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FATIGUE PERFORMANCE OF SINGLE SPLICED BOLTED JOINTS IN PREFABRICATED STEEL BRIDGE DECKS

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The fatigue strengths of bolted lap joints under axial load and single-spliced bolted joints in bridge deck system under bending were examined on an experimental base. In order to evaluate the local stress on the faying surface of the bolted joint, the structural restraint factor was introduced based on the measured stresses.
Keywords : *high strength bolted joint, lap joint, fatigue, steel bridge deck*

1. INTRODUCTION

Some of the reinforced concrete bridge decks which are facing deterioration problems due to heavy traffic must be replaced. Considering the great influences on social and economic activities, however, it is very difficult in some cases to stop the traffic completely. Therefore, it is necessary to find the method to redeck quickly and easily at low cost, yet with high quality, to cope with the limited working time available. Many improvements including grid decks, precast decks, and cast-in-place concrete decks, have been devised for the redecking. However, recent bridge rehabilitation experiences show that the steel orthotropic deck based on battle deck floor system, has more advantages than any other redecking system[1].

For field joints of deck plates in bridge deck system, double-spliced bolted joints are currently used. However, if we can use single-spliced joints in which high strength bolts are inserted in the shop prior to paving, all assembling works of deck unit can be carried out at the underside of deck. Furthermore, the use of single-spliced joints with flat head bolts can eliminate the additional pavement thickness due to the presence of upper splice on the deck and also can minimize the damage of pavement due to the projection of splice plates and bolt heads.

The use of bolted lap joints are usually avoided because of concern over the inherent eccentricity that many result in out-of-plane bending. The bending stress combines with the normal stress may reduce the fatigue strength of the joint. The ECCS fatigue recommendation[2] demands that the effect of stress arising from joint eccentricity, i.e. secondary bending stress, should be calculated and taken into account. The AASHTO specification[3] prohibits axially loaded joints which induce out-of-plane bending in connected material. However, structural behavior of bolted joints of deck plates in the prefabricated steel bridge deck system seems to be the same as those of the girder splices[4]. The fatigue performance of single spliced bolted joints in the steel bridge deck system is studied experimentally in this report. Beside this study, the structural behavior of the deck system with single spliced bolted joint was examined through the statical loading test on fall scale bridge deck models[6].

2. SPECIMENS

The steel used for the specimens is the atmospheric corrosion resisting steel for welded structure JIS SMA 50 A ($\sigma_Y = 421$ MPa, $\sigma_B = 529$ MPa). **Fig.1** illustrates the configurations and dimensions of specimens. Mill scales on the fay surfaces were removed by grinding. Torque shear type high strength bolts (TC bolt, M 22, F10T) and bearing type high strength bolts (M 22, B10T) are used as fasteners. The TC bolt has a round and thin bolt head and the bearing bolt has flat bolt head. The clamping forces are introduced to all fasteners by the fastening torque of 50 kgf-m. Two types of deck model specimens are used, in which fasteners are the variations.

Joint specimens are tested under axial tension loading. Deck model specimens are tested under positive and negative bending moments. The stress

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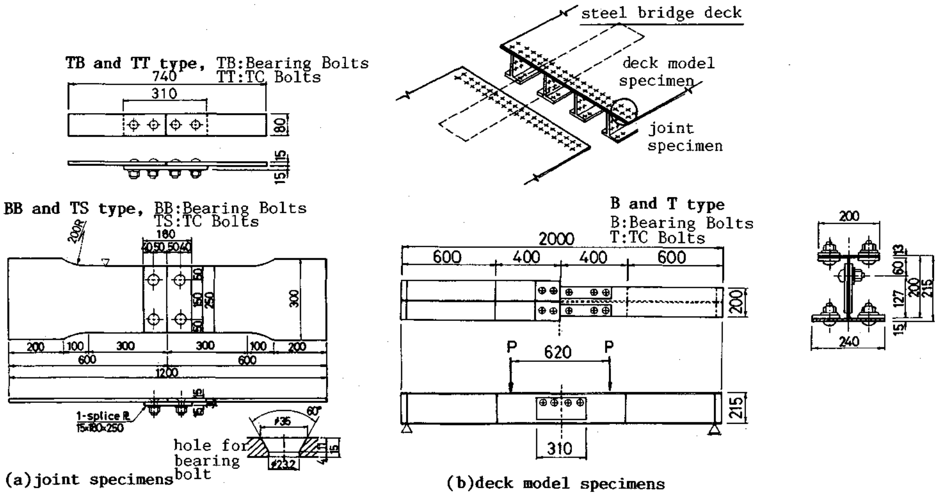

Fig.1 Configurations and Dimensions of Specimens.

