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Fatigue Design of the Honshu-Shikoku Bridges in Japan

Dimensionnement à la fatigue des ponts de Honshu-Shikoku au Japon

Ermüdungsfestigkeitsnachweis der Honshu-Shikoku Brücken in Japan

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SUMMARY
This report describes the fatigue design concepts used for the Honshu-Shikoku steel bridges. In particular, design load conditions, fatigue strength of welded joints and welding conditions in fabrication are discussed.

RESUME
Cet article décrit les bases du calcul à la fatigue utilisées pour le dimensionnement des ponts métalliques de Honshu-Shikoku. Il commente en particulier les charges de calcul admises, la résistance à la fatigue des assemblages soudés ainsi que les conditions de soudure lors de la fabrication.

ZUSAMMENFASSUNG
Der Beitrag beschreibt die Bemessungskonzepte, die bei den Honshu-Shikoku Stahlbrücken angewendet wurden. Insbesondere werden die Lastannahmen und die Ermüdungsfestigkeit geschweisster Verbindungen sowie die Schweissbedingungen während der Herstellung beschrieben.

1. INTRODUCTION

Of the Honshu-Shikoku bridges on the three routes, the bridges on the Kojima-Sakaide route are designed to be of the highway and railway combination type, and the total number of trains within 100 years of the service life is expected to be 9.5×10^6. And as the quenched and tempered high strength steel of $58 \sim 80$ kg/mm^2 class which is rarely used for bridges will be used in the Honshu-Shikoku bridges considerably, the fatigue design is one of the important problems.

Therefore, Honshu-Shikoku Bridge Authority has conducted fatigue tests on many small specimens made with quenched and tempered high strength steel, furthermore, the Authority has conducted fatigue tests on large scale specimens of truss models and various kinds of welded joints made with quenched and tempered steel since 1975, by using a large scale fatigue testing machine specially provided which has a capacity of 400 tons dynamic loading.

This report describes the basic idea of the fatigue design of the Honshu-Shikoku bridges which has been decided as a result of consideration of such tests.

2. TRAIN LOAD

Construction of highway with four lanes and railway with four tracks (two for ordinary line cars and two for Shinkansen cars) are planned on the bridge on the Kojima-Sakaide route (Fig. 1), but the limit of simultaneous passage of two trains has been considered on the design of a suspension bridge in point of view of economy. The train load adopted is the same with the one provided in the design standards of the Japanese National Railways as shown in Fig. 2. As the loaded length of the influence line of the stiffning truss, tower and cable of suspension bridge is comparatively long, only the load of the pulled cars needs to be considered. Therefore, for simplification of calculation, it has been decided to design by the use of equivalent uniform loads.

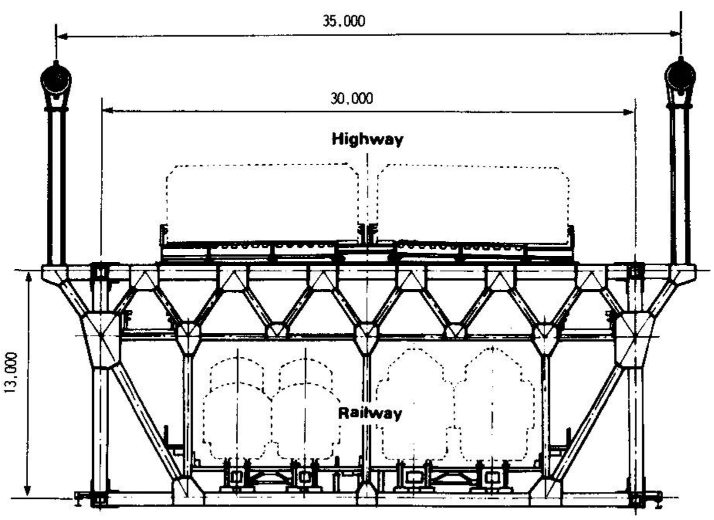


Fig.1. Cross-Section of suspension bridge (Kojima-Sakaide Route)

