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EFFECT OF BOLT DIRECTION ON THE BEARING CAPACITY OF DOUBLE SHEAR CONNECTIONS

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ABSTRACT

The direction of bolts and its effect on the bearing capacity of double shear bolted connections has been examined in this paper. Sixteen specimens with up to four bolts have been tested under tensile load. These specimens have been sorted into two series (L, T) according to the bolt direction with applied loads. The experimental results have clearly indicated that the bearing capacity of connections had been considerably affected by changing the direction of bolts. With tear-out failure, All specimens of L series showed high bearing capacity and good ductility while block shear failure was the distinguishing feature of specimens of T series.

KEYWORDS: double shear, high strength bolt, load direction, bearing capacity, plates

تاثير اتجاه البرغي على السعة التصميمية للوصلات الثنائية القص

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الخلاصة

اتجاة البراغي وتاثيرها على سعة التحمل للوصلات المزدوجة تم اختباره في هذا البحث . تم فحص ستة عشر نموذج. لقد تم تصنيف النماذج الى مجموعتين وحسب اتجاه البراغي مع القوه المسلطة . وقد اثبتت النتائج بان السعه التصميمية للوصلات المزدوجة تتاثر تاثيرا كبيرا بتغير اتجاه البراغي وان النماذج التي بها البراغي باتجاة القوه اظهرت قوة تحمل عاليه مع مطيلية عالية وانها جميعها فشلت بخلع البليت بالكامل بينما فشل القص كان هو السمه السائدة لمجموعة النماذج ذات البراغي الموضوعة باتجاة عرضي مع القوة المسلطه.

1. INTRODUCTION

In steel structures, high strength bolts are commonly used to form bolted connections. In these connections the load be transferred from main plate to the splices by friction between plates. In bearing-type connections, the load is assumed to be larger than the frictional resistance caused by tightening the bolts, with the results that the plates slip a little on each other, putting the bolts in shear and bearing. In this study and to focus on the bearing failure, the shearing failure of bolts has been excluded.

With satisfactory end distances and deformation around bolt holes is not a design consideration (that is the deformation $>$ 0.25 in), the bearing strength of bolted connections is determined by AISC as the following equation (AISC Steel construction manual, 2005).

$$1.5\, l_c\, t\, F_u \;\leq\; 3\, dt\, F_u \qquad (1)$$

Where, l_c is the clear distance between the hole edge to the plate end or two hole edges, t refers to the plate thickness, d is the bolt diameter, and F_u represents the steel plate tensile strength.

Kim and Yara (1999) indicated that the above equation gives very conservative values compared to the values obtained from experimental tests and the justification of this underestimate values of strength is to prevent tear-out failure from happening.

Teh and Uz (2014) studied the effect of rolling direction on the bearing strength capacity of a double shear bolted connection of cold-reduced steel sheets. This study showed that the AISI (American Iron and Steel Institute) provision for bearing capacity was reasonably accurate if load was applied in the rolling direction of sheet steel, but was over-optimistic in the perpendicular direction.

Kue-chen and et al. (2013) studied the effect of the number of bolts and the edge distance on bearing capacity of bolted connection at elevated temperature experimentally and numerically. Based on the results of their study, a minimum edge distance of 3d has been recommended with a modification to equation (1) has been proposed to reflect the effect of fire.

Based on observations, Kue-chen and et al. (2013) suggested to use the reduction factor, U, used for the effective net area in the net fracture (in shear lag) to modify the bearing strength connections with multi-bolts.

According to what mentioned above, more investigations are needed about other factors that may affect the bearing capacity of bolted connections such as the direction of holes according to applied load.

In this study sixteen specimens of double shear bolted connections have been tested under tensile load. Up to four high strength bolts have been positioned in a perpendicular and parallel directions according to applied load. Variable thicknesses of plate, 4 mm, 6 mm and 8 mm, were used to configure the specimens. The experimental results have clearly indicated that the bearing capacity of connections were considerably affected by changing the direction of bolts, and AISC underestimates the bearing capacity of connections with bolts positioned longitudinally with the applied load.

