An Experimental Study on Slip Strength of HSFG Bolted Joints Treated with High-Friction Inorganic Zinc-Rich Paint

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ABSTRACT

Recently for the purpose of cost reduction in construction, rationalization of high-strength friction grip bolted joints in plate girder bridges is encouraged. As a method of the rationalization, it is proposed to increase the design slip factor specified as 0.4 in the Japanese Specifications for Highway Bridges (JSHB)[1]. Since it is relatively small compared with other countries and the increase of the factor leads directly to the reduction of the number of bolts, high-friction inorganic zinc-rich paint having high slip factor over 0.7 was developed through tensile tests in this study.

1. INTRODUCTION

In recent years, in accordance with the enlargement of cross-sections by adoption of bridges with greater girder spacing, the number of HSFG bolts has been increased, and the size of splices has been expanded. To reduce the number of bolts, it is proposed to increase the design slip factor specified as 0.4 in JSHB. While the shift of the design method from allowable stress design method to performance based design method, the increase of slip factor is expected to contribute to rationalization of bolted joint. As shown in Table 1, although various values are already specified according to the conditions of the friction surfaces in the design criteria of other countries, slip factor specified in the JSHB is uniformly 0.4, and the value in Japan is relatively small compared with one of other countries. On the other hand, increase of slip factor is expectable with the development of the paint technique in recent years.

With these backgrounds, many tensile tests using specimens with inorganic zinc-rich paint were carried out, and the conventional zinc-rich paint was improved and new high- friction paint has been developed. This paint has the same functions, such as the corrosion protection performance and the working performance, as that of conventional one.

2. EXPERIMENT PROCEDURE

As shown in Fig. 1, a tensile specimen has the bolt arrangement of one-line two-rows, and was designed so that the base plates and the splices did not yield before load reached slip strength. The grade of the steel material is SM490Y and M22(F10T) was used for high-strength bolts. Inorganic zinc-rich paint was applied to the friction surfaces after shot-blasting. A painting scene is shown in Photo 1.

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Table 1 International comparison of slip factor

slip factor	the treatment or the condition of the friction surface	slip factor	the treatment or the condition of the friction surface
●Eurocode[2] (1997)		●AASHTO[3] (1994)	
0.50	shot-blasting or grid-blasting	0.33	the surface with clean mill scale
0.50	zinc based metal spray guaranteed the slip factor 0.5 at least after shot-blasting or grid-blasting	0.50	class A coating after blasting
0.30	the surface removed loose scale after cleaned by wire brushing or flame cleaning	0.50	blasting
0.20	none	0.40	class B coating after blasting
		0.40	the rough surface with galvanization
●ISO[4] (1997)		●SIA[5] (1979)	
0.33	the surface with clean mill scale	0.30	the surface with clean mill scale
0.40	the surface removed mill scale and loose scale and after exposure outdoors	0.50	sand-blasting or flame cleaning
0.50	shot-blasting or grid-blasting	0.40～0.50*	zinc based metal coating after sand-blasting
0.50	inorganic zinc-rich painting with thickness under 60 micrometer	0.30～0.45*	zinc based organic coating after sand-blasting
0.35	organic zinc-rich painting with thickness under 60 micrometer	0.35	the rough surface with galvanization
0.40	blasting on the galvanized surface with thickness over 50 micrometer	The value of * is depened on the process of the painting	
●BS[6] (1982)		●DIN[7] (1990)	
0.45	the surface removed mill scale and loose scale and after exposure outdoors	0.50	shot-blasting or grid-blasting
0.50	shot-blasting or grid-blasting	0.50	flame cleaning twice
0.35	inorganic zinc-rich painting	0.50	alkali silica zinc powder painting
●the Japanese Specifications for Highway Bridges[1] (2002)			
0.40	the rough surface removed mill scale		
0.40	thick inorganic zinc-rich painting		

As shown in Table 2, experiments are 32 cases in total, and the main parameters are paint composition, film thickness and surface roughness. In consideration of the dispersion, three specimens were tested in each case.

