PLASTIC DESIGN
IN
HIGH STRENGTH STEEL

Proposal for Further Studies
of Flange and Web Local
Buckling

Fritz Engineering Laboratory Report 297.13

June 1964

Fritz Engineering Laboratory
Lehigh University
Bethlehem, Pennsylvania
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1. INTRODUCTION

(a) Summary of Work on High Strength Steel

A project, which has as its aim the extension of plastic design procedures to include steels of up to 50 ksi yield stress, has been in progress at Lehigh University since 1962. Within the framework of this project, work is being carried on to determine material properties and basic member behavior and to extend this knowledge to predict the behavior of frames.

A summary of the tests which have been completed to date is given in Table 1. Reports describing the experimental and theoretical aspects of the investigation are listed as References (1) to (10). These reports reflect the progress of this project from its inception (1962) to the present time.

Within this period rational methods have been developed to deal with lateral instability of beams and to determine the spacing and stiffness of the required bracing (4). In addition, an attack has been made on the problem of flange local buckling (8).

(b) Previous Local Buckling Studies

Early investigations into flange buckling of wide flange members have assumed that the flange must not buckle locally until it has been compressed into the strain-hardening range, or in other words, until it has become fully yielded (11). This requirement is justified,
as in a practical structure the portion of a member which is likely to local buckle will also be in the fully yielded condition\(^{(8)}\).

Present local buckling provisions are based mainly on the work of Haaijer\(^{(11)}\) which assumes the flange to be fully yielded and subjected to a uniform compressive stress which is equal to the yield stress of the material, \(\sigma_y\). Haaijer selected the value of the modulus of rigidity, \(G\); in the fully yielded condition, from the results of tests on angle sections and then chose a rotational restraint for the flange from wide flange test results. Haaijer's procedure led to a critical \(b/t\) value of 17.0 for \(\sigma_y = 36\) ksi, \((b\) is the flange width and \(t\) the flange thickness).

A recent study by Lay\(^{(8)}\) has amended Hasijer's work slightly. Lay considered the torsional buckling of the flange restrained by the web in order to evaluate the restraint coefficient. The modulus of rigidity, \(G\), was then obtained by a consideration of the discontinuous yielding process for structural steel\(^{(4)}\). This theory\(^{(8)}\) gives a \(b/t\) value of 18.4 for \(\sigma_y = 36\) ksi. The uniform applied stress is assumed to be equal to \(\sigma_y\). When a member is under moment gradient, the applied stress will be greater than \(\sigma_y\) and the critical \(b/t\) becomes 17.1. For H441 steels \((\sigma_y = 50\) ksi) the corresponding \(b/t\) values are 14.0 and 13.4. In developing equations for high strength steels, account must be taken of the reduced strain hardening stiffness as well as the change in yield stress.

A further point that has become apparent in recent work\(^{(2)}\)\(^{(6)}\) is that local buckling does not necessarily correspond to unloading of
the cross-section. In many tests a considerable post-local-buckling capacity was observed\(^{(2),(6)}\). As this capacity can be significant, it is possible that greater utilization of sections which more than satisfy the critical b/t provision will be possible.

A similar situation to that outlined above exists for web buckling. However, in this case both the experimental and theoretical studies are less well developed.

(c) Information Required

As a result of these recent local buckling investigations it has become apparent that many important questions can be answered by a relatively small testing program. While the program will provide direct answers for high strength steel it will also serve to answer many of the remaining questions for A-36 steel. The program proposed is thus an extension of the original proposal\(^{(12)}\) associated with this project. (Plastic Design in High-Strength Steel.)

Specifically, the results of this investigation will furnish an experimental check on the flange buckling model proposed by Lay\(^{(8)}\). The web buckling tests will provide experimental basis for the web geometry provisions for plastic design and will be used to develop a model on which theoretical solutions may be tested.

In both cases the post-local-buckling behavior will be observed with the aim of incorporating this additional capacity into future restrictions on flange and web geometry.
2. PROPOSED TEST PROGRAM

(a) Test Schedule

A testing program is proposed to further investigate the local buckling of wide flange shapes. The program is summarized in Table 2. All tests are to be performed on 6 WF 15.5 stub columns. This section has a b/t of 22.3 and a d/w of 25.0 (d is the total depth of the section and w is the web thickness). To increase these ratios the web and/or flanges will be reduced by machining. (See Fig. 1.)

Since the strains which are of interest are of the order of 0.022 (the strain at the onset of strain-hardening for A441 steel\(^{(6)}\)), any small changes in the residual stress pattern brought about by the machining process will be negligible.

The tests included as Series A and B are intended to investigate flange buckling under uniform compression. This will serve to determine the validity of the basic local buckling theory. Since the entire section is uniformly strained the web is not expected to exert any appreciable rotational restraint on the flanges. In Series C the neutral axis will be located so that the web is in tension, thus the rotational restraint on the flange will be greatly increased.

For the web buckling investigation, Series D is planned to investigate uniform compression while Series E will investigate the case in which the web is under a strain gradient. To eliminate the possibility of premature flange buckling, all specimens in these Series will
have their b/t ratio decreased.

