Portal frame tests, Proposal for Continuation of, November 15, 1952

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F. W. Schutz
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To: Members, Lehigh Project Subcommittee  
Structural Steel Committee  
Welding Research Council  

Proposal for Continuation of  
PORTAL FRAME TESTS  

Gentlemen:  

Attached is a proposal for the continuation of the portal frame tests which were started on the basis of the proposal of 25 August 1950 as a phase of the investigation of WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS.

One test remains of the three originally proposed and approved, and funds for this test are available. With the results and experience gained from the first two tests, however, it is considered desirable to plan the third test against the background of a further extension of the experimental portal frame investigation. The large number of variable factors influencing the behavior of such frames may thus be adequately covered in the test program with the smallest possible number of individual tests.

The Committee Members are therefore kindly asked to offer their criticism and approval as to:

1. The details of the third portal frame test as outlined herein.
2. The outline of further portal frame tests, which may be carried out within the limits of the anticipated annual budgets.

This request is in accordance with the decision of the Lehigh Project Subcommittee during its May 6, 1952 meeting in New York, following a brief discussion of the test program. Valuable ideas and suggestions received then and on various other occasions from several Committee Members have contributed greatly to this proposal, which will be presented for discussion and approval at the forthcoming Committee meeting.

Sincerely yours,

Lynn S. Beedle  
Asst. to the Director
Welded Continuous Frames and Their Components

PROPOSAL

For the Continuation of

PORTAL FRAME TESTS

by

K.E. Knudsen, F.W. Schutz and L.S. Beedle

This work has been carried out as a part of an investigation sponsored jointly by the Welding Research Council and the Department of the Navy with funds furnished by the following:

American Institute of Steel Construction
American Iron and Steel Institute
Column Research Council (Advisory)
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Fritz Engineering Laboratory
Department of Civil Engineering & Mechanics
Lehigh University
Bethlehem, Penna.

15 November 1952

Fritz Laboratory Report No. 205D.4
CONTENTS

A. Scope of Tests ............................................. 3
B. Objectives of Portal Frame Tests ......................... 5
C. General Portal Frame Test Program ....................... 6
   1. Chart of Variables .................................... 6
   2. Discussion of Variables ............................... 7
   3. Test Program ........................................ 12
D. Third Portal Frame Test ................................ 14
   1. Test Frame ........................................... 14
   2. Testing Procedure ................................ 14
   3. Predicted Frame Behavior.......................... 16
   4. Cost Estimate ....................................... 19
E. References .................................................. 19
A. **SCOPE OF TESTS**

The directives for the over-all investigation of WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS may be summarized as follows:\(^4\)

1. **Component Frame Parts (Columns, beams and connections)**
   
   Study the behavior, with emphasis on the plastic range, and develop theories to predict such behavior.

2. **Integral Frame Behavior**
   
   (a) Determine balanced frame proportions for the plastic range.
   
   (b) Develop procedures for predicting the collapse load and the plastic deformations.
   
   (c) Verify such procedures by suitable tests.

3. **Practical Applications**
   
   (a) Develop practical design procedures for utilization of the reserve plastic strength.
   
   (b) Explore the limitations in the application of such design due to fatigue, local buckling, lateral buckling, etc. (in addition to deflection limitations).

The frame tests proposed in the following will contribute information on items 2 and 3 above. The results of the first two frame tests\(^1\) furnished desired information for the particular case chosen (uniform section and vertical load). Although several series of frame tests have been carried out earlier in the U.S. and abroad, these were either mainly concerned with the elastic behavior or were performed on miniature models of rectangular cross-section. The present Lehigh investigation of nearly full-scale frames of as-delivered, commercially available sections is unique in bringing out in full force the practical limitations that may be encountered in the application of plastic-range design. As reflected by the number of desirable tests outlined in the following the task is a major one even though present work is limited to portal frame studies. Once firmly established on the basis of critical research, however, the available indications point to wide practical applications resulting in important structural advantages and
cost savings through suitable welded continuous designs.

