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Finite Element Study of Shear Tab Connections for Cold-Formed Sections

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Abstract*— *Cold-formed steel structural elements are progressively used in the industry of steel structures due to the world steel industry tendency to move toward more steel coils and strips than hot-rolled sections .Steel production in this form has the advantages of easier handling and transportation from the steel production mills to the steel-structure manufacturing plants , where it is used into cold-formed open and closed sections. In this study a detailed 3D finite element model using ANSYS version 13 is implemented. The results of the present model are compared with other previous ABAQUS program results and other experimental results. The models have different clamping force values (0% ,20% ,40% ,60%) of the max. pretension force value of H.S.Bolt M12 Grade 10.9and packing plate thickness (3 , 4 , 5 & 6 mm).

Different parameters of the tab connections are studied through several finite element models. Initially, three samples were modeled to study the effect of number of H.S Bolts Grade 10.9, having the same section area of bolts (8M8, 6M10& 4M12) on the shear resistance, three samples were modeled (using8M8) to study the effect of plate thickness (2, 3& 4mm). Furthermore, three samples were tested to study the bearing stress distribution with different number of H.S Bolts Grade 10.9, having the same diameter (4M8, 6M8, 8M8). Clamping force values of H.S.Bolt of the above mentioned models were 40 % of the max. Pretension force value. Packing plates and fixing plate with 4 mm thickness are used. It could be concluded that the present 3D finite element model using ANSYS capable of predicting experimental behavior with a good agreement. Bolts with bigger diameters preferred than smaller ones with the same global cross section area. Plate bearing stress has aparabolic distribution for all samples with different values and at the edge bolts(1st bolt)have the bigger bearing stress values.

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***Index:* Finite element, shear tab connection, cold formed section.**

I. INTRODUCTION

One of the most exciting developments in structural steel work during recent years has been the widespread and increasing use of cold-formed members and connections as the main component in the construction. The availability of larger cold-formed-sections has allowed economical industrial and residential buildings composed entirely of cold-formed members to be constructed. However, in a number of cases the connecting systems of members have not been that efficient and economic. The objective of this investigation is to study the connection behavior of shear tab connections for cold-formed section. It is expected that these structures will offer a new approach to the development of buildings for industrial and residential applications. With suitable structure forms, components and joints, appropriate structural systems are designed which will embody all the advantages of cold formed sections. In this presentation, the economical needs to use cold formed structures especially in shear tab connections. Zandan farrokh and Bryan [1] conducted a research on bearing failure of sheets and tearing in net section. To make sure that the bolt torque will not affect the ultimate load, different bolt torque ranged from 44.3 ft.lb to 73.8 ft.lb were applied. The research indicates the strength between connected cold-formed steel sheets can dictate the strength of the sheets or the assembly. Also, it was found the complete rigidity was difficult to obtain through the connection. Rogers and Hancock [2] performed 704 numbers of tests to exam the application of four different design methods. It is found that stress–strain curves, contact stiffness and frictional coefficient between element interfaces, and clamping force developed in bolt shanks are important parameters for accurate prediction of the load–extension curves of bolted connections. K.F. Chung *, K.H. Ip [3] established a finite element model with three-dimensional solid elements to investigate the structural performance of bolted connections between cold-formed steel strips and hot rolled steel plates under shear. The results of the finite element modeling are also compared with four codified design rules. It is found that the design rules are not applicable for bolted connections with high strength steels due to reduced ductility. K.F. Chung a,*, R.M. Lawson b. [4] proposed a semi empirical design formula for bearing resistance of bolted connections after calibrating against finite element results. Wallace and Schuster [5], [6] developed an investigation to study the behavior of bearing failure on bolted connection without washers. Chi-Ling Pan [7] investigated the shear lag effect on bolted cold-formed steel tension members. Yu, C. and Sheerah [9] studied cold-formed steel sheet bolted connections in oversized and short slotted holes without washers. Ke Xu [10] investigated the behavior and strength of CFS bolted connections without washers when the steel sheets have oversized and/or slotted holes and developed appropriate design equations for such connections and compared with the existing design equations in the AISI S100 (2007) [8]. Teh, L. H. & Gilbert, B. P[12] determined

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Volume 5, Issue 7, January 2016

the net section tension capacity of bolted connections in flat steel sheets. It points out that the shear lag factors embedded in the code equations either yield "anomalous" results or become irrelevant when they exceed unity. V.M.Vaghe [13] studied experimentally the effect of Stiffener/Packing plate only at the joints in cold formed channel sections which may increase the load carrying capacity of the bolted channel section subjected to axial tension. Generally shear tap connections have different and complex modes of failure so it is important to study this connection experimentally. Physical models are ideal to study the behavior and failure of such elements. However, experiments can be costly, time consuming, require adequate facilities, space setup, and skilled manpower.

