Slipping coefficient study of frictional high strength bolt joint

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Receeived 15 November 2014, www.cmnt.lv

Abstract

The finite element model was developed by the software ABAQUS based on the existed test to analyze the slipping coefficient of frictional high strength bolt joint. The effects of connecting plate thickness, distance from bolt axis to the component edge, bolt hole diameter, and pretension on slipping coefficient were discussed. The results show that the simulated slipping coefficient is about 0.23 and agrees well with the existed test results. It is smaller than the corresponding code value 0.3. Increasing connecting plate thickness or edge distance could improve the slipping coefficient slightly. Increasing bolt hole diameter or pretention would decrease the slipping coefficient slightly. At the same time, the minimum and the maximum pretension curves for M20 bolt were obtained for practical usage.

Keywords: frictional high strength bolt, slipping coefficient, pretension, bolt hole diameter

1 Introduction

High strength bolt has been widely used in construction engineering due to its obvious advantages in manufacture and installation. Frictional high strength bolt connection has advantages of mechanical performance, fatigue resistance and anti-seismic behaviour. It is a kind of main connection method in steel structure installation. The friction force between two plates is used to resist the load on the connection. The friction happening to be overcome is bearing capacity limited state for frictional high strength bolt joint [1]. The major factors on the bearing capacity are the slipping coefficient and pretension. Therefore, it is very important to deliberate the slipping coefficient and pretension.

Yiyi Chen and Zuyan Shen et al [2] carried out an experimental research on the slipping coefficient of two coating surfaces of high strength bolts connections. The results show that the slipping coefficient value of two coating surfaces is less than the code value. Qicai Li and Qiang Gu et al [3] researched the slipping coefficient treated by hard wire brushing. The results show that the slipping coefficient cannot meet the value given in codes too. Zhiming Song et al [4-5] analysed the effect of different ways to remove rust on the slipping coefficient. All above researches were based on the laboratory experiment. Some other scholars [6-7] established finite element model to research the slipping coefficient. But finite element modelling of high strength bolt involves geometric nonlinearity, material and contact nonlinearity. So the computation is complex and the slipping coefficient was not discussed. In order to make up for the lack of testing and finite element method on the study of the slipping coefficient of high strength bolts, Meng Wang et al [8] found a simple and accurate model to analyze the shearing behaviour of high strength bolted connection, on the basis of typical high strength bolts shear experiment. The shearing resistance of high strength bolt was discussed. Dayong Jin [9] and Changjiang Liu [10] et al also researched the performance of high strength bolt joint. But they did not research the slipping coefficient in detail. Tiehong Peng and Zhaoxin Hou [11] et al conducted experimental program on the pretension loss and slip resistance of high strength bolt with different bolt hole diameter. Design proposals were given on the bolt hole diameter, the corresponding large bolt hole diameter and slotted hole. The effects of connecting plate thickness, edge distance and bolt hole diameter on slipping coefficient were not discussed.

The software ABAQUS was used to develop the nonlinear finite element model of frictional high strength bolt connection. The existed test results were used to check the accuracy and applicability of this FEM model. At the same time, the influencing factors including connecting plate thickness, edge distance and the bolt hole diameter were analysed with this model. In addition, the scope of the needed pretension under a certain external load was also discussed. As a result, a curve of the minimum needed pretension was obtained for practical usage.

2 Model and verification

2.1 GEOMETRICAL MODEL AND MATERIAL PROPERTIES

According to the reference [3], the high strength bolt connection model was consistent with the specimen in that paper. The physical dimension of the model is shown in Figure 1.

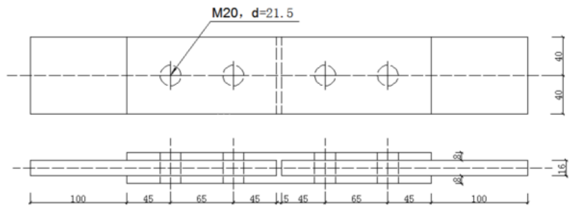

FIGURE 1 Dimensions of the model (mm)

The bolt in the specimen was grade 10.9 and 20mm in diameter. The bolt and the bolt holes were simplified as a smooth cylindrical surface. The size of hexagonal screw cap, nut and washer were selected according to the codes [12-13].

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The length of screw equaled to the sum of connecting plates thickness and washer thickness. 0.25 was taken as the friction coefficient of all the contact surfaces. The material properties are shown in Table 1.

