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ECCENTRICALLY LOADED BOLTED CONNECTIONS FOR TYPE 304 AND 3CR12 STAINLESS STEEL LIPPED CHANNELS

by

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SYNOPSIS

In this paper the results of a study on eccentrically loaded bolted connections in lipped channels are presented. The steels chosen for this study are AISI Type 304 and Type 3CR12 stainless steel.

It is concluded in this investigation that an acceptable prediction of the strength of eccentrically loaded bolted connections of stainless steel lipped channels may be obtained through the combination between the eccentric loaded equation and the normal bolted connection equations for stainless steel.

INTRODUCTION

Cold-formed steel structural members can be used very efficiently in many applications where conventional hot-rolled members prove uneconomic. Stainless steels are not only pleasing in appearance but also have corrosion-resisting as well as heat-resisting properties.

Type 304 and Type 3CR12 stainless steel sheets were obtained at the Rand Afrikaans University to be used in this investigation. Lipped channel beams 750 mm in length were formed by a press brake process.

MECHANICAL PROPERTIES

Testing Procedure

Tensile and compression test coupons were cut from each of the stainless steel sheets that were used for the beam specimens. Eight tensile and eight compression test coupons were taken from each type of stainless steel, in the longitudinal direction (the direction parallel to the rolling direction) of the section and in the transverse direction. The coupons were labeled LT and LC referring to longitudinal tension or longitudinal compression and TT and TC referring to transverse tension and compression .

Uniaxial tensile and compression tests were carried out on the specimens generally in accordance with the procedures outlined by ASTM A370-77[1]. Average strain was measured by two strain gauges mounted on either side of the coupon in a full bridge configuration. The compression test coupons were tested using a bracing jig to prevent overall buckling of the coupon about the minor axis.

Results of Coupon Tests

Stainless steels yield gradually under load. In order to compute the initial modulus, E_o, and subsequently the proportional limit, f_p, defined as the 0.01% offset strength, and the yield strength, f_y, defined as the 0.2% offset strength from experimental data, a computer programme was used. The best-fit straight line for the initial part of the stress-strain curve was obtained through a process of linear regression. This was considered the initial elastic modulus, E_o.

The mean values of the mechanical properties given in Table 1 and Table 2 were used together with Equation 1, the revised Ramberg-Osgood[2] equation, to produce the analytical stress-strain curves shown in Figure 1 and 2.

$$\varepsilon = \frac{f}{E_o} + 0.002\left(\frac{f}{f_y}\right)^n \qquad (1)$$

where

$$n = \frac{\log\left(\frac{\varepsilon_y}{\varepsilon_p}\right)}{\log\left(\frac{f_y}{f_p}\right)} \qquad (2)$$

ε	Strain
f	Stress
E_o	Initial elastic modulus
f_y	Yield strength
f_p	Proportional limit
ε_y	Yield strain offset of 0.2%
ε_p	Proportional limit strain offset of 0.01%

TABLE 1 MECHANICAL PROPERTIES OF TYPE 304 STAINLESS STEELS

Property		LT	LC	TT	TC
Initial Elastic	Min	177.8	192.4	196.4	200.4
Modulus	Mean	190.8	204.0	203	207
E_0 (GPa)	Max	215.6	192.4	207.6	219
	COV	9.1	4.1	2.3	4.1
Proportional Limit	Min	264.3	225.0	271.4	266.7
f_p (MPa)	Mean	264.9	233.3	258.5	295.9
	Max	281.3	233.3	250	375
	COV	3.1	3.0	3.6	17.9
Yield Strength	Min	358.3	337.5	372.5	358.3
f_y (MPa)	Mean	376.2	368.6	375.3	377.1
	Max	400.0	383.3	378.6	383.3
	COV	6.5	4.9	0.7	3.3
Ultimate Tensile	Min	664.0	-	666.2	-
Strength	Mean	666.7	-	666.5	-
f_u (MPa)	Max	667.9	-	666.9	-
	COV	0.2	-	0.05	-
Elongation	Min	73.0	-	77.5	-
(mm)	Mean	75.3	-	78	-
	Max	78.0	-	79	-
	COV	3.2	-	0.9	-