2. MATERIAL PROPERTIES

Two materials have been used in this research .These are steel plates and high strength bolts

2.1. Properties of Plates and Test Samples

To determine the properties of the plates used in this study, 12 samples have been configured by a CNC machine. Steel Plates with Variable thicknesses of 4mm, 6mm, and 8 mm have been cut to configure three samples each. The Geometry of these samples has been determined according to the specifications of ASTM (ASTM A370-02, 2002). Under tensile load, all samples have been tested till the fracture, Fig. 1. Due to the closeness in average values of tensile stresses of the three types of plates, one value which represents a general average value has been included in the calculations, Table 1.

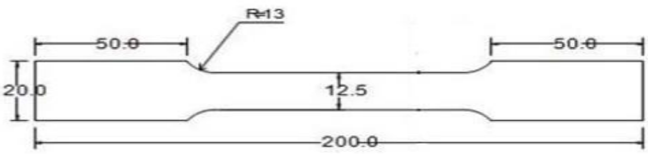

Fig. 1. Shape and Dimensions of Test Sample.

Table 1. Properties of Plates.

Type of plate	Specimens	Yield stress (Fy) (MPa)	Ultimate tensile stress (Fu) (MPa)	Average of tensile stress (MPa)	General average (MPa)
Plate of	1	270	425		
(4 mm)	2	270	432	432	
thickness	3	274	440		
Plate of	1	273	433		
(6mm)	2	261	421	430	432
thickness	3	274	435		
Plate of	1	272	420		
(8 mm)	2	281	435	433	
thickness	3	275	443		

2.2. High Strength Bolts

High strength bolts have been used to connect the plates. These bolts have been chosen to make a specimen fail in bearing not in shearing mode, Fig. 2.

Fig. 2. High Strength Bolt (5/8) in Diameter.

3. EXPERIMENTAL PROGRAM

3.1. Geometry of Specimens

To study the bearing behavior of double shear connections, sixteen specimens have been configured .Three plates, one inner and two outer; of the same thickness for each specimen have been connected by high strength 5/8 in (inches) bolts. To make the bearing failure happen in the inner plate, the thickness of each outer plate has been chosen to be equal to the thickness of the inner one. During the test, the gap between outer plates has been stuffed by a non-welding plate, Fig. 3. To control the type of failure which is bearing failure, dimensions of the plates were variable according to the thickness of plate and numbers of bolts, Table 2.

For all specimens, standard holes which are 1/16 in (inches) larger than a bolt diameter according to AISC specifications have been drilled precisely using the CNC machine (AISC manual). The distance between centers of adjacent holes was 2 2/3 times the bolt diameter and the distance between the edge of the plate and the center of the edge hole was 1.5 in. The former distance represents the minimum distance recommended by AISC provisions while the latter is more than the minimum. The specimens have been sorted into two types of series (L and T) according to the direction of holes with the direction of the applied loads, number of bolts and thickness of plates. English alphabets and Arabic numerals have been used in designate these specimens. The first character, L or T in the designation of the specimens refers to the direction of bolts either longitudinal or transverse according to the applied loads, the following first numeral refers to thickness of the plate while the second numeral refers to numbers of bolts used, Table 2.

