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Whitmore Section and Block Shear Failure Analysis on a Bolted Gusset Plate using Finite Element Method

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Abstract. In order to determine the tensile capacity of a bolted gusset plate, the Block Shear capacity often came out as the most common failure. However, in the SNI 1729-2015, it's stated on a User Note in section J4-1 that an element under tension should be checked against the Whitmore Section criterion. The analysis done in this research paper compared these two failure criteria on a few case models of a bolted gusset plate under tensile stress. The Finite Element Method, with the assistance of ABAQUS software, is used to determine the failure of the modeled cases. The results of the analysis will compare all of the gusset plate's failure criteria of the Whitmore Section, Block Shear and the Finite Element Method. This paper proposes that the Whitmore Section check is deemed unnecessary in light of Block Shear criterion which proven by the FEM as the correct failure of the plate.

1. Introduction

Gusset plate has long been used as a connecting component between two or more profiles in a steel structure. In a tensile bolted connection, there are several components that make up the connection: the truss member, the gusset plate and the bolts as connecting components between the two. This paper specifically discuss the failure criteria of the gusset plate which covers the yield and block shear failure. The Whitmore section can be defined by drawing a 30° line from the outermost pair of bolts to the inward direction until it intersects the line extension of the deepest pair of bolts. The line formed on the last pair of the bolt is called the Whitmore effective width (W_w). Then the Whitmore section is calculated from the effective Whitmore width multiplied by the thickness of plate.

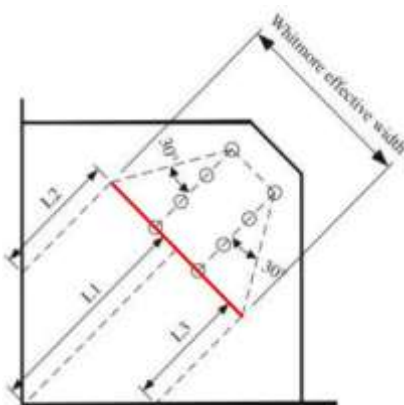


Figure 1. Illustration of the Whitmore effective width.



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Whitmore section was described by Whitmore(1952) as a reasonable method for approximating maximum tensile elastic stress incurred in a riveted gusset plate by the axial force in a connected brace. Although this method has been widely used since the late 1970s, the Whitmore section was never explicitly written in any building code until AISC 2010 in a form of User Note under section J4.1. Elements Under Tension.

According to Kulak et al (2001, p.253), the design of a gusset plate is to be checked against both Whitmore section and the block shear failure mode, and the more severe requirement resulting from them then should be applied.

The finite element method is a numerical method for solving problems of engineering and mathematical physics (Logan,2012:1). This analysis is performed by discretizing an object into connected smaller elements. The smaller the elements are, the more accurate and actual the result will be.

This paper will present the study of a few model cases of gusset plates failure mode, with the help of ABAQUS program. The result will later show the actual failure mode of said cases, then compare it with the theoretical calculation as instructed by SNI 1729-2015. And along the way, the result will also show the load distribution for each bolt attached.

2. Comparison on Whitmore Section and Block Shear

According to Dewobroto (2015), the block shear failure happened when a section experienced both shear and yield failure as shown on Figure 2.

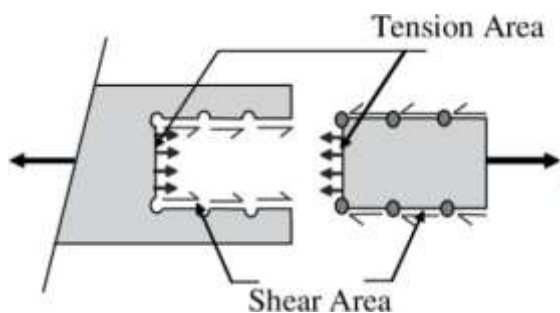


Figure 2. Block shear failure of a plate. The section parallel with the force direction experienced shear failure while the perpendicular one yield by tension.

