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# THE TORSIONAL FLEXURAL BUCKLING STRENGTH OF COLD-FORMED STAINLESS STEEL COLUMNS

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## SUMMARY

The torsional flexural buckling strength of axially loaded hat sections, cold-formed from various types of stainless steels, was investigated. The calculated inelastic torsional flexural buckling strengths are based on the tangent modulus approach. It is shown that the experimental results compare well with the theoretical predictions.

## 1. GENERAL REMARKS

Thin-walled open sections in stainless steels are more commonly used in civil engineering and architectural applications. Due to the lack of information for the design of such members in existing design codes for stainless steel[2], an extensive investigation was conducted into the torsional flexural buckling behaviour of compression members with open sections. A member of this nature may buckle at a load below the Euler buckling load, mainly because of its low torsional rigidity and the fact that the centroid and shear centre of the member section do not coincide.

## 2. STAINLESS STEELS UNDER CONSIDERATION

The stainless steels under consideration in this study are AISI Type 304, 409 and 430 as well as a modified Type 409, designated 3CR12, developed and manufactured by the specialty steel producing company, Middelburg Steel and Alloys. Type 304, 409 and 430 are well-known steels and are produced in accordance with ASTM Standard Specifications A176-85[5], A666-84[6] and A167-63[4]. A detailed description on the properties of 3CR12 is given by van der Merwe[14].

## 3. MECHANICAL PROPERTIES

### 3.1 TESTING PROCEDURE

The mechanical properties of stainless steels Type 304, 409, 430 and 3CR12 were determined from stress-strain curves obtained from uniaxial tension and compression tests in the longitudinal and transverse directions of rolling. The mechanical properties were determined in accordance with the procedures outlined by the ASTM Standard A370-77[3].

### 3.2 RESULTS

The mechanical properties, determined from experimental stress-strain curves, for stainless steels Type 304, 409,430 and 3CR12 are given in Tables 1 to 4.

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### 3.3 ANALYTICAL EQUATION

The average stress-strain curves can be drawn using the Ramberg-Osgood[13] equation as revised by Hill[9], Johnson[10] and Wang[17].

$$\varepsilon = \frac{F}{E} + 0{,}002 \left(\frac{F}{F_y}\right)^n \qquad \text{.................} \quad (1)$$

$\varepsilon$ = strain
$F$ = stress
$E$ = initial elastic modulus
$n$ = constant
$F_y$ = yield stress
$F_p$ = proportional limit

Where

$$n = \frac{1{,}301}{\log \frac{F_y}{F_p}} \qquad \text{.................} \quad (2)$$

It has been found in a study by Van der Merwe[14] and Van der Merwe and Van den Berg[15,16] and this study that Eq. 1 and 2 give conservative curves in the vicinity of the proportional limit, $F_p$.

The tangent modulus, $E_t$, is defined as the slope of the stress-strain curve at each value of stress. It is obtained as the inverse of the first derivative with respect to the strain and can be computed as

$$E_t = \frac{F_y E}{F_y + 0{,}002n\, E\left(\frac{F}{F_y}\right)^{n-1}} \qquad \text{.................} \quad (3)$$

Equations 1 to 3 are subsequently used to determine the tangent modulus in the equation which determines the torsional flexural buckling stress of columns.

## 4. INVESTIGATION OF MEMBER STRENGTH

### 4.1 MEMBERS INVESTIGATED

The profiles chosen for this study were limited to hat sections. The cross section of the profiles was chosen such that torsional flexural buckling will occur firstly in the range of slenderness ratios of interest. The profiles were formed by a press brake process.

Three thicknesses of sheet, 0,9 mm, 1,6 mm and 2,0 mm and thus three cross sectional areas were chosen for stainless steels Type 304, 430 and 3CR12. For stainless steel Type 409 only the 2,0 mm sheet could be obtained. The same cross section was chosen for each individual thickness and steel. A typical cross section is shown in Figure 1 and the cross sectional dimensions are given in Table 5.

## 4.2 PREPARATION OF MEMBERS

Columns with the cross sectional dimensions given in Table 5 were manufactured by a press brake process. Lengths which varied from 150 mm to 1800 mm were prepared. One column was prepared for each length. The ends of the columns were cold sawed and machined flat and perpendicular to the column axis.

Four strain gauges were mounted at various positions at midheight and at quarter points as shown in Figure 1. The gauges at the quarter points are especially useful for alignment, since uniformity of strains at these quarter points is the criterion used for load alignment.

## 4.3 TESTING PROCEDURE

The columns were placed in an Instron Universal Testing apparatus between two specially manufactured end fixtures which has been centred on the machine plates beforehand. These end fixtures are basically two balls on either end which allow rotation about both the major and minor axis with negligible friction. Due to the flat surface of the ends, the ends of the columns were fixed with respect to warping. These fixtures are a modified version of the original fixtures devised by Pekoz[12] and used by Fang[8]. The procedure to allign the column is described by Dat[7]. Allignment is considered satisfactorily when strains at the quarter points are uniform to within ± 5% for loads up to one third of the estimated ultimate load.

The column is loaded statically with the movement of the crosshead less than 0,5 mm per minute. Readings were taken at 5 second intervals. The load reaches a peak, then decreases slowly with accompanying rotations.

## 4.4 THEORETICAL MODELS

### 4.4.1 Tangent Modulus Approach with Virgin Mechanical Properties

The theoretical torsional flexural buckling stress for single symmetric columns can be given by the following quadratic interaction Equation[11].

$$F_{tf} = \frac{1}{2B}\left[(F_{ex} + F_t) - \sqrt{(F_{ex} + F_t)^2 - 4\,B\,F_{ex}\,F_t}\right] \quad \ldots\ldots\ldots\ldots \quad (4)$$

$F_{tf}$ = torsional flexural buckling stress

$F_{ex}$ = Euler buckling stress about symmetry axis

$F_t$ = torsional stress

$B$ = $1 - (x_0/r_0)^2$

$r_0$ = distance from the shear centre to the centroid along the principle x-axis

$r_0$ = polar radius of gyration of the cross section about the shear centre

$r_x$ = radius of gyration of the cross section about the centroidal principle x-axis

$r_y$ = radius of gyration of the cross section about the centroidal principal y-axis

In Equation 4 the stress $F_{ex}$ and $F_t$ can be obtained from the following two equations

$$F_{ex} = \frac{\pi^2 E_t}{(L_x/r_x)^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$F_t = \frac{1}{Ar_o^2}\left[G_t \cdot J + \frac{\pi^2 E_t C_w}{(L_t)^2}\right] \qquad \ldots\ldots\ldots\ldots\ldots \quad (6)$$

$E_t$ = tangent modulus
$G_t$ = tangent shear modulus
$L_x$ = effective length of compression member for bending about the x-axis
$L_t$ = effective length of compression member for twisting
$J$ = St Venant torsion constant of the cross section
$C_w$ = Torsional warping constant of the cross section
$A$ = full cross sectional area

It should be noted that the tangent modulus and the tangent shear modulus in Equation 5 and 6 should be calculated at the torsional flexural buckling stress.

