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FATIGUE STRENGTH OF CORNER WELDS OF TRUSS CHORDS CONTAINING BLOWHOLES

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One box section member whose dimensions were almost equal to the truss chord of the Akashi Strait Bridge was tested under repeated bending by using a 4 MN fatigue testing machine. The four corner joints consist of partially penetrated groove welds from outsides and fillet welds from insides. These corner joints contain blowholes with various sizes at the roots. The fatigur strengths of corner joints decrease remarkably with the increasing of blowhole size at the root of corner joints.

Keywords *: fatigue, corner welds, weld defect, truss chord*

1. INTRODUCTION

Akashi Kaikyo Bridge is now constructing at the gate of Seto inland sea will complete in 1998 as the world longest suspension bridge of 1990m span. Quenched and tempered high tensile steel of 800-MPa class is planned to be used for the chord members of stiffening truss girder. The cross sections and dimensions of these members have all been determined for wind load, and stresses due to live loads are approximately one third of these stresses. As quality control standards for such members, new fabrication standards have been set up based on the Steel Bridge Fabrication Standards for Seto Ohashi Bridge.

The design allowable fatigue stresses for corner welds of Seto Ohashi Bridge and the corresponding limit to repairs of blowholes are based on the results of full sized or 1/4-scale model fatigure tests and results of fracture mechanics analyses[1)~4)]. Regarding repair limit value for weld defects of Akashi Kaikyo Bridge they have been set similarly to Grade B members of Seto Ohashi Bridge taking into account the fact that this is to be a highway bridge. It is stipulated that the critical dimensions for repair of blowholes are width W of 3 mm and height H of 6 mm, and it is made compulsory for automatic ultrasonic test to be done.

In view of such a situation, it was decided to ascertain the fatigue strengths of thuss chord members made according to quality requirement standards for fabrication of Akashi Kaikyo Bridge. Fairly large blowholes corresponding to defects of Grade B were artificially included in specimens of corner welds.

2. METHOD OF TESTING

(1) Specimen

The configuration and dimensions of a specimen are shown in **Fig.1**. It is a box-section member of roughly the same dimensions as a truss chord of Akashi Kaikyo Bridge. This specimen has numerous attachments such as diaphragms and gussets, but only corner joints wil be discussed here. The steel used was 800-MPa high-tensile steel. The mechanical and chemical properties of the steel are given in **Table 1** and the welding materials used are in **Table 2**.

Outside single-bevel groove welds were made by submerged arc welding. In order to cause blowholes of the target sizes to occur, zinc rich paint was applied inside grooves at specific sections. Inside fillet welds were made by two-layer welding with leg length 7mm.

(2) Nondestructive Testing

After welding had been finished, automatic ultrasonic testing was done on the corner joints in 7-m portions at the respective middle parts to detect locations and sizes of defects. The automatic ultrasonic testing system was the same as that used for Seto Ohashi Bridge. The indications of which widths were greater than 0.5 mm were counted as defects.

Approximately 900 blowhole-like defects were confirmed as a result of nondestructive testing. The

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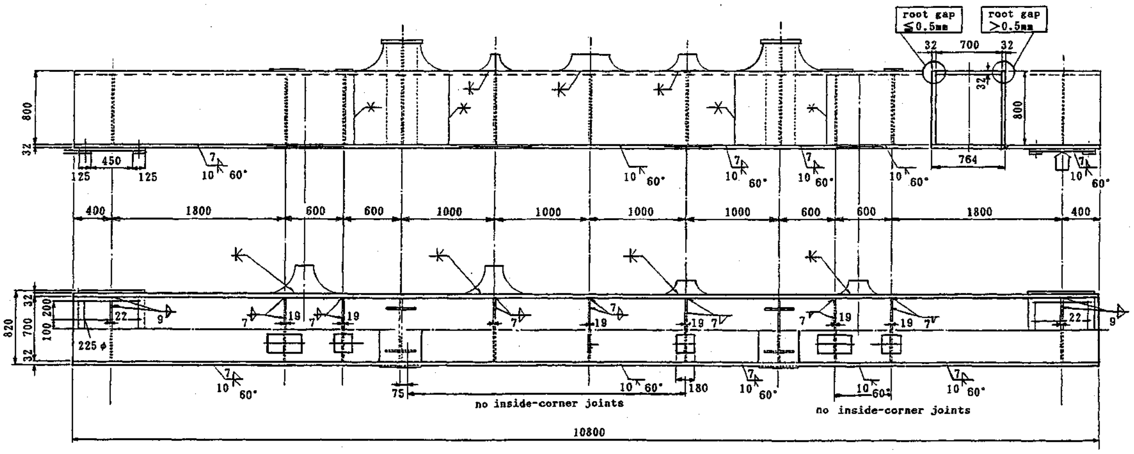


