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Changing bolt arrangement and their effect on bearing capacity of single shear connections

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Abstract: In steel structures, bolted joints are used to connect structural elements. Due to the ease of its making, the square and rectangle arrangement of bolts are the prevalent pattern in these structural joints. To investigate the effect of changing the arrangement of bolts on the bearing capacity of single shear joint, square, circular and diamond are the patterns of bolts that have been chosen in this study. Nine specimens represent all these configurations experimentally have been tested under tension load. The results indicated that the highest bearing capacity of a single shear connection could be achieved using a square arrangement of bolts. While stresses could not be equally distributed around holes in circular and diamond pattern specimens of the same connection.

Keyword: Single shear connection, Bolt, Deformation, Internal stresses, Applied load

1. introduction

In steel structures, high strength bolts are commonly used to form bolted connections. When load is applied to a connection, there may be a little slippage, as the holes are a little larger in diameter than the diameters of the bolts. As a result, the parts of the connection may bear against the bolts if the bolts themselves were strong enough to resist the shear forces, hence, the bearing strength of a bolted connection is based upon the strength of the parts being connected and the arrangement of the bolts, [1]. It is worth mentioning that the Arrangement of the bolts in the majority of structural connections is in rectangular or square patterns while there are other patterns such as a circular and diamond arrangement, which could be in some parts of automobiles and machines but not in structural elements. Hence, the idea of this paper has raised by adopting experimental work to investigate the effect of changing the arrangement of bolts of single shear connection on the bearing capacity.

[2] studied the effect of a circular bolt pattern on the behavior of an extended end-plate steel connection. In this study, full-scale experimental testing complemented with three-dimensional non-linear finite element analysis was conducted. The results of this study showed that the circular bolt pattern can



enhance the moment capacity, reduce pinching, and ultimately increase energy dissipation of the connections depending on their geometric parameters.

[3] used the finite element method to analyze different array patterns of bolts in single shear joints. In this study, circular and rectangular array patterns have been modeled using CATIA software. Both these patterns have been modeled with eight M10-high strength bolts. The result showed that the rectangular array pattern was more effective than connecting the same members with a circular array pattern by keeping the number of bolts the same.

[4] used numerical methods to analyze the mechanical behavior of bolted joints. In this research, stress distribution was assessed of two connected plates by 8 bolts in different bolt arrangement modes (i.e. rectangular, diamond and circular) under tensile loading. The results indicated that the highest and lowest stress were arisen in rectangular and diamond modes, respectively and diamond arrangement owned a higher reliability versus tensile loading.

In this paper, an experimentally work has been done to study the effective of changing an arrangement of bolts on the bearing capacity of single shear connections. Square, circular and diamond arrangements of bolts have been chosen in this research. The results indicated that the square pattern is the one that gives the higher bearing capacity among the other patterns.

2. Connection details

2.1 Arrangement and Patterns of bolts.

In this study, three patterns to arrange bolts have been chosen to connect plates in a single shear connection. Square, Circular and Diamond are the patterns used to make the connections. Within a square of 140 mm length, all the patterns have been formed. Inside the square, a circle and an inclined square have been drawn. To make all specimens of this study, bolts have been distributed at the perimeter of these three shapes as shown figure 1. The number of bolts is the second parameter, which are investigated. Four, six and eight are the number of bolts used to connect plates as shown, figure 2. Depending on the arrangement and the number of bolts, specimens have been divided into three groups, Group (S), (C) and (D). The capital letter refers to the type of arrangement of bolts and the integer to the number of bolts used.

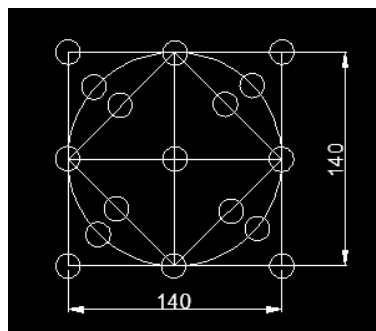


Figure 1. The layout of the three patterns.