II. SHEAR TAB CONNECTIONS

Shear tap connection as shown in Fig.1 is used in different types of structures for connecting members under tension. Examples of tension members are: buildings and bridges bracings, truss members and cables in suspended systems. Stress is given by, F =P/A where, P is the magnitude of the load and A is the member cross-sectional area. The increase in the length of a member due to axial tension under service load is Δ=PL / (E*A) Where, Δ is the axial elongation of the member (mm), P is the axial tensile force (un-factored) in the member, L is the length of the member (mm) and E is the modulus of elasticity of steel equals 2.0x105 N/mm2. Bolted and welded connections are the two main types often used in steel structures.

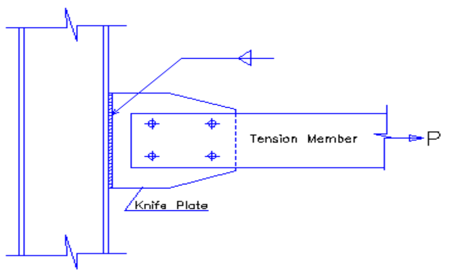

Fig. 1: Member under Tension

Bolting is common in field connections, since it is simple, economic and appropriate for safety considerations for bolted connections. Different modes of failure are shown in Fig. 2:

(a)Plate longitudinal shear failure (type I).
(b) Plate bearing failure (type II).
(c) Plate tensile failure (type III)
(d) Bolt shear failure (type IV).

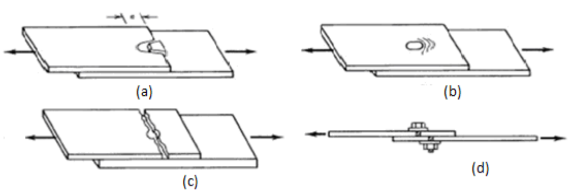

Fig. 2: Types of Failure of Bolted Connections

III. F.E.M. SIMULATION WITH NUMERICAL WORK [14].

In order to verify the present numerical model, A comparison between a previous results which was created by the finite element software ABAQUS on the bolt models is executed. The model was a single-lap thin plates joint as shown in Fig. 3. This joint consists of two plates with a thickness of 1.2 mm each and three aluminum NAS 1097 AD4, 3.2,7 mm rivets [14]. The boundary conditions used in the model are shown in Fig.4.and the studied Positions are shown in Fig.5. The displacement in the z direction in three lines of elements along x was constrained in both plates, and the applied stress, σo=160 MPa. The material property is: Aluminum 2024-T3 [14], Young's modulus E = 70.61 GPa and Poisson's ratio ν = 0.33. ANSYS model with the same properties was created to check the validity of the present modeling technique; Fig.6 shows the deformed shape of the present model. Fig.7 a and b shows the stress distributions (no friction and no pretension) through the fixing plate, at faying and outside surfaces for the sections at the center and the edge of the plate. It could be noticed that, there is a good agreement between current FEM results and previous FEM results [14]. The variation between the results is within the range of ±4%.

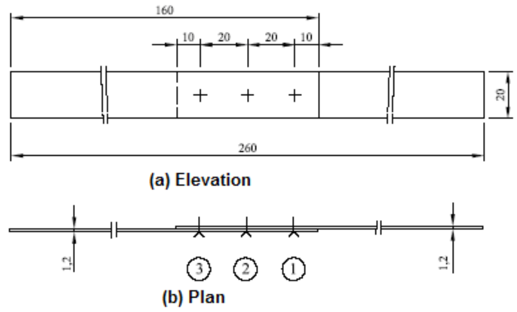

Fig.3: Model Dimensions

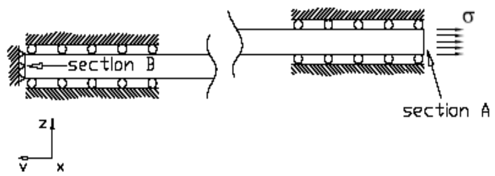

Fig.4: Plan Boundary Conditions

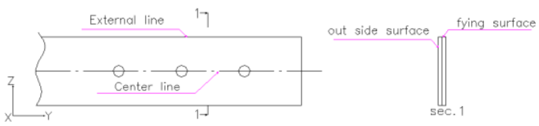

FIG.5: POSITION OF SECTIONS

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Volume 5, Issue 7, January 2016