Fig.1 Dimensions of Specimen

Table 1 Mechanical Properties and Chemical Composition

thickness of plate (mm)	yield point (kgf/mm²)	tensile strength (kgf/mm²)	elongation (%)	C.V.N. (kg·m)	Chemical Composition												
					C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Nb	V	Al	Ceq
32	81	86	23	23.1	×10²			×10³		×10²						×10³	×10²
				(-4°C)	12	27	93	11	2	18	93	44	33	-	4	-	48

Table 2 Welding Methods and Materials

welded joint	welding methods and materials
tack welds	MAG YM60C (1.2φ)
corner welds (outside) partially penetrated grooves	SAW UP49 (4.8φ) SAW MF63 (20×200)
corner welds (inside) fillet welded joints	MAG YM60C (1.2φ) MAW L60 (4φ) MAW LBF62A (6φ)

distributions of dimensions of all blowholes measured upon exposing roots by rupturing weld lines after test and the distributions of dimensions obtained by nondestructive inspection before testing are shown in **Fig.2**. Small blowholes were not detected in nondestructive testing, but blowholes of widths 1.5 mm or more were all detected. Blowholes of height 8 mm or more were removed by air gouging and rewelded.

(3) Fatigue Test

The fatigue testing machine of dynamic loading capacity 4 MN (400 tons) was used for loading. Loading, as shown in **Fig.3**, was done by the four-point bending system. The testing load was selected so that the tension flange stress range in the center portion would be 100 MPa. In order to mark fatigue crack front by beach marks, the load was lowered to one half of testing load at the specified load cycles. Detection of cracks during fatigue tests was done by visual inspection, with magnetic particle test also used as necessary. Automatic ultrasonic testing was done when 2 million cycles of loading had been completed.

(4) Root Exposure Observation of Corner Weld

As shown in **Fig.4**, corner welds and fillet welds were exposed along their roots and the conditions of defects such as blowholes existing at the roots and fatigue cracks were observed. If fatigue cracks were discovered on the surface the pieces were further broken in perpendicular directions to expose the fatigue cracks, and the occurrence and development of fatigue cracks were observed.

