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Experimental Tests and Analytical Studies of Bearing-Type Axial Steel Connection

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Abstract. The capacity of the bolted connection on steel tensile rods can be determined through capacity analysis and connection failure. In term of capacity analysis and failure of steel tensile connection, the specified tensile connection capacity is generated based on several parameters such as cross-section of rod, grade of steel, thickness and grade of the steel plate, and grade and diameter of bolts. The capacity of steel tensile connections as a result of capacity analysis and connection failure often has a lower value than the connection capacity in real conditions. In this research, the comparison of 30x30x3mm angle cross-section connections with BJ37 grade quality was connected with 2 mm steel plate (also BJ37 grade) using 8 mm bolt connectors (A307 grade), through capacity analysis, failure study, and experimental study with type of failure is bolt bearing failure. In the capacity analysis study and the failure of steel tensile connections obtained a nominal capacity is 14.21 kN with the type of failure is shear failure. In the experimental study was tested 3 specimens, the average value of ultimate capacity was 18.67 kN and the failure for all of the three specimens are shear failures. The conclusion that can be drawn from this research is both the result of analytical calculations and experimental testing in the laboratory showed a good agreement and have the same trend. The test specimens were designed on the basis of analytical calculations for bolt bearing failure, experimental test results for all of three specimens all showed a failure pattern of bolt shear. The nominal strength from the results of the analytical study with the ultimate load of the experimental study results has a difference of 31.4% with higher experimental results. Through this research is expected to be a learning-media to know one type of failure on the steel connections that is bolt shear failure, obtain a comparison between analytical calculation results referring to applicable design standards, and the results of experimental testing in the laboratory.

Introduction

Steel is widely used in the bridge structure, which is specifically a bridge with a type of truss structure as shown in Figure 1. The truss structure transmits axial forces acting like tensile and compressive forces through their components. The rod components that make up the truss are interconnected to each join with the pin type (not holding the moment or shear). The connection between components can be connected using a steel plate (side) and a mechanical connector such as bolt. The axial joint system of the tensile rods of steel comprises several types of failure probabilities, which are tensile, shear (bolt failure), bearing, and block shear types [1,4,6]. The type of tensile failure is failure occurs in the drag rod, the type of shear failure is a failure occurs on the bolt, the type of failure of the bearing is a failure occurs due to the bolt effect on the hole connection, as long as the combination of block shear type is a failure occurs in the block shear. The tensile strength of the steel tensile joints can be determined through capacity analysis and connection failure, inter alia referring to the regulations of SNI 1729: 2015 [4] or AISC 360-16 [1]. The connectivity capacity is determined based on several structural parameters such as the cross-section type and the grade of steel, the thickness and grade of the connecting plate, and the diameter and grade of the connection bolts. The capacity of steel tensile joint connections resulting from capacity analysis and connection failure often has a lower value than the connection capacity in real conditions.

Figure 1 Truss Steel bridge [5].

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The objective of the study is to study the strength capacity of axial joint of steel tensile connection by analytical method and experimental testing in the laboratory. The scope of the research is the test object that is observed is the axial connection of the pull rod, the loading method is uniaxial tensile, the number of specimens are three specimens, the test using Universal Testing Machine, in analytical calculation used assumption of 240 MPa for yield strength and 370 MPa of ultimate strength, the failure to be observed is the bolt failure on the bolt hole, the cross-section of the steel is the angle L30.30.3, the bolt used is 8 mm diameter and A307 grade.

2 Basic Theory

The analysis of the strength of steel tensile joints using bolts is based on SNI 1729:2015 [4]. The equations that must be met according to the LRFD (Load Resistance Factor Design) or in Indonesian called DFBK (Desain Faktor Beban Ketahanan) method. The strength according to the melting limit of the gross cross section in accordance with SNI 1729: 2015 Chapter D2 (a) (Equation 1).

$$\phi R_n = \phi \text{ x } F_y \text{ x } A_g \quad (1)$$

Which are:

ϕ = resistance factor for tensile yield limit, 0,90

F_y = yield strength of steel

A_g = gross cross-section of steel rod

The strength of the pull rod according to the limit of collapse on the net section in accordance with SNI 1729: 2015 Chapter D2 (b) is shown by Equation 2.