In Equations 5 and 6 the effective length factors for bending about the x-axis is 1,0 and for twisting 0,5. It is not possible to get a hinged end condition for twisting. The unbraced length of the column is taken as the distance between the two hinges and is calculated as the length of the column plus 60 mm for overall buckling and the actual length of the column for twisting.

### 4.4.2 Tangent Modulus Approach with Stub Column Mechanical Properties

In order to determine stress-strain curves for the columns, stub columns tests were made. The mechanical properties of these stub columns are given in Table 6 for stainless steels Type 304, 409, 430 and 3CR12 for the various thicknesses. The results reflect the well-known effects of cold-forming. These mechanical properties are used in subsequent calculations in the Ramberg-Osgood equations to determine the tangent modulus and tangent shear modulus to be used in Equations 5 and 6.

### 4.4.3 SSRC Curve

The 1986 Edition of the carbon steel Cold-Formed Steel Design Manual[1] specifies a parabolic fit between the proportional limit, which is assumed as half of the yield stress, and the yield stress. This method is to avoid the tedious calculations of the tangent modulus. This design curve is known as the SSRC curve.

### 4.4.4 Euler Buckling Curve using Tangent Modulus

For the sections under consideration the struts will rather fail by overall flexural buckling about the weak axis for larger slenderness ratios. the critical Euler buckling stress can be calculated by the following equation.

$$F_{ey} = \frac{\pi^2 E_t}{(L_y/r_y)^2}$$

$F_{ey}$ = Euler buckling stress about weak axis or y-axis.
$L_y$ = Effective length about y-axis.
$r_y$ = raduis of gyration about y-axis

## 4.5 RESULTS

The maximum observed experimental loads, $P_e$, are compared with the theoretical loads calculated with Equations 4, 5 and 6 in Tables 7 to 10. Two theoretical loads were calculated. The ultimate theoretical loads, $P_{uy}$, and $P_{ucy}$ were calculated using the virgin sheet yield strengths and the average yield strengths of stub columns respectively.

In Figures 2 to 11 the ultimate experimental loads are compared with the theoretical torsional flexural buckling loads calculated with Equations 4 to 6 based on the tangent modulus theory with virgin sheet mechanical properties and stub column mechanical properties. Also shown in these figures are the SSRC curve, Euler buckling curve about minor axis and the torsional flexural buckling curve where the initial modulus is used.

## 5. SUMMARY AND CONCLUSIONS

From Tables 7 to 10 and Figures 2 to 11 the following conclusions can be made.

The SSRC curve which is used in the AISI Cold-Formed Steel Design Manual[1] to predict the strength of cold-formed carbon and low-alloy steel sections can not be used for cold-formed stainless steel sections.

The torsional flexural buckling strength predicted by the tangent modulus approach, compare well with the experimental results in the short to middle column length range, but not always in the long column range. This concept has been included in the new proposed design specification[11] for stainless steels.

## 6. ACKNOWLEDGEMENT

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## NOTATION

$A$ = full cross sectional area
$B$ = width of section
$C$ = width of lip of section
$C_w$ = torsional warping constant
$D$ = depth of section
= strain
$E$ = initial elastic modulus
$E_t$ = tangent modulus
$F$ = stress
$F_{ex}$ = Euler buckling stress about x-axis
$F_{ey}$ = Euler buckling stress about y-axis
$F_p$ = proportional limit
$F_{tf}$ = torsional flexural buckling stress
$F_y$ = yield stress
$G$ = shear modulus
$G_t$ = tangent shear modulus
$J$ = St. Venant torsion constant
$k$ = constant
$L_x$ = effective length for bending about x-axis
$L_t$ = effective length for twisting
$L_y$ = effective length for bending about y-axis
$n$ = constant
$r_o$ = polar radius of gyration about shear centre
$r_x$ = radius of gyration about x-axis
$r_y$ = radius of gyration about g-axis
$R$ = inside radius of corner
$t$ = thickness of sheet
$x_o$ = distance from shear centre to centroid

## CONVERSION FACTORS

25,4 mm = 1 inch
4,448 kN = 1 kip
6,895 MPa = 1 ksi
6,895 GPa = 1000 ksi

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TABLE 1 MECHANICAL PROPERTIES OF STAINLESS STEEL 304

| MACHANICAL PROPERTY | LT | TT | LC | TC |
|---|---|---|---|---|
| Elastic Modulus E (GPa) | | | | |
| 0,9 mm sheet | 201,3 | 194,2 | 205,4 | 196,5 |
| 1,6 mm sheet | 205,8 | 202,1 | 219,1 | 214,6 |
| 2,0 mm sheet | 194,6 | 195,7 | 212,0 | 206,8 |
| Yield Strength $F_y$ (MPa) | | | | |
| 0,9 mm sheet | 288,3 | 274,1 | 283,7 | 290,5 |
| 1,6 mm sheet | 300,1 | 298,6 | 296,3 | 307,8 |
| 2,0 mm sheet | 295,0 | 301,9 | 301,5 | 313,8 |
| Proportional Limit $F_p$ (MPa) | | | | |
| 0,9 mm sheet | 197,4 | 211,3 | 154,0 | 221,1 |
| 1,6 mm sheet | 185,2 | 222,5 | 155,8 | 220,9 |
| 2,0 mm sheet | 187,9 | 219,7 | 166,1 | 226,6 |
| Tensile Strength $F_u$ (MPa) | | | | |
| 0,9 mm sheet | 682 | 639 | - | - |
| 1,6 mm sheet | 701 | 668 | - | - |
| 2,0 mm sheet | 671 | 660 | - | - |
| Average $F_p/F_y$ | | | | |
| 0,9 mm sheet | 0,68 | 0,77 | 0,54 | 0,76 |
| 1,6 mm sheet | 0,62 | 0,74 | 0,53 | 0,72 |
| 2,0 mm sheet | 0,64 | 0,73 | 0,55 | 0,72 |
| Average $F_u/F_y$ | | | | |
| 0,9 mm sheet | 2,37 | 2,33 | - | - |
| 1,6 mm sheet | 2,34 | 2,24 | - | - |
| 2,0 mm sheet | 2,27 | 2,19 | - | - |
| 50 mm Elongation (%) | | | | |
| 0,9 mm sheet | 59,2 | 61,9 | - | - |
| 1,6 mm sheet | 58,7 | 56,8 | - | - |
| 2,0 mm sheet | 58,6 | 60,1 | - | - |