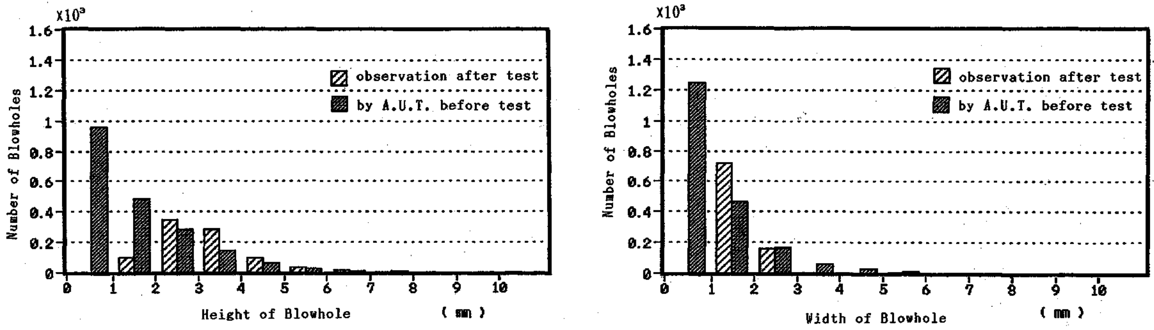


Fig.2 Sizes of Blowholes

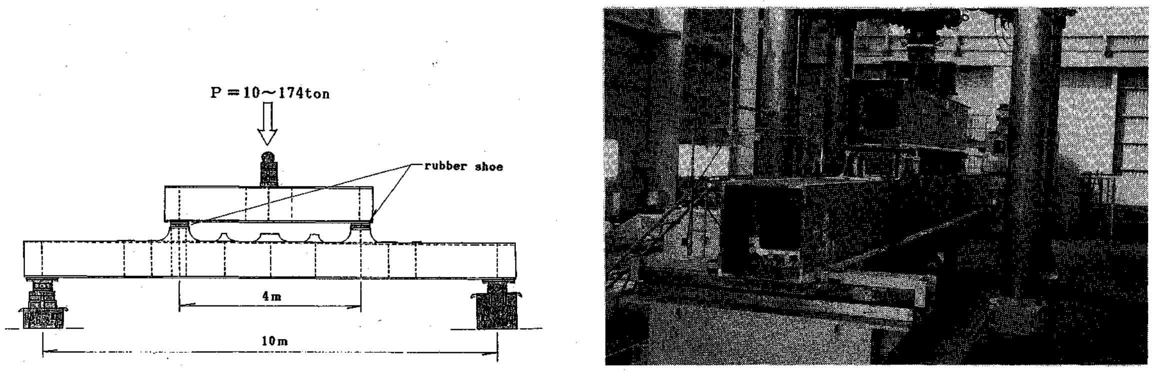


Fig.3 Test Set-up

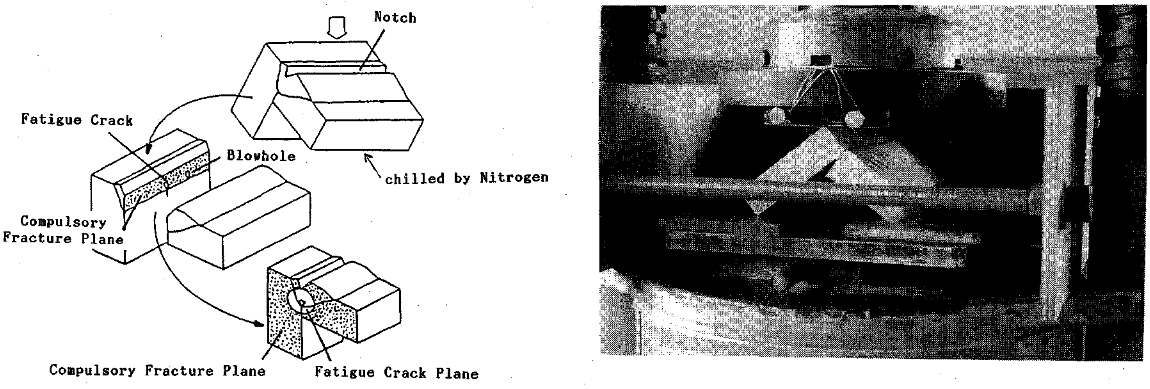


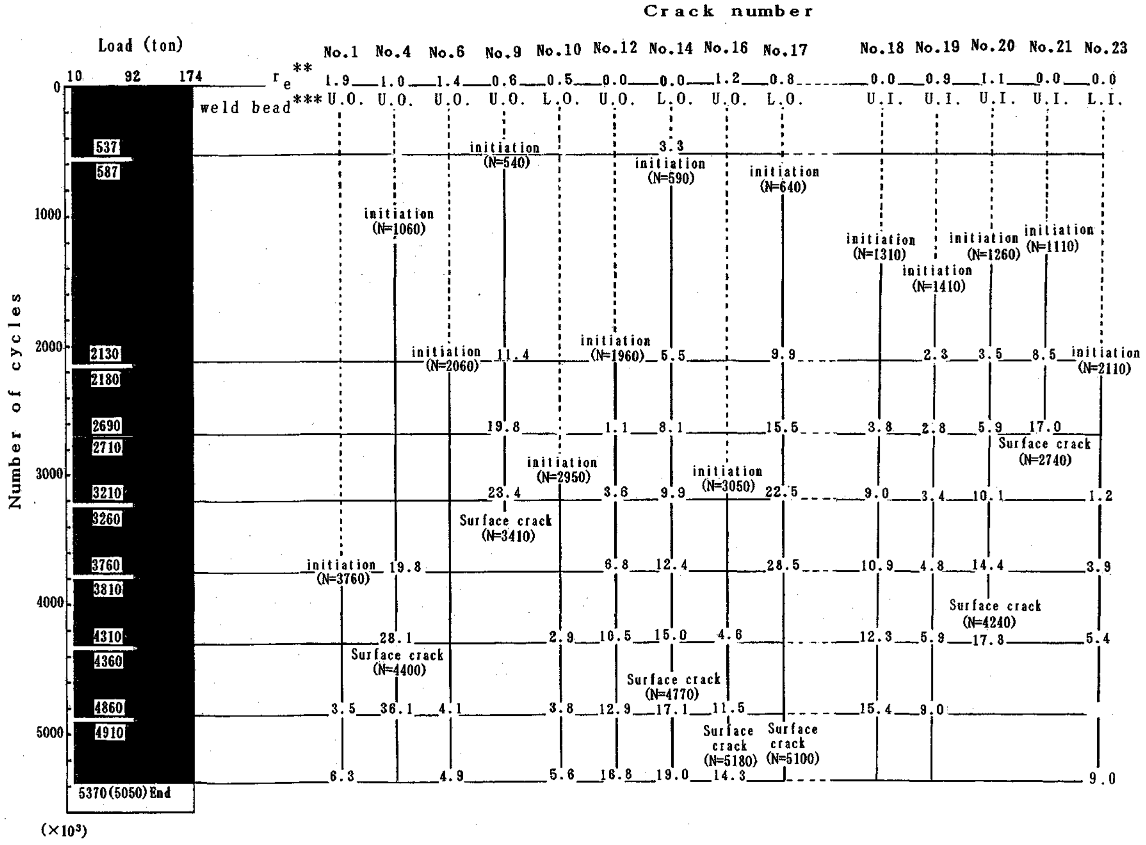
Fig.4 Observation of Fatigue Cracks

3. TEST RESULTS AND CONSIDERATIONS

(1) Progress of Testing

The progress of fatigue testing, and the conditions of fatigue crack occurrence at corner welds and discovery of the cracks at the surface are shown in **Fig.5**. There were 14 cracks for which beach marks were recognized on the failure surface out of the 29 discovered fatigue cracks upon root exposure observation. The fatigue crack initiation life in **Fig.5** is considered to have been when the innermost of the beach marks remaining on the fatigue crack surface was formed.

Examples of the appearance of a fatigue crack on the surface and of a fatigue crack surface are shown in **Fig.6**. The conditions of development of fatigue cracks from blowholes are shown in **Fig.7**. The dimensions of fatigue cracks at the various stages were read from beach marks remaining on fatigue crack surface when the cracks were exposed after testing, and correspond to the diameters of roughly



* initiation :The most inner beach mark was created.
Surface crack:The fatigue crack was observed on the surface.
Figures are the radiuses of fatigue crack (mm)
** $r_e = 1/2 \cdot D_e$ (see eq.(1))

*** weld bead
U:upper flange
L:lower flange
O;out-side partially penetrated weld
I;inner-side fillet weld