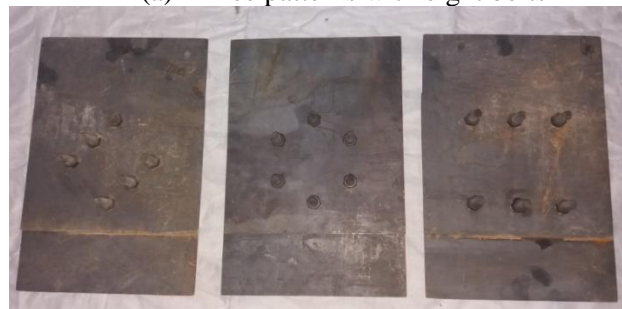
2.2. The geometry of the plates

To investigate the effect of changing the arrangement of bolts on the bearing capacity of a single shear joint, square, circular and diamond are the patterns of bolts that have been chosen in this study. Four, six and eight are the numbers of bolts used to each pattern. Hence, the total number of single

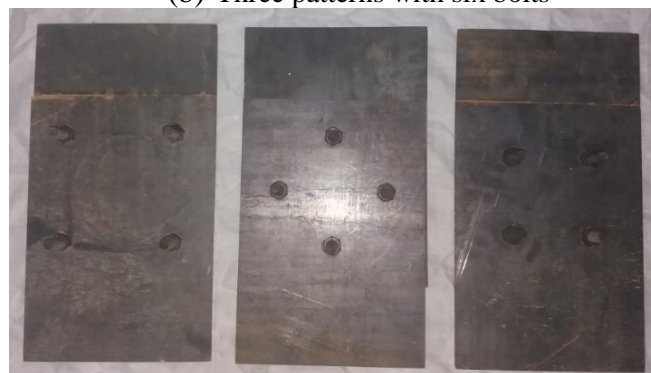
shear connection specimens experimentally investigated is nine. In single shear connection, gross section yielding, tensile fracture, bearing failure and shearing failure are the expected types of failure [5]. The two former types of failure mentioned depending directly on the dimensions of plate used while the two latter depends on the distance between bolt holes, the edge distance and the diameter of bolts used. Being this study is focused on bearing failure and to prevent yielding and fracture of the plate from happening, the dimensions of plates were variable for each set. In addition to that and to prevent shearing failure from happening, high strength bolts type M16-A490 have been used to tie all plates. For all specimens, standard holes which are (1/16 in.) larger than the bolt diameters have been drilled precisely using a Computer Numerical Control machine (CNC), [6].



(a) Three patterns with eight bolts



(b) Three patterns with six bolts



(c) Three patterns with four bolts

Figure 2. Square, circular and diamond patterns of bolts.

Table 1. Designation of specimens and their geometries.

Designation	No. of Bolts	Dimensions of plates mm	Actual Thickness of plates mm	Arrangement shape of bolts
S-4	4	340X240	3.0	Square
D-4	4	340X240	3.0	Diamond
C-4	4	340X240	3.0	Circular
S-6	6	300X240	3.0	Square
D-6	6	300X240	3.0	Diamond
C-6	6	300X240	3.0	Circular
S-8	8	400X240	3.0	Square
D-8	8	400X240	3.0	Diamond
C-8	8	400X240	3.0	Circular

2.3 Material Properties

Smooth steel plates and high strength bolts have been used to make all the types of single shear specimens in this research.

2.3.1 Properties of Plates and Test Samples

To determine the properties of the plates used in this study, three samples have been configured by a computer numerical control machine (CNC) according to the specifications of ASTM [7], figure 3. All these samples have been tested under a tensile load. Once tested samples have reached to ultimate tensile load (fracture load), the average of strength values has been recorded and listed in table 2.

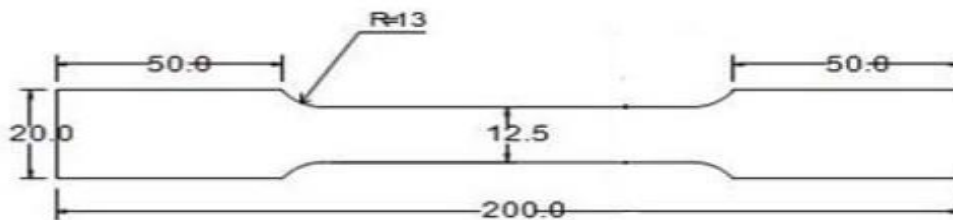
**Figure 3.** Shape and Dimensions of Tested Samples.

Table 2. Properties of Plates.

