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COMPRESSIVE STRENGTH OF SOLID ROUND STEEL MEMBERS REINFORCED WITH SPLIT PIPE(S)

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ABSTRACT

Results of experimental investigation on the compressive strength of twenty solid round steel leg member specimens of lattice communication towers reinforced with one or two split pipe(s) are presented in this paper. The reinforcement was connected to the leg members either by means of U-bolts only or by means of U-bolts and end welding. It was found that bolt torque has no significant effect in the increase on the strength. It was also concluded that using two split pipes without end welding is better than using one split pipe with end welding. Based on the test results, a simplified and conservative design procedure in accordance to the Canadian and American Standards is proposed to determine the compressive strength of solid round steel leg members reinforced with split pipe(s).

Keywords: bolt torque, compressive strength of reinforced solid round steel member, lattice tower, split pipes strengthening.

INTRODUCTION

The leg members of lattice communication towers usually consist of either angles or solid rounds. For guyed towers, which are very tall and therefore subjected to very high wind loads, solid round sections are preferred for leg members because they have low wind drag and they have equal compressive strength about all axes of buckling. Usually, these guyed towers are built of all welded prismatic sections of approximately 6 m in length (Figure 1) and joined together at the ends by means of either flange-type connections or ring-type connections.

With the increase in the use of telecommunications for voice and data transmission, there is a need for additional antennas to be located on the existing towers because of the high expense and sometimes public opposition in building new towers in urban areas. Therefore, there is a need to strengthen the existing towers to bring them in compliance with the latest antenna tower standards. Existing towers can be strengthened by reinforcing the leg members of the towers. There are several methods of strengthening the solid round leg members; (a) strengthening by means of solid round members connected to the leg member with clamps as shown in Figure 2(a); (b) strengthening by means of angle sections connected to the leg member with U-bolts as shown in Figure 2(b); and (c) strengthening by means of either one or two split pipe(s) with or without end welding as shown in Figure 2(c). Of these three methods of strengthening, the first two are used for small size leg members and the third method is the preferred method for larger size legs. The specified minimum bolt torque is applied to the U-bolts in all cases.

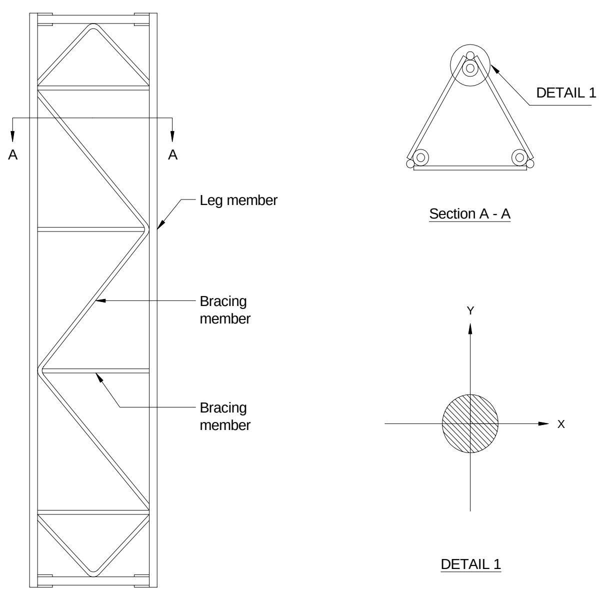


Figure 1. Typical Section of Lattice Communication Tower

Note: Discussion is expected before November, 1st 2005. The proper discussion will be published in "Dimensi Teknik Sipil" volume 8, number 1, March 2006.