High-strength bolts were fastened by 60% of bolt tension specified in JSHB at first, and then tightened by 100 % (= 225.5kN). The tension in the fixed side was increased by 10% so that a slip might not occur.

In consideration of the relaxation of high-strength bolts, the experiments were carried out more than seven days after bolts were tightened. The displacement between base plates and the axial force of bolts in case 23-32 were measured, and

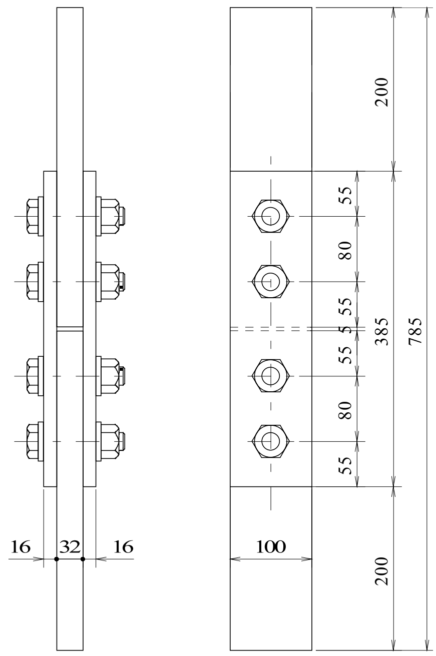


Fig. 1 A tensile specimen

load was increased linearly until a major slip occurred. An experiment setup is shown in Photo 2.

Table 2 Experiment cases

case	target base plate film thickness (μm)	target splice film thickness (μm)	target surface roughness (μmRz)	curing period	main parameters
1 - 4	20	75	80	2 weeks indoors	pigment
5 - 7	20	75	80	2 weeks indoors	zinc particle size
8 - 11	20	75	80	2 weeks indoors	resin material
12 - 15	20,75	75	80,100	2 weeks indoors	zinc particle size surface roughness film thickness
16 - 17	75	75	80	2 weeks indoors	mix proportion
18 - 22	75	75	80	2 weeks indoors	pigment
23 - 32	75	75	80	7 weeks indoors	hardened pigment

Photo 1 View of painting

Photo 2 View of experiment

3. EXPERIMENT RESULTS

An experiment result is shown in Fig. 2. The slip factor was calculated using equation (1) as shown below.

$$\mu = \frac{P_{slip}}{m \cdot n \cdot N} \qquad (1)$$

μ :slip factor

P_{slip} :major slip load

m :the number of bolts (=2)

n :the number of friction surfaces (=2)

N :initial bolt tension (=225.5kN)

A slip factor was not significantly influenced by zinc particle size or resin material, and was improved greatly by hardened pigment. This result is expected to originate that the shear capacity between coating films increased. The slip factor of case 29 was the maximum and the average was 0.783.