TABLE 2 MECHANICAL PROPERTIES OF TYPE 3CR12 STAINLESS STEEL

Property		LT	LC	TT	TC
Initial Elastic	Min	168.6	175.8	179.2	178.9
Modulus	Mean	171.2	182.0	192	192.1
E_0 (GPa)	Max	175.0	185.0	205.2	178.9
	COV	1.8	2.3	5.8	8.6
Proportional Limit	Min	233.4	233.3	256.3	212.5
f_p (MPa)	Mean	235.8	234.7	275.8	275.2
	Max	238.9	238.9	288.8	325
	COV	1.0	1.2	5.7	17.5
Yield Strength	Min	311.1	326.3	337.5	300
f_y (MPa)	Mean	314.3	330.9	345.3	330.1
	Max	316.7	333.3	356.3	375
	COV	0.7	0.9	2.6	9.7
Ultimate Tensile	Min	519.4	-	542.4	-
Strength	Mean	524.8	-	548.9	-
f_u (MPa)	Max	528.3	-	554.6	-
	COV	0.8	-	0.92	-
Elongation	Min	61.5	-	61	-
(mm)	Mean	62.9	-	63.6	-
	Max	64.5	-	66.5	-
	COV	2.0	-	3.6	-

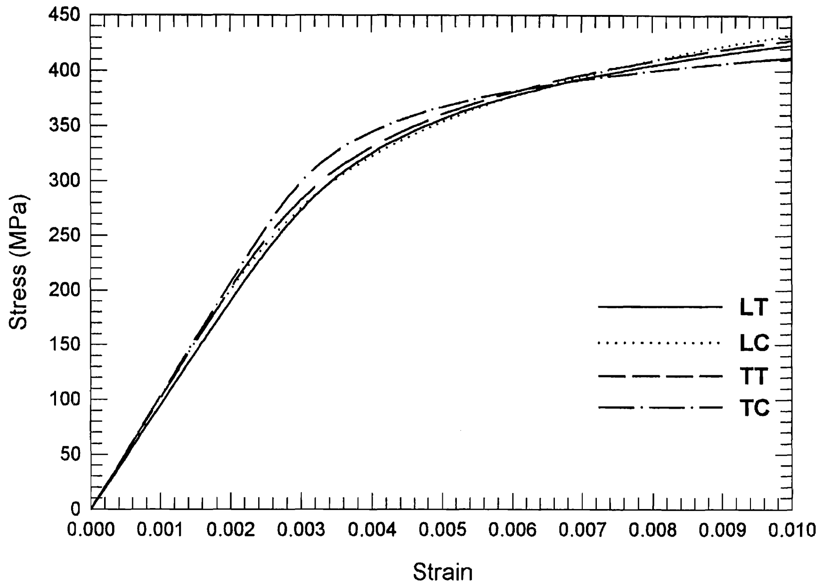


Figure 1 Analytical Stress Strain Curves for Type 304 Stainless Steel

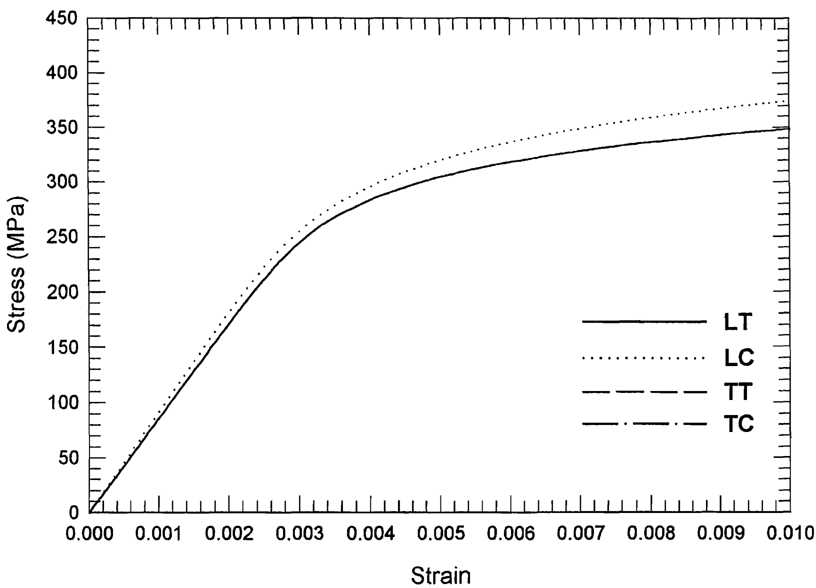


Figure 2 Analytical Stress Strain Curves for Type 3CR12 Stainless Steel

BOLTED CONNECTIONS IN STAINLESS STEEL

Failure mode II : Crumpling of steel in front of the bolt

In bolted connections with a large edge distance, failure mode II will occur where the material in front of the bolt will crumple. It can be said that the load of the connection could be dependant on the following:

- Tensile strength of the connection material, f_u
- Type of connection
- The thickness of the conneced material, t
- The ratio of the tensile strength to the yield strength of the material, f_u/f_y

Because it is almost impossible to get a theoretical relationship between the above mentioned factors due to all the different parameters an empirical method is used.

