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Abstract

This paper investigates the effect of bolt threads on the initial stiffness of double-shear bolted connections through experimental tests and numerical analyses. Eight specimens composed of 4.7 mm and 8 mm thick structural steel plates with a bolt diameter of 20 mm having varying end distances are studied. The present finite element analysis demonstrates that, as the threads cut into the connected plate, they reduce the initial stiffness of the bolted connection, which is the reason why many finite element models in the literature could not reasonably match the load-displacement curves of tested bolted connection specimens. Comparisons against alternative models are presented, and the model incorporating bolt threads are found to be best able to mimic the actual load-displacement response up to the ultimate load.

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THREAD EFFECT ON THE INITIAL STIFFNESS OF BOLTED CONNECTIONS

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Abstract: *This paper investigates the effect of bolt threads on the initial stiffness of double-shear bolted connections through experimental tests and numerical analyses. Eight specimens composed of 4.7 mm and 8 mm thick structural steel plates with a bolt diameter of 20 mm having varying end distances are studied. The present finite element analysis demonstrates that, as the threads cut into the connected plate, they reduce the initial stiffness of the bolted connection, which is the reason why many finite element models in the literature could not reasonably match the load-displacement curves of tested bolted connection specimens. Comparisons against alternative models are presented, and the model incorporating bolt threads are found to be best able to mimic the actual load-displacement response up to the ultimate load.*

Keywords: Bearing deformation; Bolted connection; Bolt thread; Connection stiffness

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1 INTRODUCTION

Although many researchers studied bolted connections experimentally and numerically [1-8], they did not model the bolt threads in their finite element (FE) analysis in predicting the load-displacement graph. Some of them used only shank bolted connections [2-4]. Those who did use threaded bolts in their experiments reported significant differences in the initial stiffness between the laboratory tests and the finite element analyses [1, 5-6]. Lim and Nethercot [1] postulated that the difference in the initial stiffness was due to the bolt thread cutting into the plate. On the other hand, D'Antimo *et al.* [6] attributed same to the local imperfections around the bolt holes, and used an artificially smaller bolt diameter to match the experimental initial stiffness. However, their method resulted in a significant underestimation of the ultimate strength [6].

Other researchers have modelled the bolt threads, but they investigated bolted connections under tension and the interaction between the threaded bolt and the nut only [7-8]. They did not simulate the thread cutting into the plate in a shear connection.

In the present study, four pairs of threaded and shank bolted connections are tested to failure (in shear-out) in order to investigate the effect of bolt threads on the initial stiffness. The significance of modelling the bolt threads in the finite element analysis is illustrated through comparisons against an independent laboratory test result [6].

Fracture analysis is outside the scope of this paper, which focuses on accurate simulation of the load-displacement response of a bolted connection up to the ultimate limit load.

2 EXPERIMENT

2.1 Test materials

Two types of steel plates were used in this study, being 4.7 mm thick Grade 400 plate with measured yield stress of 470 MPa and tensile strength of 540 MPa, and 8 mm thick Grade 250 plate with measured yield stress of 285 MPa and tensile strength of 425 MPa. Threaded and plain bolts having a diameter of 20 mm were used.

2.2 Specimen configurations and test set-up

All specimens were single bolted double-shear connections where the bolt head and nut were finger tightened, as shown in Figure 1. The inner plate was the critical component since the two outer plates were 9 mm thick steel plates having a measured yield stress of 550 MPa. The bolt holes were drilled 1 mm larger than the bolt diameter of 20 mm.

The clear end distance e_n, plate thickness t, bolt hole diameter d_h and bolt diameter d of the inner plates are provided in Table 1. The initials SP and ST refer to the shank bolted and the threaded bolted specimens, respectively. The width of all inner plates was 100 mm. The connections were designed such that the governing failure mode was shear-out. The specimens were loaded at a stroke rate of 2 mm per minute. Figure 1 shows the test set-up.