The present study is limited to flat-roof and gabled portal frames (Fig. 1a). Curved (parabolic) portal frames are of a comparatively smaller importance and are not included in the study. Referring to Fig. 1, future extensions should consider:

2. Multi-bay one-story frames
   (a) Flat
   (b) Gabled
   (c) Shed-type
   (d) Saw-tooth

3. Multi-story frames

4. Three dimensional frame structures (parallel frames with bracing) (loads applied in three directions)

Of particular interest would be a study of the validity of the simplifying assumption that external horizontal shear is distributed between all columns according to stiffnesses at any particular level of a multi-bay, multi-story frame.

---

**Fig. 1. Types of Building Frames**

(1) Portal Frames

(2) Multi-bay One-story Frames

(3) Multi-story Frames

(4) Parallel Frames with Bracing
The objectives of the proposed frame tests are as follows:

1. To check the actual behavior with that predicted by elastic and plastic analyses.
2. To check the behavior of the various frame components (beams, columns and connections) with the numerous isolated tests which have been performed.
3. To explore the relative advantages of
   a) square knees vs. haunched knees
   b) pinned base vs. fixed base
   with emphasis on the influence of these design features on the ultimate carrying capacity, especially with regard to blast loadings and combinations of alternate loadings.

The tests should furnish the answers to several specific questions which may be segregated from the above general objectives. Some of these are:

4. To what extent may the assumed elastic stress distribution deviate from the actual (due to inadequate or simplified analysis, improper hinge action, unforeseen loading cases, etc.) and the frame still carry the loads within tolerable deflection limitations?
5. May a frame, designed elastically for its normal load, be called upon to withstand occasional extraordinary loads (blast loads, overloads) through plastic action?
6. How is the rating of the various connection types in frames affected when subjected to "tension" (at the inner flange, due to side loading) as compared to the results of the isolated connection tests?
7. What rotation capacity is required of columns, beams and connections in order to develop the full plastic reserve strength of frames?

Plastic design procedures for portal frames have already been published abroad(?) indicating the extent to which plastic design has been adopted. Such methods can not be recommended for general practical applications until the results of a study as outlined above are available and the limitations imposed by local plastic buckling are established.
C. GENERAL PORTAL FRAME TEST PROGRAM

1. Chart of Variables:

The proposed portal frame study is limited to symmetrical frames with symmetrical vertical loading. The variables affecting the behavior of such frames are listed below. The choice of range of variation of these variables as indicated in the table is the result of the discussion on the following pages.

![Diagram of a portal frame]

<table>
<thead>
<tr>
<th>TYPE VARIABLE</th>
<th>VARIABLE</th>
<th>RANGE OF VARIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometrical</td>
<td>Size h</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Ratio h/L</td>
<td>1/3 (1/6)</td>
</tr>
<tr>
<td></td>
<td>Pitch f/L</td>
<td>0 1/4</td>
</tr>
<tr>
<td>Structural Sections:</td>
<td>Column Section</td>
<td>8WF40 8B13 12WF36 10WF29</td>
</tr>
<tr>
<td></td>
<td>Ratio I_B/I_C</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Knoc</td>
<td>Square Haunched Curved (Tapered)</td>
</tr>
<tr>
<td>Boundary Conditions:</td>
<td>Base</td>
<td>Pinned Fixed</td>
</tr>
<tr>
<td>Lateral Support</td>
<td>Provided</td>
<td></td>
</tr>
<tr>
<td>Longitudinal Support</td>
<td>Provided at beam axis</td>
<td>Absent beam axis</td>
</tr>
<tr>
<td>Loading</td>
<td>Vertical Load V</td>
<td>Present</td>
</tr>
<tr>
<td></td>
<td>Horizontal Load Q</td>
<td>0  V/9 V/3</td>
</tr>
</tbody>
</table>
2. Discussion of Variables

Geometrical Variables

The size of the test frames as indicated by its height \( h \) will be kept constant at 10'. A frame approaching full size is thereby tested, avoiding difficulties in interpretation of test data otherwise introduced by scale factors. The size is as large as may be conveniently manufactured and tested in the laboratory.

