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Evaluation of *K*-Factor of Preloaded Bolted Joints

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Abstract

Load-bearing capacity and resistance of preloaded joints bolts depends on the value of torque. Correlation between tightening torque and axial preloading force is made by means of k-factor, whose value depends on the mechanical characteristics of the components of bolted structural joints. In this work is presented a way that experimental evaluation factor.

Key words: *preloaded bolted joints, high-strength preloaded bolts*

Introduction

The design and checking calculation of steel structures is carried out in accordance with the standards of Eurocod 3. There are 25 standards governing the design of steel structures.

EN 1993-1-8 [1] refers to the joints using high strength preloaded bolts because much of the metal constructions are carried out using bolted joints with high-strength preloaded bolts.

Transmission of loads between the bolt (figure 1) –and components for steel construction which combines – is done by frictional forces generated between the areas of application of these contact elements, within the limits of friction forces, capable of mounting bolts to pre-stressing.

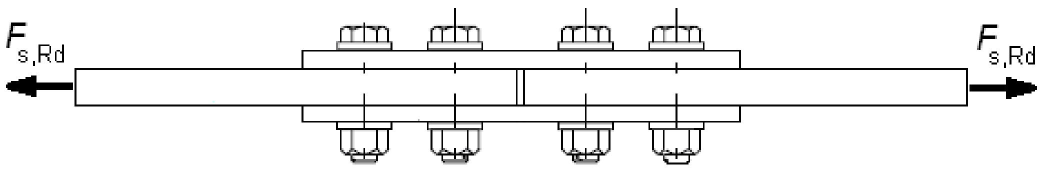

Fig. 1. Preloaded bolt joints.

Since the maximum tasks undertaken by such seams will depend on the: number of bolts; mechanical and physical characteristics of the clamped members, in particular the bolts; mechanical characteristics of surfaces in contact, and in particular the degree of processing of these surfaces, cover them with other substances, corrosion etc.; the bolts are made of alloy steel with higher resistance obtained by appropriate heat treatment and contact surfaces of the joints shall be processed in order to achieve a coefficient of friction as possible.

According to [1] for joints with high strength preloaded bolts use only screws of 8.8 and 10.9 – the first number is the ratio $f_{ub}/100$, and the second report $10 \cdot f_{yb} / f_{ub}$, the f_{yb} (= $R_{p0,2}$) is the yield strength of the steel, and $f_{ub}(=R_m^{\min})$ of the steel of bolt. All according to [1] denominations to yield strength f_{yb} and minimum tensile strength f_{ub} are given in table 1.

Table 1. Denominations for the yield strength f_{yb} and minimum tensile strength f_{ub} of high strength preloaded bolts.

Bolt class	8.8	10.9
f_{yb} (MPa)	640	900
f_{ub} (MPa)	800	1000

The design slip resistance of preloaded bolts should be taken as [1]:

$$F_{s,Rd} = \frac{k_s n \mu}{\gamma_{M3}} F_{p,C} \tag{1}$$

where: k_s is a factor what consider the deviation of contour of hole, given in Table 2; n is the number of friction surfaces; μ is the slip factor obtained either by specific tests for the friction surface in accordance with EN 1090-2 [2], Annex G or when relevant as given in Table 3 [1]; γ_{M3} = 1.25 is partial safety factor for joint for slip resistance al ultimate limit state, given in Table 2 [1]; $F_{p,C}$ is preloading force.

Table 2. Values of k_s [1].

Description	k_s
Bolts in normal holes	1.0
Bolts in either oversized holes or short slotted holes with the axis of the slot perpendicular to the direction of load transfer	0.85
Bolts in long slotted holes with the axis of the slot perpendicular to the direction of load transfer	0.7
Bolts in short slotted with the axis of the slot parallel to the direction of load transfer	0.76
Bolts in long slotted with the axis of the slot parallel to the direction of load transfer	0.63

Table 3. Slip factor, μ, for pre-load bolts [1].

Surface treatment	Class	μ
Surface blasted with shot or grit with loose rust removed, not pitted	A	0.50
Surface blasted with shot or grit: a) spray-metalized with a aluminium or zinc based product; b) with alkali-zinc silicate paint with a thickness of 50μm to 80 μm	B	0.40
Surface cleaned by wire-brushing or flame cleaning, with loose rust removed	C	0.30
Surface as rolled	D	0.20

In accordance with [2], the nominal minimum preloading force $F_{p,C}$ shall be taken as:

$$F_{p,C} = 0{,}7 \cdot f_{ub} \cdot A_s, \tag{2}$$

where: f_{ub} is the nominal ultimate strength of the bolt material; A_s is the stress area of the bolt.

As you can see strength of preloaded bolt joints depends on preloading force. Accordingly implementation of preloaded bolts (the axial load) should be carried out more specifically. For this purpose use wrenches calibrated and verified by the competent laboratories. Correlation between the torque M_s and the tension created is described by the relationship:

$$M_s = k \cdot d \cdot F_{p,C} \tag{3}$$

where d is bolt diameter and k – nut factor, sometimes called the friction factor.