Table 1: Specimen dimensions and results of laboratory tests

Specimen	F_y (MPa)	F_u (MPa)	d (mm)	d_h (mm)	e_n (mm)	t (mm)	P_t (kN)	P_t / P_p
SP1	470	540	19.7	20.8	38.7	4.7	127.8	0.95
SP2			19.7	20.9	43.5	4.7	140.3	0.95
SP3	285	425	19.65	20.9	29.9	7.9	149.9	1.06
SP4			19.57	20.8	39.2	8.1	182.2	1.00
ST1	470	540	19.7	20.8	31.4	4.7	127.2	1.14
ST2			19.8	21.0	40.1	4.7	142.9	1.05
ST3	285	425	19.78	20.9	31.4	8.1	154.2	1.02
ST4			19.8	21.0	42.1	8.1	181.9	0.93
							Mean	1.03
							COV	0.064

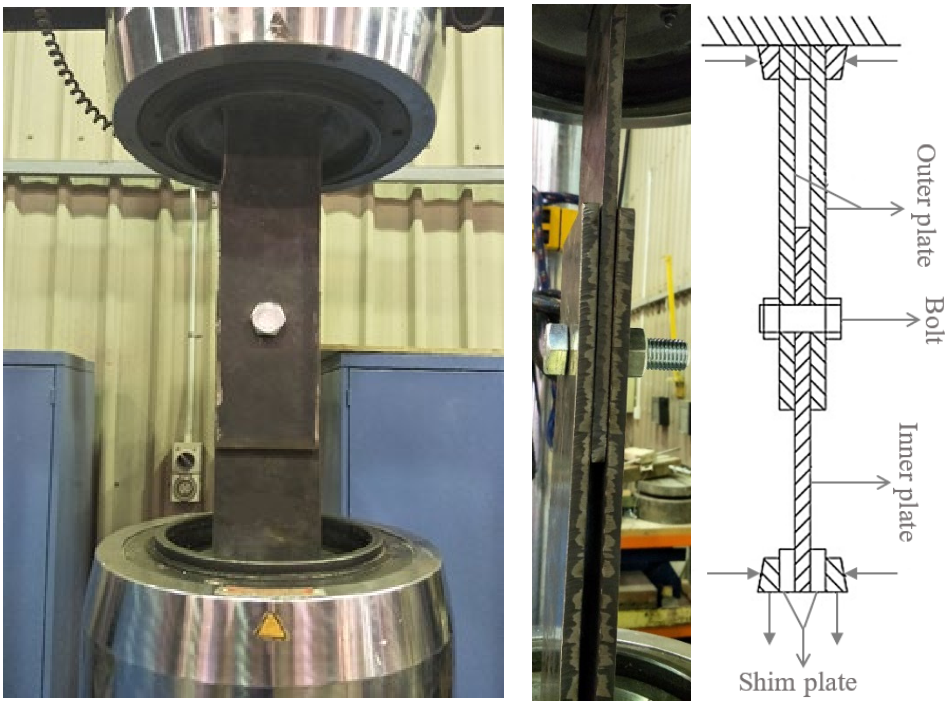


Figure 1: Test set-up

2.3 Test results and discussions

The shear-out capacities of the specimens in Table 1 were predicted using the equation proposed by Teh and Uz [12]