Equation 3 gives the ultimate strength for this failure mode[3]:

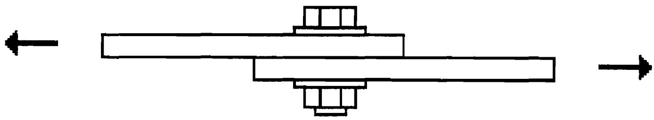
$$P_u = f_d d t \qquad (3)$$

where

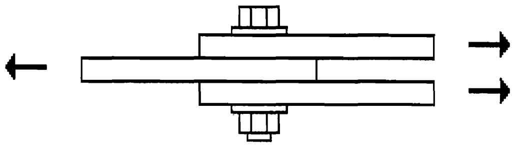
f_d the nominal bearing stress given in Table 3.

TABLE 3 NOMINAL BEARING STRESS

Thickness of connection [mm]	Type of connection See figure 3	The ratio f_u/f_y, of the connection	Nominal bearing stress
$0.9 < t < 4.7$	Inside plate of the double shear connection	≥ 1.15	$2.75 f_u$
	Single shear connection	≥ 1.15	$2.00 f_u$



(a) Single shear connection



(b) Double shear connection

Figure 3 Single- and Double Shear Bolted Connections

Failure mode IV : Shearing of the bolt

This failure mode occurs when the bearing load of the connecting part is greater than the shear strength of the bolt. This kind of failure mode occurs sudden and does not general occur in stainless steel connections. The bolts overturn and cause a decrease in the shear strength of the bolts because the bolts are in tension and not in shear.

From experimental work it has been found that the allowable shear strength of the bolts in the connection is given by Equation 4 [4]:

$$V_b = 0.6 f_{ub} \tag{4}$$

where

V_b Allowable shear strength of bolt
f_{ub} Tensile strength of the bolt material

From previous experimental research, it was found that the strength of a bolt in shear relates better with the tensile strength than with the yield strength of the bolt material.

ECCENTRICALLY LOADED BOLTED CONNECTIONS

If a load is applied to a connection that does not go trough the centroid of the connection there are extra forces on the connection because of the eccentricity of the applied load

(See Figure 4). The analysis of such a connection is based on the elastic theory together with the following assumptions for each bolt in the connection:

- Each bolt will carry an equal part of the vertical component of the load
- Each bolt will carry an equal part of the horizontal component (if any) of the load
- Each bolt will carry a proportional part of the eccentric moment of the load

The resulting force for the critical bolt in the connection is given by Equation 5 [5]

$$F_x = \sqrt{\left(\frac{Pey}{I_p}\right)^2 + \left(\frac{Pex}{I_p} + \frac{P}{n}\right)^2} \qquad (5)$$

where

P	The applied load
e	Eccentricity of the load relative to the centroid of the connection
I_p	Polar moment of inertia of the connection
x,y	Horizontal and vertical distances of the critical bolt relative to the centroid
n	Number of bolts in the connection

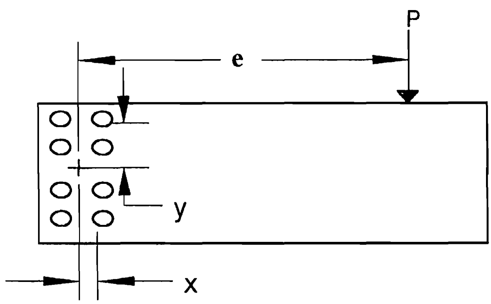


Figure 4 Detail of Bolted Connection and Applied Load

EXPERIMENTAL WORK

Preparation of members

Lipped channel sections 750 mm long were prepared from sheets of Type 304 and Type 3CR12 stainless steel. Thirty six beam specimens (18 pairs) were prepared for each type of stainless steel with varying bolt diameters and bolt combinations.

Experimental setup and procedure

The beams were tested as cantilevers and in pairs to prevent torsion. The holes for the bolted connections in the cantilever lipped channel were drilled in different diameters and combinations. The following bolt diameters were used, 8 mm, 10 mm and 12 mm. Figure 5 illustrates the bolted combinations. No washers were used in the connections between the plate and the bolt.