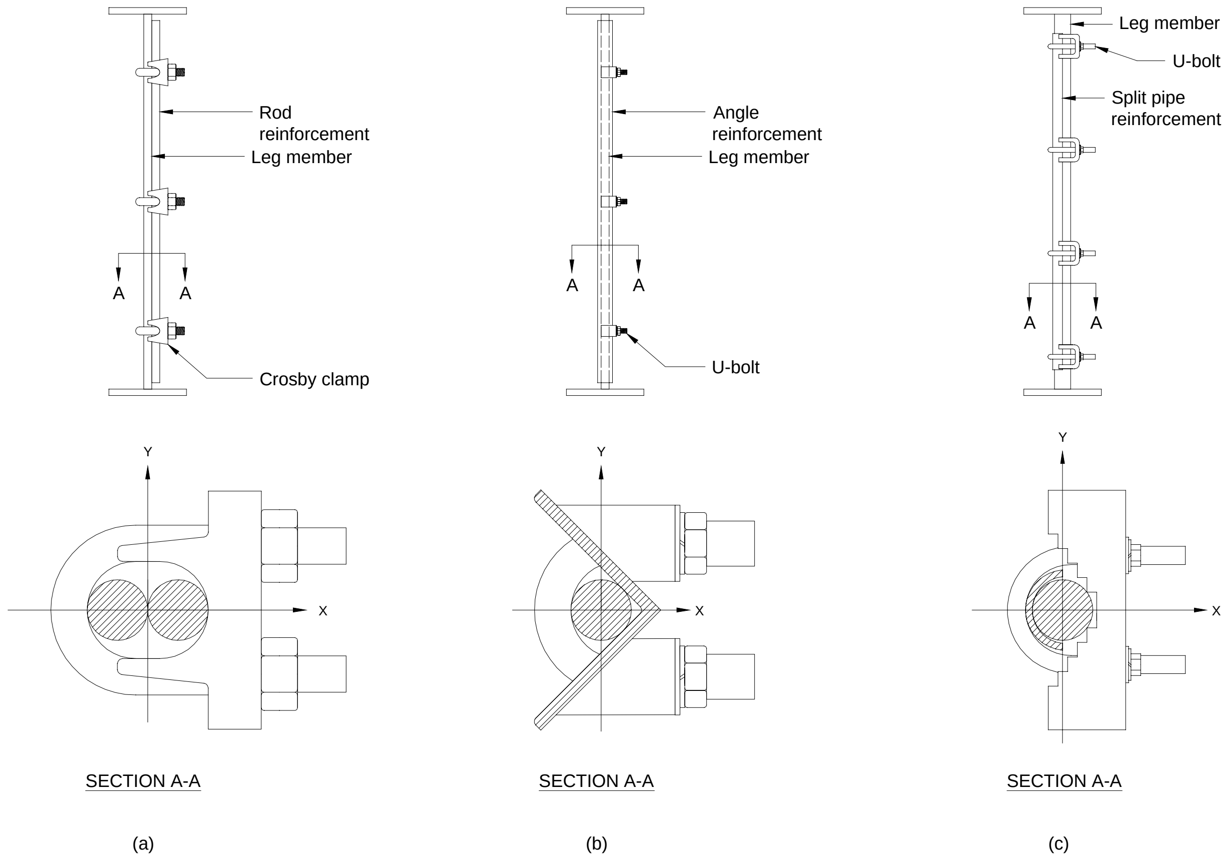


Figure 2. Leg Members with Solid Round, Angle, and Split Pipe Reinforcements

The problem faced by the communication tower designers is that there is no guidance from the Canadian or American Standards on the determination of the increase in strength due to reinforcement. With rod, angle, and one split pipe reinforcement, with or without end welding, the problem is complicated because of the eccentricity of loading. The analysis of beam columns is not easy and the intermittent connections with U-bolts provide additional difficulties. In addition, to the best of the authors' knowledge, there is no published research about the strength of leg member reinforced with split pipe(s). The current practice in the field in case of reinforcement is either to reduce the effective length of the member into half or to treat the reinforced member as a composite member. The purpose of the present investigation is to carry out experimental investigation on solid round bars with various strengthening configurations with split pipes and provide a simplified and conservative design method for use by the tower design engineers. Because of the limitations in the available laboratory facilities, tests were carried out on small size specimens only. The effect of torque applied to U-bolts during fastening was also investigated.