Value of the coefficient k is given by the manufacturer of bolts and is determined experimentally. According to k-factor are the three classes of set bolt-nut, shown in table 3. User agent of preloaded high strength bolts is required to check the value of the coefficient k.

According to the relationship (3) bolt tension generated during tightening depends on the accuracy and value of the torque and the coefficient *k*. To ensure you can use either pre-stressed of tightening method provided in table 4, unless specified restrictions on their use.

Table 3. *K*-classes

k - class	Information to be supplied
K0	No requirements for *k*-factor
K1	Range of individual test value k_i
K2	Mean test value k_m Coefficient of variation of *k*-factor V_k

Table 4. *K*-classes for tightening methods

Tightening	*k*-classes
Torque method	K2
Combined method	K2 or K1
HRC tightening method	K0 with HRD nut only or K2
Direct tension indicator (DTI) method	K2, K1 or K0

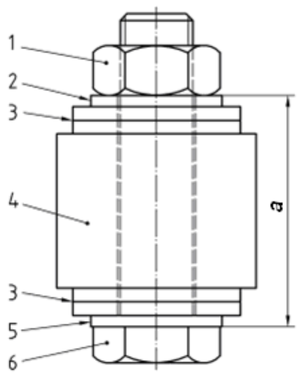

Fig. 2. Test set-up:
1 - Nut: turned during tightening; 2 - Washer of the assembly: prevented from rotating: 3 - Shim(s); 4 - Calibrated bolt force measuring device; 5 - Chamfered washer of the assembly or chamfered shim; 6 - Bolt head: prevented from rotating; *a* - Clamp length.

Fig. 3. Force washer.

Before mounting bolts, should be carried out calibration. This calibration is done by making a test to determine the necessary parameters to ensure that the minimum required pre-stressed is produced in a safe way by tightening methods indicated in [2, 3]. The test consists of the collection and measurement of agent during the gathering, bolt tension generated during tightening and torque.

For test purposes you can use a device for measuring the force in bolt according to [3], or mechanical or hydraulic equipment such as a load transducer. The torque indicator handle wrench used for the test must be those used on the site. They must have an appropriate area of application.

Separate tests must be carried out on representative samples taken from each batch of the joint involved. The test items should be selected so that all relevant aspects of their conditions must be identical. The representative must consist of a number of bolts, nuts and washers from each batch. The test set-up (see Figure 2) may include shims needed to suit the measuring device.

The test assemblies and shims shall be positioned such that:

- a washer of the assembly is placed under the nut;

- a chamfered washer or a chamfered shim is placed under the bolt head;
- the clamp length including shims and washer(s) is the minimum allowed in the relevant product standard.

Experimental Details

Examinations were carried out on high strength bolts of mechanical characteristics of the group, with the following s 10.9: M24 x 80; M24 x 115. They were placed at the disposal of the beneficiary, in each dimension have tried the 8 screws. Manufactured by the mechanical characteristics are indicated: the moment of tightening M_s = 800 Nm; the value of the factor k = 0.1 ... 0.16; preloading force $F_{p,C}$ = 220 kN. High strength bolts tested does not require the use of lubricants.

Determination of preloading force was made by direct tension indicator (DTI) method. Tests were performed on the devices which have clamp length specified for each dimension of bolt joint.

For tightening, have used the handle wrench, which enabled the reading the torque, and which are used to tightening bolts in the construction site. For the evaluation of preloading force used a resistive force transducer (force washer) produced by HBM, with call sign KMR 400, shown in Figure 3. Transducer used has the following main features: 400 kN nominal force; deviation from linearity: 10%; the sensitivity of 1.7 ... 2 mV/V. This resistive transducer has been connected to a data acquisition system ESAM Traveller Static, which was connected to a laptop.

Resistive force transducer KMR was mounted on each of the bolts, as shown in Figure 1, with the clamping length for each size of *a* bolt. After installation, using the handle wrench and load on each assembly bolt-nut, applied the following torques: M_s = 400 Nm; 550 Nm; 700 Nm; 800 Nm and 900 Nm. For each value of the moment to raise there has been preloading force in bolt.

Results

In tables 5 and 6 values obtained for the two sizes of bolts are shown.

Based on the data in tables 5 and 6 was calculated with the value of the coefficient k (3) relationship (tab. 5 and 6).