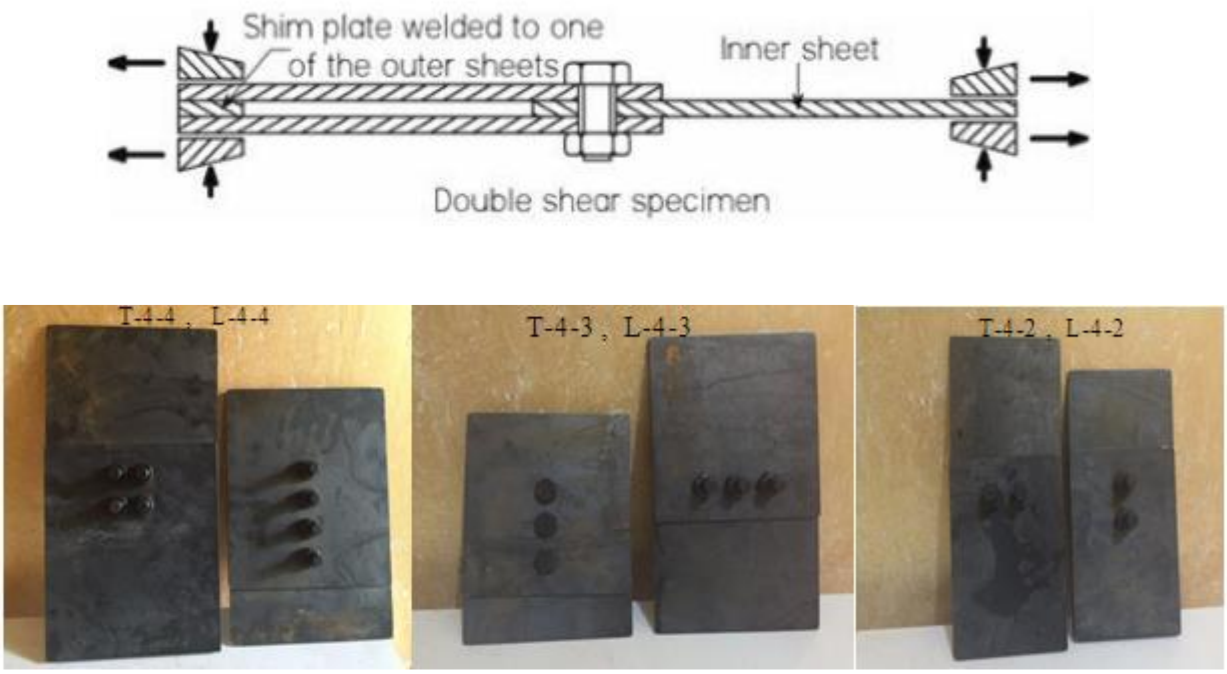

Fig. 3. Configuration of Test Specimens.

Table 2. Designation and Properties of Specimens.

Designation	No. of bolts	Direction of bolts With load	Actual thickness of plates, mm	Width of plate, mm
T-4-2	2	Transverse	3.8	150
L-4-2	2	Parallel	3.8	150
T-4-3	3	Transverse	3.8	200
L-4-3	3	Parallel	3.8	200
T-4-4	4	Transverse	3.8	260
L-4-4	4	Parallel	3.8	260
T-6-2	2	Transverse	5.9	150
L-6-2	2	Parallel	5.9	150
T-6-3	3	Transverse	5.9	200
L-6-3	3	Parallel	5.9	200
T-6-4	4	Transverse	5.9	260
L-6-4	4	Parallel	5.9	260
T-8-2	2	Transverse	7.8	150
L-8-2	2	Parallel	7.8	150
T-8-3	3	Transverse	7.8	200
L-8-3	3	Parallel	7.8	200

3.2. Discussion of Experimental results

3.2.1. Load- deformation relationships

In this study, sixteen specimens of double shear bolted connections have been tested under uniaxial tensile load. These specimens have been sorted into two types of series (L and T). L series represents eight specimens with bolts positioned in the parallel direction to the applied load while T series with bolts positioned in the transverse direction. All specimens have been tested in tension in a 600 Kn capacity universal testing machine with a displacement rate of 2 mm/min.

Fig. 4 shows the load-deformation curves for both series, while Table 3 lists the values of experimental and theoretical ultimate bearing strength of specimens. The theoretical values have been calculated by equation (1). To study the effect of bolts direction on the bearing capacity of specimens, two curves have been collected in one graph, Fig. 4.