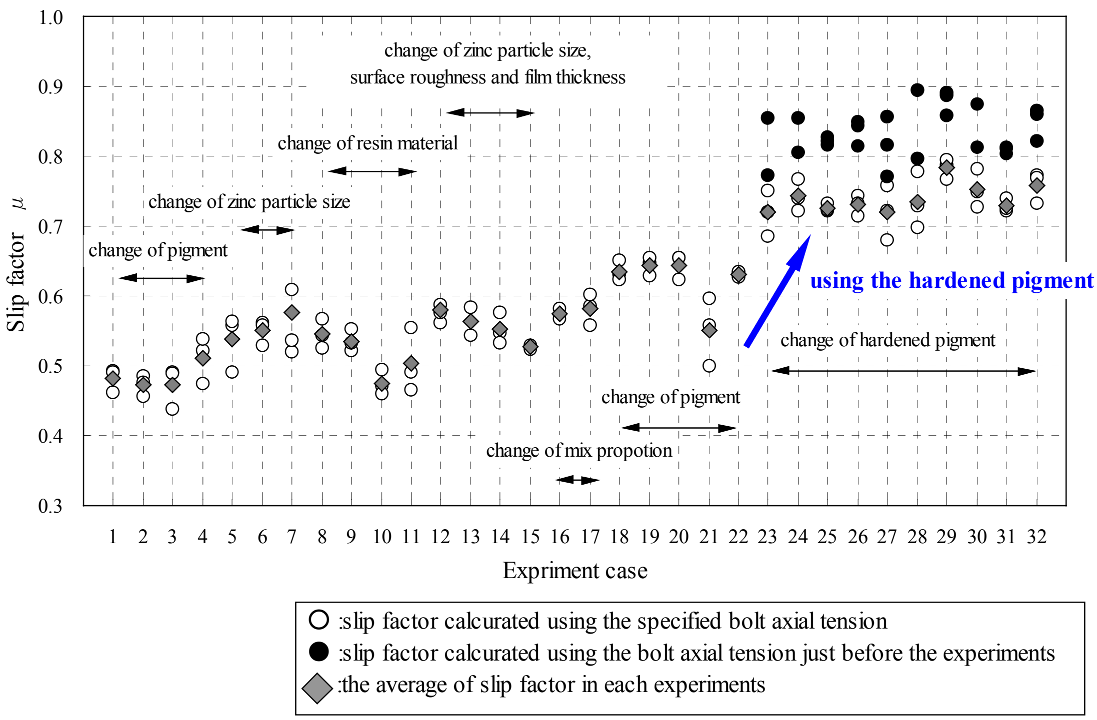


Fig. 2 Result of experiments

4.APPLICATION OF HIGH-FRICTION PAINT

Since the allowable force per high-strength bolt can be improved by increasing slip factor, it becomes possible to reduce the number of high-strength bolts and the size of splices when this developed paint is applied to actual bridges. The tentative calculation was performed in order to investigate how bolt joints can be rationalized by using this paint. The example bridge is the simple composite bridge with 4 main I-section girders shown in Fig. 3.

Although the maximum slip factor was approximately 0.8 according to the experiment results, the tentative calculation was done by setting the slip factor to 0.7 by taking safety into consideration.

The calculation result of the number of high-strength bolts is shown in Table 3 and Fig. 4, and of the weight of splices and the painting area is shown in Table 4. As compared with the conventional design, the number of high-strength bolts can be reduced by about 40% by increasing the design slip factor to 0.7. Furthermore, the size of splices becomes smaller, the painting area and weight of splices can also be reduced by about 40%. Therefore, not only the amount of painting in factories becomes smaller, but work efficiency in field is also improved. These values are almost decreased in proportion to the increment of slip factor.

5.CONCLUSIONS

Based on the results, the main conclusions are drawn as follows:

(1) High-friction inorganic zinc-rich paint having high slip factor over 0.7 was developed thorough tensile tests.

(2) In order to increase slip factor, use of hardened pigment was most effective.

(3) The number of high-strength bolts, painting area, and weight of splices can be reduced by about 40% by increasing the design slip factor to 0.7 as a result of tentative calculation.