Type of plate	Specimen No.	Yield strength (F _y) (MPa)	Ultimate tensile strength (F _u) (MPa)	Average of yield strength (MPa)	Average of ultimate tensile strength (MPa)
Plate of (3 mm) thickness	1	272	425		
	2	270	432	272	433
	3	274	440		

2.3.2 High Strength Bolts

To make sure that the failure of all these specimens would be by bearing, M16-A490 high strength bolts have been used to tie plates in all tested connections, figure 4. For shearing failure not to happen, these types of bolts have been used and failure would be limited to the bearing failure. It is worth mention that the shearing strength capacity of these type of bolts ranges between 68 to 84 Mpa, [6].

**Figure 4.** M16-A490 high strength bolt.

2.4. Test of specimens

Nine specimens of single shear connection have been tested under tension load in this research. All these specimens have been tested by computer controlled versatile electronic testing machine of capacity 1000 kN with displacement control rate of 4mm per minute, figure 5.



Figure 5. Specimen under tension by computer controlled versatile electronic testing machine.

3. Discussion of test results

3.1. Behavior of specimens under load

With initial loading and after overcoming the friction available from the snug tight condition of bolts, the load -deformation curves for all nine specimens were linear. With increasing the load, out of plane curling phenomenon started to appear. This phenomenon appeared at only one free end of both plates of the square patterns specimens while it covered all the free three ends of both plates of the circular and diamond patterns specimens, figure 7. After yielding, as it was clear from deformation around holes, the load-displacement curves became non-linear. Reaching to the ultimate load, which represents the peak of curves, the non-linearity continued while curves started to fall. For comparison, the values of bearing capacity for all specimens have been listed in the table 3. From this table, three conclusions have been drawn. These are as follows.

- 1- The bearing capacity of the square patterns specimens, group (S), were higher than the bearing capacities of diamond and circular patterns specimens, group (D) and (C), and for all sets
- 2- The bearing capacities of specimens of the four bolts are almost equal for all patterns. They were 121 kN, 121 kN, and 117 for S-4, D-4 and C-R respectively.
- 3- Despite increasing the number of bolts from 6 to 8, however, the bearing capacities of circular and diamond specimens remained close or equal. They were 163 kN and 164 kN for C-6 and C-8 respectively, while they were 158 kN and 157 kN for D-6 and D-8 respectively.