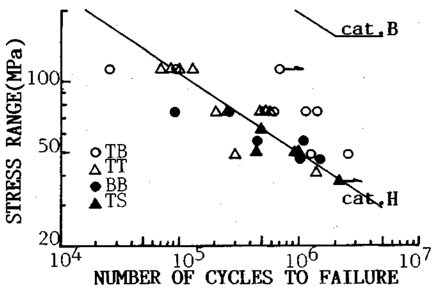

Fig.2 Fatigue Test Results of Joint Specimens.

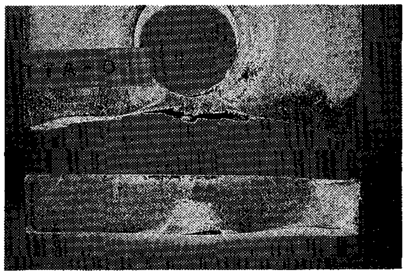

Photo 1 Failure Surface of TT-type Joint Specimen.

in the deck plate of specimen is 0-Tension under negative bending moment.

3. FATIGUE TEST RESULTS

Fig.2 shows the fatigue test results of joint specimens on the bases of nominal gross stress range. No major slips occurred during the fatigue tests of all specimens. For the purpose of comparison, the JSSC fatigue design recommendation[5] Category B curve for double spliced high-strength bolted joints and the curve H which is the lowest design curve of JSSC are shown as well. This figure indicates that the fatigue strengths of joint specimen are very low, almost equal to the lowest Curve H, and do not depend on the type of fasters. And even the Category H curve can not be applied for design.

Photo 1 shows surfaces of bolted lap joints with typical fatigue failures. The failures of joint occurred in the splice plate. The fatigue cracks initiate on the faying surface of splice plates and penetrate into splice plate, where fretting phenomena are observed on faying surfaces. The crack initiation points of most of the joints are just opposite the edge of the washer of nuts which restrains the out-of-plane deformation of the splice plate, resulting in high stress concentration. The fretting on faying surface causes further reduction in fatigue strength.

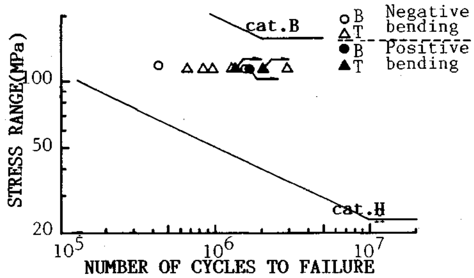

Fig.3 Fatigue Test Results of Deck Model Specimens.

The results of the positive bending fatigue test results of deck model specimens are shown in **Fig.3.** Under these loading conditions, the stresses in deck plate are always compressive, and there is no possibility of fatigue cracking unless there is any residual tensile stress and secondary distortion. One specimen failed due to the growth of fatigue crack which initiated in the welds on the web.

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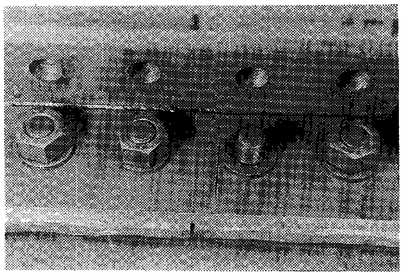

Photo 2 Failure Surface of T-type Deck Model Specimen.

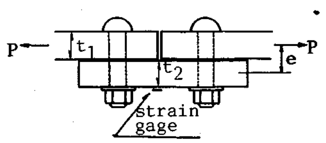

Fig.4 Model to evaluate Local Stress.

The results of the fatigue test of deck specimens under negative bending moment are also shown in **Fig.3. Photo 2** shows the specimen after fatigue tests. It shows that the fatigue cracks initiated on the faying surface just opposite of the edges of washer of nuts. The stress in the splice plate is tension under this loading condition. In spite of seperation mode of splice due to negative moment, the fatigue strengths of deck specimens are fairly high compared to the results of joint specimens. Because of the structural restrains, secondary bending stress due to the out-of-plane deformation is remarkably reduced.