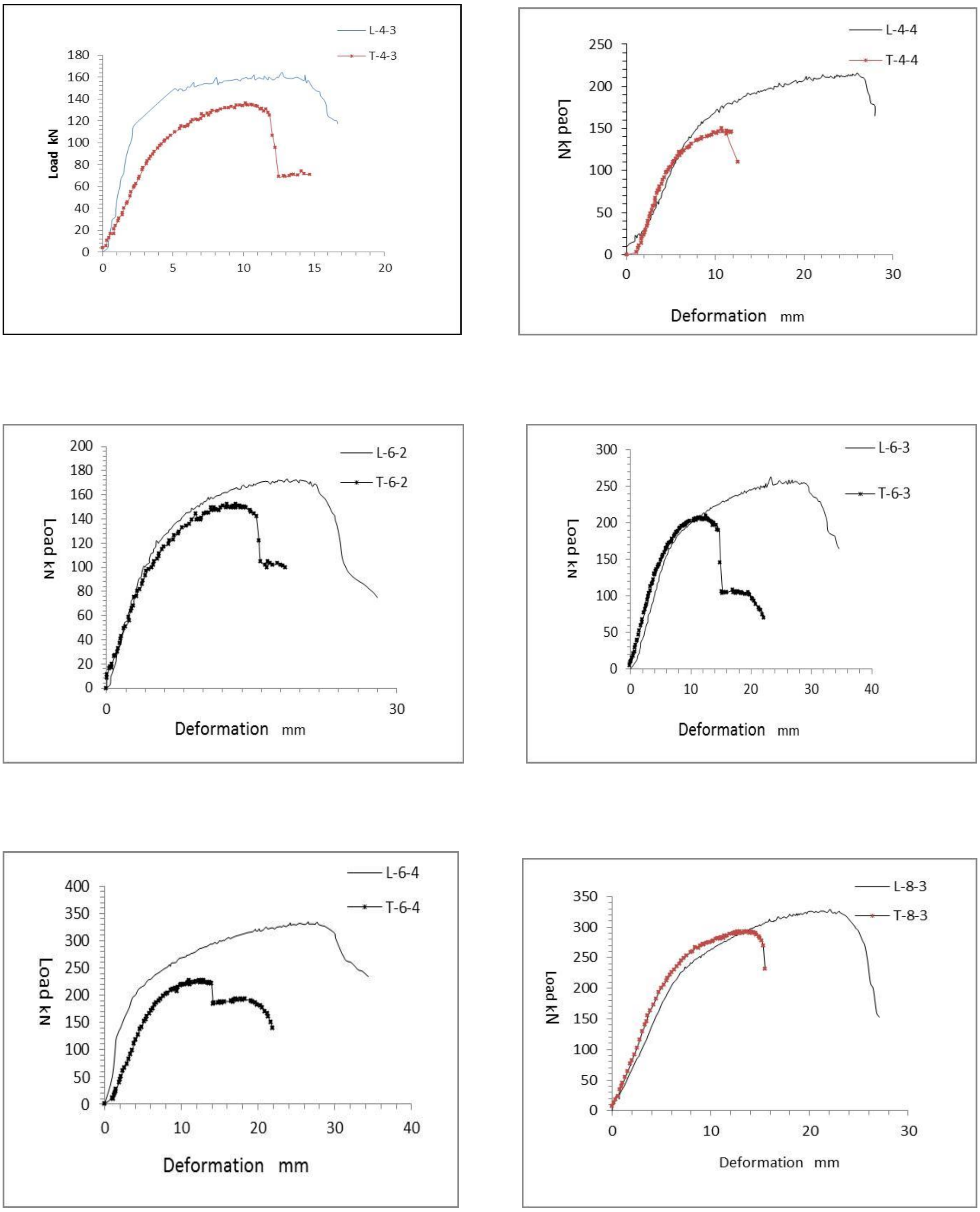

Fig. 4. Load-Deformation Curves of Specimens of Series Land T.

Each two curves represent the behavior of two specimens. Both specimens have the same geometry and number of bolts but with bolts in different directions. Experimentally, it is clear that all specimens of (L) series have achieved nominal ultimate loads (1-44) % more than their peer of specimens series T, Table 3. The same conclusion can be noted but with different ratio to theoretical results. It is worth mentioning that and during the test; all transverse holes have suffered from equal applied stresses due to the equal distance between them and the edge of the plate. These stresses have deformed the plate by enlarging the holes longitudinally, Fig. 5. As result for enlargement the holes which represents bearing failure, perpendicular tensile stresses between transvers holes were believed to have developed first and accompanied with shear stresses along two shear lines parallel to applied load. The perpendicular stresses were higher than the shear stresses so that transverse slots have appeared first and this fracture (slot) even affected upon the behavior of load–deformation curves in necking period after getting ultimate capacity, Fig. 5. With increasing the applied load, the piece of plate confined between the transverse holes and the edge has been ripped out totally. This phenomenon has been noted for all specimens of series (T). This is what is called the block shear failure.

Table 3. Experimental and theoretical bearing capacity of specimens.