The column height to beam span ratio \( h/L \) in the two first tests was one-half. Common \( h/L \)-ratios in actual portal frames lie in the range \( 1/8 \) to 1, the value \( 1/3 \) representing an "average" or common case. Other variables being considered more important, the fixed ratio \( h/L = 1/3 \) is chosen for all tests. With both \( h \) and \( L \) constant costly alterations of the test set-up are avoided.

At a later stage the influence of the \( h/L \)-ratio could be explored by performing an additional test with \( h/L = 1/6 \). The two values \( 1/3 \) and \( 1/6 \), together with the initial tests using \( 1/2 \), would cover a wide range of actual portal frames.

The pitch of most gabled portal frames fall in the range \( f/L = 1/4 \) to \( 1/3 \). The two cases \( f/L = 0 \) (flat roof) and \( f/L = 1/4 \) are representative of a large number of structures and are chosen for this investigation.

Structural Variables

The structural properties of rolled structural shapes as affected by shape factor, local buckling characteristics, lateral buckling characteristics, and residual stresses due to cooling after hot-rolling and mill straightening are most conveniently studied by tests of the component members (beams and columns). Such studies are presently underway in Fritz Laboratory. For the purpose of integral frame studies sections exhibiting average good properties with regard to both elastic and plastic behavior should be employed, except for the purpose of establishing the range as achieved by the first two frame tests of an
SWF40 section (very satisfactory plastic properties) and an 8B13 section (one of the poorest sections in the plastic range). A light section must necessarily be chosen to conform with the modest test frame dimensions.

The inclusion of the type of knee (square vs. haunched or curved) also affects the choice of section. A haunched or curved knee is usually more costly than a square one, but may nevertheless result in a more economical frame since a lighter beam and column section may be used. For fair comparison this factor must be reflected in the test program. The required section modulus of the beam is approximately proportional to the square of the beam span. A haunch length of 10% of the span thus allows a beam section with section modulus 0.64 times that required with square knees. Two light sections of the above proportion are the 12WF36 and 10WF29 sections. These are chosen for the haunched or curved knee frames and the square knee frames, respectively.

The main properties of the two sections are:

<table>
<thead>
<tr>
<th>Property</th>
<th>12WF36</th>
<th>10WF29</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>12.24 in.</td>
<td>10.22 in.</td>
<td></td>
</tr>
<tr>
<td>Width</td>
<td>6.565 in.</td>
<td>5.799 in.</td>
<td></td>
</tr>
<tr>
<td>Web Thickness</td>
<td>0.305 in.</td>
<td>0.289 in.</td>
<td></td>
</tr>
<tr>
<td>Flange thickness</td>
<td>0.540 in.</td>
<td>0.500 in.</td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>10.59 in.²</td>
<td>8.53 in.²</td>
<td>1 : 0.80</td>
</tr>
<tr>
<td>Strong Axis</td>
<td>280.8 in.⁴</td>
<td>157.3 in.⁴</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45.9 in.³</td>
<td>30.8 in.³</td>
<td>1 : 0.67</td>
</tr>
<tr>
<td>Weak Axis</td>
<td>23.7 in.⁴</td>
<td>15.2 in.⁴</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.2 in.³</td>
<td>5.2 in.³</td>
<td></td>
</tr>
<tr>
<td>Plastic Modulus</td>
<td>51.5 in.³</td>
<td>34.7</td>
<td></td>
</tr>
<tr>
<td>Shape Factor</td>
<td>1.12</td>
<td>1.12</td>
<td></td>
</tr>
</tbody>
</table>

Plastic local buckling of the compression flange of these two sections is predicted to occur at a strain equal to 76% and 85%, respectively, of the value at which strain hardening occurs.

