Measurement and Study on the Torque Coefficient of Ordinary Bolts Before and After Galvanization

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Abstract. Galvanization is widely applied to bolts as an anti-corrosion method in bolted connection of steel structures in power transmission engineer. After being galvanized by hot-dipping, the torque coefficient of bolts will be changed. To investigate this change, the torque coefficients of ordinary bolts in different grades and specifications were measured before and after galvanization. Results indicate that mean values and standard deviations of torque coefficients of the galvanized bolts increase to a certain extent, but the torque coefficients and the standard deviations tend to decline as the improvement of bolt specification, and the stress of ungalvanized ones is larger than that of hot-dip galvanized bolts in the same grade and specification.

1. Introduction

Hot-dip galvanized bolts are extensively used in transmission towers because of their low cost and good anti-corrosion resistance[1]. At present, the joints of steel towers are mostly connected by plates with galvanized bolts that mainly bear shear. During the installation process, most of the connecting bolts must be tightened to enhance the reliability and tightness of connection. And appropriate preload should be applied to enhance the stiffness and anti-loose ability of bolt joints and to prevent the lateral slid caused by transverse load between connected components. In general, preload can be controlled indirectly via torque wrenches exerting tightening torque for bolts. As an important parameter of the relationship between tightening torque and preload, the torque coefficient can significantly affect the stress conditions of bolts and connected plates. Thus, the uncertainty of torque coefficient will directly influence the application of tightening torque and further effective control of the preload acting on screws. Because improper preload leads to all sorts of problems: fracture and fatigue failure of bolts, impact damage of thread, crushing and bending of joints and loosening of nuts caused by vibration, it is of important engineering signification to determine the relationship between tightening torque and preload (i.e., torque coefficient)[2].

Some scholars have conducted related researches on the pretension of bolt yet. Peng et al.[3] studied the effects of different bolt preload on rigid and flexible flange joints experimentally, indicating that the axial, shear and bending stiffnesses of these joints applied by tightening torque are obviously smaller than those exerted by pretension in accordance with standard norms. Zhang et al.[4] developed a hydraulic tensioner to exert certain preload on high-strength bolts without standard torsion coefficients. Li et al.[5] conducted an experimental study on the fastening process of high-strength bolts, whereby
the torsion-tension and axial force-rotation angle relationships were obtained and the angles of nuts required for certain preload on high-strength bolts were summarized. At present, several domestic fastener standards have been issued, where the torque coefficients of bolts are specified in detail. Specifications of high strength bolts with large hexagon head, large hexagon nuts, ordinary washers for steel structures (GB/T 1236-2006) only stipulates the torque coefficients of high strength bolts with large hexagon head that range from 0.110 to 0.150[6], without explicit stipulation on ordinary bolts, not to mention hot-dip galvanized ordinary bolts. Thus, the installation quality of bolts in existing transmission towers are all verified indirectly by testing the tightening torque. However, in most cases, these bolts are over-screwed or under-screwed because of the uncertainty of torque coefficient, and this indeed lowers the quality of towers. In summary, the difference of torque coefficients between hot-dip galvanized ordinary bolts and ungalvanized ones should to be studied comprehensively and systematically. In this paper, the torque coefficients of commonly used hot-dip galvanized bolts in transmission engineering were tested and the relationship between tightening torque and stress was analysed to provide some references for design and construction units.