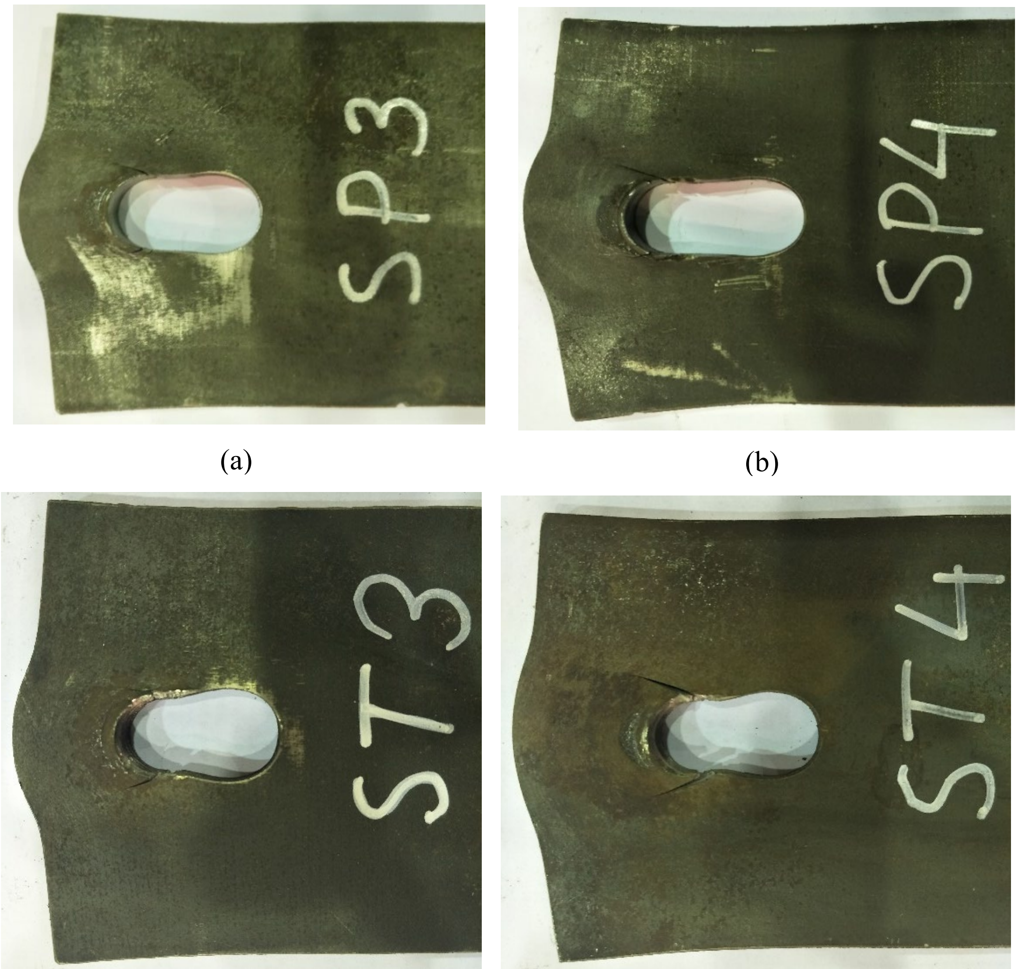
$$P_p = 1.2 L_{av} t F_u \tag{1}$$

in which

$$L_{av} = e_n + d_h / 4 \tag{2}$$

The ratios of the ultimate test load P_t to the estimate P_p obtained using Equation (1), called the professional factors, are provided in Table 1. The mean value of 1.03 with a coefficient of variation equal to 0.064 indicates that the predicted shear-out capacities of the specimens reasonably match the tested values.

Figure 2 shows some of the tested specimens. As can be seen from Table 1, specimens ST3 and ST4 had similar variables to SP3 and SP4 except for the bolt threads, respectively. A clear distinction in the shapes of the elongated bolt holes between the shank and the threaded specimens is evident.



(a) (b) (c) (d)

Figure 2: Shear-out failure of specimens (a) SP3; (b) SP4; (c) ST3; (d) ST4

Figures 3(a) and 3(b) compare the load-displacement graphs of the 4.7 mm thick threaded and shank bolted specimens. Specimens SP2 and ST2 are nominally the same except for the bolt threads. However, specimens SP1 and ST1 differ rather significantly from each other in terms of the end distance e_n, as shown in Table 1. In any case, it is evident that, among the specimens composed of 4.7 mm thick Grade 400 steel plate, the initial stiffness was significantly smaller for the threaded bolted connections.

It can be seen from Figures 3(c) and 3(d) that, among the specimens composed of 8 mm Grade 250 thick steel plate, the initial stiffness was also smaller for the threaded bolted specimens; but the difference is less pronounced compared to the 4.7 mm thick Grade 400 specimens.