CALCULATION OF COMPRESSIVE RESISTANCE AS PER CANADIAN AND AMERICAN CODES

Canadian Standard CSA S37-01 [1] specifies the compressive resistance as follows:

$$C_r = \phi \times A \times F_y \times \left(1+\lambda^{2n}\right)^{-\frac{1}{n}} \quad (1)$$

$$\lambda = \frac{KL}{r}\sqrt{\frac{F_y}{\pi^2 E}} \quad (2)$$

where:

A = gross area of cross-section
C_r = compressive resistance
E = Young's modulus of elasticity, 200 GPa
F_y = yield stress
K = effective length factor
L = unbraced length of the member
n = parameter for compressive resistance, 1.34
r = minimum radius of gyration
ϕ = resistance factor, 0.9
λ = non-dimensional slenderness parameter

Compressive resistance according to AISC-LRFD Specification [2] is as follows:

$$C_r = \phi \times A \times F_{cr} \quad (3)$$

where F_{cr} is the critical stress, λ is as defined in Equation 2, and resistance factor ϕ is 0.85.

For $\lambda \le 1.5$, $F_{cr} = 0.658^{\lambda^2} \times F_y$ (4)

For $\lambda > 1.5$, $F_{cr} = \left[\dfrac{0.877}{\lambda^2}\right] \times F_y$ (5)

EXPERIMENTAL INVESTIGATION

Description of Test Specimens

Twenty leg member specimens of 31.8 mm diameter as shown in Figure 3 were included in the investigation. Of the twenty leg member specimens, ten specimens were 737 mm long with 12.7 x 152 x 152 mm plates welded at top and bottom of the members. The other ten specimens were 1500 mm long with 12.7 x 152 x 152 mm plates welded at top and bottom of the members.

Of the ten 737 mm long specimens, two specimens were unreinforced (Figure 3) and four specimens were reinforced each with one 660 mm long semi-circular split pipe of 42.2 mm outside diameter and 3.56 mm thickness. For two of the four specimens, split pipes were connected using four U-bolts as shown in Figure 4(a), and for the other two specimens, the connection was with three U-bolts and 5 mm size, 76.2 mm long fillet welds at ends as shown in Figure 4(b).

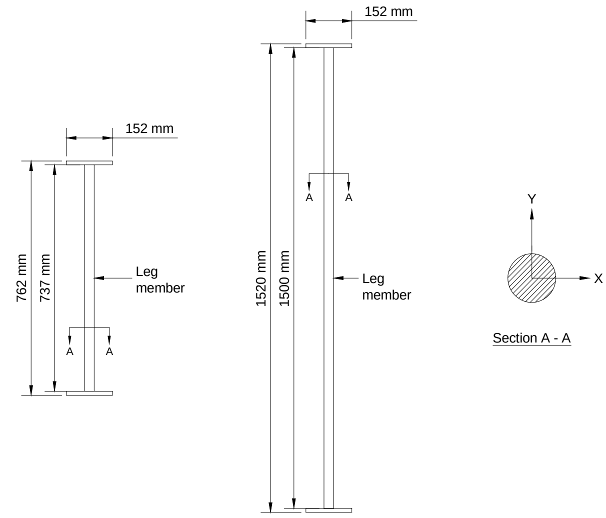


Figure 3. Unreinforced Leg Member Specimen

Four other specimens were reinforced with two 660 mm circular arc split pipes of 42.2 mm

