

Study of Block Shear Capacity of Bolted Connections in Rolled Steel Sections with Staggered Bolting

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Abstract- Block shear failure is characterized by combination of rupture on the tension plane and yielding on the shear plane(s) of a block of material. The current equation of design strength due to block shear specified in IS code fail to predict the block shear load capacity of staggered connections. Block shear is known as a potential failure mode and shall be considered as one of the governing failure mode. In the present paper, an experimental study has been done over number of bolted plate sections connected in staggered pattern. 400mm*200mm specimens with three 18mm diameter bolt holes in staggered pattern were tested on Universal Testing Machine in tension. The quality of the block shear equation specified in the IS code is compared with those achieved through experimental results. For small eccentricity, projected shear length of inclined failure plane holds good.

Keywords- Block Shear, shear connection, Staggered Bolts, Steel plates, Tension member.

I. INTRODUCTION

Block shear failure is known to be a potential failure mode which may control the load capacity of several different types of bolted connections, including shear connections at the ends of coped beams, tension member connections and gusset plates. The block shear failure occurs along a path which involves tension on one plane and shear on a perpendicular plane as shown in Fig.1.

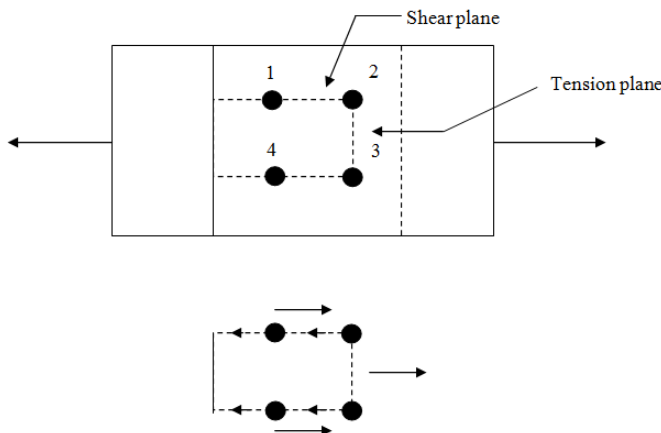


Figure 1 Block Shear Failure

This mode of failure can occur in either welded or bolted connections, but is more common in the latter because of the reduced area that results from the bolt holes. This paper deals only with bolted connections. The block shear phenomenon become a governing mode of failure with the use of high bearing strength material and high strength bolts which results in fewer bolts and smaller connection length. Failure accompanies by rupturing of the net tension plane (2-3) and yielding on the gross shear plane (1-2 and 3-4). It is also possible to have shear rupture and tension yield. Because the limit state is fracture, the controlling equation for block shear will be the one that contains the large fracture term. According to IS 800-2007 [1] the block shear strength at an end connection shall be taken as the smaller of following equation. But it does not exactly predict the design block shear strength for staggered connections.

$$T_{db} = [A_{vg}f_y / (\sqrt{3}\gamma_{m0}) + 0.9A_{nt}f_u / \gamma_{m1}] \quad (1)$$

Or

$$T_{db} = [0.9A_{vn}f_u / (\sqrt{3}\gamma_{m1}) + A_{tg}f_y / \gamma_{m0}] \quad (2)$$

According to AISC [2] 2010 specification available strength for the limit state of block shear rupture is given as

$$R_n = 0.6f_uA_{nv} + U_{bs}f_uA_{nt} \leq 0.6f_yA_{gv} + U_{bs}f_uA_n \text{ (AISC Eq.J4-5)} \quad (3)$$

In Euro code [3] the design value for block shear (termed “block tearing” in the standard) for symmetric bolt groups, under centric loading is determined from the Equation

$$V_{eff,1}, R_d = f_u A_{nt} / \gamma_{M2} + (1/\sqrt{3})f_y A_{nv} / \gamma_{M0} \quad (4)$$

Various experimental studies have been carried out for block shear analysis. Epstein [4] performed an experimental study on double-row, staggered and non-staggered bolted connections of structural steel angle. The effect of several parameters in the connection geometry was investigated. Test results were compared with the current code provisions and a revised treatment was suggested by inclusion of a shear lag factor to the equation. Gross [5] tested ten A588 Grade 50 and three A36 steel single angle tension members with various leg sizes that failed in block shear. Test results

were compared with the AISC-ASD and AISC-LRFD equation predictions and it was observed that code treatments accurately predict failure loads for A36 and A588 specimens. Orbison [6] tested 12 specimens that failed in block shear. Experimental failure loads were compared with code treatments. Recommendations were given based on the ultimate load and the strain variation along the tension plane that was measured during the experiments. Teh and Yazici [7] performed study on hot rolled steel section and demonstrated through laboratory tests that a block shear failure by the shear rupture and tensile yielding mechanism is possible for staggered bolted connections, albeit for a particular configuration only. The test results, however, confirm that the dominant mechanism for block shear failures of staggered bolted connections is the shear yielding and tensile rupture mechanism.

