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Aging of High Strength Bolted Joints in Long Service

Vieillissement des assemblages avec des boulons à haute résistance

Die Alterung von HV-Schraubenverbindungen

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SUMMARY
This paper reports the investigation on the aging of slip load and bolt tension of friction type high strength bolted joints of two bridges, one building and two types of joint models. Obtained conclusions are: In the joints of blasted plates, the slip loads were improved through aging. In the joints of coated plates, the slip loads were in firm through aging and in the joints of the above, the allowable shearing stress of a bolt is desirable to be lowered based on statistical estimation taking maintenance into consideration.

RESUME
Des recherches ont été effectuées sur le vieillissement et sur la force de glissement et la tension dans les boulons de deux types d'assemblage au moyen de boulons à haute résistance, dans le cas de deux ponts et d'un bâtiment. Dans les assemblages de tôles sablées la résistance au glissement augmente avec les années, tandis que dans les assemblages de tôles traitées, la résistance au glissement ne change pas dans le temps. Il est cependant recommandé d'abaisser la contrainte admissible pour les boulons en tenant compte de l'entretien.

ZUSAMMENFASSUNG
Die vorliegende Untersuchung befasst sich mit der Alterung von gleitfesten Schraubenverbindungen. Es wird das Zeitverhalten der Kraftübertragung über Reibung sowie der Spannungen in der Schraube dargestellt. Die Untersuchung erfolgt an Brücken-, Hochbau- und Modellverbindungen. Die erhaltenen Ergebnisse in Abhängigkeit der Alterung sind folgende: Bei sandgestrahlten Verbindungen erhöht sich der Widerstand. Bei beschichteten Oberflächen blieb der Reibungswiederstand konstant. Die zulässigen Schraubenspannungen könnten aufgrund statistischer Überlegungen reduziert werden, unter Einbezug der Unterhaltsaufwendungen.

1. INTRODUCTION

More than thirty years have passed away since high strength bolted friction type joints began to be used for many steel structures such as bridges and building constructions. During this period, many works have been published on researches and investigations concerning the slip resistance of the joints and relaxation of high strength bolts [1], but investigations about secular changes in the strength of the joints have been extremely rare. It is important to find out quantitavely the changes in the strength of joints, when maintenance of the friction joints are to be considered.

The present study investigated the quantitative characteristics of aging in mechanical properties of friction joints by using joints of actual constructions as well as model specimens, and made statistical considerations on the reliability of the joints against slipping load.

2. TEST PROGRAM

Table 1 shows the details of investigated joints. Series A and B are the joints in highway bridges currently in use. Residual tension of high strength bolts was measured at the web splices of the floor beam (15 years have passed) for series A, and at the web splices of the main box girder (4 years have passed) for series B. Bolt tension and joint slip load 4 years after construction in series C were investigated at the lattice joints (Fig. 1) of large-span trussed frames. For series D, bolt tension and slip load 13 years after assembling were measured by using model joints shown in Fig. 2. In series E, the model joints having similar shapes to that shown in Fig. 2 and coated faying surfaces were used to investigate joint behaviors 1 year and 3 years after assembling.

For surface coating, inorganic zinc-rich paint coating and zinc metallizing were used. Series A to D were the joints of blasted faying surfaces in ordinary use.

Plate materials used for these joints were JIS G 3101 SS41 (required tensile strength: $\sigma u \geq 402.1$ MPa) and JIS G 3106 SM50 ($\sigma u \geq 490.3$ MPa). Bolt materials used were JIS B 1186 F9T, F10T and F11T ($\sigma u \geq 882.6$, 980.7 and 1079.0 MPa, respectively).

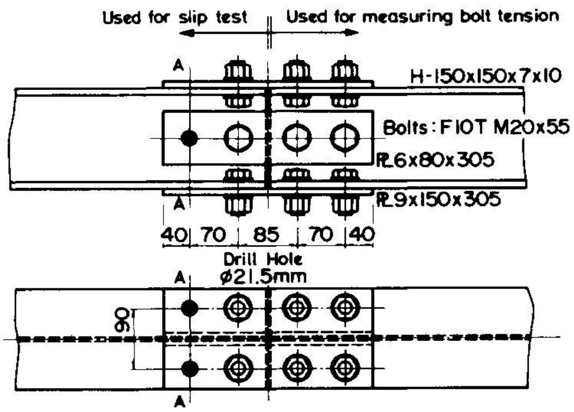
These bolts were tightened by the calibrated wrench method, turn-of-nut method [2] and slope detecting method [3] which are commonly used now in the United States and Japan.