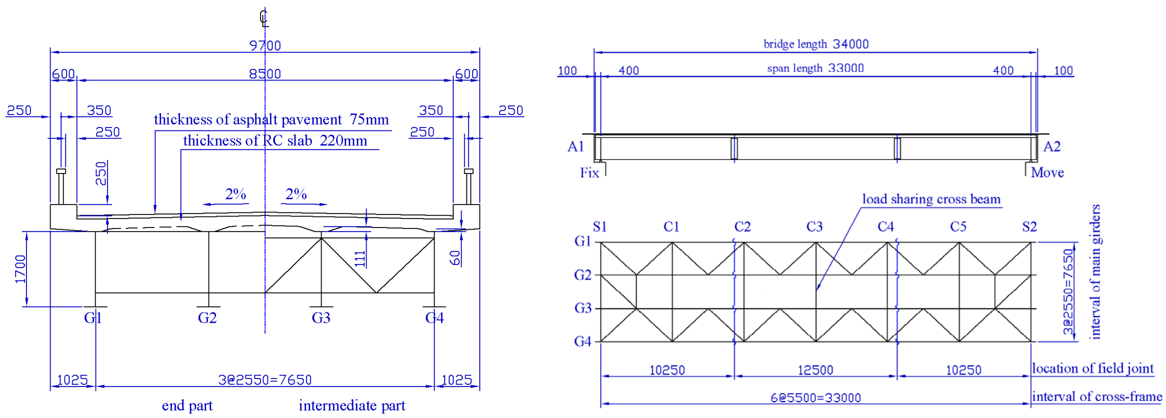


Fig. 3 General dimensions of the example bridge

Table 3 Calculation results of the number of bolts required

case	(A)	(B)
the design slip factor	0.4	0.7 (1.75)
the allowable force of high-strength bolt (kN)	96	168
the design bending moment (kN·m)	3213	
the design shear force (kN)	411	
the number of bolts in upper flange	12	8
the number of bolts in web	48	32
the number of bolts in lower flange	36	18
the total number of bolts	96	58 (1/1.66)

* The value in a parenthesis is a ratio to (A) of (B)

*The value in the table is the quantity per one joint of G1 girder.

*The allowable force is the value per two friction surfaces

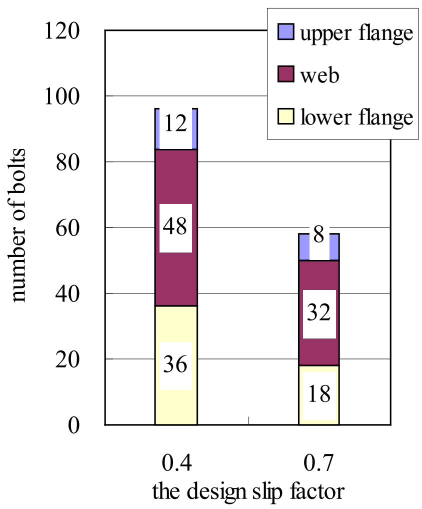
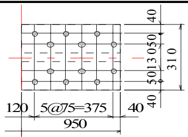
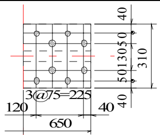
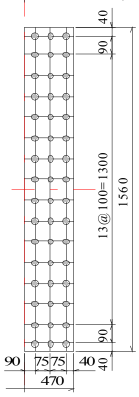
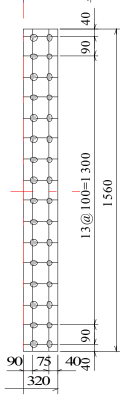
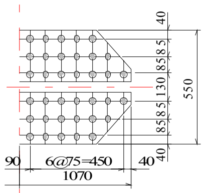
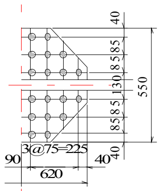


Fig. 4 The number of bolts in each member

Table 4 Calculation results of weight of splices and painting area

<table>
<tr><td colspan="2">case</td><td>(A)</td><td>(B)</td></tr>
<tr><td colspan="2">the design slip factor</td><td>0.4</td><td>0.7 (1.75)</td></tr>
<tr><td rowspan="3">the layout of bolts</td><td>upper flange</td><td></td><td></td></tr>
<tr><td>web</td><td></td><td></td></tr>
<tr><td>lower flange</td><td></td><td></td></tr>
<tr><td colspan="2">the weight of splices (kg)</td><td>326.3</td><td>204.0 (1/1.60)</td></tr>
<tr><td colspan="2">the painting area (m^2)</td><td>6.26</td><td>4.04 (1/1.55)</td></tr>
</table>

* The value in a parenthesis is a ratio to (A) of (B)

*The value in the table is the quantity per one joint of G1 girder.

6.FUTURE RESEARCH

Since only small tensile coupon tests were carried out in this study, the experiments for girder models are being scheduled.

REFERENCES

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