WELDED CONTINUOUS FRAMES
AND THEIR COMPONENTS

PROPOSAL FOR RESEARCH ON PLASTIC
DESIGN IN HIGH-STRENGTH STEELS

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I. INTRODUCTION

Recent advances in metallurgical techniques have resulted in the development of a number of low-alloy steels with a yield strength higher than that of structural carbon steel. Examples of these new steels are the ASTM A242, A440 and A441 steels, in addition to many other proprietary steels. The structural uses of these high-strength steels have increased lately and it is desirable to extend the plastic design methods to include these new materials. A complete study should consider all the different types of high-strength steels. However, the following discussion will only be concerned with steels having a yield stress of about 50 ksi.

Currently used rules in plastic design\(^{(1)}\) are based on research conducted on ASTM A7 type steels.\(^{(2)}\) These cannot apply directly to other steels because many of the material properties may be different. The purpose of this survey is to determine the extent of research necessary for the extension of plastic design to include 50 ksi yield strength steels.

II. STATEMENT OF THE PROBLEMS

Since the solution of the various problems in plastic design depends directly on the basic properties of the material,
such as the elastic, plastic, and strain-hardening stress-strain relationships, the residual stresses, etc., it is important to have adequate information on these basic properties.

Much less is known of the material properties for high-strength steel of 50 ksi yield stress than of those for A7 structural carbon steel. Among the investigations made at Fritz Laboratory only one report (3) contains useful information and this is confined to A242 steel. In this work three wide-flange shapes were studied (8WF31, 12WF50 and 12WF65). Material properties based on the limited measurements which were made are given in Table 1. It may be observed that the properties presented in Table 1 are very similar to those of A7 steel, (4,5,6,) with the exception of the yield stress and possibly the ratio $\varepsilon_{st}/\varepsilon_y$, (ratio of strain at the onset of strain-hardening to yield strain). In addition the total elongation at failure is probably somewhat smaller. Since these values were obtained from a small number of tests, further laboratory experiments are needed in order to obtain more precise information.

The following problems may need reevaluation for the extension of plastic design to high strength steel:

A. Problems for which strain-hardening is not required in the theoretical solution.

1. Hinge formation and mechanism theory.
2. Influence of shear.

3. Corner connection design.

4. Eccentrically loaded columns failing by excessive bending in the plane of the applied moments.

5. Lateral-torsional buckling of beams and beam columns.


7. **Biaxial flexure.

8. **Frame stability

B. Problems which include strain-hardening in the solution

9. Lateral bracing requirements and rotation capacity.

10. Local buckling of structural elements.

11. Deflections.

Not all of these problems will require additional work. The amount of extra effort depends on the degree of variation

* This is part of the work included in Project 269 "Compression Properties of Low-Alloy Steels".

** Solutions are not yet completed for A7 steel. Some partial results are available for (7).
of the material properties of the high-strength steels from those of A7 steel. In certain cases it will be possible to make conservative modifications of the existing results developed for A7 steel.

It is also desirable that some additional experiments be performed in order to spot-check the analytical results. Special care will be taken not to duplicate work going on elsewhere.

III. PROGRAM OF RESEARCH

3.1 Experiments on Basic Material Properties

(a) Twenty tension coupon tests and four residual stress measurements to determine the material properties.

(b) Two beam tests to obtain the moment-curvature relations (and lateral bracing requirements in conjunction with section 3.3).

(c) Two axially loaded stub column tests to determine the material properties and the residual stress level.

(d) Two eccentrically loaded stub column tests to determine the moment-curvature curves under axial load.

Parts (b), (c) and (d) will also give some local buckling information.
Further details of these experiments are presented in Table 2. The type of material for investigation is ASTM A441 steel. It is high strength steel with a yield stress of 50 ksi for thickness less than 3/4".

3.2 Analytical Work

Should the results of the suggested tests on the basic material properties show that the only essential change for high-strength steels is in the yield stress, then the various solutions to problems in plastic design (as listed in Part 2 of this survey) will need only minor revisions.

Where numerical procedures were used, somewhat more work will be required than for the other problems. Although the basis for these numerical solutions (i.e. the non-dimensional moment-curvature relationships) will remain unaltered, the interaction procedures also depend directly upon the absolute value of $\sigma_y$. It will not be necessary to recalculate the existing solutions. Typical cases need only be considered for each problem, and methods for adjusting the design charts need be found.

It is possible that the results of the suggested tests in Art. 3.1 may show significant variations from the properties
given in Table 1. Should this be the case, all the problems listed in Art. 2 will necessitate reconsideration. Some may even require new theoretical approaches. In this report no further consideration will be given to this possibility until the experiments proposed in Art. 3.1, have shown that this is indeed the case.

3.3 Structural Tests

The following experiments on structural members are thus suggested to substantiate the analytical work:

(a) Two beam tests to study the influence of shear and strain hardening.

(b) Six beam tests to study local buckling and lateral buckling in conjunction with 3.1 (b).

(c) Two beam-column tests to check column theory

Further details about these experiments are given in Table 3.