$$\phi R_n = \phi \text{ x } F_u \text{ x } A_e \quad (2)$$

Which are:

ϕ = resistance factor for tensile ultimate limit, 0,75

F_u = ultimate strength of steel

A_e = net cross-section of steel rod

The effective net width (A_e) is calculated following the provisions of SNI 1729: 2015 Chapter D3, as in Equation (3) and Equation (4).

$$A_e = U \text{ x } A_n$$

$$U = 1 - x / 1$$

Which are:

U = shear lag factor

x = excentricity of connection

l = length of connection

The net width of the trunk section cross section (A_n) is calculated following the provisions of SNI 1729: 2015 Chapter B4.3, which can be written as Eq. (5).

$$A_n = A_g - n \text{ x } d \text{ x } t$$

Which are:

n = number of bolt in the line of tensile failure

d = hole diameter for net cross-section of tensile rod

t = thickness of plate

The strength of the bolt shear at the pivot type connection, according to SNI 1729:2015 Chapter J3.6 is shown by Equation 6.

$$\phi R_n = \phi \text{ x } F_{nv} \text{ x } A_b$$

Which are:

ϕ = resistance factor for shear of bolt 0.75

F_{nv} = nominal shear stress of bolt

A_b = nominal cross-section of bolt

The strength of the bolt hole (ϕR_n), according to SNI 1729:2015 Chapter J3.10 (a) is shown by Equation 7.

$$R_n = 1.2 \text{ x } l_c \text{ x t x } F_u \leq 2{,}4 \text{ x } d_b \text{ x t x } F_u$$

Which are:

ϕ = resistance factor in term of bearing strength 0.75

l_c = clear distance hole to hole

d_b = bolt diameter

The shear strength of the block (ϕR_n) on the steel rod joints, in accordance with SNI 1729:2015 Chapter J4.3 is shown by Equation 8.

$$R_n = 0.6 \text{ x } F_u \text{ x } A_{nv} + U_{bs} \text{ x } F_u \text{ x } A_{nt} \leq 0.6 \text{ x } F_y \text{ x } A_{gv} + U_{bs} \text{ x } F_u \text{ x } A_{nt}$$

Which are:

ϕ = resistance factor in term of block shear 0,75

A_{nt} = tensile net area R_n = nomi

A_{nv} = shear net area

A_{gv} = gross area

U_{bs} = reduction coefficient for block shear failure

Experimental tests of tensile strength of tensile bars are based on ASTM E8 / E8M - 16a Standard Test Methods for Tension Testing of Metallic Materials (ASTM, 2016) with a crosshead test rate of 0.015 mm/mm/min. Figure 2 shows the Universal Testing Machine (UTM) used for experimental testing.

Fig. 2. Universal Testing Machine for tensile testing of steel joints.

3 Case Study

(5)

In this study, the steel tensile beam test of the elbow profile is equal to the quality foot BJ-37 size 30x30x3mm spliced with BJ-37 thickness steel plate 3 mm using A307 diameter bolt 8 mm diameter which has the connection configuration as shown in Figure 3. With the configuration of steel tie rod connections such as shown in Figure 2, two models of study were studied: an analytical study of the strength of steel tapered joints using bolts according to the DFBK method determined by SNI 1729:2015 and experimental studies of steel tensile joints testing using bolts in the laboratory.

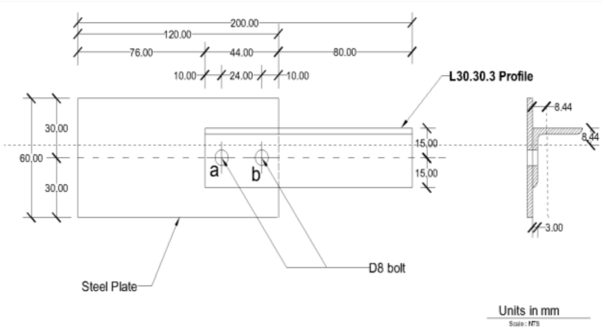

Fig. 3. Configuration of axial tensile steel connection

3.1 Analytical Study

The strength of the angle (L) rod according to the yield and the ultimate limits calculated according to Equation 1 to Eq. 5, the following results are obtained: Strength of the stem according to the melting limit conditions:

$\phi R_n = 0.90 \times F_y \times A_g = 37303$ N

The strength of the stem according to the boundary condition of pull collapse:

$\phi R_n = 0.75 \times F_u \times A_e = 24594$ N

The strength of the bolt shear at the base-type connection is calculated according to Equation 6, with the following results: Sliding strength of connection using 2 pieces of bolts:

$\phi R_n = 0.75 \times n_{baut} \times F_{nv} \times A_b = 18900$ N

The strength of the bolt hole base is calculated according to Equation 7. For this calculation it is necessary to determine the net distance (lc) between the edges of the bolt a to the edge of the tied rod and the edge of the bolt a and bolt b as shown in Figure 3.

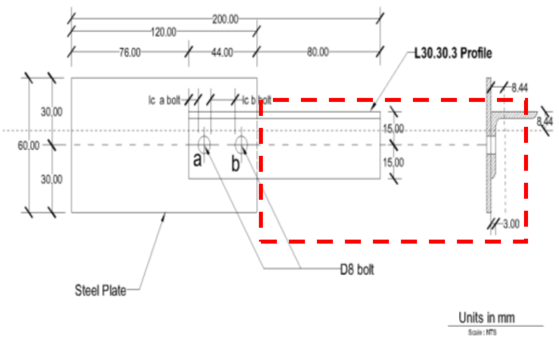

Fig. 4. Determine the clear distance (l_c) hole to hole of bolts

The strength of the bolt hole:

$R_n = 1.2 \times l_c \times t \times F_u \leq 2.4 \times d_b \times t \times F_u$

bolt a:	3552	≤	14208	→	R_{na} =	3553	N
boltt b:	10656	≤	14208	→	R_{nb} =	10656	N

so:	R_n =	R_{na} + R_{nb}					
	R_n =	14208	N N	and	ϕR_n = 10656		

The shear strength of the steel tank trunk connection joints is calculated according to Equation 8. The determination of the sliding block area is shown in Figure 4.

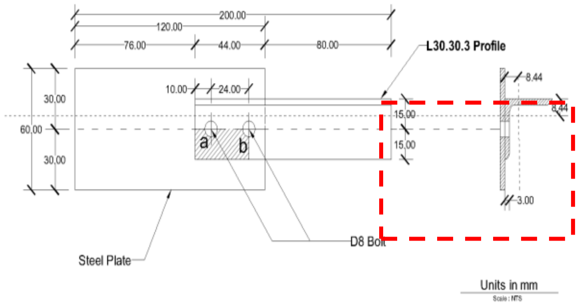

Fig. 5. Determining the block shear

Block shear strength:

$R_n = 0.6 \times F_u \times A_{nv} + U_{bs} \times F_u \times A_{nt} \leq 0.6 \times F_y \times A_{gv} + U_{bs} \times F_u \times A_{nt}$

Fracture:	$0.6 \times F_u \times A_{nv} + U_{bs} \times F_u \times A_{nt}$	=	20646	N
Yield:	$0.6 \times F_y \times A_{gv} + U_{bs} \times F_u \times A_{nt}$	=	24678	N

The smallest value that determines, so R_n = 20646 N and ϕR_n = 15485 N.

Table 1. Strength/Capacity of Steel Axial Connection

Analysis	ϕR_n (kN)	R_n (kN)	Summary
Yield Tensile Strength	37.30	41.45	-
Ultimate Tensile Strength	24.59	32.79	-
Bolt Shear Strength	18.90	25.20	-
Bearing Strength	10.66	14.21	Critical
Block Shear Strength	15.49	20.65	-

The summary of the tensile steel tie connection capacity is shown in Table 1, which is based on the analytical calculation of the capacity of the melting yield limit, the ultimate strength, the bolt strength, the bolt hole or bearing strength, and the block shear strength. From the analytical study, the configuration of the joints in this study as shown in Figure 1 has a limit of 14.21 kN (without ϕ).