2. Experimental program

According to fabrication precision, ordinary bolts can be divided into 3 types: A, B and C, 14 grades in total and type-C bolts are most commonly used in steel structure[7]. The bolts tested were all type-C hexagon head bolts and divided into 12 groups with 8 same bolts in each group, as shown in table 1.

| Group | Surface treatment | Specification | Grade | Group | Surface treatment | Specification | Grade |
|-------|-------------------|---------------|-------|-------|-------------------|---------------|-------|
| 1     | ungalvanized      | M16           | 4.8   | 7     | galvanized        | M16           | 4.8   |
| 2     |                   | M16           | 6.8   | 8     |                   | M16           | 6.8   |
| 3     |                   | M20           | 8.8   | 9     |                   | M20           | 8.8   |
| 4     |                   | M20           | 6.8   | 10    |                   | M20           | 6.8   |
| 5     |                   |               | 8.8   | 11    |                   |               | 8.8   |
| 6     |                   |               |       | 12    |                   |               |       |

The corresponding relation between tightening moment $T$ and preload $P$ is[8]

$$T = T_1 + T_2 = \frac{1}{2}PD_2\left(\mu \sec \frac{\alpha}{2} + \tan \lambda\right) + \frac{1}{2}P\mu_1D_n$$

(1)

where $T_1$ is the moment acting on screw pairs, $T_2$ is the moment acting on bearing surface (the interface between flange and nut), $P$ is the preload, $D_2$ is the middle diameter of thread, $\alpha$ is the thread angle, $\lambda$ is the helix angle, $\mu$ is the friction coefficient between screws, $\mu_1$ is the friction coefficient between interfaces and $D_n$ is the mean diameter of bearing surface. By importing the nominal diameter of bolts $D$ to equation (1), a transformation can be obtained that is

$$T = KDP$$

(2)

where $K$ is the torque coefficient commonly used in engineering and

$$K = \frac{1}{2}D_2\left(\mu \sec \frac{\alpha}{2} + \tan \lambda\right) + \mu_1D_n$$

(3)

Equation (3) indicates that the torque coefficient $K$ can be calculated by exact value with a given $D$ value. Therefore, according to the calculated $K$ value and equation (2), the $P$ value can also be calculated with a proposed tightening moment $T$ value for application to bolts.

Torque coefficients of bolts were measured by a device composed of pressure rings and a resistance strain gauge in terms of Code for acceptance of construction quality of steel structures (GB 50205-2001)[9]. The testing device and process are shown in figure 1 and figure 2, respectively.
The specific testing method was to exert proposed tightening torques on bolts respectively and then to record corresponding strains measured by the resistance strain gauge. The testing principles are as follows: a) calibrate the preload acting on bolts and the strain produced and fit the linear relation between them; b) measure the strain of bolts assembled with pressure rings under tightening torque and calculate the preload according to the strain-preload relation; the strain tested here was an intermediate variable to derive the relation between tightening torque and preload; c) calculate the torque coefficients according to equation (2) and the mean values and standard deviations of them.

3. Results and discussion

The testing results of bolt torque coefficients are shown in table 2.

| Group | Mean value | Standard deviation |
|-------|------------|--------------------|
| 1     | 0.380      | 0.070              |
| 2     | 0.342      | 0.096              |
| 3     | 0.574      | 0.103              |
| 4     | 0.199      | 0.018              |
| 5     | 0.130      | 0.003              |
| 6     | 0.161      | 0.003              |

From table 2, for bolts in the same specification and grade, the torque coefficients of galvanized bolts are more discrete and higher than those of ungalvanized ones. And for both types of bolts, those in high specification have lower torque coefficients with smaller discreteness. Because of the difference between torque coefficients of bolts in the same specification and grade before and after galvanization, the tightening torques calculated in terms of torque coefficient also varies greatly. For example, according to equation (2), the tightening torques required for 4.8-grade M20 galvanized and ungalvanized bolts are 342N-m and 200N-m, respectively, which means that bolts might be twisted off under the excessive tightening torque.

