PROPOSAL OF TESTS FOR THE LATERAL BRACING REQUIREMENTS OF PLASTICALLY DESIGNED BEAMS*

INTRODUCTION

One of the basic assumptions made in designing a structure for ultimate strength by plastic design methods is that a "plastic hinge" can be formed. That is, the section must be capable of undergoing sufficiently large rotations within a limited region, so that moments may be redistributed to develop the full strength of the structure.

To achieve these large rotations, provisions must be made to prevent the member from prematurely failing by lateral buckling or local buckling. The local buckling problem has been adequately investigated, and rules for the prevention of local buckling have been recommended. (1) The problem of lateral buckling is at present not yet completely

* This proposal supercedes proposal 205H.1, "Lateral Bracing Requirements" (June 30, 1955). The tests proposed in 205H.1 were not performed because it was felt that theoretical developments had not progressed sufficiently far for a test program.

(1) WRC-ASCE, COMMENTARY ON PLASTIC DESIGN IN STEEL, Art.6.1 "Local Buckling", ASCE Proceedings, EM4, October 1959.
solved, and it is the purpose of this proposed test-program to investigate hitherto unexplored phases of the problem and to find out whether current design recommendations can be improved.

An investigation of the lateral buckling behavior of beams can be grouped into the following three closely interrelated categories:

(1) The determination of the critical combination of loading and unbraced length which will cause the inception of buckling.

(2) The determination of the ultimate strength (that is, the post-buckling strength) of beams failing by lateral buckling.

(3) The determination of the required strength and stiffness of lateral bracing.

Current research on inelastic lateral buckling has been largely confined to the first of these categories, because this is the case where it is possible to obtain mathematically tractable solutions. (2) Because of the nature of the solution, only the critical length corresponding to a given maximum loading (in the case of plastic design, $M_p$ at one or both ends

(2) For a discussion of this work see "Literature Survey on Lateral Instability and Lateral Bracing Requirements" by G.C. Lee, Fritz Laboratory Report No. 205H.2, October 1959.
of the beam segment under investigation) can be obtained from this analysis. One such solution\(^{(3)}\) was developed by assuming that portions of the beam are either fully strain-hardened or fully elastic at the inception of buckling. Based on this analysis, design rules were developed\(^{(4)}\)(\(^{(5)}\)) for the required spacing of bracing in plastically designed beams.

Completed work on the post buckling behavior of beams and on the requirements for adequate bracing is currently not available because of the extremely complicated nature of the problem. Theoretical solutions at Lehigh University were only possible after making major simplifications even for the simplest loading cases, and it is felt that further theoretical investigations may yield a solution which resembles only remotely the situation in actual structures. After investigating all possible theoretical approaches, it was decided that a solution to the problem in question (that is, the development of design rules for

\(^{(3)}\) "The Lateral Torsional Buckling of Yielded Structural Steel Beams" by M.W. White.


\(^{(5)}\) WRC-ASCE "Commentary on Plastic Design in Steel" Art. 6.3 "Lateral Buckling" EM4, October 1959.
lateral bracing requirements) can best be achieved by experimental means. The proposed test program represents the initiation of this work.

OBJECTIVES OF THE PROPOSED TESTS

The objectives of the proposed tests are to determine:

(1) the post-buckling strength and rotation capacity of beams,
(2) the influence of the restraint due to the adjacent span on the behavior of the beam after initiation of lateral buckling,
(3) the required rigidity and strength of various types of bracing arrangements,
(4) the relationship between the lateral displacement, the twisting and the applied moments at, and after buckling (this information may be helpful for an analytical solution to the problem).

The main variables are the following:

(1) Beam size.
(2) Unbraced length.
(3) Loading condition.
(4) Stiffness of purlin.
(5) Type of purlin.

(6) Method of purlin attachment.

(7) Length of adjacent span.

(8) Number of critical braced spans.

The variables which will be investigated in the first test series are the unbraced length, and the size (and stiffness) of purlin; the other above listed variables will remain constant. After an evaluation of the results of these tests, further tests will be proposed to investigate the influence of the other variables.