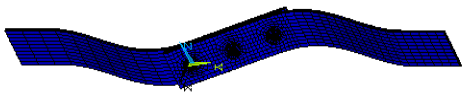
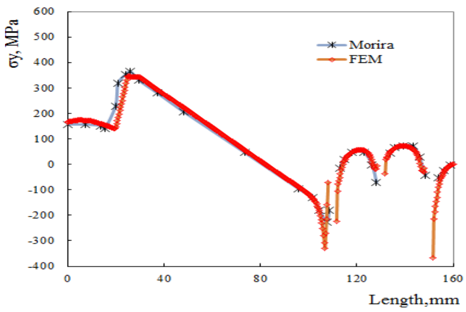
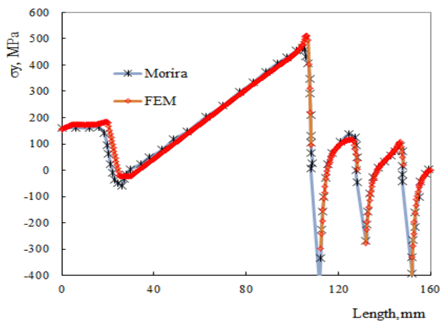


Fig. 6: Deformed shape of current FEM

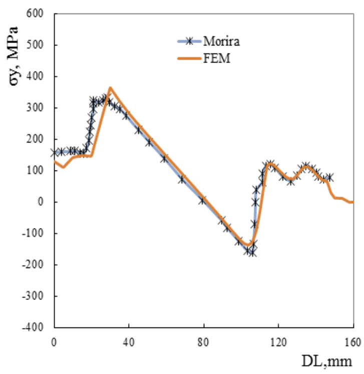


OUTSIDE SURFACE

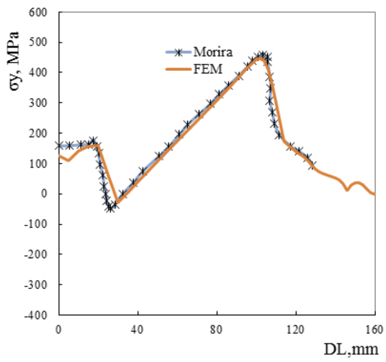


Faying Surface

7.a) Stresses on center line section



Outside surface



Faying Surface

7. b) Stresses on external line section

Fig. 7: Present and previous finite element modeling results

IV. F.E.M. SIMULATION WITH EXPERIMENTAL WORK.LPFUL HINTS

A) Experimental Work

1000 kN (tension) capacity universal testing machine is used in testing all specimens. The load was applied quasi-statically. Steel yield strength equals 240 N/ mm2, the modulus of elasticity of steel equals 2.0*105 N/mm2 and poisson,s ratio equals 0.3.

**** Specimens***

Eight specimens were tested to study the effect of clamping force values (0%,20%,40%& 60%) of max pretension value of bolt M12 (10.9) with ordinary washers in two cases without and with using of packing plate 4mm thickness. Additional four samples were tested to study the effect of packing plate thickness (3mm-4mm-6mm-8mm) with pretension 60%.

**** Specimens Geometries***

The experimental testing consists of tension plate specimens as shown in Fig. 8 fabricated from rolled steel plate. All specimens are of 400 mm length, 3mm thickness of tension plate, 80mm width and the fixing plate is 4mm thickness. All specimens are fastened, with four double row H.S Bolts Grade 10.9. The tests consist of 3 sets as indicated in Tables 1, 2and 3. In set 2 only packing plate 4 mm is used while in set 1 no packing plate is used and in set 3 packing plates with different thicknesses are used

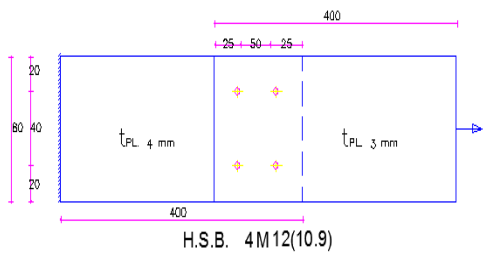


Fig.8: Specimen Geometry

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International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 7, January 2016

B) Results and Discussion

Deformed shape of current FEM and experimental work are shown in Fig.9 and 10. Relations between applied force and elongation are shown in Fig.11 to22. It could be noticed that, there is a good agreement between current FEM results and previous reference [14]. The variation between the results is within the range of ±10%.