J.D. Griffiths(2) has shown that the ratio $I_B/I_G$ between the moments of inertia of the beam and column section has a comparatively minor influence on the elastic moment distribution. The following relative values are taken from Ref. (2) for $h/L = 1/3$ by interpolation, and are valid for uniform vertical loading and pinned bases:
In the plastic range the influence of this ratio may become more pronounced as the sequence of hinge formations may be altered. This variable is, however, considered less important than those included in the study, and the ratio $I_p/I_c = 1$ will be used in the tests proposed herein.

The type of corner connection, on the other hand, is a major variable factor in the test program proposed. Common types of square, haunched and curved knees are included. The type of knee, and even comparatively minor knee design details, may heavily affect the ultimate carrying capacity of the frame. The choice of type and details is guided by the earlier isolated connection tests (3) which point to means of preventing moment or shear yielding and lateral or local buckling of various types of knees. Referring to these tests a square knee of type 8B (Fig. 3) and a haunched knee of type 2B are selected.

It would be desirable later to also include the test of a frame with tapered members. Such a frame is not shown in the present program but may be considered in possible future revisions of the test program.

For vertical loading only, the additional stiffness provided by haunched or curved knees contributes little to increase the elastic or plastic strength of flat roof frames unless secondary effects like foundation settlement or imperfect hinge action must be considered. Side loading is therefore included for all test frames with haunched or curved knees.
Variables in Boundary Conditions

Pinned-base portal frames are by far the most predominant in the United States (except in the case of heavy crane columns), while fixed bases are often used abroad. Such fixity as may be present due to construction practices are often neglected in this country. A trend towards fixed-end columns is now apparent, however, prompted by the marked increase in strength gained under lateral loads such as blasts. An experimental quantitative verification of this advantage is desirable. Consequently pinned as well as fixed bases are included in this test program.

Lateral support is required in regions where the yield stress level is exceeded in order to avoid premature lateral buckling. Such supports are usually present in actual frames to some extent in the form of bracing, purlins, etc., at least on the top flange. In the plastic range more extensive lateral support is required than in conventional elastic design. Lateral support will be provided at all critical points including the corner connections.

Longitudinal support at the elevation of the beam axis was provided in the two first frame tests since side-sway was not wanted in these introductory tests. The introduction of lateral loads in the plane of the frame eliminates the longitudinal support. Partial roof loading, which would cause side-sway, is not considered in this program.

Variables in Loading

Vertical loading is included in all tests. Simulating uniformly distributed load from dead weight of framing and roofing and from snow load the rectangular test frames will be subjected to concentrated third-point loading. This approximation causes less than 10% increase in the elastic and plastic deflections, and results in the same initial yield load and ultimate load as a uniformly distributed load. Also for the gabled frames the uniform load will be simulated by a suitable choice of concentrated loads.
Horizontal loading is introduced in this continuation of the frame test program. Actual structures are subjected to such loads due to wind, blasts, or earthquake.

Considering wind, the relative intensity of the total vertical load to the total horizontal load on a portal frame may be estimated as follows:

(a) Economical bay length \( l \) for a frame of span \( L = 30' \),
\[
1 = 12' + \frac{L}{10} = 12 + 3.0 = 15.0' \quad (*)
\]
(b) Wind load 20 psf (AISC Spec. 4c), column height 10', gives:
\[
Q = 20 \cdot 15.0 \cdot 10 = 300k \quad \text{per frame.}
\]
(c) Vertical load due to: frame 4 psf.
    purlins 3 "
    rafters 3 "
    roofing 10 "
    snow & wind 40 "
\[
V = 60 \cdot 15.0 \cdot 30 = 27,000k \quad \text{per frame.}
\]
(d) Ratio of total horizontal to total vertical load \( Q/V = 1/9 \).

This value is included in the test program, the ratio being maintained constant in tests simulating wind.