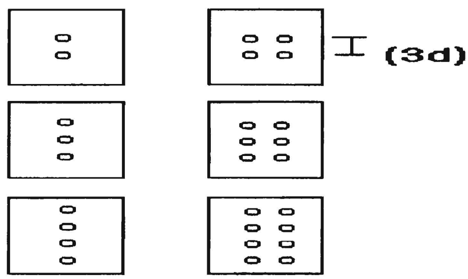


Figure 5 Different bolted combinations

A load was applied to the cantilevers using a hydraulic Instron actuator. Loading was stopped once the load dropped below the maximum recorded load. The maximum reading was taken and the value tabled to use in further calculations.

RESULTS

The experimental results of the tests on bolted connection strengths of stainless steel lipped channel cantilevers are given in Table 4 and 5 and Figure 6 and 7.

In the calculations of the theoretical values, the factor used for the nominal bearing load in Equation 3 from Table 3 was 2.00. This factor however, is for bolted connections with washers. The experimental failure loads were obtained for bolted connections without washers.

Discussion of results

In Figure 6 and 7 the solid circular data points represent the experimental load as per number of bolts in the connection for the 8 mm diameter bolts. The non-solid circular data points represent the 10 mm diameter bolts and the triangular data points the 12 mm diameter bolted connections.

The theoretical values of the load, represented by the lines, were obtained for Type 3CR12 (8 mm, 10 mm, 12 mm) and Type 304 (10 mm, 12 mm), by making use of Equation 3 and 5. The failure mode in these bolted connections involved the crumpling of the material in front of the bolts. Equation 4 and 5 was only used to determine the theoretical load in the case of Type 304 (8 mm) stainless steel bolted connections. Shearing of the bolts occurred instead of the crumpling of the material.

The theoretical values were compared with the experimental values and the mean values together with the coefficient of variation were calculated and can be seen in Table 4 and Table 5.

The results of tests show that the mean value is less than one, which is unsatisfactory. The reason for this low value below one is that no washers were used in the connections.

According to various other specifications[1,3], the factor that was obtained from Table 3, may be reduced by about 10% if no washers are used. Thus the average ratio, P_{exp}/P_{theo} of 0.98 may change to 1.08. With this mean value the results are satisfactory.

The symbols in Table 4 and Table 5 have the following meanings.

- P experimental — The experimental load that the bolt combination could withstand in the tests that were done.
- P theoretical — The theoretical load calculated with the combination of the equation for eccentric bolt connections and the normal bolt connection equations for stainless steel.
- P exp / P theo — The ratio of above mentioned loads.

CONCLUSION

It can be concluded from this study that an acceptable prediction can be made for eccentrically loaded bolted stainless steel connections for failure mode II and IV when the eccentric load and the normal bolt equations are used. The experimental results compare well with the theoretical predictions. Further studies will have to be done to confirm the influence of the washers on the bolted connections.

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3) American Iron and Steel Institute, Cold-Formed Steel Design Manual, August 19, 1986 Edition with December 11, 1989 Addendum.

4) Zandanfarrokh F. and Bryan E.R., Testing and Design of Bolted Connections in Cold-Formed Steel Sections, Eleventh International Speciality Conference on Cold-Formed Steel Structures St. Louis, Missouri, USA., October 20-21, 1992.

5) The South African Institute of Steel Construction, Southern African Steel Construction Handbook (Limit States Design), Second Edition 1992.

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TABLE 4 EXPERIMENTAL RESULTS FOR TYPE 304 STAINLESS STEEL

Bolt combination	e (mm)	Polar moment Ip (mm4)	Bolt diameter	P (load) experimental [kN]	P (load) theoretical [kN]	P exp / P theo
1x2	458	288	8	1.34	1.52	0.88
1x3	458	1152	8	3.41	3.14	1.09
1x4	458	2880	8	4.89	6.09	0.80
2x2	470	1152	8	4.11	4.10	1.00
2x3	470	3168	8	8.17	10.75	0.76
2x4	470	6912	8	13.31	22.18	0.60
1x2	455	450	10	2.84	2.81	1.01
1x3	455	1800	10	6.71	5.62	1.19
1x4	455	4500	10	10.52	9.35	1.13
2x2	470	1800	10	7.71	7.45	1.03
2x3	470	4950	10	14.43	13.06	1.10
2x4	470	10800	10	18.18	20.23	0.90
1x2	452	648	12	3.25	4.07	0.80
1x3	452	2592	12	8.12	8.14	1.00
1x4	452	6480	12	12.68	13.55	0.94
2x2	470	2592	12	10.52	10.67	0.99
2x3	470	7128	12	17.94	18.72	0.96
2x4	470	15552	12	22.41	29.00	0.77
				Mean		0.98
				COV		15.39