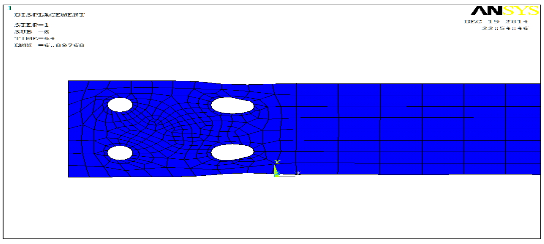

Fig.9: Deformed Shape of Current FEM

Fig.10: Deformed Shape of Experimental Work

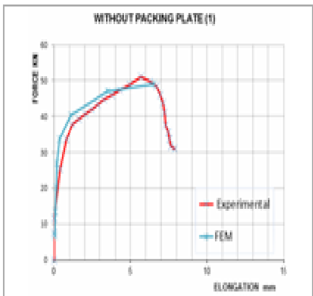

Fig.11: Validation of Relation between Elongation and Force for Specimen (1)

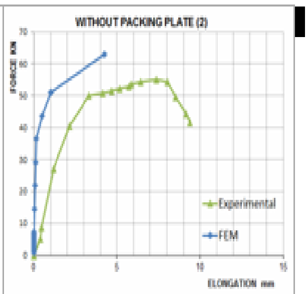

Fig.12: Validation of Relation between Elongation and Force for Specimen (2)

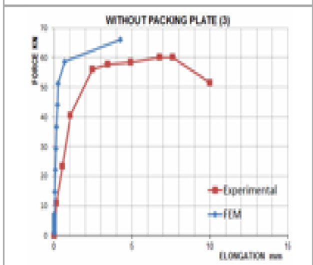

Fig.13: Validation of Relation between Elongation and Force for Specimen (3)

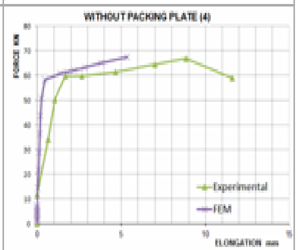

Fig.14: Validation of Relation between Elongation and Force for Specimen (4)

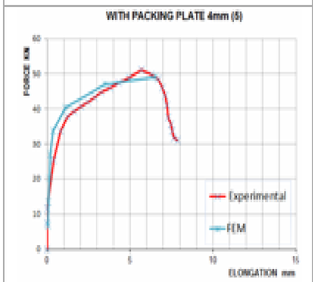

Fig.15: Validation of Relation between Elongation and Force for Specimen (5)

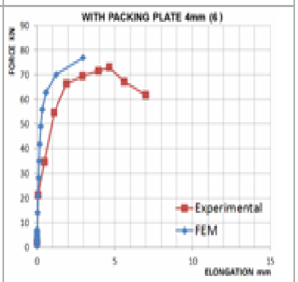

Fig.16: Validation of Relation between Elongation and Force for Specimen (6)

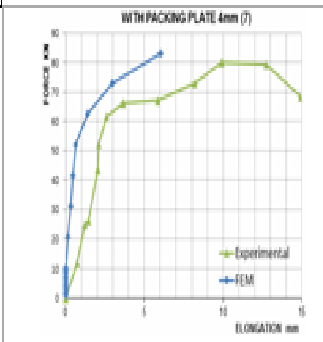

Fig.17: Validation of Relation between Elongation and Force for Specimen (7)

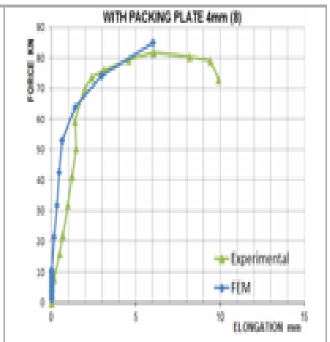

Fig.18: Validation of Relation between Elongation and Force for Specimen (8)