Block shear capacity as stated by the code should be determined by :

$$R_n = 0.6 F_u A_{nv} + U_{bs} F_u A_{nt} < 0.6 F_y A_{gv} + U_{bs} F_u A_{nt} \quad (1)$$

where

F_u = ultimate tensile strength (MPa)

F_y = yield strength (MPa)

A_{nv} = net shear cross sectional area (mm²)

A_{gv} = gross shear cross sectional area (mm²)

A_{nt} = net yield cross sectional area (mm²)

U_{bs} = tensile distribution (uniform) $U_{bs}=1$

But this study will use the formula proposed by Teh and Deierlein (2017) that has been checked with 161 block shear specimen and proven correct.

$$\begin{aligned} R_n &= F_u A_{nt} + 0.6 F_u A_{ev} \\ &= F_u [(n_l - 1)(g - d_h) + 1.2 \{(n_r - 1)p + e_l - \frac{2(n_r - 1)}{4} d_h\}] t \end{aligned} \quad (2)$$

where

t = thickness of the plate (mm)

n_l = number of bolt rows in direction of loading

n_r = number of bolt rows perpendicular to direction of loading

As for the Whitmore section criterion, Kulak et al (2001 p.244) stated that the design of gusset plates has long been based on simple methods of analysis. Whitmore observed that the locations of the maximum tensile and compressive stress were near the ends of the tension and compression diagonals, respectively. This area was obtained by multiplying the thickness of the plate by an effective length. The effective length was estimated by constructing 30° lines from the outer fasteners in the first row to their intersection with a line perpendicular to the line of action of the external load and passing through the bottom row of fasteners.

Therefore, the Whitmore section capacity can be formulated by

$$R_n = F_u A_e = F_u W_w t \quad (3)$$

$$= F_u [(n_l - 1)(g - dh) + \{2(n_r - 1)p \tan 30^\circ - dh\}] t \quad (4)$$

where

t = thickness of the plate (mm)

n_l = number of bolt rows in direction of loading

n_r = number of bolt rows perpendicular to direction of loading

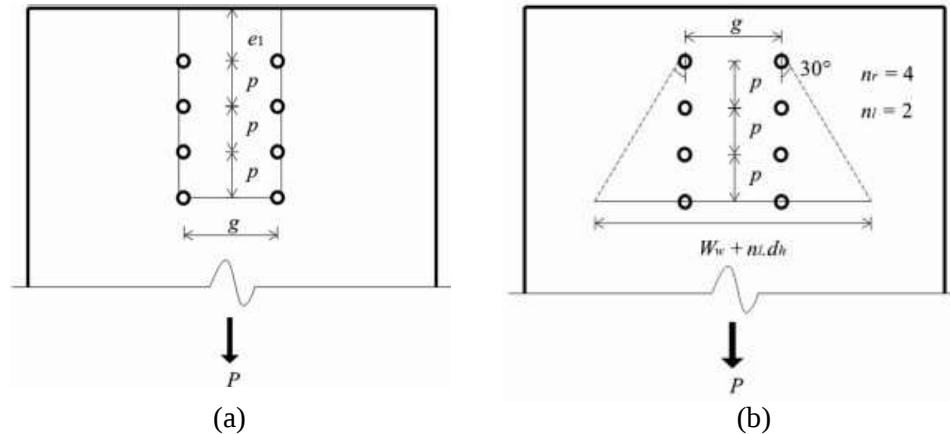


Figure 3. Illustration for capacity formula on (a) block shear and (b) Whitmore section

3. Finite Element Modelling

The typical model of all cases is as shown on Figure 4. The gusset plate is restrained on one side, connected to a brace through bolts on the opposite. Then a force is applied on the brace, pulling the plate the opposite direction of the restraint creating tensile stress. In order to simplify the modelling, only the gusset plate will be modeled with a few adjustments.



Figure 4. Illustration of the typical model of the cases .