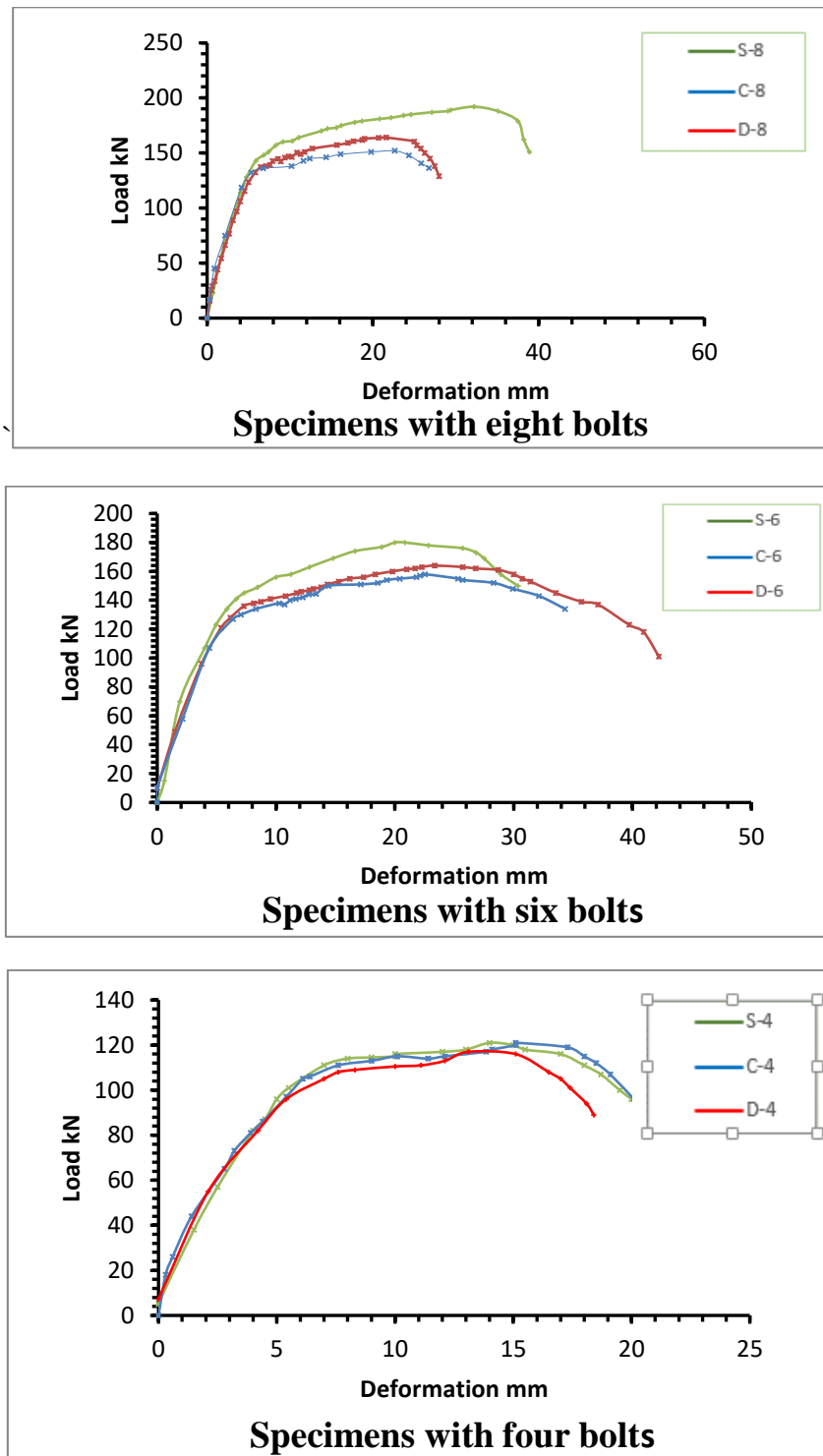
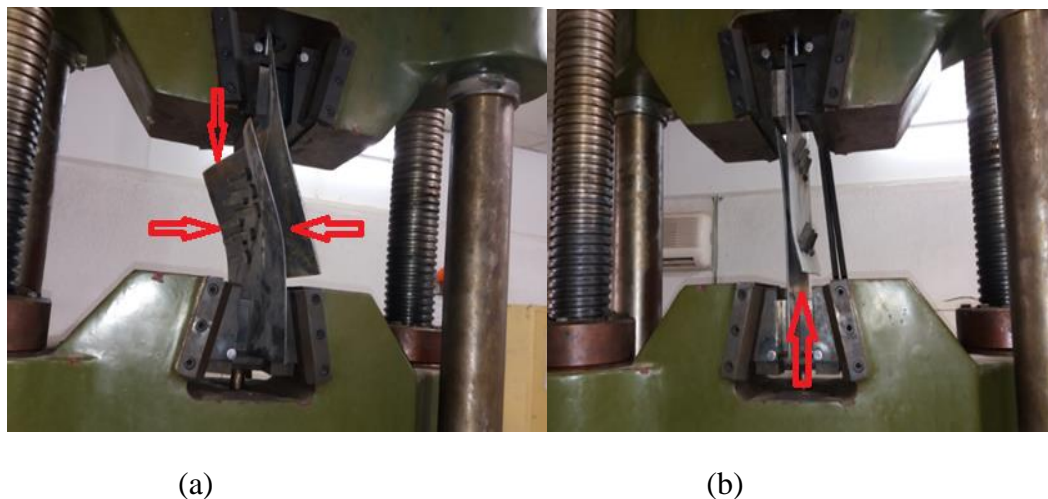


Figure 6. Load–deformation curves of specimens under loads.

It was noticed after giving a careful look at the failed plates that the deformations around the holes for all sets of square pattern specimens were almost equal, figure 8-a. The equal deformations around holes, without doubt, came from equal stresses applied on the edges of these holes by the bolts, that is, all the edges of these holes contributed to resist the applied loads equally as a result of this arrangement. Changing the patterns of the bolts to circular and diamond had a great effect to make only the outermost holes of these patterns contributing to resist the applied loads. to remain some other holes intact in these patterns is a clue to not contribute them to resist the applied load, figure 8.

Theoretically , the bearing capacity of specimens is a result of an equal contribution of total holes regardless of their arrangement . However, the results of this research have proved the contrary. This is so clear in figure 8-b in which the largest deformation has been noted at the outermost holes with less deformation around the other holes of groups (D) and (c) . the high capacity of square pattern specimens resulted from the nature of distributing of bolts in which all holes, which may be considered as outermost ones , appeared almost the same deformations.