3.2 Experimental Study

In the experimental study testing of steel tensile joints were prepared 3 specimens according to the configuration of Figure 1. Tensile tests were performed using Universal Testing Machine (UTM). On specimens welded a special clamp of stainless-steel material to ensure the steel connection receives an axial force optimally as shown in Figure 6. Before tensile testing begins, the three test objects are erect on the bolts so that all trimmed steel rod joint elements can work optimally to load. The initial conditions of the three test pieces of steel tug joints are shown in Figure 6. Tensile testing is performed on each connection with axial force axial force of 5mm/min until each specimen fails due to the axial force of attraction received. The tensile test results are shown in Figure 7.

In Figure 8, the three specimens experience a failure on the plate according to the predicted of the analytical study. Tensile test result, obtained load curve to deformation (P-D curve). From the P-D curve we get the proportional limit load value (P_y) and the ultimate load value (P_u) of the steel tensile bearing test specimen shown in Figure 9 and Table 2.

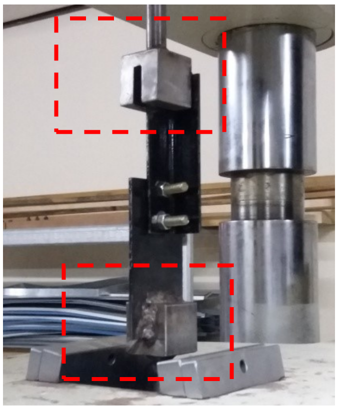

Fig. 6. Setup of specimen on Universal Testing Machine (UTM)

(a) Specimen 1 (b) Specimen 2 (c) Specimen 3

Figure 7 All of 3 (three) specimens.

(a) Specimen 1 (b) Specimen 2 (c) Specimen 3

Fig. 8. Failure of 3 (three) specimens

From Table 2 we get the average value of the three test pieces of steel tug joints. For a proportional limit load (P_y) of 12872.33 N and for ultimate load (P_u) of 18669.33 N. Design limit (R_n) of analytical study results of 14.21 kN or 14208 N (without ϕ). When compared with the ultimate load value of the experimental (P_u) experimental results on average of 3 (three) specimens is 18669.33 N means that the experimental study results have 31.40% greater value.

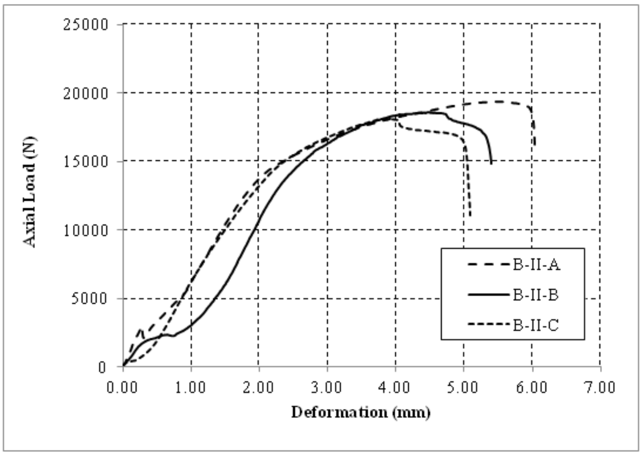

Fig. 9. P-D curves of Steel Axial Connection Specimen

Table 2 Results of Proportional (P_y) and Ultimate (P_u) Loads

Specimen	P_y (N)	D_y (mm)	P_u (N)	D_u (mm)
B-II-A	11565.42	1.65	19376.36	5.47
B-II-B	15231.94	2.70	18581.79	4.48
B-II-C	11819.64	1.77	18049.83	3.86
Average	12872.33	2.04	18669.33	4.60

4 Conclusion

The conclusions that can be obtained from this research are both the result of analytical calculations and experimental testing in the laboratory showed a good agreement and the same trend. The test specimen was designed on the basis of analytical calculations for bolt bearing failure, experimental test results for 3 (three) test specimens all showed a failure pattern of bolt shear. The nominal strength of the analytical study with the ultimate load of the experimental study results has a difference of 31.4% with higher experimental results. Through this research is expected to be a learning-media to know one type of failure on the steel connections that is bolt shear failure, obtain a comparison of analytical calculation results referring to applicable planning standards and the results of experimental testing in the laboratory.

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