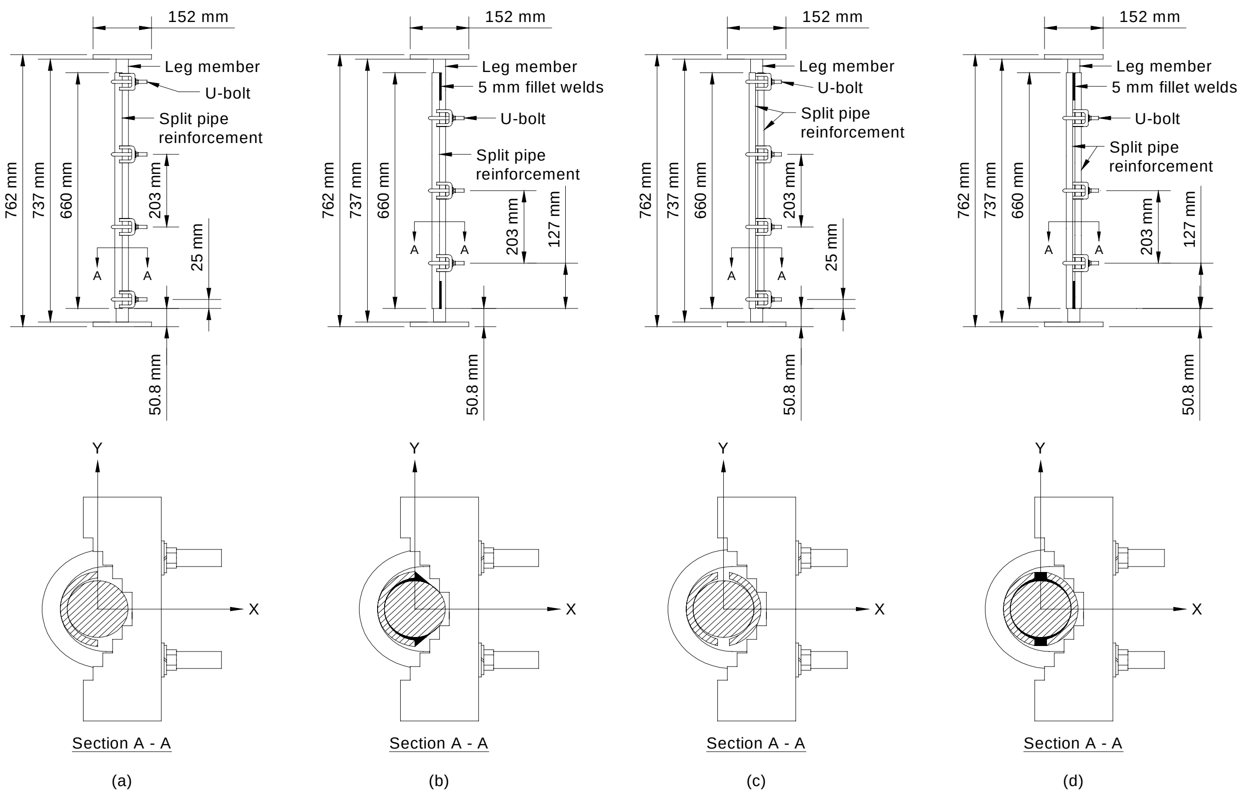


Figure 4. Reinforced Leg Member Specimen (737 mm Long)

outside diameter and 3.56 mm thickness. For two of the four specimens, the two split pipes were connected to the specimen using four U-bolts as shown in Figure 4(c), and for the other two specimens, the connection was with three U-bolts and 5 mm size, 76.2 mm long fillet welds at ends as shown in Figure 4(d). The split pipes were circular segments and not semi-circular, to make it possible to use two-sided reinforcement. The details of the specimens are given in Table 1. The spacing of the U-bolts is such that the non-dimensional slenderness parameter λ of the leg member is less than 0.25.

The ten 1500 mm long specimens were also fabricated in a similar fashion, except that seven U-bolts were used to connect the reinforcement to the leg members as shown in Figures 5(a) to 5(d). The details of these specimens are given in Table 2.

To study the effect of bolt torque on the increase in the strength, two different torques, i.e. 27 Nm and 41 Nm, were applied to the U-bolts as shown in Tables 1 and 2. From mill test certificates, the yield stress of the split pipe used as the reinforcing member was 439 MPa.