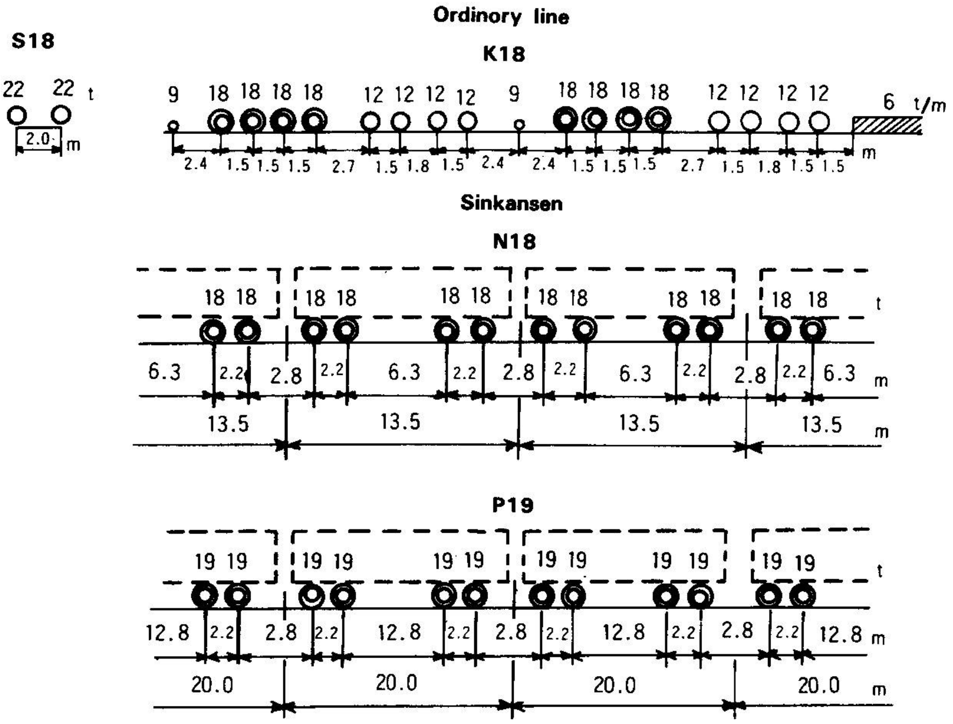


Fig.2. Train load

2.1 TRAIN LOAD FOR STATIC DESIGN

The load of the Shinkansen has been set at an average load intensity of 3.8 t/m of a passenger train P19 (300 per cent of the passenger capacity) and the maximum loaded length at 320 m (train of 16 cars). The load intensity of the ordinary line has been set at 3.8 t/m, same as that of the Shinkansen line in consideration of real weights and wheel distance of cars etc., and the maximum loaded length at 370 m in consideration of the tractive force of locomotive engines.

2.2 TRAIN LOAD USED FOR FATIGUE DESIGN

It has been decided that 2.7 t/m per one track (maximum loaded length 400 m), average load intensity obtained by the modified Miner's rule, is to be used as the train load used for fatigue design in consideration of frequency distribution and the simultaneous passage of trains to be limited to a single track. And it has also been decided that, in order that the cumulative effects of the passage of various kinds of trains on a single and double tracks may be considered, allowable fatigue stress is to be modified according to the degree of cumulative effects.

3. ALLOWABLE FATIGUE STRESS

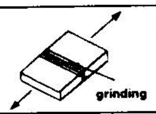
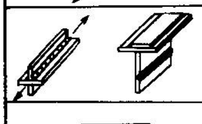
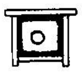
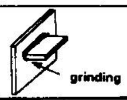
The joint details have been classified into four grades with respect to the normal stress and three grades with respect to the shearing stress based on many test data and the fatigue strength, and the allowable fatigue stress at 2×10^6 loading cycles has been fixed for each of grades.

Furthermore, in order that the cumulative effects of various trains within 100 years of the service life may be considered, the S-N curve of each grade has been fixed and modified coefficients of allowable fatigue stress have also been fixed by using the modified Miner's rule.