There are 9 case models in total, each with different amount of bolts and different size of the plate adjusted to accommodate the full length of the Whitmore width. The row of bolts are increased each time in order to find the failure trend of the cases. For every cases, a few fixed variables are made as such : 10 mm plate thickness (t), 20 mm bolt hole diameter (dh), 30 mm bolt to edge distance (e) and 60 mm gauge between each bolt holes (g). The 9 case models are as follows :

Table 1. Case models dimension

Case	Amount of bolts	width mm	length mm
M2	4	250	150
M3	6	320	210
M4	8	390	270
M5	10	460	330
M6	12	530	390
M7	14	600	450
M8	16	670	510
M9	18	740	570
M10	20	810	630

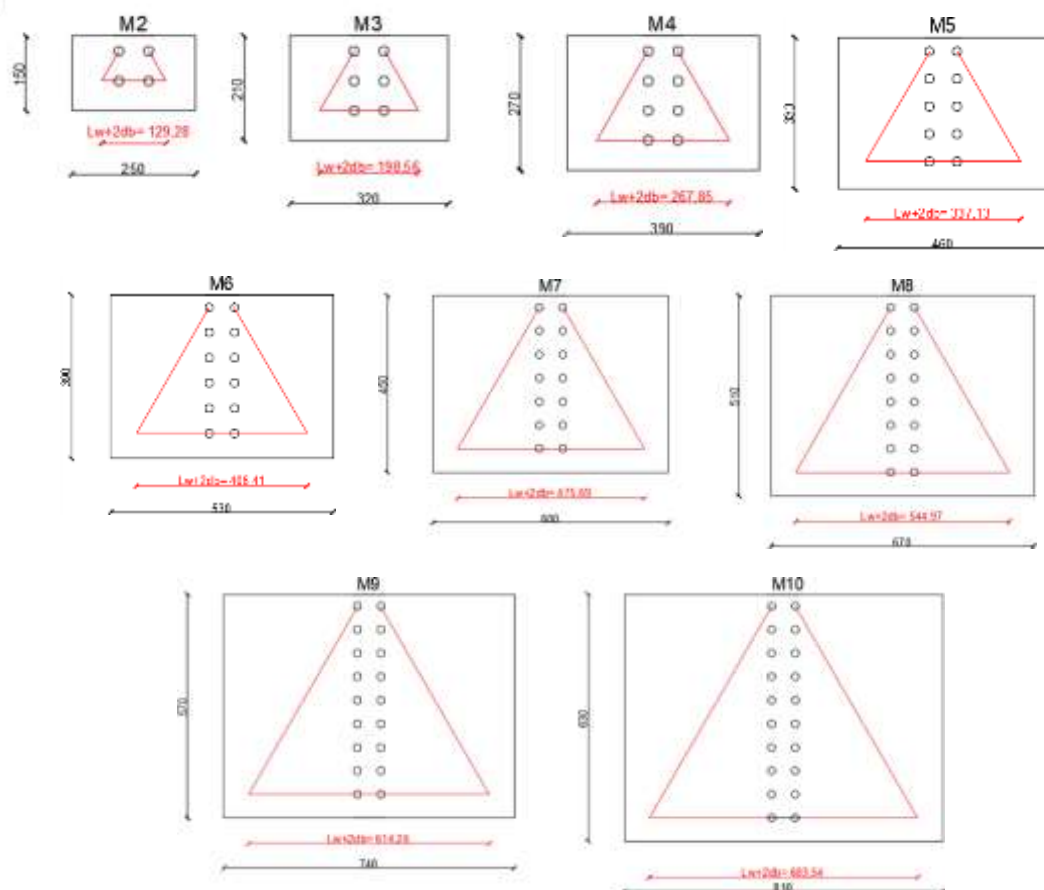


Figure 5. M2-M10 case model sketches

Considering the thin geometry of the gusset plate and assuming there are no out of plane stress, 2D plane stress elements are used to model all the cases with 0.3 poisson ratio to accommodate the out of plane strain. The material used is a BJ41 Indonesia steel with following properties : 7.8×10^{-9} tonne/mm³ density, 2×10^5 MPa Young's Modulus, with maximum stress $F_y=250$ MPa and $F_u=410$ MPa. The non-linearity geometry factor will be represented in a plotting of simplified stress-strain relationship with maximum elongation of 18%.