TABLE 1 Material properties

Part	Connecting plate	Bolt
Elongation	20%	20%
Yield stress(MPa)	235	900
Tensile limit (MPa)	450	1000
Young's modulus (MPa)	206000	206000
Density (kg/m3)	7800	7800
Poisson's Ratio	0.3	0.3

2.2 FINITE ELEMENT MODEL

ABAQUS was used to establish the numerical simulation model. Because of the symmetry of the loads and the structure, a half of the model was taken to analyze the mechanical characteristics of the high strength bolt, and the middle of this model was treated as symmetrical boundaries. The C3D8R element was selected to simulate connecting plates and bolts. There were 24154 nodes and 18356 elements in the model after meshing. The finite element model is shown in Figure 2.

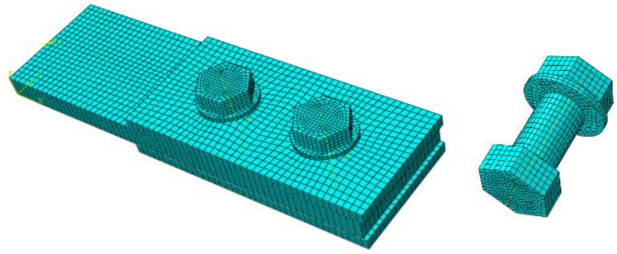

FIGURE 2 Finite element model of the connection

2.3 LOADING

The pretension of 155kN, 186kN and 124kN was applied on the bolt separately by the Bolt Load of ABAQUS/Standard. The contact forces between bolts and connecting plates were the pretensions imposed by the Bolt Load from the output of Abaqus. It indicated that bolt pretension was applied successfully.

2.4 RESULTS

The curve of load-displacement at load point is shown in Figure 3. It can be seen that the bearing capacity increase linearly with the rise of displacement when the load value has not reached 144kN. The working process of frictional high strength bolt connection just happens in this stage. Then the curve has an obvious platform because of the relative slip between blots and connecting plates. After the slip phase, the bearing capacity has a rapid improvement for the bolt bars slipped and contacted closely with the bolt holes. Then the curve shows a working process of bearing-typed high strength bolt connection. In that case, the bearing capacity greatly improves until the appearance of large plastic deformation in materials. According to this load-displacement curve, the value of slipping load can be obtained, that is 144kN.

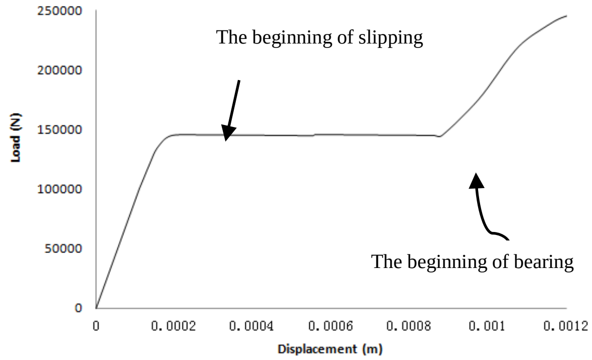

FIGURE 3 The curve of load-displacement at load point

The mechanical behaviours of specimen S1, S2 and S3 in the reference [3] were simulated in this paper and the corresponding sliding loads were also obtained. Slipping coefficient was calculate according to Eq.(1).

$$\mu = \frac{N}{n_f \cdot \sum P}, \tag{1}$$

where, nf is the number of the friction surfaces, N is the slipping load, μ is the slipping coefficient, ∑P is the sum of pretension on one side of the connecting plate.

The slipping coefficient values of high strength bolt obtained from experiments and simulations are shown in Table 2. The results show that the simulated values were in agreement with the experimental values. The code [13] provides that slipping coefficient prepared by hard wire brushing or untreated Q235 steel was 0.3. However, the simulation results show that the slipping coefficient was about 0.2303, it is smaller than the code value.

TABLE 2 The values of high strength bolt of experiments and simulations

specimens	Pretension (kN)	Slipping load (kN)		Slipping coefficient		The relative error
		The experimental value	*The simulated value*	*The experimental value*	*The simulated value*	
S1	155	140	144	0.2258	0.2323	2.9%
S2	186	170	172	0.2285	0.2315	1.3%
S3	124	120	119	0.2420	0.2391	1.1%

According to Table 2, it can be concluded that the biggest relative error between simulated values and experimental values was 2.9%. Simulated value was consistent with the experimental value very well.

3 Discussion

3.1 EFFECT OF CONNECTING PLATE THICKNESS ON SLIPPING COEFFICIENT

In order to analyze the effect of connecting plate thickness on sliding coefficient, the slipping coefficients in connecting plate thickness of 10mm, 12mm, 14mm, 16mm, 18mm, 20mm and the pretension of 155kN were calculated. The results are shown in Table 3.