Table 1 Tested Joints

Test Series	Joints	Time Elapsed	Faying Surface of the Joints	Bolt Tightening Method	Type of Bolts	Type of Steel
A	Composite Girder Bridge Bridge Length : 1,350 m Width : 7.0m	15 yrs.	Shot Blasted	Calibrated Wrench Method	JIS B 1186 F11T 7/8-in.	JIS G 3106 SM50
B	Box Girder Bridge Bridge Length : 443.8m Width : 28.3m	4	Shot Blasted	Slope Detecting Method	F10T M22	SM50
C	Trussed Gabled Frame Span 79.2m × Depth 86.4m Height : 55m	4	Shot Blasted	Slope Detecting Method	F10T M20	SM50
D—1 D—2	Model Specimen Model Specimen	13 13	Shot Blasted Shot Blasted	Calibrated Wrench Method Turn of Nut Method	F9T 5/8-in.	JIS G 3101 SS41
E—1 E—2	Model Specimen Model Specimen	1 3	Coated with Zinc-Rich Primer Zinc Metallized	Calibrated Wrench Method	F11T M22	SM50

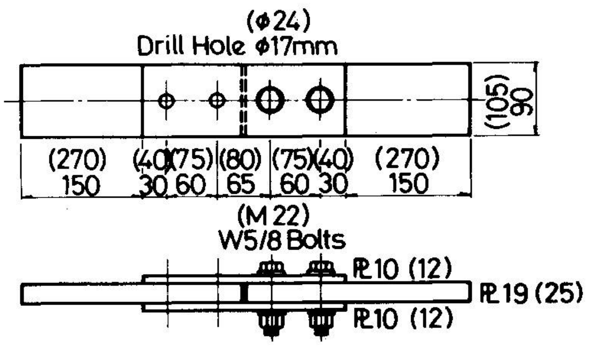
Bolt tension was (1) estimated by the use of gages at the head or shank of the bolt for series A, B, C and E, or (2) calculated from changes in the bolt length measured with a micrometer after releasing the nut for series D.

Slip tests were conducted for series C, D and E. The joint slip was determined by relative displacements measured with clip gages set between the main plate and the splice plate of the joint.



Note: A half number of bolts(5bolts) in A–A were loosened before slip tests.

Fig. 1 Tested Joint for Series C



Descriptions in parentheses show those of series E.

Fig. 2 Tested Joints for Series D and E

3. RESULTS AND DISCUSSIONS

3.1 Aging in Bolt Tension

Table 2 shows the results of bolt tensions measured immediately after installation and after various long durations. Fig. 3 shows the reduction of bolt tension against that of immediately after installation. Furthermore, Fig. 3 shows the past test data [4] which were obtained when F8T, F10T and F11T bolts were tightened by the turn-of-nut method. From these test results, it has been concluded that the reduction of bolt tension after long duration is about 20% regardless of the differences in the tightening methods, kind of bolt sets and steel grade of joints, or in the faying surface conditions with or without coatings.

Table 2 Comparison of Bolt Tensions

Test Series	At Installation			After Long Duration			Time Elapsed
	Bolt Tention (kN)		Number of Bolts	Bolt Tention (kN)		Number of Bolts	(yrs.)
	Mean	St. Dev.		Mean	St. Dev.		
A	227.5 1)	——	—	183.4	22.36	16	15
B	270.7	3.628	5	236.3	10.20	24	4
C	229.9	8.041	56	196.0	15.40	96	4
D–1	88.3	5.296	7	65.7	9.414	15	13
D–2	133.4	0.785	4	95.1	19.25	24	13
E–1	233.1	0.422	10	195.1	3.256	10	1
				197.7	2.893	6	3
E–2	233.1	0.373	10	199.4	5.658	10	1
				202.5	3.521	6	3

1) Calculated based on a torque-bolt tension relationship

3.2 Aging in Slip Resistance

Table 3 shows the results of slip loads obtained by slip tests conducted 24 to 48 hours after installation and after long duration. It is clearly shown that the slip load of surface blasted joints increases as the years pass. The slip load of surface coated joints showed two types of results, i.e, a gradual decrease 3 years after installation for series E-1 and conversely a slight increase for series E-2.

Therefore, a great increase in slip load after the passage of several years may not be expected for the surface coated joints.