Fig.5 Load History, Initiation and Propagation of Fatigue Cracks

disk-like cracks.

Fatigue cracks discovered on the surface of outside single-bevel groove welds were nine, all of which had initiated from weld roots and had grown to appear at the surface. Of the nine fatigue cracks, five cracks were in the compression flange (upper flange). Fatigue cracks discovered on the surface of inside fillet welds were at two places. Crack No.21 was judged to be a fatigue crack existing inside through automatic ultrasonic testing performed at 2 million cycles of loading, and subsequently was discovered at the surface of the specimen at 2.62 million cycles.

(2) Fatigue test results

The relationships of stresses measured in the vicinities of locations where fatigure cracks were detected at surfaces and the number of cycles of loading at the times of discovery are shown in **Fig.8** separately for compression sides (upper flange) and tension sides (lower flange). The straight lines A, B, C and D, and A′, B′, C′, and D′ are the allowable stress range lines in fatigue design standards for Honshu-Shikoku Bridges. For repetitions of compressive stresses, 1.3 times the allowable stress range for tensile stresses is taken. The test results are plotted in the vicinity of the category C′ design line for the tension side, and slightly below the Category C design line for the compression side. This is a fairly low fatigue strength compared with the results of large-scale fatigue tests previously carried out because of the existence of large blowholes⁷⁾.