Designation	Experimental ultimate load kN	Type of failure	∗ Nominal ultimate capacity By Eq.1 and Eq.2 kN	Increasing ratio in ultimate capacity
T-4-2	98	Block shear	88.1	18.3%
L-4-2	116	Tear-our	123	
T-4-3	136	Block shear	128	20.5%
L-4-3	164	Tear-our	184	
T-4-4	149	Block shear	137	44.9%
L-4-4	216	Tear-our	245	
T-6-2	151	Block shear	137	13.9%
L-6-2	172	Tear-our	190	
T-6-3	208	Block shear	199	24.9%
L-6-3	259	Tear-our	285	
T-6-4	280	Block shear	213	19.6%
L-6-4	335	Tear-our	380	
T-8-2	219	Block shear	181	1%
L-8-2	221	Tear-our	252	
T-8-3	289	Block shear	262	13.8%
L-8-3	329	Tear-our	377	

∗ $(1.5\, l_c\, t\, F_u \le 3\, dt\, F_u)$ x No. of bolts $l_c = 24.93\, mm$

$(0.6\ F_u\ A_{nv} + F_u\ A_{nt} \le 0.6\, F_y\, A_{gv} + F_u A_{nt})$

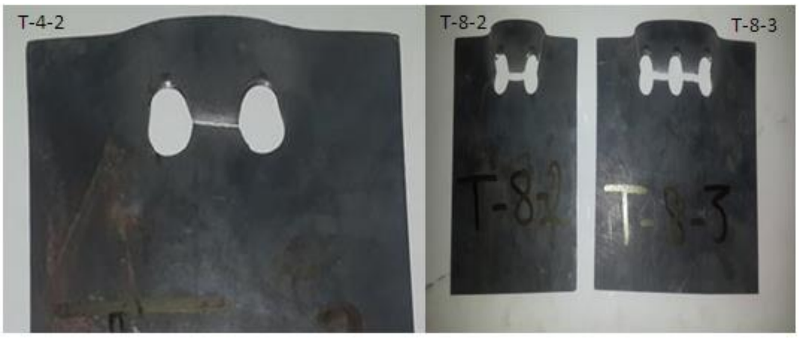

Fig. 5. Block shear failure of specimens of T serise.

To calculate the ultimate strength of connections which fail by block shear rupture ,the AISC specification J4.3 states as follows

$$R_n = 0.6 \ F_u \ A_{nv} + \ F_u \ A_{nt} \leq 0.6 \ F_y \ A_{gv} + F_u A_{nt} \quad (2)$$

Where, A_{gv} and A_{nv} are gross and net area supjected to shear respectivily while A_{nt} is net area subjected to tension. Fig. 6, Ilustrate the tension path and shear path of block shear failure in a plate

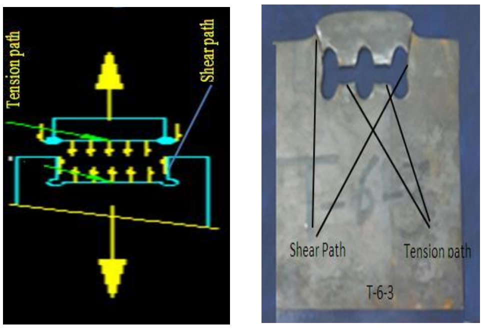

Fig. 6. Blok Shear Rupture in a Digram and plate T-6-3.

With regard to the specimens of series L, in which the direction of bolts is parallel to the applied load. In additional to the higher bearing capacity that has been achieved, there was an another remarkable merit which has been clearly noted. It is the high ductility, Fig. 3. The applied stresses on holes for each specimen were noted to be unequal, Fig. 7. Because of the phenomena of inequality in stresses, Some nearby points of high stress have reached to the yielding but other far points have not . With increasing the load, the yield spread out to other points causing the specimens to fail but with high resistance and more ductility . The noted failure was tear out for all specimens of series L, Fig. 8.

Fig. 7. Tear-out failure of specimens of L series.

It was clear that two types of failures distinguished the two series, block shear and tear out failures. These two modes of failure are defined as specimens reach its ultimate strength. The ultimate strength is the maximum strength in the load-displacement curves. Eventually, it is concluded that the bearing capacity of double shear connection might be considerably affected by changing the direction of bolts.

Fig. 8. Tear-out failure of specimens of L series.

4. CONCLUSION

In this study, sixteen specimens of double shear bolted connections have been examined under uniaxial tension. These specimens have been sorted into two series (L, T) according to the bolt direction with applied loads. The experimental results have clearly indicated that the bearing capacity of double shear connections might be considerably affected by changing the direction of bolts. With tear-out failure, all specimens of L series showed high bearing capacity and good ductility while block shear failure was the distinguishing feature of specimens of T series.

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