IV. RESEARCH PROPOSAL

The research on the extension of Plastic Design to high-strength steels of 50 ksi yield strength is proposed to follow the outline listed below:

(1) The experiments for the determination of the
basic material properties are to be performed first. The details of this work are given in Art. 3.1 and in Table 2 of this proposal. The material to be used is A441 steel.

(2) The research will be continued along analytical lines as outlined in Art. 3.2 and along experimental lines as outlined in Art. 3.3 and Table 3 of this proposal if the results of the experiments on the material properties indicate that the basic behavior of A441 steel is not significantly different from A7 steel. At present it is expected that this will be so.

(3) The problems will be reevaluated and a new proposal will be prepared in the case that the tests in step 1 above reveal radical differences in the material properties between the A441 and the A7 steel. Such differences could be the absence of strain-hardening or the absence of a sufficiently long yield plateau.

The research herein is prepared as part of the planned program of work within the Welded Rigid Frames Project at Lehigh University for the fiscal year of 1961-1962, and no additional funds are here solicited.
<table>
<thead>
<tr>
<th>Section</th>
<th>8WF31</th>
<th>12WF50</th>
<th>12WF65</th>
</tr>
</thead>
<tbody>
<tr>
<td>E (ksi) Modulus of Elasticity</td>
<td>31,300*</td>
<td>31,800*</td>
<td>30,500*</td>
</tr>
<tr>
<td>$\sigma_{ys}$ (ksi) Static Yield stress</td>
<td>54.5*</td>
<td>52.0*</td>
<td>55.0*</td>
</tr>
<tr>
<td>$\sigma_{rc}$ (ksi) Max. compressive residual stress</td>
<td>14.2</td>
<td>7.5</td>
<td>14.5</td>
</tr>
<tr>
<td>$\frac{\sigma_{rc}}{\sigma_{ys}}$</td>
<td>0.26</td>
<td>0.15</td>
<td>0.26</td>
</tr>
<tr>
<td>$\frac{\epsilon_{st}}{\epsilon_{y}}$</td>
<td>10.2</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>$E_{st}$ (ksi) Strain-hardening Modulus</td>
<td>715*</td>
<td>626</td>
<td>593</td>
</tr>
<tr>
<td>Material</td>
<td>High strength low alloy steel. (The chemical composition is given in Table 1 of Ref. 3). ASTM A242.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Weighted means.

**TABLE 1. SUMMARY OF MATERIAL PROPERTIES OF ASTM A242 STEEL FROM REF. 3**
<table>
<thead>
<tr>
<th>Section</th>
<th>Section</th>
<th>Section</th>
<th>Section</th>
<th>Purposes and Observations of Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>bit</td>
<td>d/w</td>
<td>b/t</td>
<td>d/w</td>
<td>E, $\sigma_y$, $\epsilon_{st}$, $E_{st}$</td>
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<tr>
<td>8WF31</td>
<td>18.48</td>
<td>8B13</td>
<td>15.75</td>
<td>10WF25</td>
</tr>
<tr>
<td>Tension</td>
<td>Coupon Tests</td>
<td>5</td>
<td>5</td>
<td>5</td>
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<tr>
<td>Residual</td>
<td>Stresses by Sectioning</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Beam Tests</td>
<td>(L/r_y = 30)</td>
<td>$\sigma_{rc}$</td>
<td>$M_p$, $M-\phi$, $\phi_{st}$</td>
<td></td>
</tr>
<tr>
<td>Axial Stub Col. Tests</td>
<td>(24&quot;)</td>
<td>(42&quot;)</td>
<td>$\sigma_{rc}$, ave.</td>
<td>$\sigma-\epsilon$ relationships</td>
</tr>
<tr>
<td>Eccentric Stub Col. Tests</td>
<td>(24&quot;)</td>
<td>(42&quot;)</td>
<td>$\sigma_{rc}$, $M-\phi$-P relationships</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks**
- Typical column section comparison of results with those of A7 steel can be made.
- Spot check for local buckling.
- Typical beam section comparison of results with those of A7 steel can be made.
- Column section with thickness approaching maximum for this yield stress value (50 ksi).

**TABLE 2.** PROPOSED EXPERIMENTAL PROGRAM FOR THE DETERMINATION OF THE BASIC MATERIAL PROPERTIES (ASTM A441)
<table>
<thead>
<tr>
<th>Test</th>
<th>Purposes and Observations</th>
<th>Number of Tests</th>
<th>Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam</td>
<td>Influence of Shear and Strain-hardening</td>
<td>2</td>
<td>8B13</td>
</tr>
<tr>
<td>Beam</td>
<td>Local Buckling Strength of Flanges and Web and Lateral Bracing Spacing for Constant Moment</td>
<td>2</td>
<td>8B13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>10WF25</td>
</tr>
<tr>
<td>Beam-Column</td>
<td>The Behavior of Columns with Applied End-Moments</td>
<td>2</td>
<td>8WF31</td>
</tr>
</tbody>
</table>

**TABLE 3. PROPOSED PROGRAM OF STRUCTURAL TESTS FOR HIGH STRENGTH STEEL (ASTM A441)**
REFERENCES

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