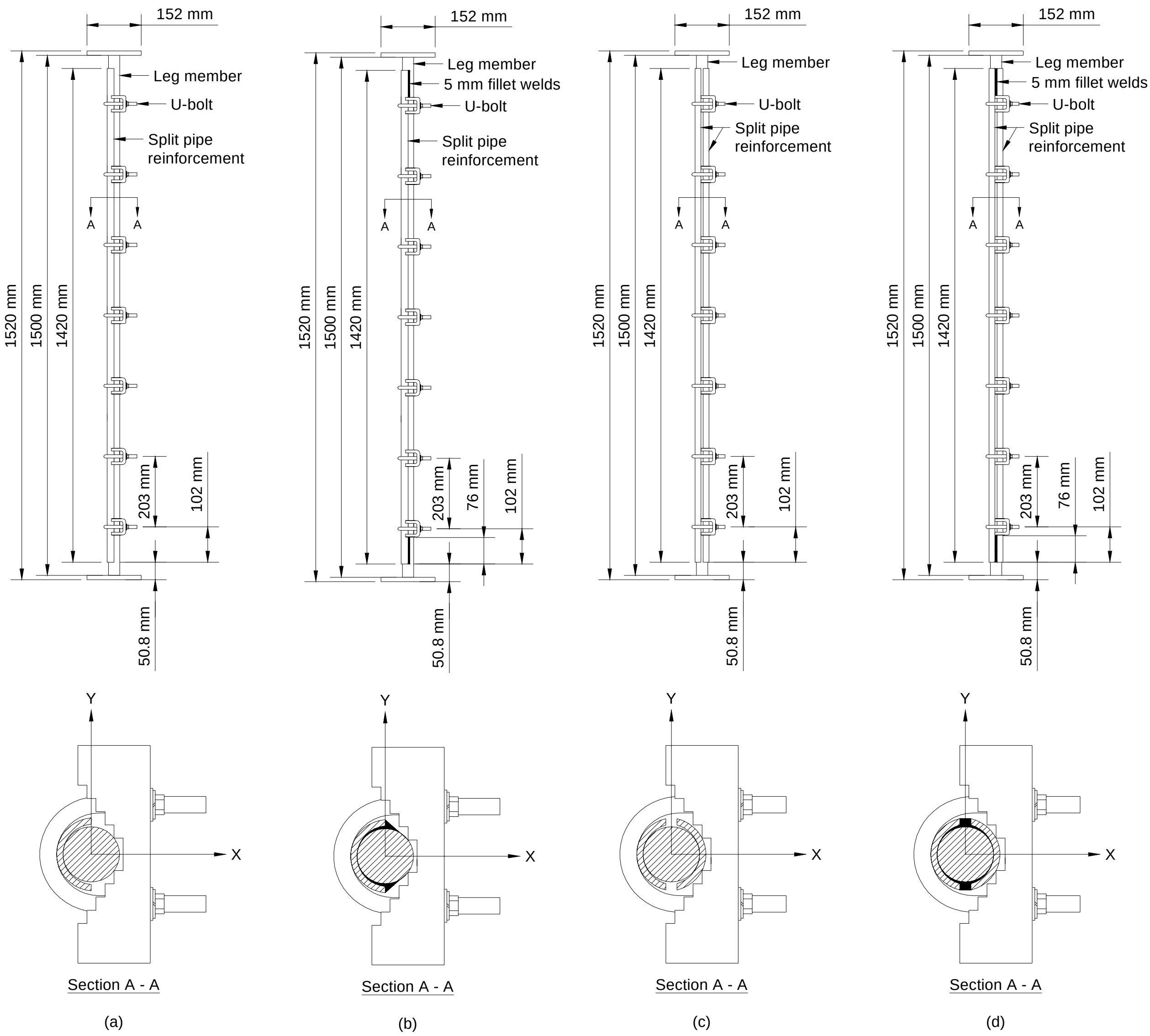


Figure 5. Reinforced Leg Member Specimen (1500 mm Long)

Table 1. Details and Failure Loads of 38.2 mm Diameter, 737 mm Long Test Specimens

Specimen ID	Reinforcing member	Number of U-Bolts	Bolt torque	Failure load	Increase in compressive strength due to reinforcing	Average
			Nm	kN	kN	kN
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
RF-4-A	-	-	-	220	-	-
RF-4-B				233		
RFA-3-A	Semi-circular split pipe on one side without end welding	4	27	240	13.5	19.5
RFA-3-B			41	252	25.5	
RFA-5-A	Semi-circular split pipe on one side with end welding	3	27	278	51.5	39.5
RFA-5-B			41	254	27.5	
RFA-4-A	Circular arc split pipes on two sides without end welding	4	27	262	35.5	35.5
RFA-4-B			41	255	28.5*	
RFA-6-A	Circular arc split pipes on two sides with end welding	3	27	300	73.5	85.0
RFA-6-B			41	323	96.5	

Note:
* Specimen RFA-4-B was initially crooked (resulting in low failure load) and is not included in the computations

Table 2. Details and Failure Loads of 38.2 mm Diameter, 1500 mm Long Test Specimens