The loading to be expected from a "standard" atomic blast, outside the region of virtually complete destruction (within one-half mile from ground zero), is estimated at 90 psf horizontal pressure and 70 psf vertical pressure\(^{**}\). The latter, combined with the dead load, also adds up to 90 psf. The ratio \( Q/V = 1/3 \), corresponding to \( h/L \) of one-third, is therefore chosen for the simulation of blast loading. A further discussion of this and related problems is given in Ref. 5.

The horizontal loading resulting from earthquake, being a mass effect, tends to concentrate towards the top of the column. Such loading is not specifically included in these tests. The wind loading \( Q = V/C \)

should theoretically be applied at column third-point and top in proportion to wall areas. The blast loading, considering the siding stripped, will reach a higher value near the top of the column, and could be simulated by three equal, concentrated loads at the column third-points and top. However, in order to simplify the experimental work concentrated loads will be applied at the column third-points only, the magnitude of these two remaining loads being correspondingly increased. In the case of wind loads this approximation causes a maximum error in the moment distribution of less than 4% in regions which remain elastic throughout the test, and about 1% in regions entering the plastic range.

3. Test Program

The foregoing discussion results in the selection and combination of variables as shown in the following two tables.

The sequence of tests is shown in the left hand column of Table I. Tests 1 and 2 are completed and Test 3 will be started upon approval of this proposal. Table II is intended to give a clearer picture of the variables studied by each group of tests.

The proposed sequence is dictated by the consideration of introducing preferably one new variable at a time. Two pin-based frames with square knees being tested under vertical loads only, side loading is next added. Test 4 differs from Test 3 in having fixed bases. Tests 5 and 6 are similar to Tests 3 and 4 except for the haunched knees which will be designed later. These two variables are at present considered the most important.

The possible later inclusion of a test with $h/L = 1/6$ and another test of a tapered frame is not shown in the tables.

The four next test frames are sketched in Fig. 2, p. 13.
### TABLE I. PORTAL FRAME TESTS

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Geometrical Var.</th>
<th>Structural Variables</th>
<th>Boundary Variables</th>
<th>Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L ft.</td>
<td>h/L</td>
<td>Pitch</td>
<td>Column Section</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
<td>1/2</td>
<td>0</td>
<td>8WF40</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>1/2</td>
<td>0</td>
<td>8H13</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>1/3</td>
<td>0</td>
<td>12WF36</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>1/3</td>
<td>0</td>
<td>12WF36</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>1/3</td>
<td>0</td>
<td>10WF29</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>1/3</td>
<td>0</td>
<td>10WF29</td>
</tr>
<tr>
<td>7</td>
<td>30</td>
<td>1/3</td>
<td>0</td>
<td>10WF29</td>
</tr>
<tr>
<td>8</td>
<td>30</td>
<td>1/3</td>
<td>1/4</td>
<td>10WF29</td>
</tr>
<tr>
<td>9</td>
<td>30</td>
<td>1/3</td>
<td>1/4</td>
<td>10WF29</td>
</tr>
<tr>
<td>10</td>
<td>30</td>
<td>1/3</td>
<td>1/4</td>
<td>10WF29</td>
</tr>
<tr>
<td>11</td>
<td>30</td>
<td>1/3</td>
<td>1/4</td>
<td>10WF29</td>
</tr>
</tbody>
</table>

### TABLE II. VARIABLES STUDIED IN FRAME TESTS

<table>
<thead>
<tr>
<th>FOR EFFECTS OF:</th>
<th>COMPARISON TESTS NO.:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type Knee:</td>
<td></td>
</tr>
<tr>
<td>Haunched vs. Square</td>
<td>5 - 3 6 - 4</td>
</tr>
<tr>
<td>Haunched vs. Curved</td>
<td>8 - 10 9 - 11</td>
</tr>
<tr>
<td>Column Bases:</td>
<td></td>
</tr>
<tr>
<td>Pinned vs. Fixed</td>
<td>3 - 4 5 - 6</td>
</tr>
<tr>
<td>Pitch:</td>
<td></td>
</tr>
<tr>
<td>Flat vs. Gabled</td>
<td>5 - 8 7 - 9</td>
</tr>
<tr>
<td>Section:</td>
<td></td>
</tr>
<tr>
<td>Section change only</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Combined with knee change</td>
<td>3 - 5 4 - 6</td>
</tr>
<tr>
<td>Loading:</td>
<td></td>
</tr>
<tr>
<td>Wind vs. No lateral load</td>
<td>2 - 3</td>
</tr>
<tr>
<td>Wind vs. Blast</td>
<td>6 - 7</td>
</tr>
</tbody>
</table>