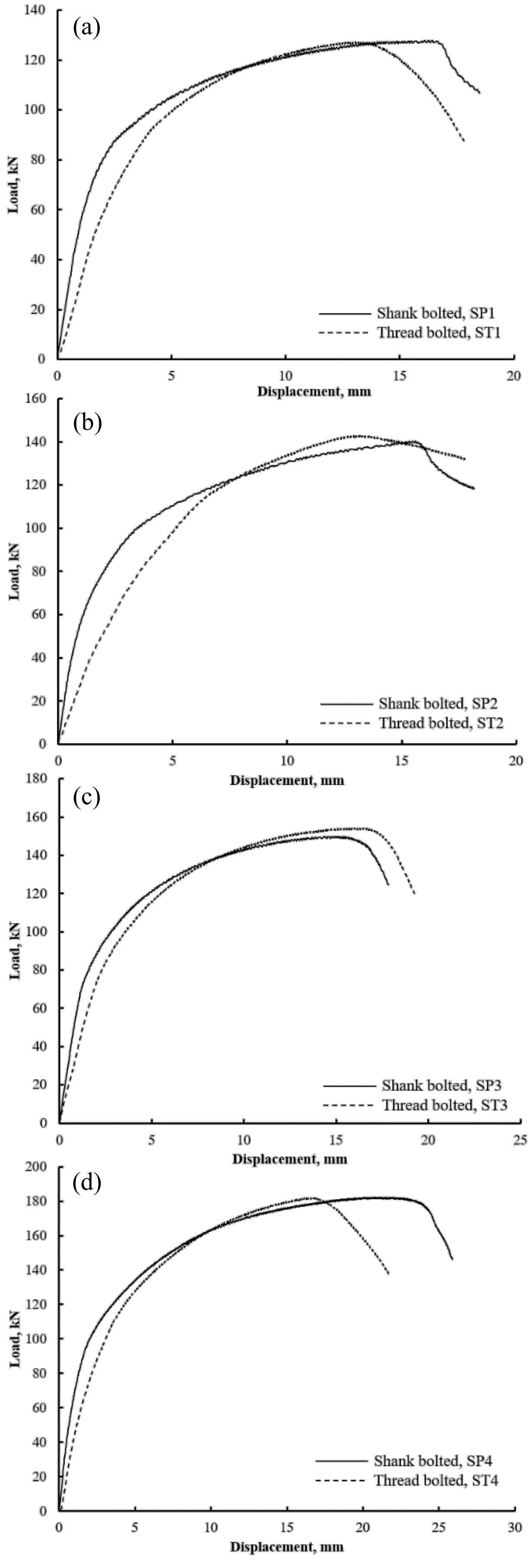


Figure 3: Experimental load-displacement graphs of (a) SP1 & ST1; (b) SP2 & ST2; (c) SP3 & ST3; (d) SP4 & ST4

3 FINITE ELEMENT SIMULATION

The present finite element (FE) model used the hexahedral eight-node reduced integration brick element C3D8R available in ABAQUS 6.14 Standard [13]. The Dynamic implicit method was used to carry out the nonlinear analysis of the bolted connections. The bolts were modelled as rigid body as they experienced minimal deformations during the laboratory tests. Displacement controlled quasi-static movement of the bolt was used to simulate loading of the inner plate by the bolt. The plasticity of the steel material was handled through the von Mises yield criterion and the Prandtl-Reuss flow rule with isotropic hardening. The elastic modulus was taken as 200 GPa, and the Poisson's ratio was 0.3.

The three-parameter Ramberg-Osgood [14] equation was used to derive the stress-strain curve from the measured yield stress and tensile strength. Taking advantage of the symmetry of the double-shear connections studied in the present work, only a quarter of the specimen was modelled. Contact was modelled in the manner described by Clements & Teh [15]. However, the present model included the bolt threads as described below.

ISO [9-11] defines the basic profile and available thread sizes for a range of bolt diameters. There are typically two types of threads, coarse and fine threads with an intermediate thread size available for some bolts. The relationship between the thread pitch and depth is given in Equation (3). Figure 4 defines the dimensions of shank and threaded bolts.

$$t_d = \frac{\sqrt{3}}{2} t_p \tag{3}$$

where t_d is the thread depth and t_p is the thread pitch.