TABLE 2 MECHANICAL PROPERTIES OF STAINLESS STEEL 409

| MACHANICAL PROPERTY | LT | TT | LC | TC |
|---|---|---|---|---|
| Elastic Modulus E (GPa) | | | | |
| 0,9 mm sheet | - | - | - | - |
| 1,6 mm sheet | - | - | - | - |
| 2,0 mm sheet | 185,8 | 209,1 | 191,4 | 231,5 |
| Yield Strength $F_y$ (MPa) | | | | |
| 0,9 mm sheet | - | - | - | - |
| 1,6 mm sheet | - | - | - | - |
| 2,0 mm sheet | 224,3 | 232,0 | 229,6 | 237,4 |
| Proportional Limit $F_p$ (MPa) | | | | |
| 0,9 mm sheet | - | - | - | - |
| 1,6 mm sheet | - | - | - | - |
| 2,0 mm sheet | 166,6 | 191,0 | 166,5 | 188,2 |
| Tensile Strength $F_u$ (MPa) | | | | |
| 0,9 mm sheet | - | - | - | - |
| 1,6 mm sheet | - | - | - | - |
| 2,0 mm sheet | 389 | 397 | - | - |
| Average $F_p/F_y$ | | | | |
| 0,9 mm sheet | - | - | - | - |
| 1,6 mm sheet | - | - | - | - |
| 2,0 mm sheet | 0,74 | 0,82 | 0,73 | 0,79 |
| Average $F_u/F_y$ | | | | |
| 0,9 mm sheet | - | - | - | - |
| 1,6 mm sheet | - | - | - | - |
| 2,0 mm sheet | 1,74 | 1,71 | - | - |
| 50 mm Elongation (%) | | | | |
| 0,9 mm sheet | - | - | - | - |
| 1,6 mm sheet | - | - | - | - |
| 2,0 mm sheet | 40,5 | 38,1 | - | - |

TABLE 3 MECHANICAL PROPERTIES OF STAINLESS STEEL 430

| MACHANICAL PROPERTY | LT | TT | LC | TC |
|---|---|---|---|---|
| Elastic Modulus E (GPa) | | | | |
| 0,9 mm sheet | 195,7 | 213,8 | 205,1 | 227,2 |
| 1,6 mm sheet | 196,2 | 222,3 | 198,4 | 220,9 |
| 2,0 mm sheet | 195,2 | 222,5 | 186,2 | 224,1 |
| Yield Strength $F_y$ (MPa) | | | | |
| 0,9 mm sheet | 334,2 | 363,0 | 331,7 | 377,6 |
| 1,6 mm sheet | 330,9 | 355,8 | 316,1 | 377,3 |
| 2,0 mm sheet | 312,3 | 331,5 | 287,4 | 346,2 |
| Proportional Limit $F_p$ (MPa) | | | | |
| 0,9 mm sheet | 234,6 | 287,4 | 209,1 | 295,2 |
| 1,6 mm sheet | 218,8 | 289,9 | 193,7 | 306,9 |
| 2,0 mm sheet | 214,8 | 262,5 | 168,0 | 271,4 |
| Tensile Strength $F_u$ (MPa) | | | | |
| 0,9 mm sheet | 521 | 549 | - | - |
| 1,6 mm sheet | 517 | 556 | - | - |
| 2,0 mm sheet | 513 | 561 | - | - |
| Average $F_p/F_y$ | | | | |
| 0,9 mm sheet | 0,70 | 0,79 | 0,63 | 0,78 |
| 1,6 mm sheet | 0,66 | 0,82 | 0,61 | 0,81 |
| 2,0 mm sheet | 0,69 | 0,79 | 0,58 | 0,78 |
| Average $F_u/F_y$ | | | | |
| 0,9 mm sheet | 1,56 | 1,51 | - | - |
| 1,6 mm sheet | 1,56 | 1,57 | - | - |
| 2,0 mm sheet | 1,64 | 1,69 | - | - |
| 50 mm Elongation (%) | | | | |
| 0,9 mm sheet | 22,9 | 25,5 | - | - |
| 1,6 mm sheet | 30,3 | 27,8 | - | - |
| 2,0 mm sheet | 30,0 | 28,4 | - | - |

TABLE 4 MECHANICAL PROPERTIES OF 3CR12

| MACHANICAL PROPERTY | LT | TT | LC | TC |
|---|---|---|---|---|
| Elastic Modulus E (GPa) | | | | |
| 0,9 mm sheet | 201,9 | 230,6 | 222,4 | 253,5 |
| 1,6 mm sheet | 196,3 | 218,8 | 223,2 | 248,5 |
| 2,0 mm sheet | 188,3 | 219,7 | 186,1 | 223,9 |
| Yield Strength $F_y$ (MPa) | | | | |
| 0,9 mm sheet | 307,2 | 338,9 | 318,6 | 345,1 |
| 1,6 mm sheet | 316,6 | 349,6 | 326,2 | 361,9 |
| 2,0 mm sheet | 276,6 | 301,9 | 279,1 | 309,6 |
| Proportional Limit $F_p$ (MPa) | | | | |
| 0,9 mm sheet | 235,6 | 273,3 | 217,2 | 269,6 |
| 1,6 mm sheet | 234,3 | 276,1 | 216,1 | 279,5 |
| 2,0 mm sheet | 199,3 | 235,1 | 195,3 | 256,4 |
| Tensile Strength $F_u$ (MPa) | | | | |
| 0,9 mm sheet | 482 | 506 | - | - |
| 1,6 mm sheet | 472 | 492 | - | - |
| 2,0 mm sheet | 435 | 456 | - | - |
| Average $F_p/F_y$ | | | | |
| 0,9 mm sheet | 0,77 | 0,81 | 0,68 | 0,78 |
| 1,6 mm sheet | 0,74 | 0,79 | 0,66 | 0,77 |
| 2,0 mm sheet | 0,72 | 0,78 | 0,70 | 0,83 |
| Average $F_u/F_y$ | | | | |
| 0,9 mm sheet | 1,57 | 1,49 | - | - |
| 1,6 mm sheet | 1,49 | 1,41 | - | - |
| 2,0 mm sheet | 1,57 | 1,51 | - | - |
| 50 mm Elongation (%) | | | | |
| 0,9 mm sheet | 27,2 | 23,9 | - | - |
| 1,6 mm sheet | * | * | - | - |
| 2,0 mm sheet | 36,1 | 33,9 | - | - |

* Specimen broke outside gauge marks.