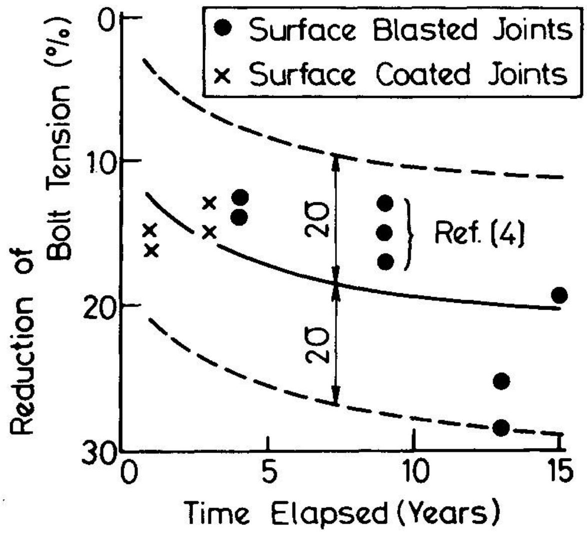


Fig. 3 Aging in Bolt Tensions

Table 3 Slip Test Results

Test Series	At Installation					After Long Duration					
	Slip Load (kN)		Slip Coefficient		Number of	Slip Load (kN)		Slip Coefficient		Number of	Time Elapsed
	Mean	St. Dev.	Mean	St. Dev.	Tested Joints	Mean	St. Dev.	Mean	St. Dev.	Tested Joints	(yrs.)
C	635.0	——	0.46	——	1	744.0	55.48	0.63	0.056	10	4
D−1	210.7	15.29	0.60	0.044	7	233.2	22.39	0.89	0.086	7	13
D−2	303.0	20.59	0.57	0.039	7	348.5	14.64	0.88	0.079	7	
E−1	450.9	18.67	0.48	0.020	10	419.1	24.15	0.54	0.031	5	1
						419.1	35.66	0.53	0.053	5	3
E−2	491.1	19.61	0.53	0.021	10	487.2	13.85	0.61	0.018	5	1
						522.0	40.91	0.64	0.050	5	3

The slip coefficient μ which is governed by the condition of the faying surface and bolt tension is generally defined by the following equation:

$$\mu = \frac{P}{f \cdot \sum_{i=1}^{n} B_i} \qquad \text{(i)}$$

where
- P : slip load
- f : the number of faying surfaces
- n : the number of bolts
- B_i: the i-th bolt tension

The slip coefficients in Table 3 were calculated from eq.(i) on the basis of the values of slip load and bolt existing tension of respective joints. This table indicates that a great increase in the slip coefficient may be expected after long duration for the surface blasted joints. As far as the present tests were concerned, the rate of increase were 40 to 50% for the surface blasted joints. On the other hand, for the surface coated joints, the slip coefficient after long duration shows no great difference from that at the initial stage. It can be said, therfore, that the surface coated joint is more liable to cause slip after long duration than the surface blasted joint, if the reduction in bolt tension due to relaxation is taken into condideration.

3.3 Reliability of Bolted Joint in Long Service

On the assumption of normal distribution, $N(m, \sigma)$ about P, μ and B, the mean value of m_P of P and standard deviation σ_P are defined by the following equations:

$$m_P = m_\mu \cdot m_B \cdot f \cdot n \qquad \ldots\ldots \text{(ii)}$$

$$\sigma_P{}^2 = f^2\{\sigma_\mu{}^2 \cdot n \cdot (n \cdot m_B{}^2 + \sigma_B{}^2) + n \cdot m_\mu{}^2 \cdot \sigma_B{}^2\} \quad \ldots \text{(iii)}$$

where suffixes P, μ and B are the slip load, slip coefficient and bolt tension, respectively.

Probability p of occurrence of less slip loads than design load P_{al}, slip generation probability, is obtained as:

$$p = 1 - \frac{1}{\sqrt{2\pi}} \int_t^\infty \exp\left(-\frac{t^2}{2}\right) dt \qquad \ldots\ldots \text{(iv)}$$

where $t = \dfrac{P_{al} - m_P}{\sigma_P}$, $P_{al} = \tau_{al} \cdot A \cdot f \cdot n$,

τ_{al} : allowable shearing stress, A : nominal area of bolt shank

In order to calculate p after long duration, (1) the distribution of B is assumed from Fig. 3 to be as follows:

$m_B = 0.8 \times 1.05B_o$, B_o : minimum required tension

$\sigma_B = 0.1B_o$

(2) the slip coefficient μ of surface blasted joints is assumed to be N (0.88, 0.088) from test series D in Table 3, while μ of surface coated joints to be N (0.60, 0.048) from the past test results [5].

When design load P_{al} was adopted from AISC specification, the value p was calculated as 1.3×10^{-5} (n=100) for surface blasted foints, thereby indicating that the risk of joint slip is virtually nil. Whereas, for surface coated joints, $p = 4 \times 10^{-2}$ was obtained, thus indicating that joint slip is liable to occur.

The probability p_o of slip occurrence for surface coated joints, comes to be 1.3×10^{-3}, when the effect of relaxation of bolt tension is ignored.

Therefore, it will be considered that τ_{al} is better to reduce 10% or more of the currently used value in AISC (τ_{al} = 203.0 MPa for inorganic zinc rich painted joint using ASTM A325 bolts) by inverse operation of eq. (iv), if the design condition $p = p_o$ is adopted.

Consequently, although surface coating of structural members is indispensable for the maintenance of steel structures, the allowable shearing stress of the bolts should be reduced below the currently employed values in order to ensure safety of the joints.

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