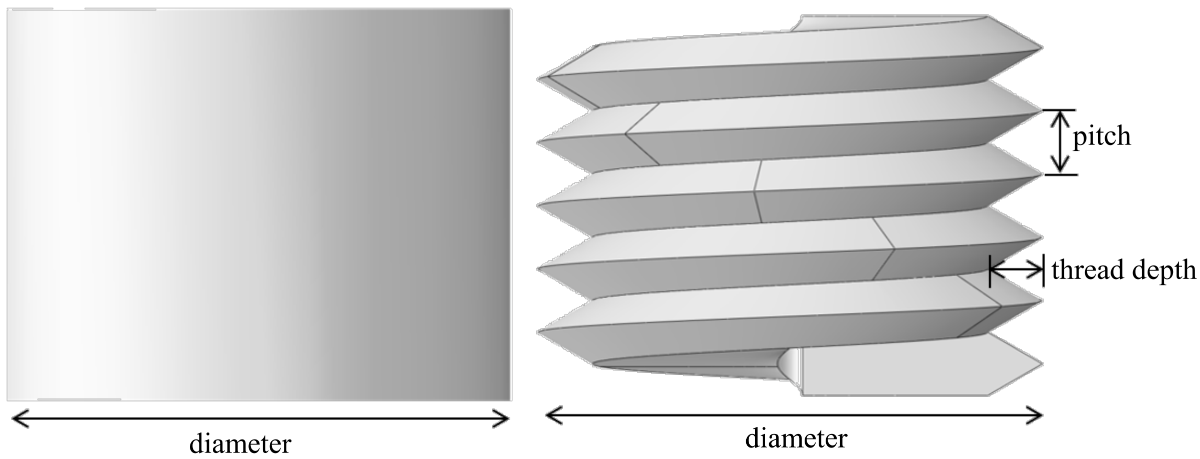
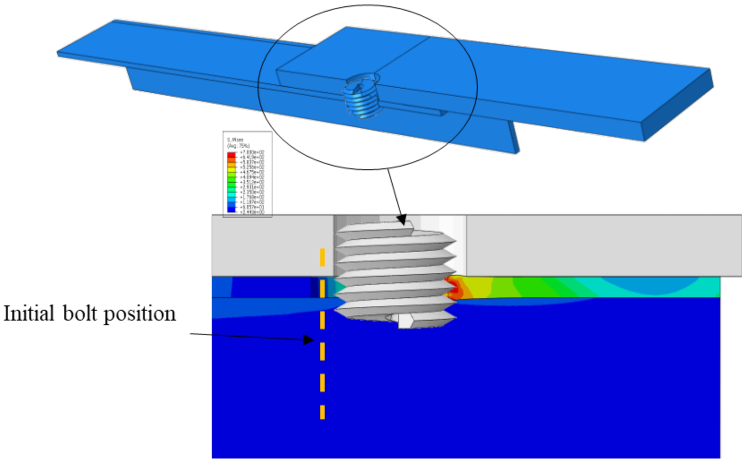
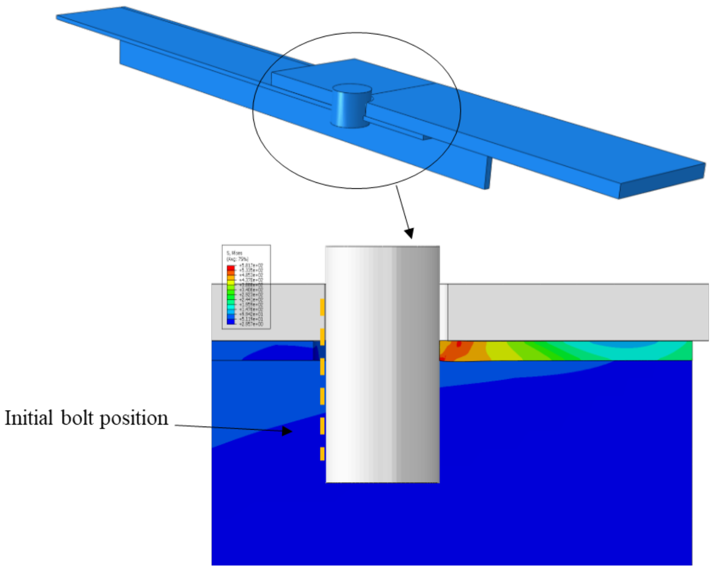


Figure 4: Dimensions of shank and threaded bolts

In the Part module of ABAQUS [13], a threaded bolt was modelled using 3D deformable solid with revolution and pitch. In the Step module of ABAQUS, unsymmetric matrix storage was used for the equation solver. In the Interaction module, node to surface discretization was used for surface to surface contact definition. Finally, in the Interaction property definition, tangential behaviour was defined using penalty formulation and a friction coefficient of 0.3.