PROPOSAL

It is proposed to test two series of beams to destruction. Each beam is subdivided into three equal spans (Fig. 1), of which the center span is subjected to uniform moment. In each case, the center span is the critical span. The material for each beam will be a 10WF25 as-rolled, wide-flange section of ASTM-A7 steel, obtained from the same ingot and the same rolling, and subjected to identical cooling and straightening. This particular section
has been chosen because it is a narrow beam of relatively low lateral-torsional resistance \( \left( \frac{K_T}{Ad^2} = 465 \times 10^{-6}, (6) \right) \) and yet its local buckling resistance, as characterized by the b/t ratio \( (b/t = 13.4) \) is adequate.

The proposed two series of tests are as follows:

1. **Simply Supported Beam Tests**

   This test series is comprised of 5 tests (LB-9, LB-10, LB-11, LB-12 and LB-13, as shown in Table 1). It is desired to leave everything identical for these tests, with the exception of the length. The length will be varied from \( 30r_y \) to \( 45r_y \), as shown in Table 1. One of the test beams has an open length; its length will be determined after the completion of the first four tests. The purpose of these tests is:

   (a) to determine the influence of the unsupported length on the post-buckling strength of the beams,

   (b) to determine the influence of the lateral restraint by the adjacent spans on the post-buckling behavior of the critical span,

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(6) "Inelastic Lateral Torsional Buckling of Eccentrically Loaded WF Columns" by T.V. Galambos.
(c) to evaluate the lateral reaction forces at the supports (2) and (3) if possible (this information may be used for the guidance of the design of the purlins of the subsequent tests),

(d) to obtain moment versus lateral deflection and twist curves under carefully controlled end conditions (this information is to be used in a theoretical determination of the post-buckling strength of simply supported beams).

The test set-up is shown in Fig. 2, and the details of the supports at (1) and (2) are shown in Fig. 3. The load will be applied downward through jacks at the ends of the beam (points (1) and (4)). The interior supports (representing the ends of the test segment of the beam) consist of the following (see Figs. 2 and 3): the beams are hung from a support beam by means of wire cables; the details of the connection permit free lateral rotation at the joints. Lateral deflection and twist is prevented by a set of braces which permit transverse deflection but not lateral deflection or twist. Load cells for measuring the lateral force during buckling will be incorporated if practicable. The test beam is guided between knife edges which will permit lateral rotation. The top view of the deformed beam (Fig. 1) at the start of buckling shows that the inflection points will be
at the support-points; thus the end conditions are exactly known, and the test-results may be checked with known theories.

2. Tests with Purlins

For the remaining six tests the lateral supports of the previous tests are replaced by purlins at (2) and (3) (see Fig. 4). The variables are the size and length of the purlins. It is planned to start with relatively light purlins, and to increase the size of the purlins (keeping their length constant) until a sufficient stiffness is found, such that the beam is able to deliver the required plastic rotation at full moment capacity. (Possibly two or three tests are necessary.)

As a second variation in this series, the length of purlin, is to be changed within a range usually recommended in elastic design practices. (7) (Purlin depth = \( \frac{1}{24} \) of their span.) Three or possibly four tests are felt to be sufficient.

The proposed tests are summarized in Table 1. It is planned to use I-sections for all purlins. The test set-up for this series of tests is shown in Fig. 4(a). The only differences between this and the previous test series are the following:

(a) the span length will be kept constant (at the optimum critical length determined by the first tests),

(b) the knife edge set at the two interior supports will be replaced by actual purlins bolted to the compression flange of the beam.

Details for the set-up are given in Fig. 4(b).

Supplementary experimental work includes coupon tests and residual stress measurements.

Possible future test-programs are outlined in Table 2. These test-schemes are subject to modifications after the completion of the presently proposed experiments.
DATA

The following data will be taken during the tests:

a. Loads.

b. Transverse deflections along the length of the beam in the plane of web.

c. Rotations at the ends.

d. Lateral deflections along the length of the beam, and twisting at center section.

e. Reaction forces at supports.

f. Yielding process of the specimen.