In order to further clarify the relationship between tightening torque and preload, torque coefficient was more deeply studied. According to the above-mentioned testing method, a series of incremental tightening torques was applied to the same bolt orderly and the corresponding strains were recorded. Because the relationship between tightening torque and strain in the elastic range is linear and turns to nonlinear when the former exceeds limit value, in terms of Construction machinery—Test methods of tightening torque for bolts[10] and in consideration of the maximum tightening torque pressure rings can bear, the upper limits of tightening torque of bolts in various grades and specifications were graded, as shown in table 3.
Table 3. Grading scheme of tightening torque.

| Group | Upper limit (N∙m) | Tightening torque value (N∙m) |
|-------|-------------------|------------------------------|
| 1     | 160               | 40 60 ... 160               |
| 2     | 160               | 40 60 ... 160               |
| 3     | 240               | 60 90 ... 240               |
| 4     | 200               | 40 60 ... 200               |
| 5     | 300               | 60 90 ... 300               |
| 6     | 400               | 60 100 ... 380              |

| Group | Upper limit (N∙m) | Tightening torque value (N∙m) |
|-------|-------------------|------------------------------|
| 7     | 160               | 40 60 ... 160               |
| 8     | 160               | 40 60 ... 160               |
| 9     | 240               | 60 90 ... 240               |
| 10    | 200               | 40 60 ... 200               |
| 11    | 300               | 60 90 ... 300               |
| 12    | 400               | 60 100 ... 380              |

A series of relation curves between the tightening torque and stress are drawn in figure 3 to figure 8 and discussed as follows.

Figure 3. Relation between the tightening torque and stress of grade-4.8 M16 bolts.

Relations between the tightening torque and stress of grade-4.8 ungalvanized and galvanized bolts are shown in figure 3 and figure 4, respectively. The bolt stress increases with the tightening torque, which is consistent with the actual situation, and the relation curves are linear with small fluctuation because the preload is in the elastic range.

Figure 4. Relation between the tightening torque and stress of grade-4.8 M20 bolts.

Relations between the tightening torque and stress of grade-4.8 ungalvanized and galvanized bolts are shown in figure 5 and figure 6, respectively. As same as the tightening torque-stress curve distribution regularity of grade-4.8 bolts, the bolt stress of grade-6.8 also grows with the tightening torque but the curves of latter are more stable.
Relations between the tightening torque and stress of grade-8.8 ungalvanized and galvanized bolts are shown in figure 7 and figure 8, respectively. The tightening torque-stress curves of grade-8.8 M20 ungalvanized and galvanized bolts are almost straight and coincided lines.

According to the relationships between tightening torque and stress, the stress in ungalvanized bolts is higher than that in the same specification and grade of galvanized bolts under the equivalent tightening torque. Because in the same specification and grade, the galvanized bolts generally have larger torque coefficients than the ungalvanized ones, and in turn resulting in smaller preload and stress on the basis of equation (2). In addition, the differences among tightening torque-stress relations of bolts in diverse specifications and grades varies in statistics. For example, the standard deviations of torque coefficients of 4.8-grade M16 ungalvanized and galvanized bolts are respectively 0.0770 and 0.187, several times those of 8.8-grade M20 ungalvanized and galvanized bolts, which are 0.003 and 0.004, respectively. Therefore, for the bolts in different specifications and grades, their stress differences are in direct ratio with the corresponding standard deviations of torque coefficients that the smaller standard deviation and discreteness are, the smaller stress difference presents.

4. Conclusions and suggestions
In this paper, a batch of bolts in 3 grades and 2 specifications were tested on their torque coefficients before and after galvanization and incremental tightening torques were applied to the same bolt orderly to obtain the relation between tightening torques and stress. The following conclusions may be drawn.

1. For the bolts in the same grades and specifications, the torque coefficients of galvanized bolts are greater and more discrete than those on the ungalvanized ones.

2. The torque coefficients of high-specification bolts have smaller discreteness than those of the bolts in low specification.

3. The stress in ungalvanized bolts is higher than that in the galvanized ones under the same tightening torque and in the same grades and specifications, and stress is inversely proportional to torque coefficient.

4. Under the same tightening torque, the stress differences among ungalvanized and galvanized bolts in different grades and specifications are in proportion to the standard deviations of corresponding torque coefficients.

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