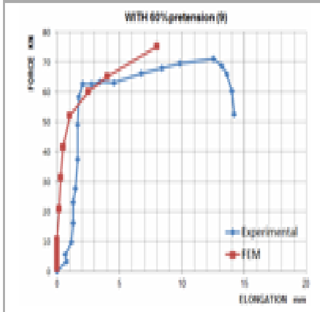

Fig.19: Validation of Relation between Elongation and Force for Specimen (9)

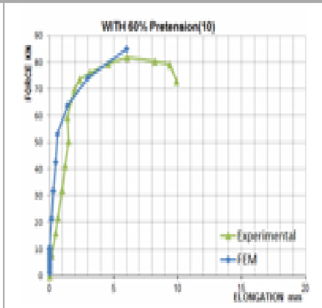

Fig.20: Validation of Relation between Elongation and Force for Specimen (10)

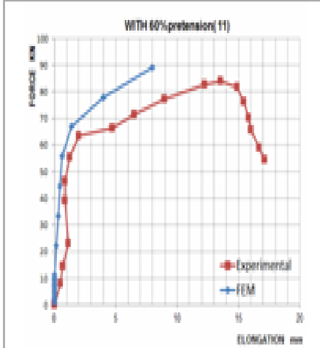

Fig.21: Validation of Relation between Elongation and Force for Specimen (11)

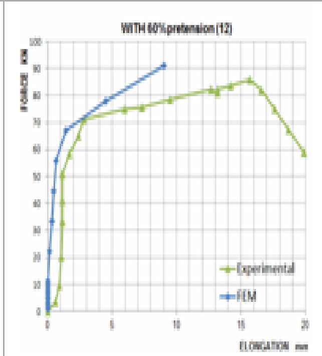

Fig.22: Validation of Relation between Elongation and Force for Specimen (12)

-Increasing the clamping force up to 60% of maximum pretension force of the connecting H.S.B bolt and using a packing might lead to increase of total shear force capacity of the connection by about 60% and by about 34% if not using packing plate.

- Increasing packing plate thickness as parameter might increase the shear force capacity of the connection.

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Volume 5, Issue 7, January 2016

Table(1): A comparison of Specimens without packing plate (set 1) : FFM vs. Test					
Specimen no.	clamping %	Clamping force (N)	Test Ultimate load (KN)	FEM Ultimate load (KN)	% Fult.test / Fult.FEM
1	0%	0	51	49	104%
2	20%	10580	55	63	87.5%
3	40%	21160	60	66	90.9%
4	60%	31740	67	70	95.7%

Table(2): A comparison of Specimens with packing plate 4 mm (set 2): FFM vs. Test					
Specimen no.	clamping	Clamping force (N)	Test Ultimate load (KN)	FEM Ultimate load (KN)	% Fult.test / Fult.FEM
5	0%	0	51	49	104%
6	20%	10580	73	76	95.3 %
7	40%	21160	80	82	97.6 %
8	60%	31740	81	84	96.4 %

Table(3): A comparison of Specimens with clamping 60% (set 3): FFM vs. Test				
Specimen no.	packing plate thickness (mm)	Test Ultimate load (KN)	FEM Ultimate load	% Fult.test / Fult.FEM
9	3	69	75	92%
10	4	81	85	95.3 %
11	6	84	89	94.4 %
12	8	86	91	94.5 %

V. NUMERICAL STUDY CASES

**** Specimens Geometries***

All models consist of tension plate specimens fabricated from rolled steel plate. All specimens are of 400 mm length, 80mm width. H.S Bolt Grade 10.9 is used. Clamping force values of H.S.Bolt of the above mentioned models were 40 % of the max. Pretension force value. Packing plates and fixing plate with 4 mm thickness are used.

A) Effect of Change Number of Bolts with the Same Area of Bolts.

Three samples were modeled to study the effect of number of H.S Bolt Grade 10.9, with the same section area of bolts (8M8, 6M10, 4M12) on the shear resistance with 3mm plate thickness as shown in Fig.23.

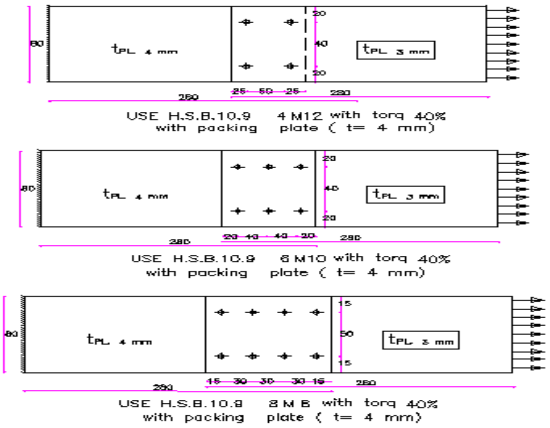

Fig.23: Specimen Geometry in Case of Change Number of Bolts with the Same Area of Bolts.