TABLE 5 EXPERIMENTAL RESULTS FOR TYPE 3CR12 STAINLESS STEEL

Bolt combination	e (mm)	Polar moment I_p (mm)	Bolt diameter	P (load) experimental [kN]	P (load) theoretical [kN]	P exp / P theo
1x2	458	288	8	1.32	1.47	0.90
1x3	458	1152	8	3.12	2.94	1.06
1x4	458	2880	8	5.64	4.90	1.15
2x2	470	1152	8	3.83	3.96	0.97
2x3	470	3168	8	7.22	6.93	1.04
2x4	470	6912	8	11.74	10.72	1.10
1x2	455	450	10	2.11	2.31	0.91
1x3	455	1800	10	4.72	4.63	1.02
1x4	455	4500	10	8.12	7.71	1.05
2x2	470	1800	10	6.11	6.14	1.00
2x3	470	4950	10	10.62	10.77	0.99
2x4	470	10800	10	15.28	16.67	0.92
1x2	452	648	12	3.12	3.55	0.88
1x3	452	2592	12	6.79	6.71	1.01
1x4	452	6480	12	10.81	11.17	0.97
2x2	470	2592	12	8.42	8.79	0.96
2x3	470	7128	12	14.79	15.43	0.96
2x4	470	15552	12	20.13	23.90	0.84
				Mean		0.98
				COV		7.81

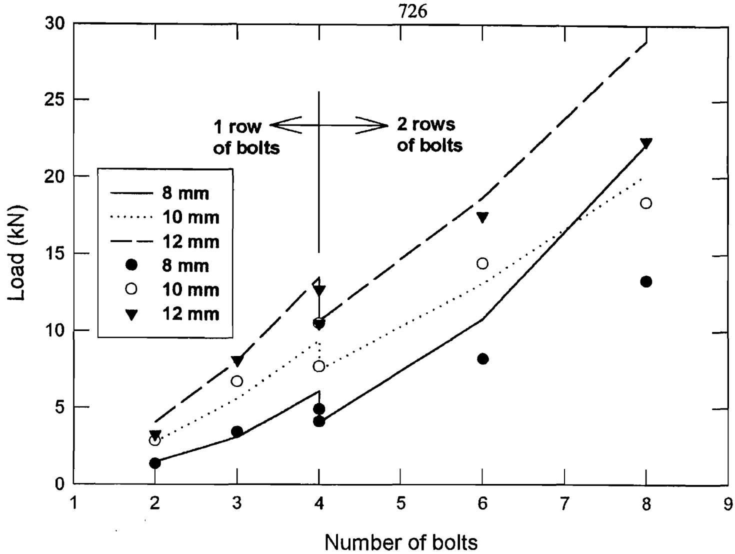

Figure 6 **Theoretical and Experimental loads for Type 304 Stainless Steel**

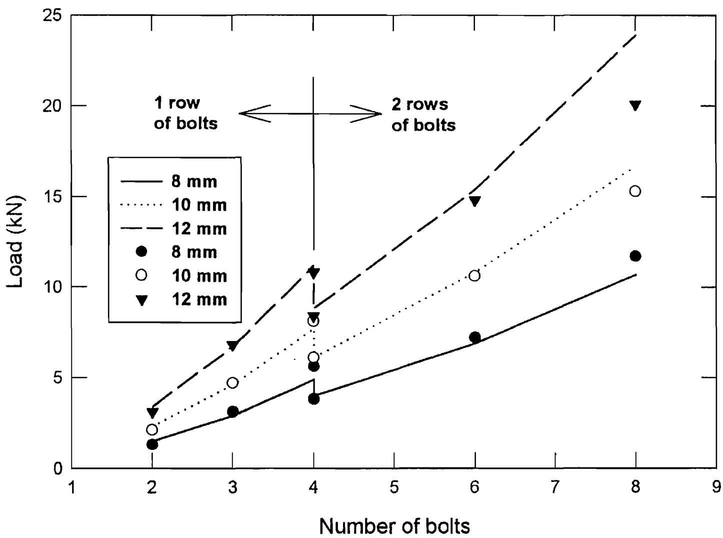

Figure 7 **Theoretical and Experimental loads for Type 3CR12 Stainless Steel**