To simplify the model even further, the position of the restrain and the load nodes will be switch. Based on the assumption that only the half-upper side of the bolt holes will receive the load transferred from the bolts, said area will be restrained as the load will be move to the lower edge of the plate. This modelling is illustrated in Figure 6 as an example of the M7 model with loads and restrains already applied. And same circumstances will also be applied to the other models.

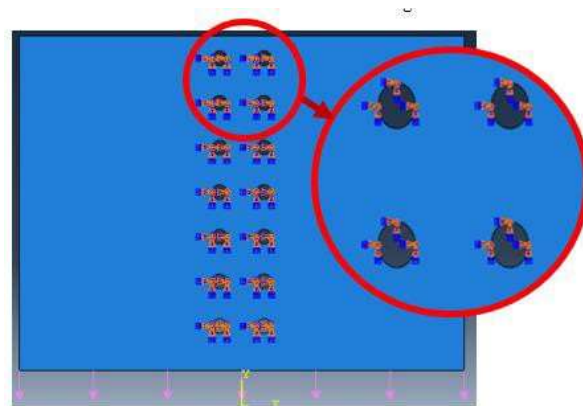


Figure 6. M7 models with restrained half upper side of the bolt holes and pressure applied on the lower edge of the gusset plate .

4. Analysis Results

The von mises stress contour will be used to determine the failure criteria of the plates modeled. The contours of all the models in Figure 7 show that there are no stress concentration along the Whitmore width. It can be concluded that all of the models failed by the block shear criterion as depicted by the von mises contour along the block shear area.

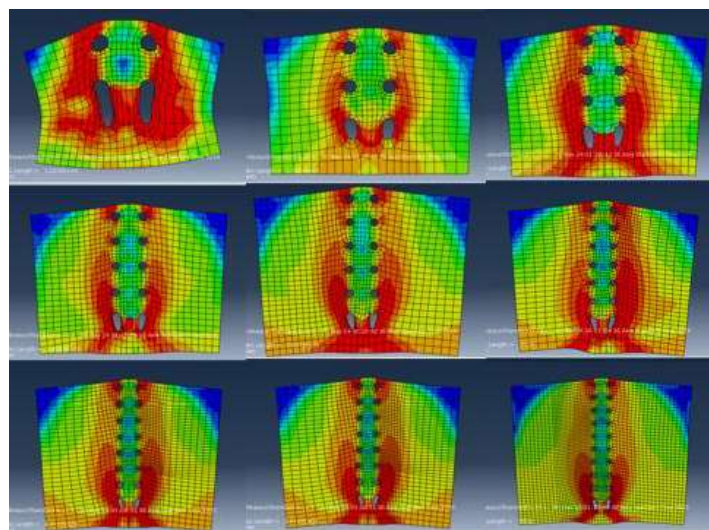


Figure 7. Von Mises contours for M2-M10 models

The results of the finite element modelling analysis, as well as the theoretical capacity suggested by the code will be presented in Table 2 and Figure 8 below.

Table 2. Comparison of gusset plates capacity prediction

Index	Whitmore Capacity KN	Block Shear Capacity KN	FEM Capacity KN	% error BS vs FEM %
M2	366.056	533	597.36	12.08
M3	650.112	779	866.50	11.23
M4	934.169	1025	1046.51	2.10
M5	1218.225	1271	1246.51	1.93
M6	1502.281	1517	1501.90	1.00
M7	1786.338	1763	1676.94	4.88
M8	2070.394	2009	1879.24	6.46
M9	2354.450	2255	1933.41	14.26
M10	2638.507	2501	2299.81	8.04