B) Effect of Plate Thickness (using8M8).

Three samples were modeled (using8M8) to study the effect of plate thickness (2, 3, 4mm) as shown in Fig.24.

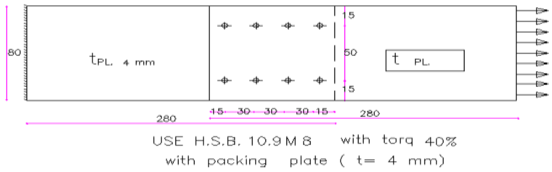

Fig.24: Specimen Geometry in Case of Study the Effect of Plate Thickness (using8M8).

C) Effect of Different Number Bolt having the Same Diameter (4M8, 6M8, 8M8) with 3mm Plate Thickness.

Three samples were tested to study the bearing stress distribution with different number of H.S Bolt Grade 10.9, having the same diameter (4M8, 6M8, 8M8) with 3mm plate thickness as shown in Fig.25.

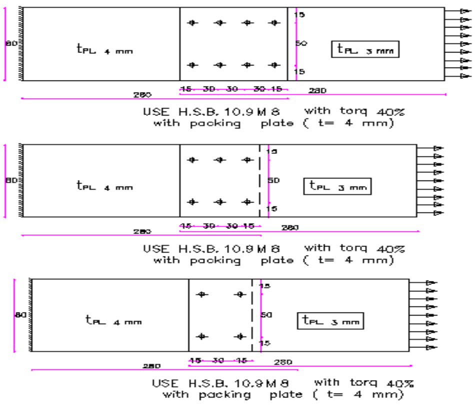

Fig.25: Specimen Geometry in Case of Study the Effect of the Bearing Stress Distribution with Different Number of H.S Bolt having the Same Diameter.

VI. RESULTS AND DISCUSSION

A) Effect of Change Number of Bolts with the Same Area of Bolts.

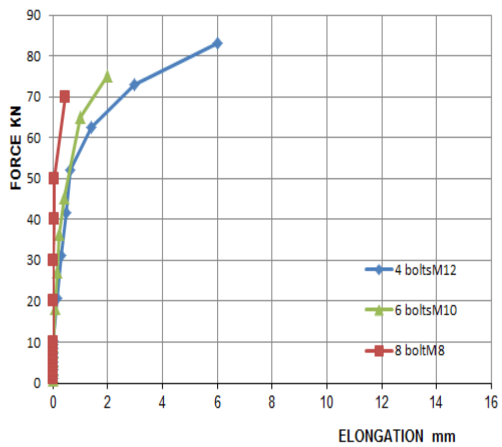

Fig.26: Relation between Axial Force and Elongation in Case of Change Number of Bolts with the Same Area of Bolts.

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Volume 5, Issue 7, January 2016

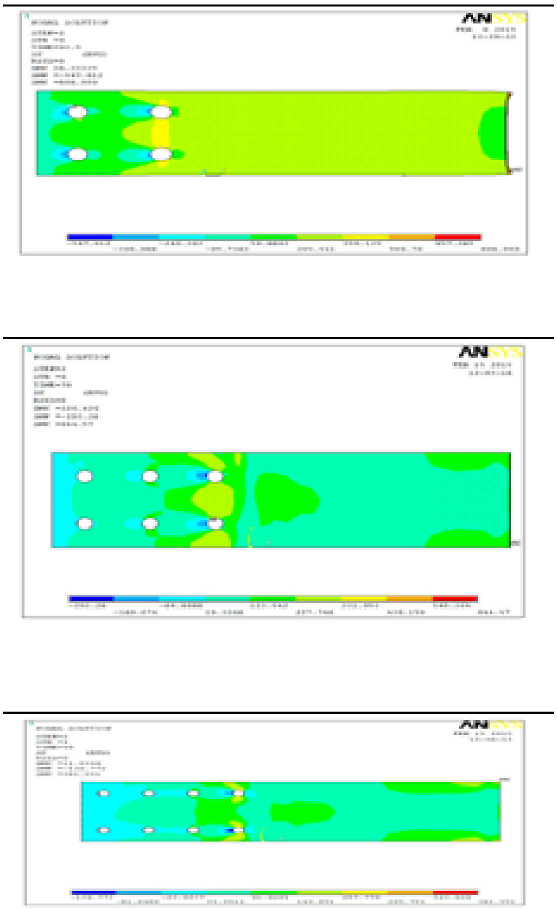

Fig.27: Stress Distribution in Case of Change Number of Bolts with the Same Area of Bolts.