TABLE 5 DIMENSIONS OF HAT SECTIONS

| TYPE | B (mm) | D (mm) | C (mm) | t (mm) | R(mm) | A(mm$^2$) |
|---|---|---|---|---|---|---|
| 304 | 27,2 | 19,8 | 9,9 | 0,88 | 1,38 | 71,95 |
| 304 | 43,2 | 30,5 | 15,3 | 1,61 | 2,01 | 194,55 |
| 304 | 63,0 | 40,9 | 20,6 | 1,96 | 3,30 | 332,85 |
| 409 | 64,9 | 44,6 | 20,3 | 1,93 | 2,10 | 364,04 |
| 430 | 27,8 | 19,5 | 10,7 | 0,85 | 1,06 | 66,66 |
| 430 | 50,4 | 30,1 | 15,5 | 1,54 | 1,56 | 196,54 |
| 430 | 65,7 | 43,8 | 20,7 | 1,91 | 1,98 | 339,89 |
| 3CR12 | 27,4 | 19,9 | 10,0 | 0,97 | 1,26 | 70,76 |
| 3CR12 | 46,1 | 29,8 | 15,5 | 1,56 | 1,54 | 194,50 |
| 3CR12 | 63,8 | 41,3 | 21,2 | 1,95 | 2,84 | 328,09 |

TABLE 6 MECHANICAL PROPERTIES OF STUB COLUMNS

| TYPE | t (mm) | E (GPa) | Fy (MPa) | Fp (MPa) | Fp/Fy |
|---|---|---|---|---|---|
| 304 | 0,9 | 210.0 | 310,0 | 170,0 | 0,55 |
| 304 | 1,6 | 227,7 | 330,8 | 160,3 | 0,54 |
| 304 | 2,0 | 189,9 | 309,1 | 160,3 | 0,52 |
| 409 | 2,0 | 198,1 | 248,7 | 173,5 | 0,70 |
| 430 | 0,9 | 197,7 | 366,4 | 195,0 | 0,53 |
| 430 | 1,6 | 203,1 | 351,1 | 218,9 | 0,62 |
| 430 | 2,0 | 206,9 | 303,2 | 174,2 | 0,57 |
| 3CR12 | 0,9 | 240,3 | 370,0 | 230,7 | 0,62 |
| 3CR12 | 1,6 | 219,4 | 345,0 | 203,5 | 0,59 |
| 3CR12 | 2,0 | 209,6 | 302,6 | 182,5 | 0,60 |

TABLE 7 STRENGTH OF STRUTS FOR STAINLESS STEEL TYPE 304

| LENGTH (mm) | T (mm) | $P_e$ (kN) | $P_{uy}$ (kN) | $P_{uyc}$ (kN) | $P_{uy}/P_e$ | $P_{uyc}/P_e$ |
|---|---|---|---|---|---|---|
| 150 | 0,9 | 21,9 | 20,4 | 22,3 | 1,08 | 0,98 |
| 300 | 0,9 | 17,3 | 16,3 | 17,7 | 1,06 | 0,98 |
| 400 | 0,9 | 16,6 | 14,1 | 15,3 | 1,18 | 1,09 |
| 800 | 0,9 | 8,0 | 8,8 | 9,3 | 0,91 | 0,86 |
| 1200 | 0,9 | 3,2 | 5,8 | 5,9 | 0,85 | 0.54 |
| 150 | 1,6 | 69,1 | 57,6 | 64,4 | 1,20 | 1,08 |
| 300 | 1,6 | 54,2 | 57,3 | 63,4 | 0,94 | 0,85 |
| 450 | 1,6 | 53,5 | 47,4 | 52,6 | 1,12 | 1,02 |
| 600 | 1,6 | 47,6 | 41,0 | 45,6 | 1,16 | 1,04 |
| 900 | 1,6 | 35,9 | 32,6 | 35,9 | 1,10 | 1,00 |
| 1500 | 1,6 | 18,7 | 22,6 | 24,1 | 0,83 | 0,78 |
| 1800 | 1,6 | 15,9 | *17,1 | *17,1 | 0,93 | 0,93 |
| 150 | 2,0 | 104,3 | 100,4 | 102,9 | 1,04 | 1,01 |
| 300 | 2,0 | 104,5 | 100,4 | 102,9 | 1,04 | 1,02 |
| 450 | 2,0 | 93,2 | 96,6 | 101,0 | 0,96 | 0,93 |
| 600 | 2,0 | 92,0 | 85,0 | 87,7 | 1,09 | 1,05 |
| 900 | 2,0 | 73,2 | 69,8 | 70,5 | 1,05 | 1,04 |
| 1200 | 2,0 | 58,6 | 59,3 | 59,2 | 0,99 | 0,99 |
| 1800 | 2,0 | 39,0 | 44,3 | 43,6 | 0,88 | 0,89 |

TABLE 8 STRENGTH OF STRUTS FOR STAINLESS STEEL TYPE 409

| LENGTH (mm) | T (mm) | $P_e$ (kN) | $P_{uy}$ (kN) | $P_{uyc}$ (kN) | $P_{uy}/P_e$ | $P_{uyc}/P_e$ |
|---|---|---|---|---|---|---|
| 150 | 2,0 | 98,2 | 83,6 | 90,6 | 1,18 | 1,09 |
| 300 | 2,0 | 92,4 | 82,3 | 90,6 | 1,11 | 1,02 |
| 450 | 2,0 | 87,6 | 76,8 | 83,7 | 1,14 | 1,04 |
| 600 | 2,0 | 78,8 | 71,6 | 77,2 | 1,10 | 1,02 |
| 900 | 2,0 | 73,2 | 64,3 | 68,5 | 1,14 | 1,06 |
| 1200 | 2,0 | 66,3 | 58,4 | 61,2 | 1,14 | 1,09 |
| 1500 | 2,0 | 51,3 | 52,5 | 54,0 | 0,98 | 0,95 |