4. EVALUATION ON FATIGUE STRENGTH BASED ON LOCAL STRESS

The stress on the faying surface of splice plate at the center of the joint is the governing factor for the fatigue strength of joint. Due to the eccentricity, the out-of-plane deformation is induced in the lap joint. The stress on the faying surface of splice plate is considered to be the combination of the primary axial stress and secondary bending stress.

Fig.4 illustrates the simple model to evaluate the local stress on the faying surface of the splice plate from where fatigue cracks initiate. The local stress on the faying surface at that point when subjected to an eccentric axial load can be calculated by Eq.(1).

$$\sigma=\sigma_n+\lambda\frac{P\cdot e}{I}\cdot\frac{t_2}{2} \qquad (1)$$

Where, P is the applied force, σ_n is the nominal axial stress in splice plate, λ is the structural restraint factor, I is the moment of inertia of splice plate, $e=1/2\cdot(t_1+t_2)$, t_1 is the thickness of base plate, t_2 is the thickness of splice plate.

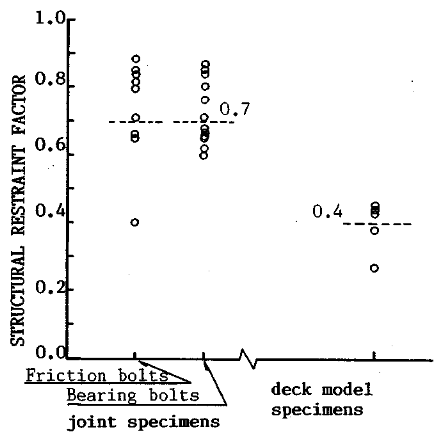

Fig.5 Structural Restraint Factor.

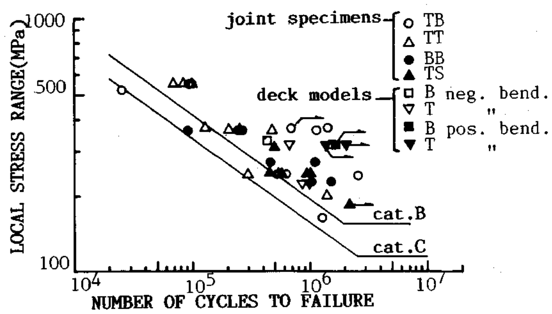

Fig.6 Local Stress Based *S-N* Diagram.

We introduced the structural restraint factor in Eq.(1) to evaluate the local stress. The value of structural restraint factor depends on the joint geometry and can be obtained as the ratio between the measured bending stress and the calculated bending stress on the surface of splice plate, expressed as follows.

$$\lambda=\frac{\text{measured stress}}{\text{calculated stress}} \qquad (2)$$

Fig.5 shows the values of for each type of joints. The mean value of structural restraint factors are 0.69 for joint specimens and 0.39 for deck specimens. Hence, it is proposed that the restraint factor for joint specimens is 0.7 and for deck specimen is 0.4. However, further study is required to obtain generalized restraint factors for different joint geometry.

Fig.6 indicates the fatigue strengths of lap joint specimens and deck specimens on the basis of local stress ranges at the faying surfaces of splices which are calculated by Eq.(1). This figure indicates that in case the stress ranges are arranged for local stress range, the JSSC Fatigue Design Category B can be applied to the fatigue strength of single spliced joint.

5. CONCLUSION

The principal results in this study are the followings :

(1) Fatigue strength of the lap joints under axial load was very low due to the secondary stress induced by eccentricity and the severe fretting of faying surfaces.

(2) In the single-spliced joints of bridge deck system, the distorsion in the out-of-plane direction was restricted, and the secondary stress in the joint was remarkably reduced. This reduction of secondary stress resulted in the improvement of fatigue strength.

(3) In order to evaluate the local stress on the faying surface, the structural restraint factor was introduced. On the bases of local stress range, the JSSC category B curve can be applied to the single-spliced joints.

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プレハブ鋼床版中の単せん断型ボルト継手の疲労強度

三木千壽・范　恒達・川井　豊

プレハブ鋼床版のデッキプレートの現場継手部への適用を想定して，単せん断型高力ボルト摩擦継手の疲労強度を実験的に検討した．疲労試験は１枚の添接板を有する継手型試験体と，デッキプレートと縦リブから構成される梁試験体について実施した．疲労亀裂が発生する接触面における局部応力を評価する目的で，継手の形式により決まる構造拘束係数を導入し，局部応力を基準とした疲労強度の評価法を提案した．