Cunningham [8] performed a statistical study to assess the American block shear load capacity predictions. Even though, both ASD and LRFD equations predicts the failure loads with a reasonable level of accuracy on an average, it was observed that both the ASD and LRFD block shear predictions have drawbacks in terms of anticipated failure modes. It was evident from the test results that tension and shear planes do not rupture simultaneously as assumed in ASD specification. Kulak and Grondin [9] performed a statistical study on evaluation of LRFD rules for block shear capacities in bolted connections with test results. It was stated that there were two equations to predict the block shear capacity but the one including the shear ultimate strength in combination with the tensile yield strength seemed unlikely. As a conclusion, Kulak and Grondin recommended different equations for predicting the block shear capacities for gusset plates and coped beams. Dr. Mohan Gupta and Dr. L. M. Gupta [10] performed finite element analysis and examined the block shear capacity of steel single as well as double angles, for bolt holes in one or more rows, and with staggered and non-staggered holes. The study suggests that there is a considerable improvement in values of professional factors when the concept of effective block gross shear area is used in the computations. Topkaya [11] discussed Finite Element parametric studies on block shear failure of steel tension members and conducted test to develop simple block shear load capacity prediction equations that are based on finite element analysis. Based on the parametric study block shear load capacity prediction equations were developed. The predictions of the developed equations were compared with the experimental findings and were found to provide estimates with acceptable accuracy. Clement and Teh [12] presents the nonlinear contact finite brick element analysis results that confirm the location of the active shear planes, indicated by regions of maximum shear stresses. The finite-element analysis also found that shear

stresses approach zero toward the free downstream end of the connection block.

In this paper an experimental study has been conducted to understand the effect of some variables on block shear capacity in steel plates with staggered bolt configuration. Geometric and material variables are defined as the spacing between bolts, end distances, edge distances, pitch, gauge, yield strength (f_y), ultimate strength (f_u) of material. A triangular form of staggered holes pattern in two gauge line was analyzed. These holes were placed in a triangular form which results symmetrical gauge and stagger line to occur.

II. EXPERIMENTAL STUDY

A total of 24 triangular shaped staggered connections were analyzed. Specimen had a dimension of 400mm and 200mm in length and width respectively with 5mm plate thickness. Analyzed specimens had an ultimate strength value of 410MPa and yield strength value of 250MPa. High strength bolts of 8.8 grade and 16mm in diameter were used.

The test was performed on Universal testing machine (UTM). Above mentioned 24 specimens were classified into 8 sets as A, B, C, D, E, F, G, H. Pitch in each set was increased by 5mm. The set A possess non-staggered bolt configuration. Rest 7 sets were having staggered bolt configuration.

The edge (e) and end (E) distances were kept as 60mm and 25mm respectively. Gauge (g) was kept as 40mm as shown in fig.2. For 16mm diameter bolt the diameter of bolt hole was taken as 18mm.

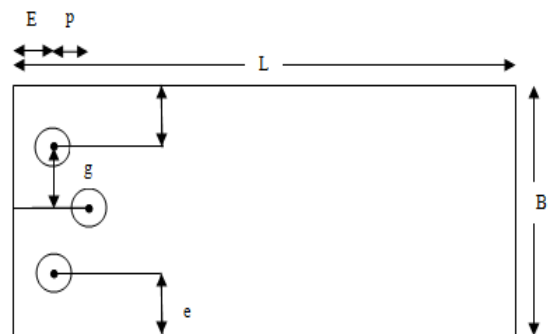


Figure 2 Test setup and details of tested steel plate

III. RESULTS AND DISCUSSIONS

Table 1 summarizes the details of tested steel specimen

Table 1 Test results

Set	specimen	End distance E (mm)	Edge distance e (mm)	Pitch p (mm)	U.L (K.N)
A	A1	25	60	0	99.74
	A2	25	60	0	105.94
	A3	25	60	0	102.72
B	B1	25	60	5	114.19
	B2	25	60	5	110.86
	B3	25	60	5	118.62
C	C1	25	60	10	128.71
	C2	25	60	10	123.99
	C3	25	60	10	131.18
D	D1	25	60	15	142.59
	D2	25	60	15	137.11
	D3	25	60	15	138.37
E	E1	25	60	20	151.98
	E2	25	60	20	150.23
	E3	25	60	20	151.73
F	F1	25	60	25	167.22
	F2	25	60	25	163.35
	F3	25	60	25	172.23
G	G1	25	60	30	176.47
	G2	25	60	30	181.80
	G3	25	60	30	177.76
H	H1	25	60	35	186.65
	H2	25	60	35	189.59
	H3	25	60	35	191.90

IS code presents an incorporation of $p^2/4g$ developed by Cochrane [13] for stagger when dealing with net tension failure, but do not as yet explicitly deal with stagger effects when dealing with block shear.

IV. CONCLUSION

1. IS code predicts an approximate failure mechanism.
2. A new equation was developed for staggered three bolt pattern.
3. For small eccentricities projected shear length of inclined failure plane(s) holds good

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