The size of fatigue crack on the surface when they were detected were varied. **Fig.9** shows the relationship between nominal stresses at the locations of cracks seeking the life and predicted fatigue lives when all fatigue cracks, including those discovered through exposure of roots after testing, had reached lengths of 10 mm, based on the condition of fatigue crack development such as

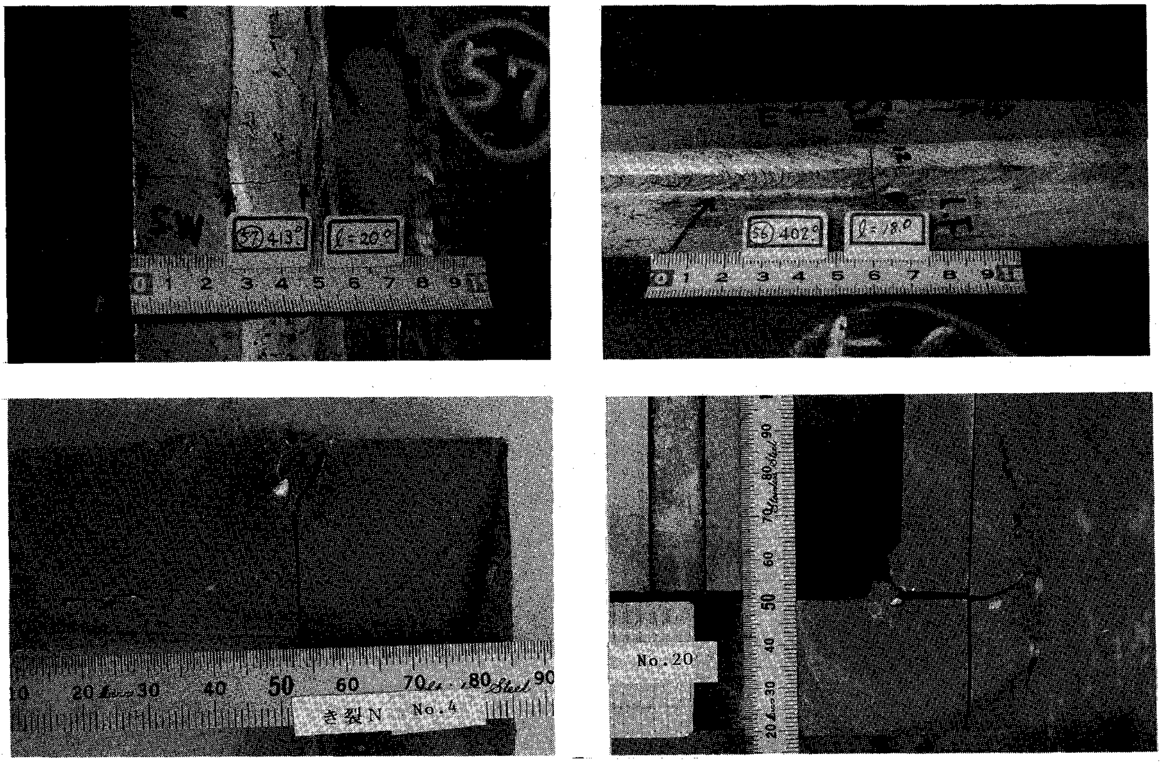


Fig.6 Fatigue Cracks

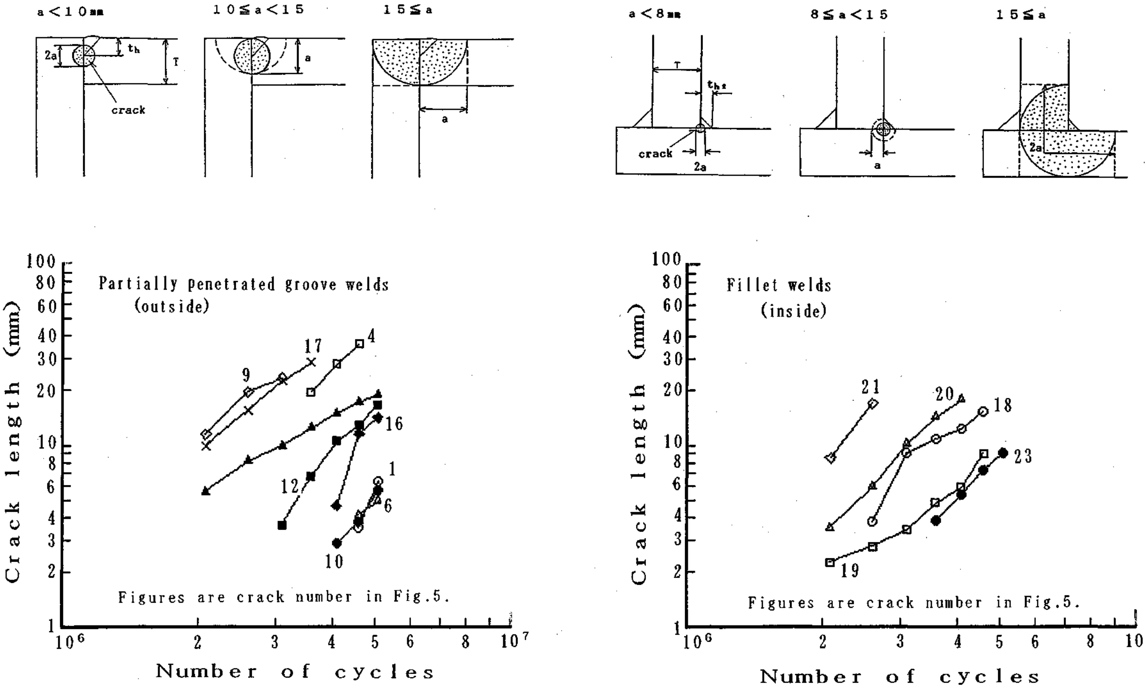


Fig.7 Changes of Fatigue Crack Size

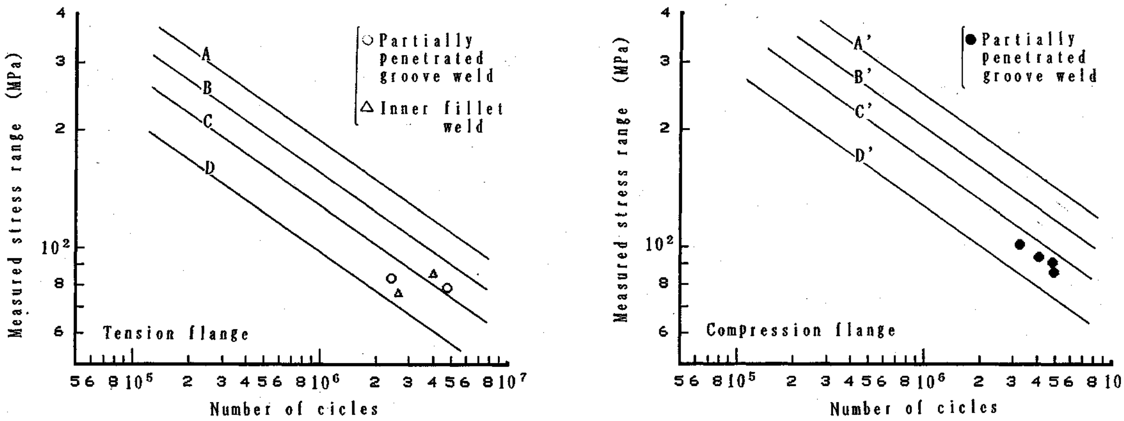


Fig.8 Fatigue Test Results (Measured Stress Range v.s. Fatigue Crack Detected Life)