* Overall buckling controlled ultimate load

TABLE 9 STRENGTH OF STRUTS FOR STAINLESS STEEL TYPE 430

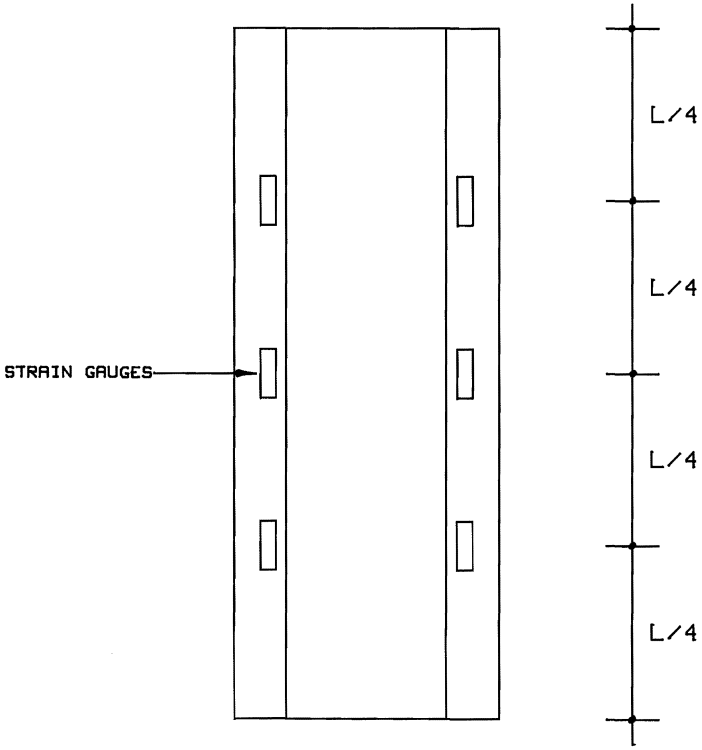
| LENGTH (mm) | T (mm) | $P_e$ (kN) | $P_{uy}$ (kN) | $P_{uyc}$ (kN) | $P_{uy}/P_e$ | $P_{uyc}/P_e$ |
|---|---|---|---|---|---|---|
| 150 | 0,9 | 25,6 | 22,1 | 24,4 | 1,16 | 1,05 |
| 300 | 0,9 | 21,2 | 17,9 | 19,3 | 1,19 | 1,10 |
| 400 | 0,9 | 20,6 | 15,9 | 16,5 | 1,30 | 1,25 |
| 600 | 0,9 | 15,6 | 12,8 | 12,4 | 1,22 | 1,27 |
| 800 | 0,9 | 9,3 | 9,9 | 9,5 | 0,94 | 0,98 |
| 1200 | 0,9 | 6,4 | *5,1 | *5,1 | 1,25 | 1,25 |
| 1500 | 0,9 | 4,2 | *3,3 | *3,3 | 1,27 | 1,27 |
| 150 | 1,6 | 69,8 | 62,1 | 69,0 | 1,12 | 1,01 |
| 300 | 1,6 | 68,0 | 59,0 | 65,2 | 1,15 | 1,04 |
| 450 | 1,6 | 64,7 | 50,8 | 56,1 | 1,27 | 1,15 |
| 600 | 1,6 | 57,0 | 45,0 | 49,8 | 1,27 | 1,15 |
| 900 | 1,6 | 41,9 | 36,4 | 39,9 | 1,15 | 1,05 |
| 1200 | 1,6 | 33,1 | 29,5 | 31,2 | 1,12 | 1,06 |
| 1500 | 1,6 | 27,5 | *22,2 | *22,2 | 1,24 | 1,24 |
| 150 | 2,0 | 111,3 | 97,7 | 103,1 | 1,14 | 1,01 |
| 300 | 2,0 | 116,0 | 97,7 | 103,1 | 1,19 | 1,12 |
| 450 | 2,0 | 104,1 | 92,2 | 97,8 | 1,12 | 1,06 |
| 600 | 2,0 | 93,4 | 82,0 | 86,7 | 1,14 | 1,08 |
| 900 | 2,0 | 77,3 | 68,1 | 74,4 | 1,14 | 1,09 |
| 1200 | 2,0 | 66,8 | 58,0 | 60,2 | 1,15 | 1,11 |
| 1750 | 2,0 | 30,2 | 42,4 | 43,1 | 0,71 | 0,70 |

* Overall buckling controlled ultimate load

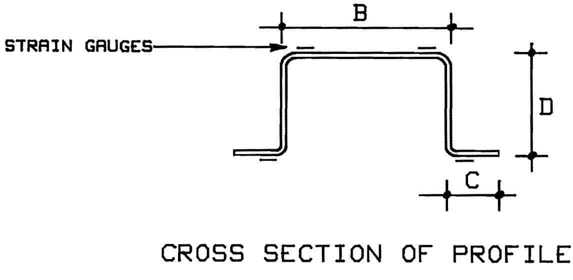
TABLE 10 STRENGTH OF STRUTS FOR TYPE 3CR12 STEEL

| LENGTH (mm) | T (mm) | $P_e$ (kN) | $P_{uy}$ (kN) | $P_{uyc}$ (kN) | $P_{uy}/P_e$ | $P_{uyc}/P_e$ |
|---|---|---|---|---|---|---|
| 150 | 0,9 | 26,0 | 22,5 | 26,2 | 1,15 | 0,99 |
| 300 | 0,9 | 23,0 | 18,8 | 21,3 | 1,22 | 1,08 |
| 400 | 0,9 | 20,1 | 17,1 | 18,9 | 1,18 | 1,06 |
| 500 | 0,9 | 17,9 | 15,7 | 17,0 | 1,14 | 1,05 |
| 800 | 0,9 | 10,7 | 11,9 | 12,0 | 0,90 | 0,89 |
| 1200 | 0,9 | 5,8 | *5,9 | *5,9 | 0,98 | 0,98 |
| 150 | 1,6 | 71,3 | 63,4 | 67,1 | 1,12 | 1,06 |
| 300 | 1,6 | 61,2 | 60,3 | 65,5 | 1,01 | 0,93 |
| 450 | 1,6 | 59,8 | 53,2 | 55,9 | 1,12 | 1,08 |
| 600 | 1,6 | 51,9 | 48,2 | 49,4 | 1,08 | 1,05 |
| 1200 | 1,6 | 28,8 | 33,9 | 32,6 | 0,85 | 0,88 |
| 1500 | 1,6 | 19,2 | *24,1 | *24,1 | 0,80 | 0,80 |
| 1800 | 1,6 | 19,3 | *16,9 | *16,9 | 1,14 | 1,14 |
| 150 | 2,0 | 100,4 | 91,6 | 99,3 | 1,10 | 1,01 |
| 300 | 2,0 | 94,4 | 91,6 | 99,3 | 1,03 | 0,95 |
| 450 | 2,0 | 84,8 | 85,0 | 94,4 | 1,00 | 0,90 |
| 600 | 2,0 | 80,2 | 78,8 | 84,5 | 1,02 | 0,95 |
| 900 | 2,0 | 69,9 | 69,4 | 71,1 | 1,01 | 0,98 |
| 1200 | 2,0 | 56,2 | 61,9 | 60,8 | 0,91 | 0,93 |
| 1800 | 2,0 | 38,9 | 46,3 | 44,1 | 0,84 | 0,88 |