TABLE 3 Slipping coefficients with different connecting plate thickness

Connecting plate thickness(mm)	Pretension (kN)	Slipping load (kN)	Slipping coefficients
10	155	137	0.2212
12	155	138	0.2226
14	155	144	0.2323
16	155	144	0.2323
18	155	147	0.2366
20	155	147	0.2371

According to Table 3, it can be seen that the slipping coefficient increases slightly with the increase of the plate thickness. The slipping coefficient was still less than the required value in the Code.

3.2 EFFECT OF EDGE DISTANCE ON SLIPPING COEFFICIENT

The minimum edge distance was 1.5 d0 in the Code, and the maximum was the min {4d0, 8t}. So in the real project, the value area of the edge distance was broad. The slipping coefficients in the edge distance of 30mm, 35mm, 40mm, 45mm, 50mm, 55mm, 60mm, 70mm, and the pretension of 155kN were calculated. The results are shown in Table 4.

TABLE 4 Slipping coefficients with different edge distance

Edge distance (mm)	Pretension (kN)	Slipping load (kN)	Slipping coefficient
30	155	142	0.2283
35	155	144	0.2323
40	155	144	0.2323
45	155	147	0.2369
50	155	148	0.2379
55	155	148	0.2382
60	155	148	0.2387
70	155	149	0.2398

According to Table 4, with the increase of edge distance, the area of contact surface increases. The slipping coefficient increases slightly. But the slipping coefficient still couldn't meet the required value in the Code.

3.3 EFFECT OF BOLT HOLE DIAMETER ON SLIPPING COEFFICIENT

The Code provides that connecting plate bolt hole diameter should be 1.5~2.0mm large than the bolt diameter. However, taking the relative displacement between the connecting plate and bolts into account, increased bolt hole diameter could also be used in actual steel structure engineering. The slipping coefficients in different bolt hole diameters including 21.5mm, 22mm, 23mm, 24mm, 25mm and 25.5mm were calculated. The results are shown in Table 5.

TABLE 5 Slipping coefficients with different bolt hole diameter

Bolt hole diameter (mm)	Pretension (kN)	Slipping load (kN)	Slipping coefficient
21.5	155	144.03	0.2323
22	155	143.88	0.2321
23	155	143.55	0.2315
24	155	143.22	0.2310
25	155	142.56	0.2299
25.5	155	142.23	0.2294

According to Table 5, when the bolt hole diameters are in the interval of 21.5mm to 25.5mm, the slipping coefficient decreased slightly with the increase of bolt aperture. The slipping coefficient was less than the code value.

3.4 EFFECT OF PRETENSION ON MECHANICAL BEHAVIOUR OF THE BLOT

3.4.1 Calculation results

According to the Code [13], the bearing capacity of each frictional high strength bolt in the shear connection was calculated by Eq.(2).

$$N_v^b = 0.9 \times n_f \times \mu \times P, \qquad (2)$$

where, nf is the number of the friction surfaces, μ is the slipping coefficient, P refers to the pretension of each high-strength bolt.

The slipping coefficient of Q235 steel is about 0.3. And the design pretension of the grade 10.9 and 10mm diameter high-strength bolt is 155kN. So it could be concluded that the design bearing capacity of each slip-critical high-strength bolt is within 84kN. Therefore, the forces in the external loads within 170kN are calculated. The forces of bolt in different external loads including 170kN, 140kN, 110kN, 80kN, 50kN, 20kN were calculated.

Work Condition 1: The Mises stress results in external load of 170kN and pretension of 183.5kN is shown in Figure 4, and equivalent plastic strain is shown in Figure 5.

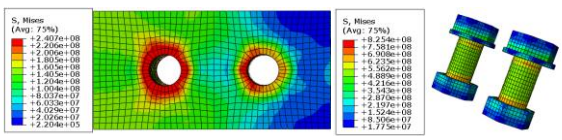

FIGURE 4 The Mises stress of connecting plates and bolts in Work Condition 1

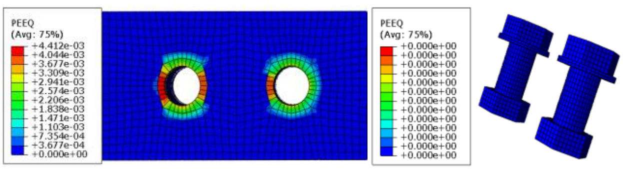

FIGURE 5 The equivalent plastic strain of connecting plates and bolts in Work Condition 1

Work Condition 2: The Mises stress results in external load of 170kN and pretension of 210kN is shown in Figure 6, and equivalent plastic strain is shown in Figure 7.