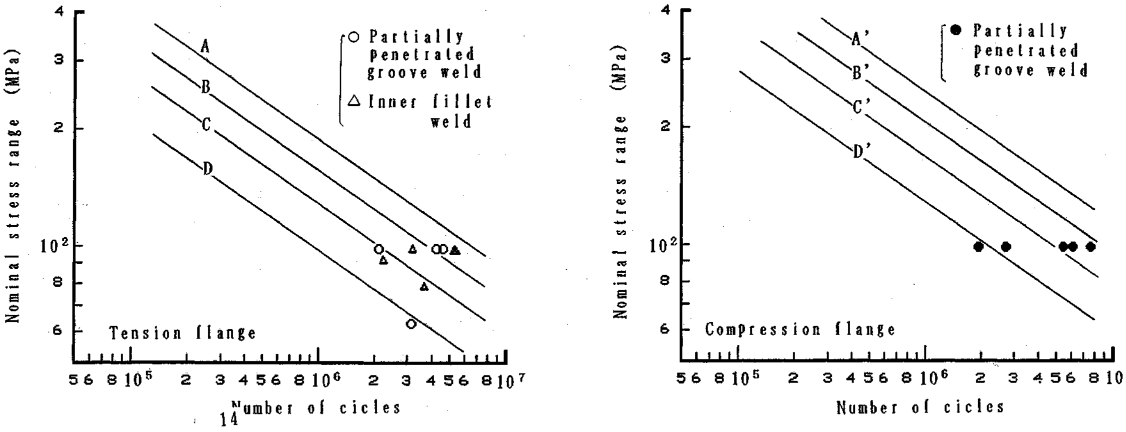


Fig.9 Fatigue Test Results (Nominal Stress Range v.s. Fatigue Life with 10mm Fatigue Crack in Diameter)

shown in **Fig.7**. Fatigue crack length of 10mm, corresponds roughly to the size when the crack appears at the surface. In fatigue design of corner joints in Honshu-Shikoku Bridges, the time when a fatigue crack initiated at the root has grown to the surface is taken to be the fatigue life, and crack length of 10mm corresponds roughly to this definition of life. The relationships between the norminal stresses of the various fatigue cracks and life for crack length of 10mm are scattered over a wide distribution range, and there are some which are lower than the Category D design curve.

In the fatigue design standards for Honshu-Shikoku bridges, when the quality classifications of Grade AA and Grade A are satisfied, allowable fatigue stress of Category B is used. Corner welds of quality classification Grade B are applied to truss members of acting stress range/allowable fatigue stress range out more than 0.5. The allowable stress range for Category B is 12.75 kg/mm^2 at 2×10^6 cycles, and 0.5 of this is 6.4 kg/mm^2, lower than the 8 kg/mm^2 for Category D. That with the experimental results here, joints of Grade B are safe at allowable stress of Category D is indicated, and it may be said that fatigue design

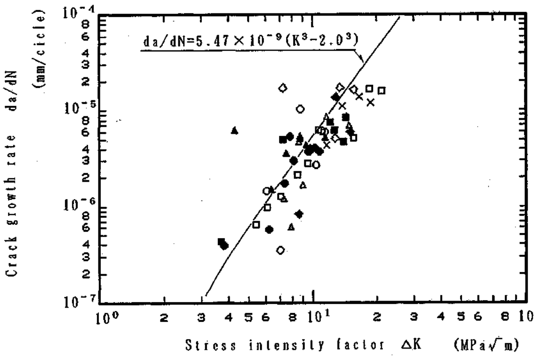


Fig.10 Fatigue Crack Propagation Rate and Stress Intensity Factor Range, obtained from Beach Markes