* Overall buckling controlled ultimate load



ELEVATION OF PROFILE



CROSS SECTION OF PROFILE

FIGURE 1 LAYOUT OF STRAIN GAUGES

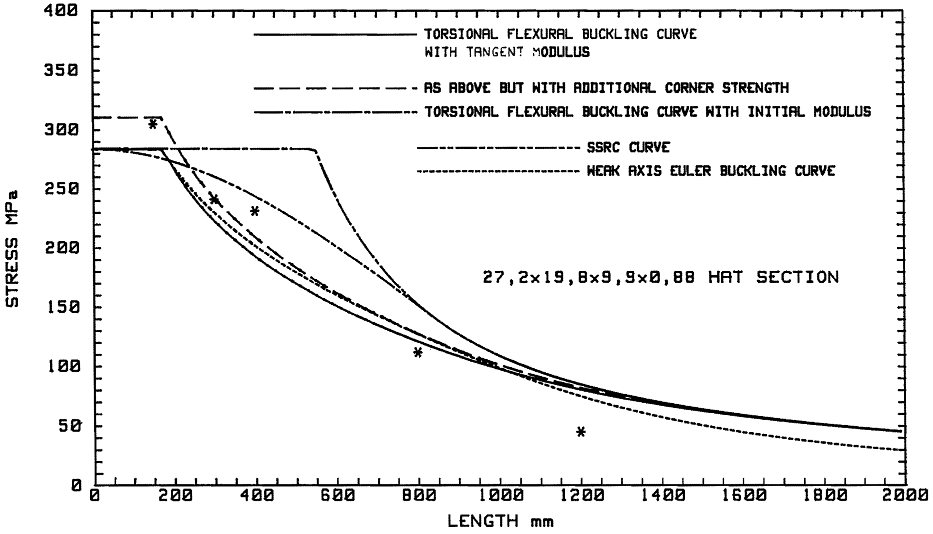


FIGURE 2  TORSIONAL FLEXURAL BUCKLING STRESS VS LENGTH FOR STAINLESS STEEL TYPE 304 - 0,9 mm SHEET

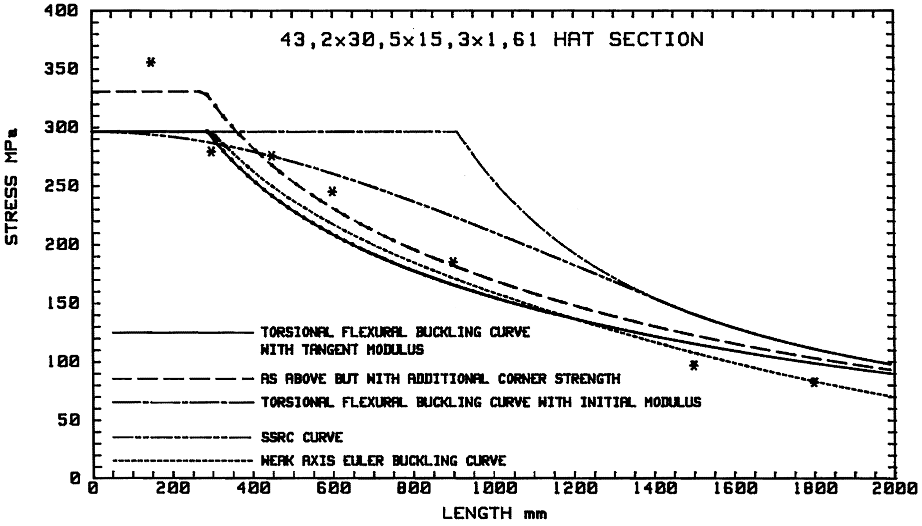


FIGURE 3  TORSIONAL FLEXURAL BUCKLING STRESS VS LENGTH FOR STAINLESS STEEL TYPE 304 - 1,6 mm SHEET

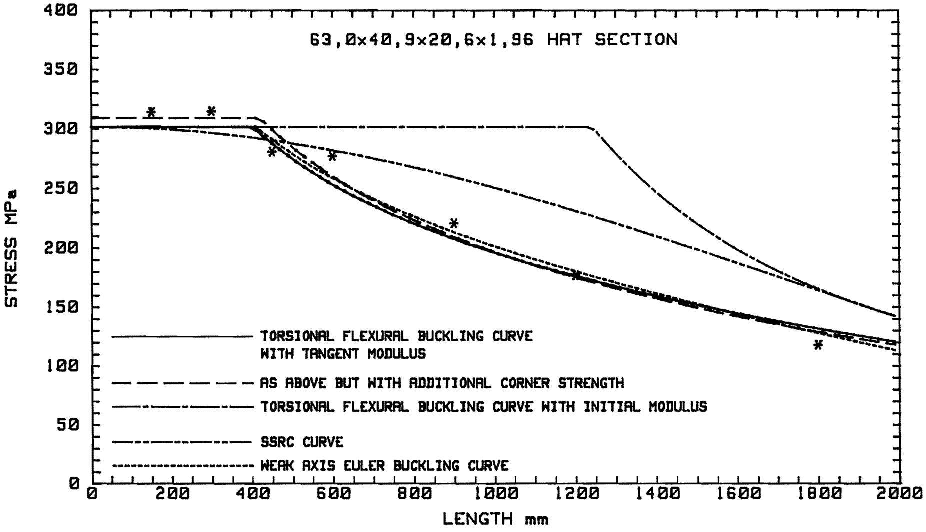


FIGURE 4 TORSIONAL FLEXURAL BUCKLING STRESS VS LENGTH FOR STAINLESS STEEL TYPE 304 - 2,0 mm SHEET