Table 5. The results of measurements

M_s, Nm	Bolt 1 M24x80		Bolt 2 M24x80		Bolt 3 M24x80		Bolt 4 M24x80	
	$F_{p,C}$, kN	k	$F_{p,C}$, kN	k	$F_{p,C}$, kN	k	$F_{p,C}$, kN	k
450	115.4	0.143	128.5	0.146	104	0.180	117.56	0.159
550	138.9	0.146	155.4	0.147	135	0.170	141.92	0.161
700	202.5	0.147	196.5	0.148	178.14	0.164	184.04	0.158
800	**228.5**	**0.149**	**246.2**	**0.135**	**215.43**	**0.155**	**213.63**	**0.156**
900	251.1	0.153	275.2	0.136	243.94	0.154	246.04	0.152

M_s, Nm	Bolt 5 M24x80		Bolt 6 M24x80		Bolt 7 M24x80		Bolt 8 M24x80	
	$F_{p,C}$, kN	k	$F_{p,C}$, kN	k	$F_{p,C}$, kN	k	$F_{p,C}$, kN	k
450	140.51	0.133	124.7	0.150	120.29	0.156	119.39	0.157
550	164.92	0.139	148.21	0.155	141.87	0.161	121.58	0.188
700	214.72	0.136	190.54	0.153	181.16	0.161	166.92	0.175
800	**247.96**	**0.134**	**226.04**	**0.147**	**213.49**	**0.156**	**205.95**	**0.162**
900	294.95	0.127	263.53	0.142	241.53	0.155	251.43	0.149

Table 6. The results of measurements

M_s, Nm	Bolt 1 M24x115		Bolt 2 M24x115		Bolt 3 M24x115		Bolt 4 M24x115	
	$F_{p,C}$, kN	k	$F_{p,C}$, kN	k	$F_{p,C}$, kN	k	$F_{p,C}$, kN	k
450	118.5	0.158	116.04	0.162	111.04	0.169	120.7	0.155
550	143.5	0.160	138.5	0.165	136.5	0.168	131.4	0.174
700	205.3	0.142	207	0.141	188.3	0.155	185.5	0.157
800	**230.2**	**0.145**	**222.6**	**0.150**	**220.5**	**0.151**	**218.9**	**0.152**
900	253	0.148	279.2	0.134	256.9	0.146	238.5	0.157
M_s, Nm	Bolt 5 M24x115		Bolt 6 M24x115		Bolt 7 M24x115		Bolt 8 M24x115	
	$F_{p,C}$, kN	k	$F_{p,C}$, kN	k	$F_{p,C}$, kN	k	$F_{p,C}$, kN	k
450	108.12	0.173	115	0.163	117.9	0.159	106.6	0.176
550	141.5	0.162	130.2	0.176	128	0.179	140.8	0.163
700	181.6	0.161	183.2	0.159	177.2	0.164	180.6	0.161
800	**215.8**	**0.154**	**212.6**	**0.157**	**210**	**0.159**	**238.3**	**0.140**
900	249.3	0.150	240.9	0.156	240.6	0.156	267	0.140

According to [2,4], for the two strings values of coefficient k, commensurate with the size and M24x80 and M24x115, respectively determine the arithmetic mean k_M and standard deviation s. These calculated values are given in table 7.

Table 7. Statistical data processing

Bolt	k_M	s	$0{,}08k_M$
M24x80	0.152521	0.012162	0.012202
M24x115	0.15749	0.010628	0.012658

To validate the results, standard deviation shall not exceed 8% [4] of the average value of the coefficient, as can be seen from table 7 that condition is fulfilled by the two sizes of bolts.

Conclusions

From the analysis of the values obtained and presented in table 5 … 7 recommendation a few conclusions:

- In general, values of k are within the range prescribed by the manufacturer, namely between 0,1 ... 0,16, any of the overruns interval can be explained by 10% deviation from linearity of the transmitter by force;
- The average values of the coefficient k_M are within the range given by the manufacturer; For these values at some point tightening M_s = 800 Nm, shown by the manufacturer in bolts develops maximum preloading force $F_{p,C}$ = 218 kN which leads to a maximum stress σ_{max} = 617 MPa max. If the bolts are made of steel with f_{ub} = 900 MPa then, tension σ_{max} is less than 0.7 f_{ub} = 700 MPa as required norm. For this reason it is recommended that the tightening is not less than M_s = 800 Nm for bolts made of steel with f_{ub} = 100 MPa, in order to avoid overrunning the flow of the material where the coefficient k would have at the beginning of the interval 0,1 … 0,16.

References

1. * * * – EN 1993-1-8 *Eurocode 3: Design of steel structures; Part 1-8: Design of joints.*

2. * * * – EN 1090-2 *Eurocode 1*: *Execution of steel structures and aluminium structures; Part 2. Technical requirements for steel structures*
3. * * * – EN 14399-2 *High-strength structural bolting assemblies for preloading; Part 2: Suitability test for preloading;*
4. * * * – STAS 9330-84 *Poduri de cale ferată şi şosea. Îmbinări cu şuruburi de înaltă rezistenţă. Prescripţii de proiectare şi execuţie.*

Evaluarea factorului *k* al asamblărilor cu şuruburi de înaltă rezistenţă pretensionate

Rezumat

Capacitatea portantă şi rezistenţa îmbinărilor prin şuruburi de înaltă rezistenţă pretensionate depinde de valoarea momentului de strângere. Corelarea dintre momentul de strângere şi efortul axial dezvoltat în şurub se face prin intermediul factorului k, a cărui valoare depinde de caracteristicile mecanice ale elementelor asamblării. În lucrare este prezentată o modalitate de evaluare experimentală a acestui factor.