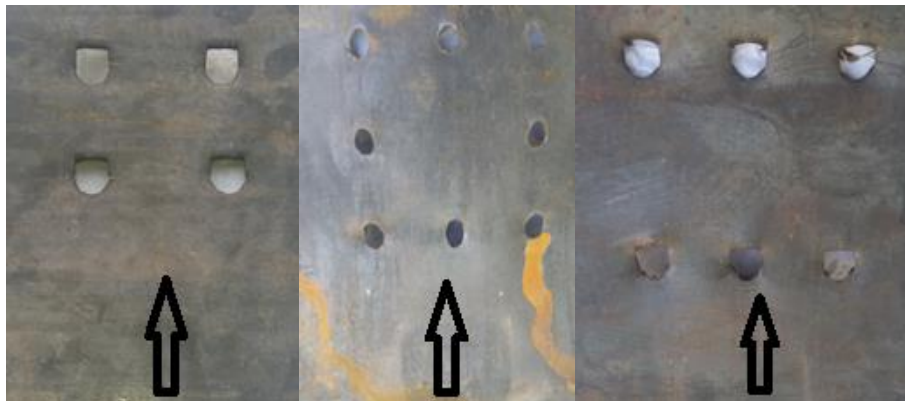
Out of plane curling at three free ends

Out of plane curling at on free end only

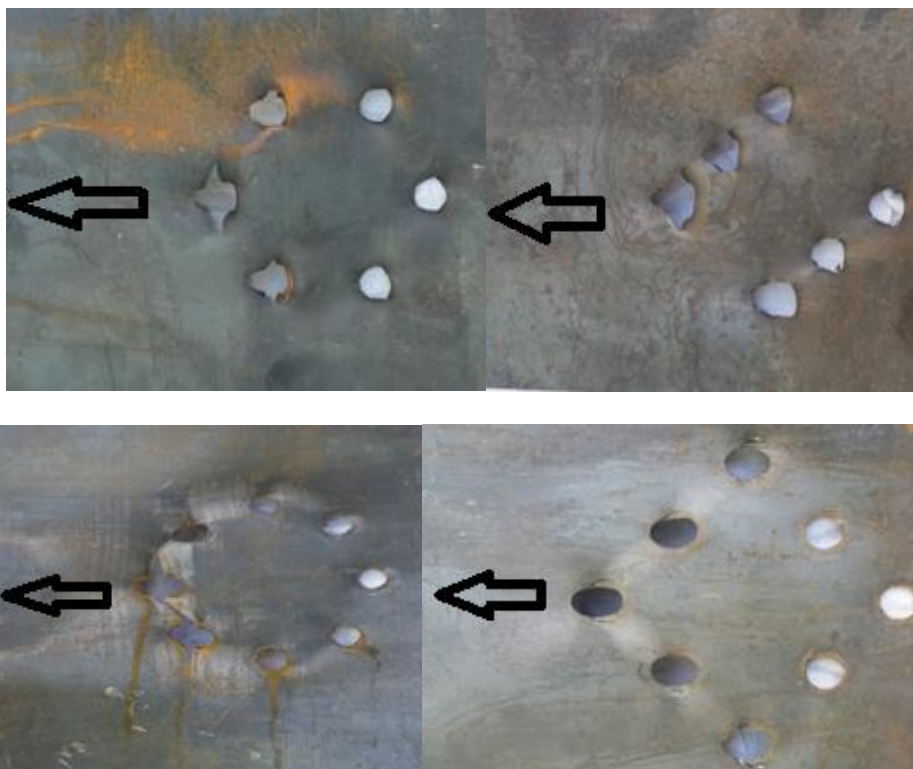
Figure 7. Out of plane curling phenomena.

Table 3. Ultimate load of specimens.

Designation	S-4	D-4	C-4	S-6	D-6	C-6	S-8	D-8	C-8
Ultimate Load (kN)	121	121	117	180	158	163	192	157	164



(a) Almost equal deformation around the holes in the square patterns specimens



(b) Unequal deformations around holes in diamond and circular patterns specimens

Note: the black arrow refers to the direction of the applied load

Figure 8. Deformations around the holes.

4. Conclusions

Nine specimens of single shear connections have been experimentally tested under tensile loads. The main parameters that have been studied in this research are the arrangement of bolts. Square, circular and diamond are the patterns that have been used to arrange bolts in these nine specimens. The results indicated that the highest bearing capacity of a single shear connection could be achieved using a square arrangement of bolts. while stresses could not be equally distributed around holes in some other types of single shear connections.

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