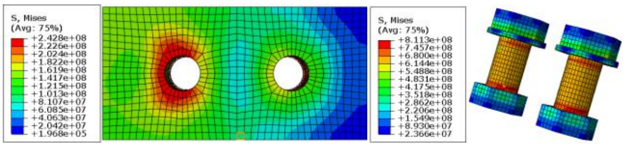

FIGURE 6 The Mises stress of connecting plates and bolts in Work Condition 2

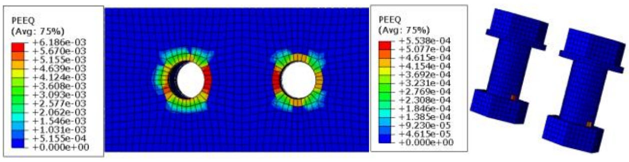

FIGURE 7 The equivalent plastic strain of connecting plates and bolts Work Condition 2

According to the figures above, it could be obtained that when the pretension reaches to 210kN, the equivalent plastic strain of the connecting plate is too large and results in the connection failure. When the pretension is 183.5kN, slips between connecting plates and bolt occur and the bolt fails. As a result, only apply a certain range of pretension on the bolt, can the bolt work normally.

3.4.2. Minimum and maximum pretension curves of M20 high strength bolt

The pretension curve of M20 high strength bolt is shown in Fig. 8. The lower curve and upper curve are separately the lower bound and upper bound of pretension force. The upper bound means the equivalent plastic strain of the connecting plate is too large and the lower bound means that the slip happened.

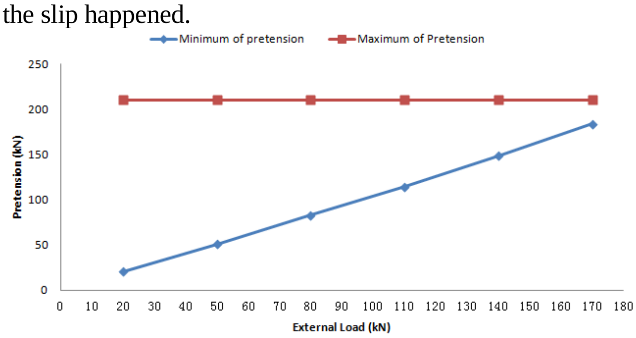

FIGURE 8 Pretension curves

As seen in Figure 8, the upper bound of pretension force specific to all tensions is 210kN. That is, the maximum pretension force is largely depending on whether the equivalent plastic strain of the connecting plate is too large or not. And the lower bound of pretension force would increase with the rise of tension. Based on the simulation results, the relation between the needed pretension and tension was obtained. It can be described by a power function. The function is shown in Eq.(3).

$$P = 0.9475N^{1.0223}, \tag{3}$$

where, P is the needed pretension, and N is the tension.

Furthermore, the value of bolt bearing capacity calculated by the Code will lead to unsafe connection for the slipping coefficient and pretention are relatively smaller.

3.4.3 Slipping coefficient check

6 experiment specimens were simulated, the corresponding slipping coefficients in different external loads were calculated according to Eq.(1). The results are shown in Table 5.

TABLE 6 Slipping coefficient

Specimen	Slipping load (kN)	Pretension (kN)	Slipping coefficient
1	170	183.5	0.2316
2	140	148.5	0.2357
3	110	114.5	0.2402
4	80	83.0	0.2410
5	50	51.0	0.2451
6	20	20.5	0.2439

As shown in Table 6, the slipping coefficient under tension could not meet the required value in the Code. The slipping coefficient decreases with the increase of pretension slightly.

4 Conclusions

From the above investigation, the following conclusions can be drawn:

(1) The slipping coefficient of simulation is reasonable and is agreed with that in existed tests.

(2) The slipping coefficient in the Code for prepared by hard wire brushing or untreated Q235 steel is 0.3, however the simulated results and tests show the slip coefficient is about 0.23, which is smaller than the code value. It means the code value is relatively larger, it may cause unsafe connection.

(3) The slipping coefficient increase slightly by increasing connecting platethickness and edge distance. Increase of the bolt hole diameter result in the decrease of slipping coefficient, but the effect is not obvious. Increase of the pretension lead to the decrease of slipping coefficient too.

(4) The lower bound and upper bound of pretension force to a certain tension are given for M20 bolt.

Acknowledgement

Support for this research by Foundation of National Science of China (51279206), and Beijing Natural Science Foundation (3144029).

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