TABLE(4): A COMPARISON BETWEEN EGYPTIAN CODE AND ANSYS ANALYSIS.

Model	Factored design bearing force KN	ANSYS bearing force KN
4M12	31.1	82
6M10	38.9	75
8M8	41.47	70

The results proposed by Egyptian code and Ansys numerical analysis discovered differences.

Factored design bearing stress = 0.6* Fult.*d*t*N (Egyptian code)

Where:

d: bolt diameter.

t: plate thickness.

N: number of bolts.

It concluded that the code results is reversed with Ansys results that the section is subjected to tension force that causes a deformation due to bearing at the first hole location (weakest part). When the friction disappeared, bearing failure occurred. By increasing the applied load the bearing occurred in the second bolt holes.

And another reason is summarized in this table

Model	Clamping force(A) KN	Factored design bearing force(B) KN	Summation A,B KN	ANSYS bearing force KN
4M12	31.15	31.1	62.25	82
6M10	21.6	38.9	60.5	75
8M8	7.8	41.47	49.27	70

Section resist du to bearing and friction of clamping force. 4M12 have less Factored design bearing force but more clamping force which is reversed with8M8. It is clear that the Summation A,B is consistent with ANSYS bearing force.

Fig.26. shows a comparison between the load displacement curve for the three cases i.e 4M12, 6M10, and 8M8. It can be found that by decreasing the bolt diameter the elastic limit of the joint decrease. The reason is that for smaller diameters of bolts and holes the stress under the bolt becomes very high compared with the bigger diameters at the same total surface area.

Furthermore, joints with bigger diameters show more elongation, ductility. The reason is that the stress distribution is more uniform under the bolt and less stress concentration is found, which causes more uniform distribution for the plastic strain before reaching to the beak and causing the final failure.

And also joints with bigger diameters sustain more forces then more stress and more strain.

B) *Effect of Plate Thickness (using8M8).*

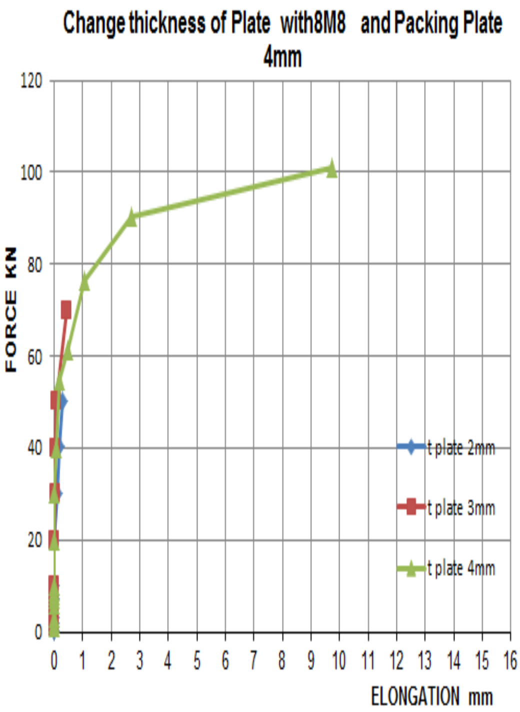

Fig. 28: Relation between Axial Force and Elongation in Case of Change plate thickness (using8M8).

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Volume 5, Issue 7, January 2016

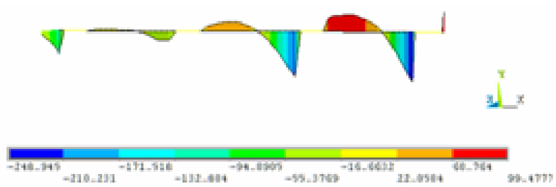

Fig.29: Stress Distribution (4mm plate thickness)

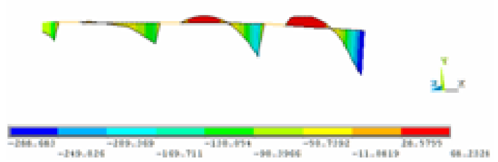

Fig.30: Stress Distribution (3mm plate thickness)

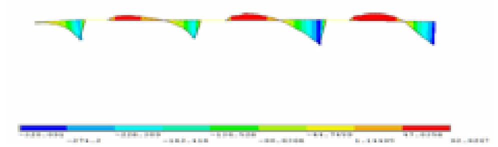

Fig.31: Stress Distribution (2mm plate thickness)

Fig. 28 Show that the relation between elongation and force it is observed that anon linear behavior due to contact from clamping force.