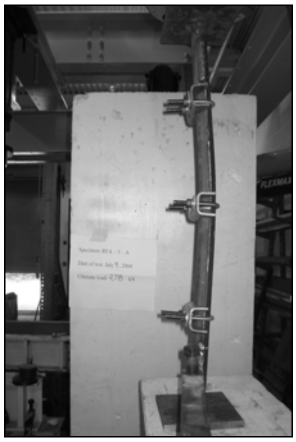
Specimen ID	Reinforcing member	Number of U-Bolts	Bolt torque	Failure load	Increase in compressive strength due to reinforcing	Average
			N.m	kN	kN	kN
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
RF-5-A	-	-	-	138	-	-
RF-5-B				135		
RF-5-C				139		
RFA-7-A	Semi-circular split pipe on one side without end welding	7	27	147	10.5	10.5
RFA-9-A	Semi-circular split pipe on one side with end welding	7	27	172	35.5	41.0*
RFA-9-B			41	183	46.5	
RFA-8-A	Circular arc split pipes on two sides without end welding	7	27	180	43.5	43.5
RFA-8-B			41	185	48.5**	
RFA-10-A	Circular arc split pipes on two sides with end welding	7	27	207	70.5	65.0
RFA-10-B			41	196	59.5	

Notes:
* Both of the specimens were bent about their strong axis, therefore they are not included in the comparison shown in Table 3(b)
** Specimen RFA-8-B was bent about its strong axis, and therefore is not included in the computation of average increase in strength

Testing of Specimens and Results

The top and bottom plates of the specimen were clamped to the test structure to prevent lateral displacement of the specimen during testing. Load was applied concentrically in small increments from the top of the specimen through a hydraulic jack until the specimen failed. The applied load was measured by means of a 445 kN load cell. Figure 6 shows the test setup and the 737 mm long reinforced specimens after failure. The maximum applied loads were recorded and are presented in column 5 of Tables 1 and 2 for 737 mm and 1500 mm long specimens, respectively. The increase in the strength due to reinforcement is shown in column 6 of Tables 1 and 2. It can be seen from column 6 of Tables 1 and 2 that increased bolt torque has no significant effect on the increase in the strength of the test specimens.

(a) Test Setup



(b) Specimens after Failure

Figure 6. Photographs of Experimental Investigation

By comparing specimens RFA-5 and RFA-9 (reinforced with one split pipe with end welding) with RFA-4 and RFA-8 (reinforced with two split pipes without end welding) respectively, it can be concluded that there is no significant difference between them. Since welding is expensive and hazardous to carry out in the field, it is better to use two split pipes without end welding than one split pipe with end welding to gain the necessary increase in strength.

PROPOSED METHOD FOR CALCULATING THE COMPRESSIVE RESISTANCE OF LEG MEMBERS REINFORCED WITH SPLIT PIPE(S)

Based on the experimental investigation, the following simplified and conservative method is proposed to determine the increase in the compressive resistance of solid round members reinforced with split pipe(s) as shown below:

(i) Take the effective length KL as 0.5 times the length of the reinforcement. The effective length factor K is taken as 0.5 since during experimental investigation, it was noticed that the U-bolts and end welding provide rotational restraint at the connection points.

(ii) Calculate the radius of gyration for one-split pipe reinforcement about the axis shown in Figure 7(a) and for two-split pipe reinforcement about the axis shown in Figure 7(b).

(a) For one split pipe, the minimum radius of gyration is about the Y'-axis passing through the centroid of the split pipe

(b) For two split pipes, the minimum radius of gyration is about the X'-axis passing through the centroid of the two split pipes

Figure 7. Axis for Calculation of Minimum Radius of Gyration

(iii) Calculate the compressive resistance (C_r) of the split pipe(s) using Equations 1 and 3 for Canadian and American Standards, respectively.

(iv) Take the increase in strength as 30% of calculated C_r for specimen without end welding and 60% of calculated C_r for specimen with end welding. These percentages make the calculated values agree with experimental results.