(a) with threads



(b) without threads

Figure 5: Deformed FE models of Specimen HX-2-M12 at an applied load of 30 kN

The present study analysed the HX-2-M-12 specimen (test 6) reported by D'Antimo *et al.* [6] using two models, one incorporating threads and the other without threads. Each specimen was a 2 mm thick square hollow section (SHS) having a 12 mm bolt passing through two sides. The coarse thread pitch of a 12 mm bolt was 1.5 mm.

The FE simulation used the measured material properties and dimensions provided by D'Antimo *et al.* [6]. Figure 5 shows the deformed shapes of the threaded and shank bolted models at an applied load of 30 kN. At this point, the displacements of the threaded and the shank models were 1.3 mm and 0.4 mm, respectively. The thread cutting into the plate of the SHS specimen as evident in Figure 5(a) is responsible for the difference in the initial stiffness between the threaded and the shank models.

Figure 6 compares the load-displacement graphs obtained from the laboratory test and from the FE analysis with a threaded bolt, which shows the accuracy of the threaded model up to the ultimate test load. The necessity of modelling the bolt threads is evident in Figure 7, which compares the load-displacement graphs obtained from the various FE models against the laboratory test result. It can also be seen that the use of an artificially smaller bolt diameter to match the initial stiffness [6] resulted in a significantly lower ultimate load estimate while still predicting a significantly higher initial stiffness.

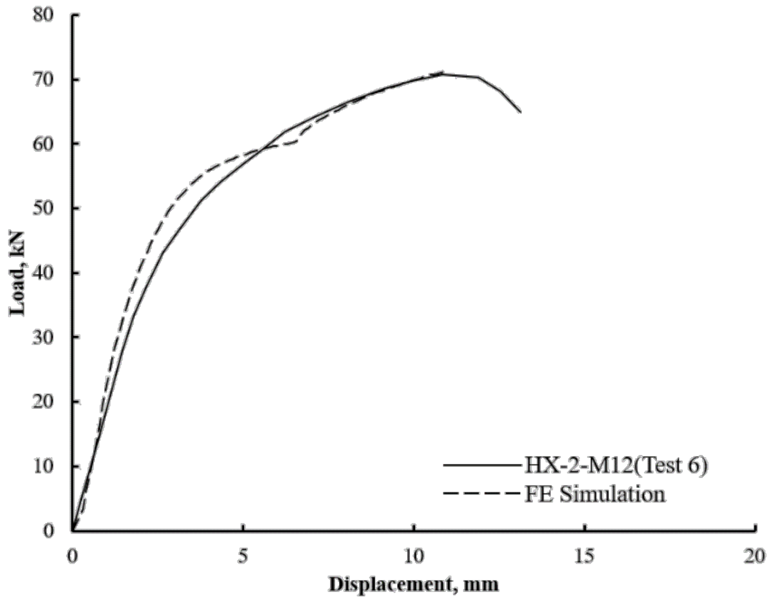


Figure 6: Load-displacement graphs: Experiment vs FE simulation (threaded)

