**Zeitschrift:** IABSE reports = Rapports AIPC = IVBH Berichte
**Band:** 66 (1992)

**Artikel:** Full-size fatigue test of bridge cables
**Autor:** Miki, Chitoshi / Endo, Takeo / Okukawa, Atsushi
**DOI:** https://doi.org/10.5169/seals-50695

# Full-size Fatigue Test of Bridge Cables

## Essais à fatigue sur des câbles d'un pont existant

## Ermüdungsversuche an Original-Brückenkabeln

**Chitoshi MIKI**
Prof. of Civil Eng.
Tokyo Inst. of Techn.
Tokyo, Japan

**Takeo ENDO**
Exec. Dir.
Honshu-Shikoku Bridge Auth.
Tokyo, Japan

**Atsushi OKUKAWA**
Chief Eng.
Honsshu-Shikoku Bridge Auth.
Tokyo, Japan

Chitoshi Miki, born in 1947, received his doctoral degree from Tokyo Institut of Technology in 1979. He has been involved in research in fatigue and fracture of bridge structures.

Takeo Endo, born in 1935, received his civil engineering degree from Waseda University in 1958. Since then he worked for the Ministry of Construction and now he is responsible for the design and construction of Honshu-Shikoku Bridges.

Atsushi Okukawa, born in 1944, received his doctoral degree from University of Tokyo in 1973. He joined the Honshu-Shikoku Bridge Authority and has beeen involved in the design of many suspension bridges and cable-stayed bridges.

**SUMMARY**
Fatigue tests by axial tension and bending were carried out on specimens having the same thickness and anchorage structure as the cable system of an actual bridge and fatigue performances of various types of cable systems were studied.

**RÉSUMÉ**
L'article décrit les essais à la fatigue en traction et flexion axiales, effectués sur les échantillons qui, quant à la section et à la disposition d'ancrage, correspondent exactement à un système de câbles d'un pont existant. Ce faisant, il examine les propriétés que différents types de câbles peuvent présenter à la fatigue.

**ZUSAMMENFASSUNG**
Ermüdungsversuche in achsialem Zug und Biegung wurden an Proben durchgeführt, die bezüglich Dicke und Verankerungskonstruktion dem Kabelsystem einer vorhandenen Brücke entsprochen haben. Dabei wurden die Ermüdungseigenschaften unterschiedlicher Kabeltypen untersucht.

## 1. INTRODUCTION

The series of full-sized fatigue tests of cable systems including anchorages have been carrying out since 1974 at the Honshu-Shikoku Bridge Project which includes suspension bridges and cable stayed bridges of largest-in-the-world class is reported in this paper. Cables used as structural members of bridges are of the three varieties of main cable of suspension bridge, hanger rope, and diagonal stay cable of cable stayed bridge. Of these cables, the proportion of dead load in tensile force is large in the main cable of a suspension bridge and fatigue is not a problem in many cases. In case of hanger ropes, the proportion of live load making up tensile force becomes large, and there will be cases of fatigue being of concern. For hanger ropes of the Honshu-Shikoku suspension bridge, CFRC (Center Fit Rope Core) type, a form of strand rope is to be used.

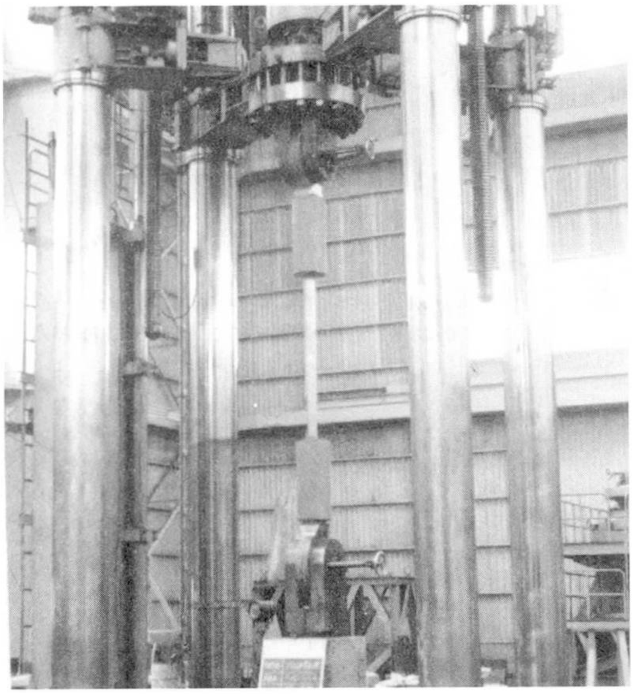
As for stay cables of a cable stayed bridge, the proportion made up by live load is large. Especially, the Kojima-Sakaide route of the Honshu-Shikoku bridges has combination highway and railroad bridges and in case of a cable-stayed bridge of the route there is great tensile force variation due to train loads, and giving consideration to tensile fatigue is of importance. Locked coil rope (LCR), a type of spiral rope, or parallel wire strand (PWS) is often used for stay cables of cable stayed bridges.