An example calculation for specimen RFA-3 is given as follows:
Cross-sectional area of the split pipe, A = 216 mm²
Critical stress,

$$F_{cr} = 0.658^{\lambda^2} \times F_y = 0.658^{0.82^2} \times 439 = 331\ \text{MPa}$$

Young's modulus of elasticity, E = 200 GPa
Yield stress of the split pipe, F_y = 439 MPa
Effective length factor, K = 0.5
Length of the split pipe, L = 660 mm
Parameter for compressive resistance, n = 1.34
Minimum radius of gyration of the split pipe, r_y = 6.00 mm
Resistance factor, ϕ=0.9 for CSA S37-01 and 0.85 for AISC-LRFD Specification
Non-dimensional slenderness parameter,

$$\lambda = \frac{KL}{r}\sqrt{\frac{F_y}{\pi^2 E}} = \frac{0.5 \times 660}{6.00} \times \sqrt{\frac{439}{\pi^2 \times 200000}} = 0.82$$

(a) Compressive resistance of the split pipe based on CSA S37-01:

$$C_r = \phi \times A \times F_y \times \left(1 + \lambda^{2n}\right)^{-\frac{1}{n}}$$

$$= 0.9 \times 216 \times 439 \times \left(1 + 0.82^{2\times 1.34}\right)^{-\frac{1}{1.34}} = 60.3\ \text{kN}$$

Increase in the compressive resistance of the member, 30% of C_r = 18.1 kN

(b) Compressive resistance of the split pipe based on AISC-LRFD Specification:

$$C_r = \phi \times A \times F_{cr} = 0.85 \times 216 \times 331 = 60.7\ \text{kN}$$

Increase in the compressive resistance of the member, 30% of C_r = 18.2 kN

The calculations and results based on the proposed method are given in Tables 3(a) and 3(b). These tables also show comparison between the results obtained based on the proposed method and experimentally determined values.

Table 3a. Proposed Design Method for One- or Two-Split Pipe(s) Reinforcement without End Welding

Specimen ID	Area of reinforcing member (mm²)	Minimum radius of gyration of reinforcing member* (mm)	Length of reinforcing member (mm)	λ	Increase in strength based on proposed method		Increase in strength based on the test
					30% of C_r based on Eq. 1	30% of C_r based on Eq. 3	
Column 1	*Column 2*	*Column 3*	*Column 4*	*Column 5*	*Column 6*	*Column 7*	*Column 8*
RFA-3	216	6.00	660	0.82	18.1	18.2	19.5
RFA-4	369	12.5	660	0.39	41.2	38.7	35.5
RFA-7	216	6.00	1422	1.77	7.1	6.8	10.5
RFA-8	369	12.5	1422	0.85	30.2	30.6	43.5

Note: * See Figures 7(a) and 7(b)

Table 3b. Proposed Design Method for One- or Two-Split Pipe(s) Reinforcement with End Welding

Specimen ID	Area of reinforcing member (mm²)	Minimum radius of gyration of reinforcing member* (mm)	Length of reinforcing member (mm)	λ	Increase in strength based on proposed method (kN)		Increase in strength based on the test (kN)
					60% of C_r based on Eq. 1	60% of C_r based on Eq. 3	
Column 1	*Column 2*	*Column 3*	*Column 4*	*Column 5*	*Column 6*	*Column 7*	*Column 8*
RFA-5	216	6.00	660	0.82	36.2	36.4	39.5
RFA-6	369	12.5	660	0.39	82.4	77.4	85.0
RFA-9	216	6.00	1422	1.77	14.1	13.6	-
RFA-10	369	12.5	1422	0.85	60.5	61.2	65.0

Note:* See Figures 7(a) and 7(b)

CONCLUSIONS

Based on the research, the following conclusions can be drawn:

a. From the results shown in column 6 of Tables 1 and 2, it is concluded that bolt torque has no significant effect on the increase of the compressive strength of the solid round members reinforced with split pipe(s).
b. There is no significant difference between using one split pipe with end welding as reinforcement and two split pipe(s) without end welding. It is recommended that two split pipe(s) without end welding be used instead of one split pipe with end welding.
c. The design method proposed is simple and conservative for determining the increase on the compressive resistance of solid round leg members reinforced with split pipe(s).

ACKNOWLEDGEMENTS

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