(\frac{E_t c}{I_t} + 0.25\right) \sec \frac{k}{\bar{r}} \sqrt{\frac{F}{E}} + \left(\frac{E_t c}{I_t} + 0.25\right) \sec \frac{k}{\bar{r}} \sqrt{\frac{F}{E}}\right)^2}}}} \]

Apparently, the design formula has neglected the compressive stress due to non-uniform torsion. Study will be made to determine the magnitude of the stress thus introduced and attempt will be made to modify the above design formula if desirable.

Appendix III

COLUMN TESTS T-8

Notes on a test to compare with Cambridge test F22B8 for the purpose of investigating scale effect.

PURPOSE:

(a) Investigate scale effect. Observe if collapse occurs after the formation of a single complete yield plane in the as-yet unyielded flange. See "Discussion", note 1.

(b) Part of general program. Under test condition "c" (described below) obtain a point on the collapse interaction curve.

RESULTS OF F22B8 AND 9 (Cambridge tests)

Section shown in Fig. 1a. Loading applied as shown in Fig. 4. Interaction curve for the section shown in Fig. 5.

In F22B8 the attempt was made to make the column collapse by the application of beam loads only. The elastic behavior is shown dotted in Fig. 5. This was not possible (due to limitation in beam capacity) so that collapse was brought about by the addition of axial load.

The computed magnitudes of moments are shown in Fig. 14, plotted against axial load with the interaction curve shown. Values are somewhat approximate. Magnitude of axial load at collapse is shown for both B8 and B9.

TEST SPECIMEN: Cambridge personnel have previously agreed to 8WF31, 16 feet in length. L/r in y-direction is 95 which is very close to B8. Note that L/r in x-direction will be twice as great in Lehigh test as in B8. See table in Fig. 13 for comparison. Compare cross-sections in Figs. 1a and 3.

LOADING: Plan is the reverse of usual Lehigh method. Bending moment will be held constant while axial load is increased to collapse.

Plan of the test shown in Fig. 14. \[ M/M_p = 0.22 \]. On 8WF31 use \[ M = 0.22 \times M_p \]

\[ M = 0.22 \times 1200 = 264 \text{ kip-inches} \]

This method of loading will load the column in the most severe manner insofar as flanges are concerned. Fig. 12 shows condition of test.

(1) Fig. numbers indicated in appendix refer to figures that follow, not to those in main text.

(2) Subsequently changed to \( M_A = M_C = 176 \text{ kip-inches} \).
Progress Report I

Appendix III

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MARCH 8, 1950

NUMBER OF TESTS: One test only is planned at the present time. Others that are desirable would be a comparison with B9 and a duplicate of the one here proposed except with an 8EL13 section and a length of 80" (approx.). This is a more exact approximation to \( L/r_x \) of Cambridge B8. If many lines are formed in both flanges of the above proposed tests, the demonstration of a scale effect would seem evident. Further tests might not then be necessary.

Discussion of Column Test T-8

(1) In Figs. 16 and 17 are shown the yield line patterns taken from Cambridge tests F22B3 and F22B9. Flange patterns only are shown. In the case of F22B9, Fig. 16, collapse followed immediately the formation of line "A". In B9 (Fig. 17) considerable yielding under constant load took place after the critical line had formed before collapse occurred.

(2) As will be seen from Fig. 13, \( L/r_x \) is not simulated very well by the proposed test. This is why an 8EL13 has been recommended for the future.

(3) From the work at the University of Washington on lateral buckling of beams additional information should be obtained.

The same phenomenon described in (1) above occurred on lateral buckling of beams tests at Cambridge. The same section was used in these tests as in B8. Thus, the "one-line" phenomenon seems to run throughout most of the Cambridge tests, but may not be corroborated in larger scale tests.

(4) The Cambridge group will probably study this problem further. If a correlation of results is obtained, then we would hope that a large number of model tests could be made at Cambridge, a fewer number of full-scale tests at Lehigh then being required. As was noted in Progress Report G, we expect to receive the Cambridge proposed test program soon.
FIG. 1
(a) Test specimen to scale as used in the L-beams used in F228A, B.
(b) b/c=1.0 A
Suggested additions.

FIG. 2
Table of dimensions of various WF sections reduced to depth of 2" for comparison.
Note: Scale factor different in each case.

FIG. 3
Scale draw of some length test specimens.

FIG. 4
Dimensions of F228A and 9 Frame.

FIG. 5
Interaction curve for section, Fig 2A.
Appendix III

FIG. 6

Approximate proportions of frame to study influence of relative beam and column stiffness.

FIG. 7

More complete simulation at corner.

FIG. 8

End plate attachment scheme

(not shown in Fig. 6, but intended to be bolt to heavily blocks which can be drilled and tapped)

FIG. 9

Holding down device

FIG. 10

Mirrors on stanchions

FIG. 11

Reduction of "stub" distance

TABLE OF L/P VALUES IN LEHIGH PROGRAM
Fig. 14
Results of B8 & B9 and basis for Lehigh T8

Collapse, B8
3.67 tons

Collapse, B9
4.6 tons
(no loads on beams)

Pattern of proposed Lehigh test T8

Collapse of T8
Equivalent P = 3.34 tons
M = 0.89 tons-in at θ

M
P - tons

M
M C
0.89 = M
M/A P C = 2.2

0.32 = M C

Curve based on θ = 15.6°
**Fig. 16**

**Successive Failure of F2288**

**Fig. (a)**

View looking at compression flange. No lines present in tension flange.

Beam loads at max.

P = 0

**Fig. (b)**

Tension flange just prior to collapse. When lines met at A collapse occurred. See Fig (c)

**Fig. (c)**

Tension flange after collapse.

**Fig. 17**

Lines in F2288

Collapse followed formation of this line

This one yielded first, at lower load.