INSTRUMENTATION

The following instrumentation is to be used for taking the above mentioned data:

a. Amsler indicator (load will be applied through a pair of hydraulic jacks).

b. Dial gages along the length of the beam.

c. Dial gages near the ends.

d. Transit and scales.

e. Load cells and SR-4 strain indicator.
### TABLE 1

<table>
<thead>
<tr>
<th>Series</th>
<th>Test No.</th>
<th>L</th>
<th>Support Condition at (2) and (3)</th>
<th>Variables</th>
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<tr>
<td>1</td>
<td>LB-9</td>
<td>30ry</td>
<td>Simply supported*</td>
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<td></td>
<td>LB-10</td>
<td>35ry</td>
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<td>40ry</td>
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<td></td>
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<td>45ry</td>
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<td></td>
<td>LB-13</td>
<td>Open</td>
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<tr>
<td>2**</td>
<td>LB-14</td>
<td>***</td>
<td>Purlins attached to compression flange****</td>
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<td>LB-15</td>
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</table>

* Joint is free to rotate transversely and laterally; joint is fixed against lateral movement and twisting; joint is fixed against warping.

** The number of tests in series 2 may alter slightly depending upon the results obtained in the preceding tests.

*** Optimum length as determined by previous tests.

**** Size, shape and length of purlins to be determined after tests LB-9 through LB-13 are completed.
TABLE 2

Outline of Possible Future Experiments on the Lateral Buckling of Beams

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>Present proposal</td>
</tr>
</tbody>
</table>
| II    | 1. Repeat phase I with moment gradient.  
       | 2. Repeat portion of phase I with different purlin shapes. (i.e., channels)  
       | 3. Repeat portions of phase I with different means of attaching the purlin to the beams. |
| III   | Tests of two parallel beams connected by purlins subjected to constant moment and to moment gradient. |
| IV    | Tests of continuous beams supported by purlins; the ends of the beam to be welded to plastically designed corner connections (as proposed in 205H.1). |
| V     | Test of a full sized frame designed according to the most up-to-date plastic design methods. |
Purpose:

(1) Postbuckling as influenced by length
(2) Influence of lateral restraint

FIGURE 1
FIGURE 3

(a) 
- P
- jack
- roller
- end plate
- triangular frame
- bolts
- base beam

(b) 
- cable
- hook and eye
- turnbuckle
- stiffeners

Plate (welded on)
- angles
- bolts
- plate
- base
- beam
Fig. 3-b

cable and
turnbuckle

stiffener
test span

Fig. 3-a

cable
jack
roller

bolts

purlin

steel pipe

block

four bolts

beam

Fig. 4-b

end plate

plate
(welded on)

beam

purlin

purlin stiffener

(b)

FIGURE 4
To: Members, Lehigh Project Subcommittee

Messrs: Higgins, T.R. Grover, L. Kreidler, C.
Amirikian, A. Jameson, W.H. Lawson, H.W.
Crowley, J.M. Johnston, B.G. Newmark, N.M.
Dill, F.H. Jones, J. Pisetzner, E.
Epstein, S. Kavanagh, T.C. Stuchell, R.M.
Fox, J.M. Ketter, R.L. Vasta, J.

Re: Beam Tests (Lateral Bracing Requirements)

Gentlemen:

This letter is to forward to you our recommendations for tests to determine the lateral bracing requirements of plastically designed beams on the project "Welded Continuous Frames and Their Components". A proposal (205H.3) is attached. The principal objective of these tests is to determine the required stiffness of the lateral bracing (purlins) of beams in plastically designed rigid frames, such that the beams may deliver their required rotation capacity at the plastic hinges.

We are anxious to commence the first tests as soon as possible. Therefore we would like to have your opinion and ask that you please return the enclosed postcard by April 6, 1960. There will, of course, be opportunity to discuss this program at the next committee meeting.

Sincerely yours,

Lynn S. Beedle
Project Director

TVG:rt

Encl: (Report 205H.3 and postcard)

cc: Messrs: Spraragen, W.
Estes, E.R., Jr.
Koopman, K.H.