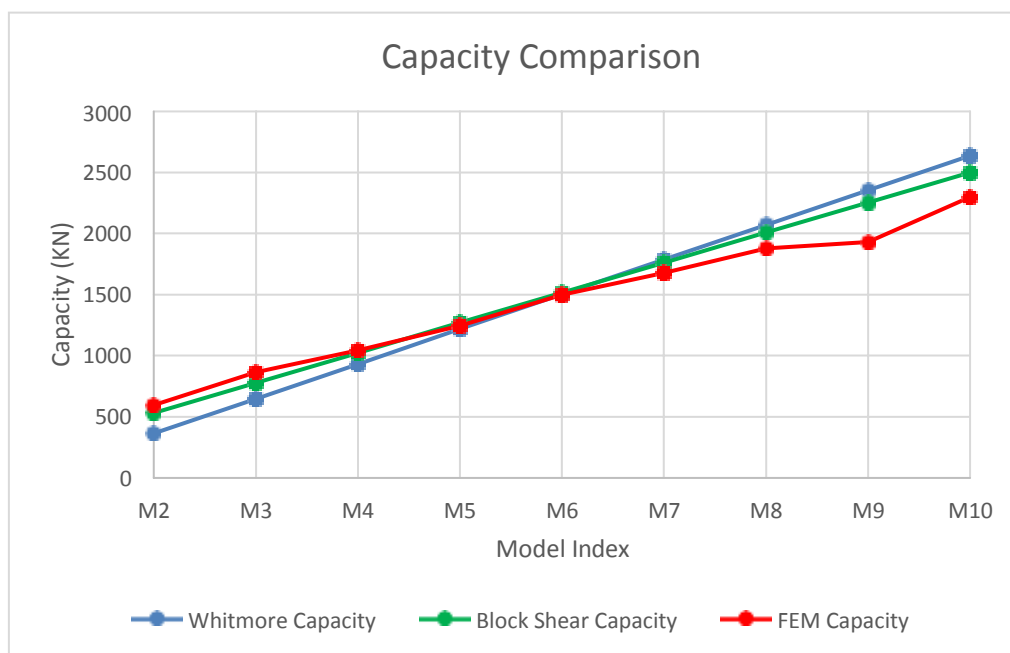


Figure 8. capacity comparison graphs for M2-M10 models

5. Conclusion

For a standard bolted connection satisfying the SNI 1729-2015 for bolt spacing and end distance, both Whitmore section and block shear lead to similar results if there are approximately 6 or 7 rows of bolts. This paper has shown that the correct failure is the block shear criterion. As for connection with 2 or 3 rows of bolts, the Whitmore criterion proved to be excessively conservative. Conversely, for connection having more than 8 rows of bolt, the Whitmore criterion overestimated the maximum capacity by a huge margin.

On the other hand, the block shear criterion predicted correctly all of the plate's failure with an average of 6.89 % of deviation between the actual and the theoretical strength. To be concluded, this paper proposed that the Whitmore section criterion proven redundant in light of the block shear check.

References

- [1] AISC. (2010), Specification for Structural Steel Buildings, ANSI/AISC 360-10, American Institute of Steel Construction, Chicago, Illinois.
- [2] Badan Standarisasi Nasional 2015.SNI.03-1729-2015: Spesifikasi untuk Bangunan Gedung Baja Struktural, Indonesia.
- [3] Dewobroto,Wiryanto.2015. Struktur Baja Perilaku, Analisis & Desain. Jakarta:Lumina Press
- [4] Elliot, M.D. and Lip H. Teh. 2018. "Whitmore Tension Section and Block Shear".ASCE
- [5] Higgins, Christopher, A. Ekin Senturk and O. Tugrul Turan.2010."Comparison of Block-Shear and Whitmore Section Methods for Load Rating Existing Steel Truss Gusset Plate Connection".ASCE
- [6] Kulak, G. L., J. W. Fisher, and J. H. A. Struik. 2001. *Guide to design criteria for bolted and riveted joints*. 2nd ed. Chicago: AISC.
- [7] Logan, D. L. (2012), A First Course in the Finite Element Method. 5th ed., Nelson, Canada.
- [8] Schultz,H.C., W. Sobek, K.J. Habermann.2000.*Steel Construction Manual*. Birkhauser,Germany
- [9] Whitmore, R. E. 1952. Experimental investigation of stresses in gusset plates. Bulletin No. 16. Knoxville, TN: Univ. of Tennessee.