A Pilot Study on the Strength of 5Ni – Cr – Mo – V Steel Columns

An experimental investigation of the mechanical properties and strength of columns made of a high-toughness alloy steel

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ABSTRACT—These tests were part of an over-all study of the residual stresses in, and the column strength of, welded built-up and rolled heat-treated A514 steel columns. The present investigation on 5Ni – Cr – Mo – V steel extended the previous work on A514 steel columns. The test program consisted of one 10W112 column tested in the “flat-end” condition, a stub-column test, seven standard tension-coupon tests, ten compression-coupon tests, and two sets of residual-stress measurements at two separate positions along the column. Results show that the stress-strain relationship of this high-toughness alloy steel can be well represented by the Ramberg-Osgood equation, and the column strength can be predicted by using the tangent-modulus concept.

List of Symbols

- b = width of the flanges
- E = modulus of elasticity
- $E_t$ = tangent modulus
- $e = e/E/\sigma$, measured maximum out-of-straightness
- $K,n$ = constants in Ramberg-Osgood representation
- $L/r = \text{slenderness ratio}$
- $P = \text{axial force}$
- $s = \sigma/\sigma_1$
- $v = \text{deflection}$
- $x = \text{coordinate along the length of the column}$
- $y = \text{distance of a point on the section to the neutral axis}$
- $\varepsilon = \text{strain}$
- $\sigma = \text{stress}$
- $\sigma_y = \text{secant yield stress}$
- $\sigma_{cr} = \text{buckling (critical) stress}$
- $\sigma_{st} = \text{static yield stress}$

Introduction

Due to the increasing demands for higher stresses in, and larger sizes of, structures such as long-span bridges, heavy-walled pressure vessels and hydrospace and space vehicles, the development and the use of weldable quenched-and-tempered constructional steels has been greatly accelerated. Other investigators have reported that 5Ni – Cr – Mo – V steel with a yield strength of about 140 ksi shows the good weldability, toughness and strength needed to fulfill these purposes. The 5Ni – Cr – Mo – V HY-130(T) steel was developed by U. S. Steel under Naval Ship System Command Contract NObs. 88540.

A great deal of research has been conducted on the investigation of metallurgical and welding characteristics of this steel. This report is limited to the study of a rolled heat-treated wide-flange section and, in particular, to its column strength and mechanical properties.

This pilot investigation included studies of:

1. The stress-strain relationship under a constant strain rate accepted by ASTM Standards in the elastic range, and under a zero strain rate in the inelastic range.
4. Column behavior and theoretical predictions of strength.

Information from this study will indicate the possibility of using this steel for highly stressed structural members.

Description of Tests

One piece of the rolled heat-treated 10W112 section of approximately 30-ft length was furnished by U. S. Steel Corp.* The member was austenitized by heating to 1500°F for 2 hr, and water quenched to ambient temperature. Then, it was tempered by heating to 1050°F for 2 hr, and water quenched.

The chemical composition (in percent) is:

- Carbon 0.08
- Manganese 0.77
- Phosphorus 0.007
- Sulfur 0.012
- Silicon 0.28
- Nickel 4.92
- Chromium 0.54
- Molybdenum 0.51
- Vanadium 0.07
- Aluminum 0.012

* The material was from an experimental heat produced during the development of HY-130(T) steel on NAVSEC Contract NObs. 88540.
Fig. 1—Layout of the delivered piece

(1) Residual-stress measurement, compression coupons and stub-column test.

(2) Column test.

(3) Residual-stress measurement and tension coupons.

TABLE 1—OUTLINE OF TEST PROGRAM

<table>
<thead>
<tr>
<th>Description</th>
<th>Length</th>
<th>Number of tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column test</td>
<td>19 ft 5 in.</td>
<td>1</td>
</tr>
<tr>
<td>Stub-column test</td>
<td>3 ft 4 in.</td>
<td>1</td>
</tr>
<tr>
<td>Residual-stress measurement</td>
<td>11 in.</td>
<td>2</td>
</tr>
<tr>
<td>Tension-coupon test</td>
<td>1 ft 8 in.</td>
<td>7</td>
</tr>
<tr>
<td>Compression-coupon test</td>
<td>2 in.</td>
<td>10</td>
</tr>
</tbody>
</table>

Because of the very high strength of 5Ni - Cr - Mo - V steel and the large size of this 10Wf112 section, the ultimate load for a pinned-end column of medium slenderness ratio would exceed the capacity of the pinned-end test fixture available in Fritz Laboratory. Therefore, the column was tested in the flat-ended condition.

The details of layout of specimens cut from the section are shown in Fig. 1. In Table 1, an outline