3.1 CLASSIFICATION OF JOINTS

Table 1 shows the classification of grades of representative joints and Table 2 the allowable fatigue stresses.

Table1 Classification of joint details

Joint details	Category	
	41~53kg/mm² Class Steels	58~80 kg/mm² Class Steels
	A	
	A	B
	C	C* / D
	C	

* Regular bead shape of fillet weld

Table2. Fatigue allowable stress (R=0)

Category	Fatigue allowable stress
A	15.3 kg/mm²
B	12.75 kg/mm²
C	10.5 kg/mm²
D	8.0 kg/mm²

The test results of longitudinal groove welded joints made with quenched and tempered steel indicated that the fatigue strength of the large scale truss model specimens was considerably low due to welding defects (blowholes etc.) at the corner welding of truss chord member. And the tests of longitudinal groove welded and box section specimens revealed that the fatigue strength of the box section specimens was considerably lower than that of the longitudinal groove welded specimens. The limits of defects of longitudinal groove welded joints have been fixed by these test results and the longitudinal groove welded joints made with quenched and tempered steel has been classified as the category "B" shown in Table 2.

With respect to transverse fillet welded joint, the results of tests indicated that the fatigue strength with large specimens tends to be lower than small ones. In the case of quenched and tempered steel, since the use of low hydrogen electrodes for welding makes bead convex and reduces the fatigue strength, the category has been classified as "C" same as mild steel on condition of use of improved electrodes to make good bead shape of fillet weld.

3.2 S-N CURVE

The fatigue tests of large specimens revealed that fatigue cracks are formed at an extremely early stage of the repeated load and nearly all their lives until failure are spent for the growth of fatigue-cracks. The curve of the S-N line to be used for design will be assumed $-1/m$ (m means the fixed number of the Paris's rule). Judging from the many test data in Japan, the value of m was fixed at 4 to mild steel (41 ~ 53 kg/mm^2 grade) and 3 to quenched and tempered steel (58 ~ 80 kg/mm^2 grade). Then, the S-N curve (Fig. 3) of each grade has been fixed on the assumption that the value of ΔK_{th} (the threshold stress intensity factor for fatigue-crack propagation) is zero.

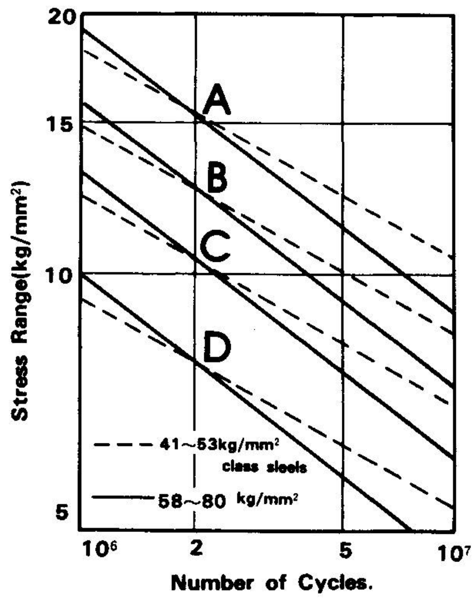


Fig.3. SN curves

4. STANDARDS FOR FABRICATION OF STEEL BRIDGES

Results of fatigue tests of large specimens have been reflected on the standards for fabrication of bridge members. On these standards, the accuracy and cleanness of the groove and the limits of welding defects have been fixed, furthermore the welding tests on the chord members having two panels with actual scale of bridge should be obliged prior to the fabrication of bridge. With respect to the longitudinal groove welding, it has been introduced that defects in the root section are to be inspected by splitting and exposing the section, and with respect to the fillet welding to install diaphragms, it has been introduced that the shapes should be examined. And also welding conditions must be determined by each fabrication plant.

5. POSTSCRIPT

This report is a summary of studies and discussions by the committee for structural problems of Honshu-Shikoku bridges in Japan Society of Civil Engineers. The authors wish to express their appreciation to each member of the committee.

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