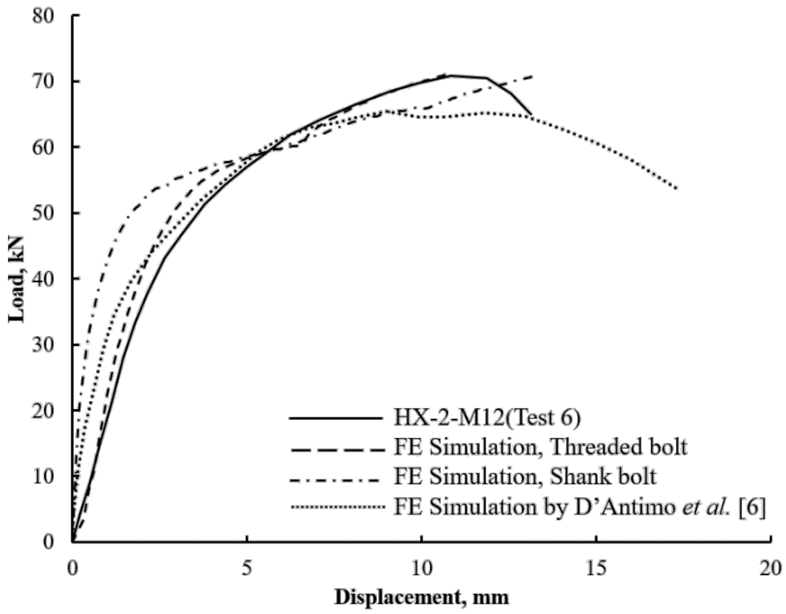


Figure 7: Comparison of FE load-displacement graphs

4 CONCLUSIONS

The paper has presented the laboratory test results of threaded and shank bolted connections loaded in shear to compare their initial stiffnesses against each other. The threaded specimens have been found to possess significantly lower initial stiffnesses than those of the comparable shank specimens.

Finite element analyses using models with and without bolt threads have confirmed that the presence of the threads reduces the initial stiffness of a bolted connection in shear. For a finite element analysis to accurately simulate the load-displacement response of a bolted connection in shear up to the ultimate load, it is necessary to model the bolt threads.

It has been found that the finite element model incorporating bolt threads is better able to mimic the load-displacement behaviour of an independent test specimen than the model employing an artificially smaller bolt.

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REFERENCES

[1] Lim J. B. P., Nethercot D. A., “Stiffness prediction for bolted moment-connections between cold-formed steel members”, Journal of Constructional Steel Research, 60, 85-107, 2004.

[2] Salih E.L., Gardner L., Nethercot D.A., “Bearing failure in stainless steel bolted connections”, Engineering Structures, 33, 549-562, 2011.

[3] Moze P., Beg D., “Investigation of high strength steel connection with several bolts in double shear”, Journal of Constructional Steel Research, 67, 333-347, 2011.

[4] VanGaasbeek C.J., Numerical modelling of bolted joints. An applied finite element analysis approach, Master’s Thesis, Rensselaer Polytechnic Institute, Hartford, Connecticut, 2015.

[5] Yang L., Wang Y., Guan J., Zhang Y. and Shi Y., “Bearing strength of stainless steel bolted connections”, Advances in Structural Engineering, 18(7), 1051-1062, 2015.

[6] D’Antimo M., Demonceau J. F., Jaspart J. P., Latour M., Rizzano G., “Experimental and theoretical analysis of shear bolted connections for tubular structures”, Journal of Constructional Steel Research, 138, 264-282, 2017.

[7] Haidar N., Obeed S., Jawad M., “Mathematical representation of bolted-joint stiffness: a new suggested model”, Journal of Mechanical Science and Technology, 25(11), 2827-2834, 2011.

[8] Zhang D., Gao S., Xu X., “A new computational method for threaded connection stiffness”, Advances in Mechanical Engineering, 8(12), 1-9, 2016.

[9] International Organization for Standardization. ISO general purpose screw threads-Basic profile-metric screw threads, ISO 68-1, Geneva, Switzerland, 1998.

[10] International Organization for Standardization. ISO general purpose metric screw threads-Selected sizes for screws, bolts and nuts, ISO 262, Geneva, Switzerland, 1998.

[11] International Organization for Standardization. ISO general purpose metric screw threads-tolerances, ISO 965-1, Geneva, Switzerland, 2013.

[12] Teh, L. H. & Uz, M., "Ultimate shear-out capacities of structural steel bolted connections”, Journal of Structural Engineering, 141(6), 04014152-1-04014152-9, 2015.

[13] ABAQUS Analysis User’s Manual, Version 6.14. Providence RI, Dassault Systèmes, ABAQUS, 2014.

[14] Ramberg W, Osgood WR. (1943). "Description of Stress-strain Curves by Three Parameters". National Advisory Committee for Aeronautics, Technical note No. 902.

[15] Clements, D.D.A., and Teh, L.H., “Active shear planes of bolted connections failing in block shear”, Journal of Structural Engineering, 139 (3), 320-327, 2013.