By increasing Plate Thickness increases the bearing resistance increase and the total elongation increase at the same force. It is noted that the first two rows sustain the majority of load.

C) Effect of Different Number of Bolt having the Same Diameter (4M8, 6M8, 8M8) with 3mm Plate Thickness.

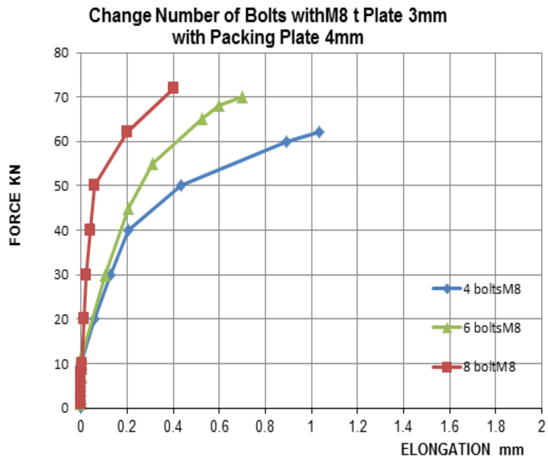

Fig. 32: Relation between Axial Force and Elongation in Case of Change Number Bolts.

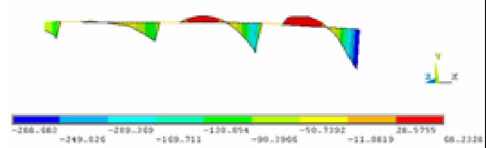

Fig.33: Stress Distribution (8M8)

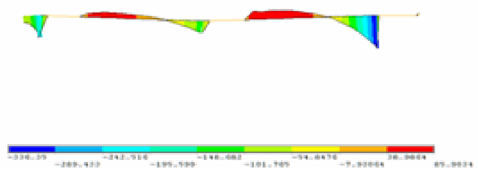

Fig.34: Stress Distribution (6M8)

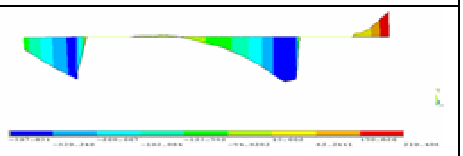

Fig.35: Stress Distribution (4M8)

Fig.32 Show that the relation between elongation and force.

By increasing number of bolts increases the connection stiffness that decreases the total elongation at the same force.

It is noted that the first two rows sustain the majority of load.

Friction of clamping force is very small then the early collapse of friction occurred then bearing early occurred then plate collapse at the weakest part at the 1st bolt (Ft=t *Anet*fy =69KN) which is consistent with and equal to the three bolts ultimate load.

VII. CONCLUSIONS

The resistance of shear tap connections for thin plates or cold formed sections is greatly affected by using high strength bolts with ordinary washers, applying clamping force and using packing plates:

1-3D finite element modeling using ANSYS capable of predicting experimental behavior with a good agreement.

2-Increasing the clamping force up to 60% of maximum pretension force of the connecting H.S.B bolt and using a packing might lead to increase of total shear force capacity of the connection by about 60% and by about 34% if not using packing plate.

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3- Increasing packing plate thickness as parameter might increase the shear force capacity of the connection.
4- Bolts with bigger diameters preferred than smaller diameter with the same cross section area.
5- Bearing stress has a parabolic distribution for all samples with different values and the edge bolts(1st bolt)have the bigger bearing stress values.

Recommendations for Future Research
1-Study of connection under repeated and dynamic loads.
2-Study the behavior connections subjected to eccentric tension.
3-Study the effect of number of bolts with the same bearing area.
4-Effect of pretension in the bolts with the same section area.
5-Comparison between factored design Egyptian code and ANSYS bearing failure force.
6-Comparison between AISI S100 (2007) and ANSYS bearing failure force.

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