![Fig. 2. Test Frames 3, 4, 5, and 6.](image-url)
D. THIRD PORTAL FRAME TEST

1. Test Frame

Proportions and details of the third test frame are shown in Fig. 3.

The columns are pin-ended. As in the first two tests a roller base is provided at one column to enable the measurement of the redundant horizontal reaction.

Corner connection type 8B is used also in this test to facilitate the interpretation from the test data of the effect of horizontal loads. The adequacy of this rather simple connection is established by separate connection tests and the previous frame tests.

Lateral support is provided at critical points along beam and columns and at the corners. Stiffeners are placed at all load points.

The frame is to be manufactured of as-delivered members and tested in the as-welded condition.

2. Testing Procedure

As discussed on p. 10 of this proposal third-point vertical loading will be used in this test (Figs. 3 & 4). The actual condition of a portal frame beam loaded through purlins is intermediate between uniform loading and third-point loads, and the approximation to an actual moment diagram is consequently even better than previously indicated.

The details of the load application is shown in Fig. 4. Lateral displacement of the beam due to the horizontal loads necessitates a horizontal sliding arrangement for the vertical loading jacks.

The horizontal loading in this test simulates wind load which on most actual frames are carried by the windward column through loads from the girts. Such loading causes beam action of the windward column and compressive axial force in the frame beam. In some frame tests including side-sway these effects have been neglected or reversed by the use of tensile side loading at the beam axis level. In the present test equal concentrated loads will be applied at the column third-points which closely simulates wind forces acting on the columns through girts.
Fig. 3. Third Test Frame
The horizontal reaction of one column base is measured by ring dynamometers inserted in the horizontal reaction assembly of the type previously used\(^{(6)}\). The horizontal reaction at the other support is found by subtraction from the known applied side load.

The instrumentation, gage locations, and measurements to be taken are similar to those described\(^{(6)}\) for the first two frame tests and will not be presented in detail in this proposal. Only a brief discussion follows:

**Forces.** Ring and tube dynamometers will be used to measure the applied vertical and horizontal loads and the redundant horizontal reaction.

**Deflections.** Deflections in the direction of the applied loads will be measured at all critical points, using mechanical deflection dials.

**Local Flange Buckling.** Deflections dials will also be used to give an early indication of local flange buckling.

**Rotations.** Rotation indicators will be used exclusively to measure the curvature at critical sections of the rolled sections and the rotation across corner connections. The rotation indicator has been found to be superior to level bars or other means of measuring rotations.

**Strains.** SR-4 strain gages will be applied at critical locations on beam, columns and connections. Advantage will be taken of the experience that gages mounted in the regions that remain elastic throughout the test may be used to determine the moment distribution around the frame in the plastic range.

3. **Predicted Frame Behavior**

Shown in Fig. 5 are:

(a) Moment distribution around the frame as the yield point is reached.

(b) Moment distribution before collapse.

(c) The increase with load of the beam centerline deflection.

These curves are typical of the complete set of curves showing the predicted frame behavior that will be prepared before performing the test.
Fig. 4  Schematic Test Set-Up for Third Portal Frame Test
Fig. 5 PREDICTED FRAME BEHAVIOR

(a) Elastic Limit Moment Distribution

(b) Moment Distribution at Collapse

(c) Increase with Load of Beam Centerline Deflection
4. Cost Estimate

The cost of performing and reporting Test 3 is estimated at $1500.00.

The total cost of the full additional program containing 8 frame tests is estimated at $10,000.00.

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