To determine the material properties and residual stress distribution several auxiliary tests will be performed.

(b) Measurement

The stub column tests will be performed under static loading in the 800 kip capacity screw type machine. Strains along the length of the stub column will be measured over a 2" gage length by means of a Whittemore mechanical gage. The deformations of the cross section will be measured by dial gage arrangements so that the onset of local buckling may be observed. These measurements will be continued well into the post-local-buckling range to provide a record of this aspect of behavior.
3. FINANCES

The cost of these experiments has been included in the regular 1964 - 1965 budget for the "Plastic Design in High Strength Steel" project, and therefore this proposal does not include a request for additional funds.
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<th>RESIDUAL STRESS MEASUREMENTS</th>
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<th>BEAM TESTS</th>
<th>BEAM - COLUMN TESTS</th>
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<tr>
<td>8WF31</td>
<td>HT-3,4,5,6,7</td>
<td>HT-9</td>
<td>HT-2, ECC.</td>
<td>HT-39</td>
<td>HT-40 UNBRACED</td>
</tr>
<tr>
<td></td>
<td>HT-53,54,55,56</td>
<td></td>
<td>HT-8 CONC.</td>
<td>BRACED</td>
<td>L/1R = 80 P/PR0.4</td>
</tr>
<tr>
<td>14WF78</td>
<td>HT-22,23,24,25</td>
<td>HT-19</td>
<td>HT-18 ECC.</td>
<td>HT-25</td>
<td>L/1R = 86</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>HT-20 CONC.</td>
<td>HT-42</td>
<td>L/1R = 22.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HT-43</td>
<td>L/1R = 22.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HT-52</td>
<td>L/1R = 72.8</td>
</tr>
<tr>
<td>8B13</td>
<td>HT-11,12,13</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>10WF25</td>
<td>HT-15,16,17</td>
<td></td>
<td></td>
<td>HT-41</td>
<td>L/1R = 25</td>
</tr>
<tr>
<td></td>
<td>HT-33,34,35</td>
<td></td>
<td></td>
<td>HT-31</td>
<td>L/1R = 30</td>
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<tr>
<td></td>
<td>*(HT-44,45,46,47,48,49,50,51)</td>
<td></td>
<td></td>
<td>HT-29</td>
<td>L/1R = 35</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HT-37</td>
<td>L/1R = 37.5</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>HT-30</td>
<td>L/1R = 40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HT-36</td>
<td>L/1R = 45</td>
</tr>
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</table>

# SERIES OF TESTS SPECIFICALLY TO OBTAIN E8H THE STRAIN-HARDENING MODULUS

#* SPANS WERE ADJUSTED SO THAT L/1R = 30, 45, 45

TABLE 1. HIGH STRENGTH STEEL TESTS
### TABLE 2. PROPOSED TEST PROGRAM

<table>
<thead>
<tr>
<th></th>
<th>SERIES 'A'</th>
<th>SERIES 'B'</th>
<th>SERIES 'C'</th>
<th>SERIES 'D'</th>
<th>SERIES 'E'</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STEEL</strong></td>
<td>A441</td>
<td>A36</td>
<td>A441</td>
<td>A441</td>
<td>A441</td>
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<tr>
<td><strong>LOADING</strong></td>
<td><img src="image.png" alt="Diagram" /></td>
<td><img src="image.png" alt="Diagram" /></td>
<td><img src="image.png" alt="Diagram" /></td>
<td><img src="image.png" alt="Diagram" /></td>
<td><img src="image.png" alt="Diagram" /></td>
</tr>
<tr>
<td><strong>POSITION OF NEUTRAL AXIS</strong></td>
<td>(\infty)</td>
<td>(\infty)</td>
<td>Junction, Fig. - Web</td>
<td>(\infty)</td>
<td>Within Web</td>
</tr>
<tr>
<td><strong>PURPOSE OF TEST</strong></td>
<td>Flange Buckling</td>
<td>Flange Buckling</td>
<td>Flange Buckling ((P_L) in tension provokes additional restraint)</td>
<td>Web Buckling</td>
<td>Web Buckling (Change in N.A. Position varies restraint)</td>
</tr>
<tr>
<td><strong>VARIATION OF GEOMETRY</strong></td>
<td>(b/t = 22.3 - 10.0)</td>
<td>(b/t = 22.3 - 14.0)</td>
<td>(b/t = \frac{(b/t)_{crit}}{\text{SERIES 'A'}\text{SERIES 'A'}})</td>
<td>(d/w = 25.0 - 40.0)</td>
<td>(d/w = \frac{(d/w)_{crit}}{\text{SERIES 'D'}})</td>
</tr>
<tr>
<td><strong>NO. OF TESTS</strong></td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>6</td>
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</table>

Test specimens GWF 15.5 modified as per Fig. 1.

A441
TO DECREASE b/t, REMOVE CROSS-HATCHED AREAS

TO INCREASE d/w, REMOVE SHADEd AREAS

FIG. 1. STUB COLUMN
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