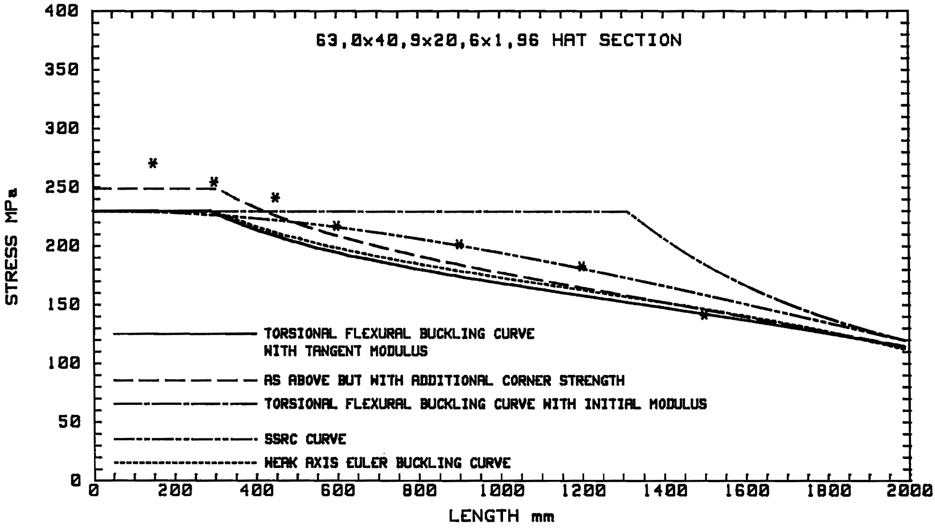


FIGURE 5 TORSIONAL FLEXURAL BUCKLING STRESS VS LENGTH FOR STAINLESS STEEL TYPE 409 - 2,0 mm SHEET

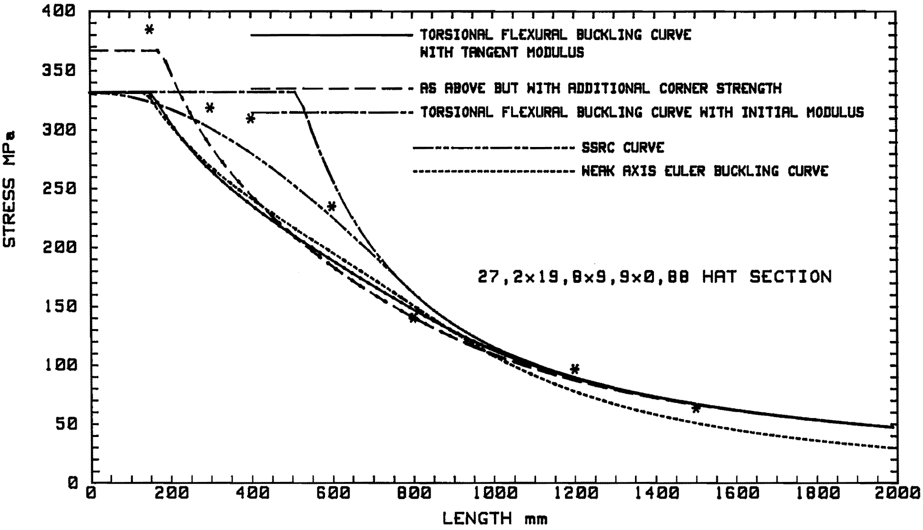


FIGURE 6 TORSIONAL FLEXURAL BUCKLING STRESS VS LENGTH FOR STAINLESS STEEL TYPE 430 - 0,9 mm SHEET

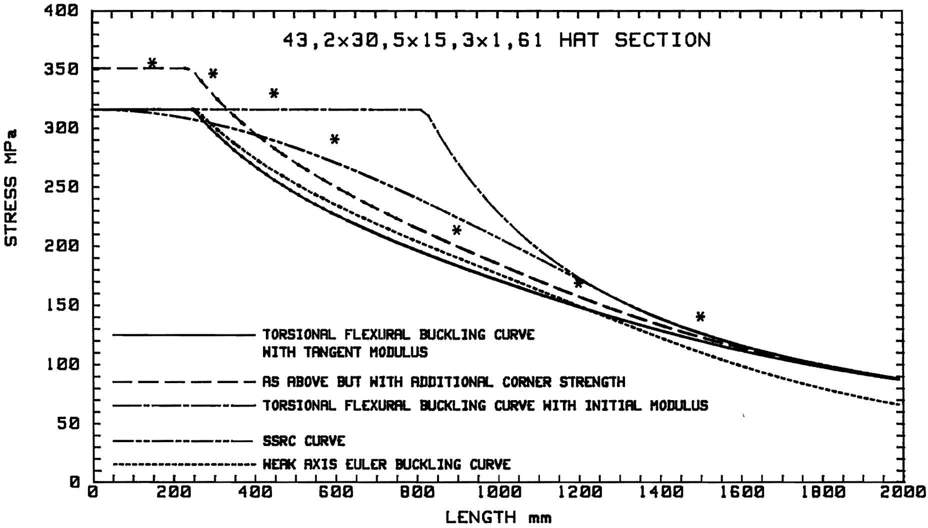


FIGURE 7 TORSIONAL FLEXURAL BUCKLING STRESS VS LENGTH FOR STAINLESS STEEL TYPE 430 - 1,6 mm SHEET

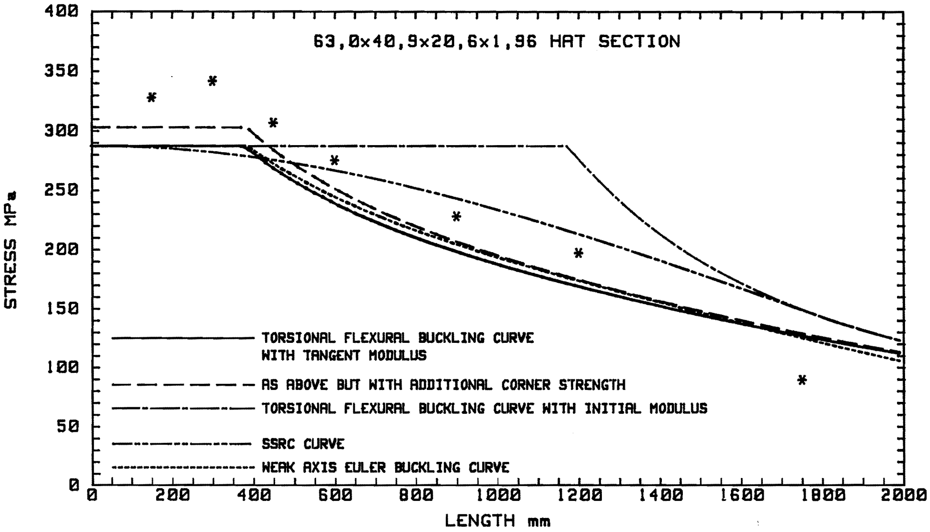