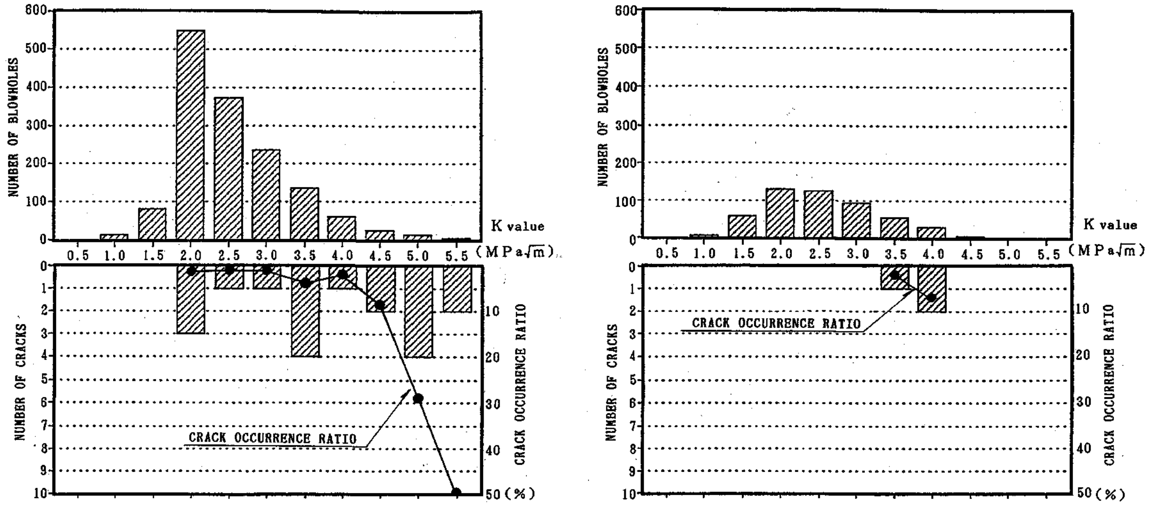


Fig.11 Distribution of Initial K values from Equivalent Diameters, Number of Cracks and Crack Occurrence Ratio from Blowholes

and quality standards for corner joints being considered for application at present are reasonable.

(3) Fatigue Crack Growth from Blowhole

Fig.10 shows plots of fatigue crack growth rate da/dN [mm/cycle] obtained from the spaces of beach marks and stress intensity factor range ΔK [MPa$\sqrt{\text{m}}$] calculated from sizes of beach mark remaining on the individual fatigue failure surfaces. The straight line in the figure is the fundamental fatigue crack growth curve used when obtaining the allowable stress range and critical flaw dimensions⁶⁾, and agree well with the da/dN-ΔK relationship obtained here from beach marks. This indicates that the modeling of fatigue crack from blowhole and the fundamental fatigue crack development curve had been appropriate.

(4) Possibility of Fatigue Crack Occurrence from Blowholes

Fig.11 shows the distributions of initial stress intensity valuse which are calculated from converted diameters of blowholes, numbers of blowhole from where fatigue cracks had occurred and crack occurrence ratio from blowholes.

The converted diameter is the diameter when the blowhole is considered as a fatigue crack of equivalent disk shape, and is given by the equation below⁵⁾.

Converted Diameter $D=0.94\times W^{0.29}\times H^{0.48}$ ……………………………………(1)

provided that W and H are width and height fo blowhole, respectively. Crack occurrence ratio is the ratio of the number of blowholes from which cracks occurred to the total number of blowholes occurring at the entire lines of longitudinally-welded beads.

A trend for fatigue crack occurrence ratio to become higher as the stress intensity factor of converted cracks becomes larger is seen, with the occurrence ration rising sharply from 4 to 5 MPa $\sqrt{\text{m}}$. Fatigue cracks did not occur when stress intensity factors were not more than 2 MPa$\sqrt{\text{m}}$. This 2 MPa$\sqrt{m}$ coincides with the threshold value of fatigue crack growth used for calculation of repair limit dimensions of blowholes⁷⁾.

4. CONCLUSIONS

The principal results obtained on conducting fatigue tests of truss chords fabricated aiming for quality classification Grade B and containing blowholes of fairly large dimensions are as follows :

(1) Fatigue strengths of corner welds of grade B quality are fairly low, and allowable fatigue stress for Category D is applicable.

(2) Differences are not seen between tension side (lower flange) and compression side (upper flange) in occurrence of fatigue cracks from blowholes and properties of develop. There is a trend for the number of cracks occurring to be larger at compression flanges.

(3) The relationship of da/dN-ΔK which were obtained from beachmarks on the fatigue failure surface are very close to the fundamental da/dN-ΔK curve of fatigue design.

(4) The ratio of fatigue crack occurrence from blowholes becomes higher as the stress intensity factor for cracks converted from blowholes becomes higher. Fatigue cracks do not occur when the stress intensity factor is not more than 2 MPa$\sqrt{m}$.

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ブローホールを含んだトラス弦材角溶接部の疲労強度

三木千寿・奥川淳志・大江慎一・安井成豊

明石海峡大橋の補剛トラス弦材とほぼ等しい断面の部材の曲げ疲労試験を行い，角溶接部の疲労強度を検討した．角溶接部の要求品質レベルはB等級であり，かなり大きな寸法のブローホールが含まれている．このような品質の角溶接部に対しては本州四国連絡橋設計基準のD等級の許容応力度（2×10^6回で80 MPa）を適用することが適当である．