FIGURE 8 TORSIONAL FLEXURAL BUCKLING STRESS VS LENGTH FOR STAINLESS STEEL TYPE 430 - 2,0 mm SHEET

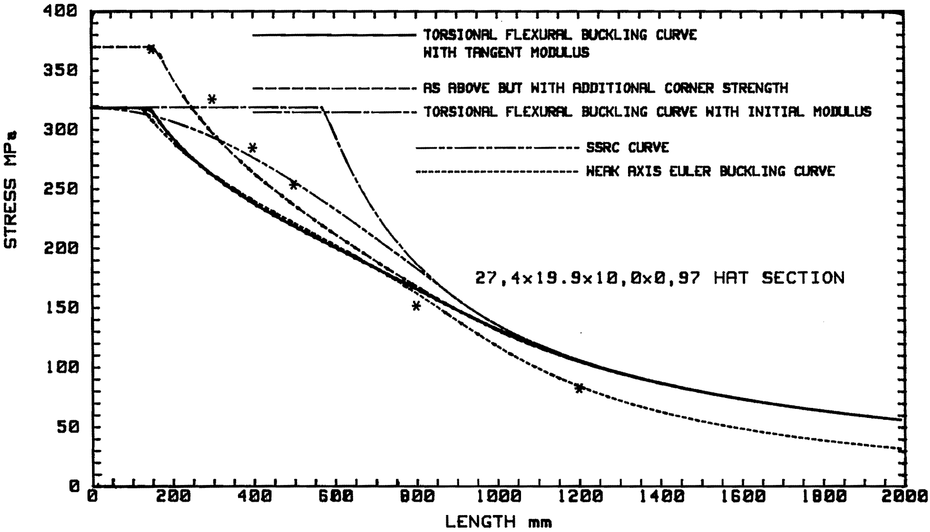


FIGURE 9 TORSIONAL FLEXURAL BUCKLING STRESS VS LENGTH FOR TYPE 3CR12 STEEL - 0,9 mm SHEET

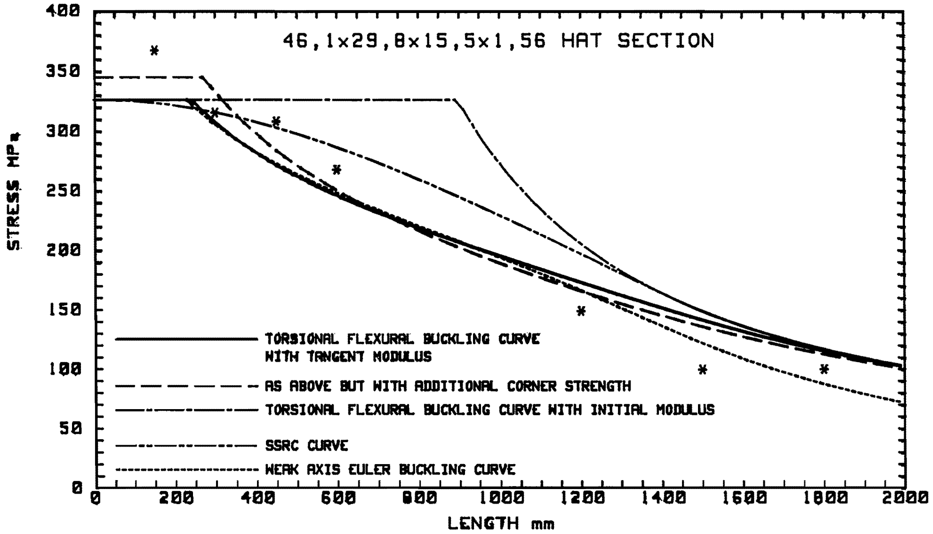


FIGURE 10 TORSIONAL FLEXURAL BUCKLING STRESS VS LENGTH FOR TYPE 3CR12 STEEL - 1,6 mm SHEET

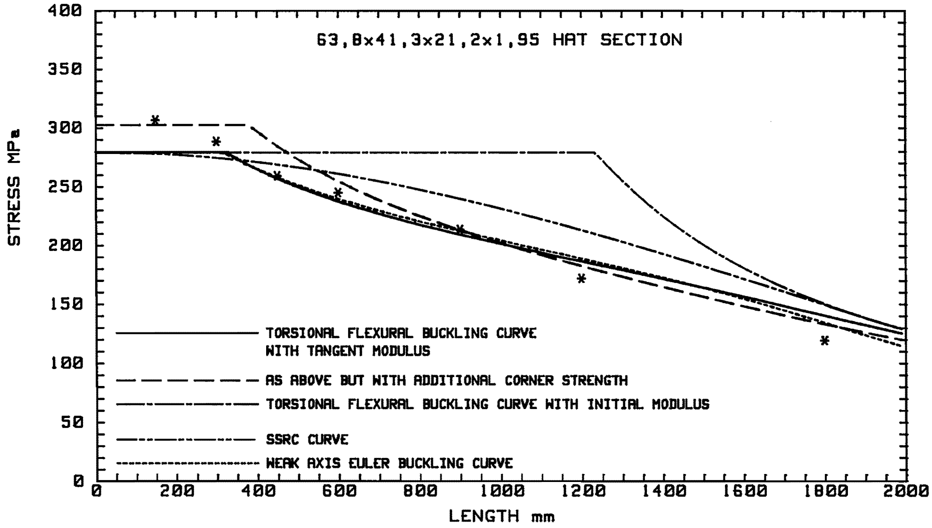


FIGURE 11 TORSIONAL FLEXURAL BUCKLING STRESS VS LENGTH FOR TYPE 3CR12 STEEL - 2,0 mm SHEET