As fatigue of cable and rope, fatigue due to bending is a problem besides fatigue due to axial force. For example, with stay cables of a cable stayed bridge, bending occurs in the anchored parts of the cables due to deflections produced in girders by application of live load and variations in sagging due to axial force. Furthermore, deflection oscillations are induced in cables by wind and these may also be a cause of fatigue.

In view of the above, fatigue tests by axial tension and bending were conducted on specimens having the same thickness and anchorage structure as the cable system of an actual bridge, and the fatigue performances of various types of cable systems were investigated.

## 2. SPECIMENS

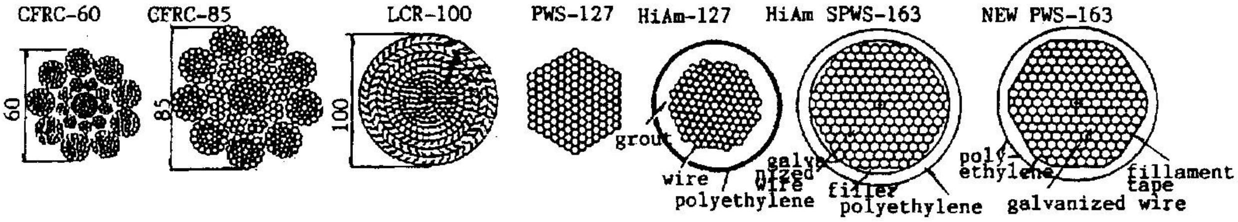
The specimens tested in the study are listed in Table 1. Both ends of cables of CFRC, LCR, and PWS types were anchored with sockets made of zinc-copper alloy (Zn 98%, Cu 2%). Wires of PWS, HiAm and NEW-PWS are 160kg/mm$^2$ class and wires of HT-PWS are 180kg/mm$^2$ class steels. High fatigue-strength sockets were attached to both ends of HiAm and NEW-PWS cables. These cables, HiAm 163 of non-grouted type (HiAm SWPC) and NEW-PWS 163 are planned to be used in Tatara Bridge to be the longest cable stayed bridge in the world.



## 3. METHOD OF TESTING

Tensile fatigue tests were conducted using the 400-ton fatigue testing machine shown in Fig. 1. Bending

| type of test | | cable system | cable length(mm) | number of specimen | remarks |
|---|---|---|---|---|---|
| Tension | | CFRC-60 | 1990 | 9 | R=0.05-0.07 |
| | | CFRC-85 | 1810 | 6 | R=0.3-0.4 |
| | | LCR-100 | 2750 | 2 | R=0.39-0.49 |
| | | PWS-169 | 1760 | 2 | R=0.59-0.66 |
| | | HiAm-91 | 1930 | 4 | R=0.62-0.72 |
| | | HiAm-127 | 1830 | 5 | R=0.45-0.58 |
| | | HT-PWS-127 | 1750 | 4 | R=0.60-0.66 |
| Bending | Series -I | PWS-127 | 4100 | 6 | d=+15mm |
| | | CFRC-85 | 4100 | 6 | d=+15mm |
| | | LCR-100 | 4100 | 2 | d=+15,20mm |
| | Series -II | HiAm SPWS-163 | 10000 | 2 | θ=+0.9 |
| | | NEW PWS-163 | 10000 | 2 | θ=+1.0 |



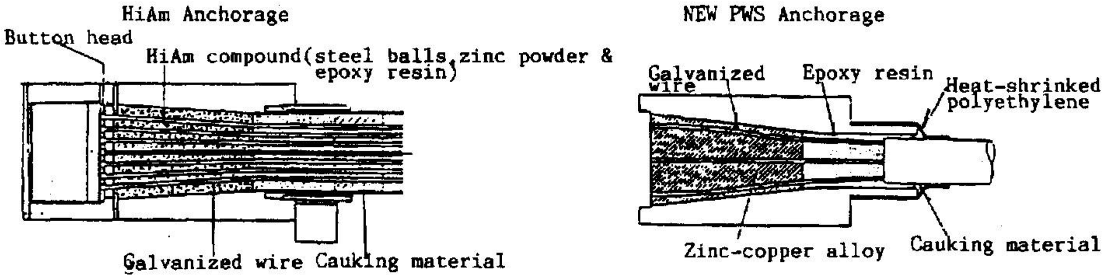




Table 1 Tested cable systems

fatigue tests were performed using the two bending fatigue testing machines shown in Fig. 2. Both testing machines had jacks for inducing tensile axial forces in cables, frames to sustain these forces, and devices to apply repetitive loads to the middle portions of cables. Loading, with the Type A testing machine for Series I, is by a system of applying forced displacement by motor drive, and with the Type B testing machine for Series II, is by a system of controlling displacement by an electro-hydraulic jack.

Series I had the purpose of investigating the bending fatigue strength of hanger ropes of suspension bridges, and similarly to attachment of hanger ropes in an actual bridge, a zinc collar of bell mouth shape at the front end is attached at the mouth of the socket so that the socket will not be directly bent. The drive section also has a collar with both ends rounded attached to the cable to prevent abrupt flexural deformation from occurring.

Series II had the objective of examining the bending fatigue strengths of anchorage portions of stay cables in cable stayed bridges, and therefore, the front ends of sockets were left in a manner that they could be directly bent.

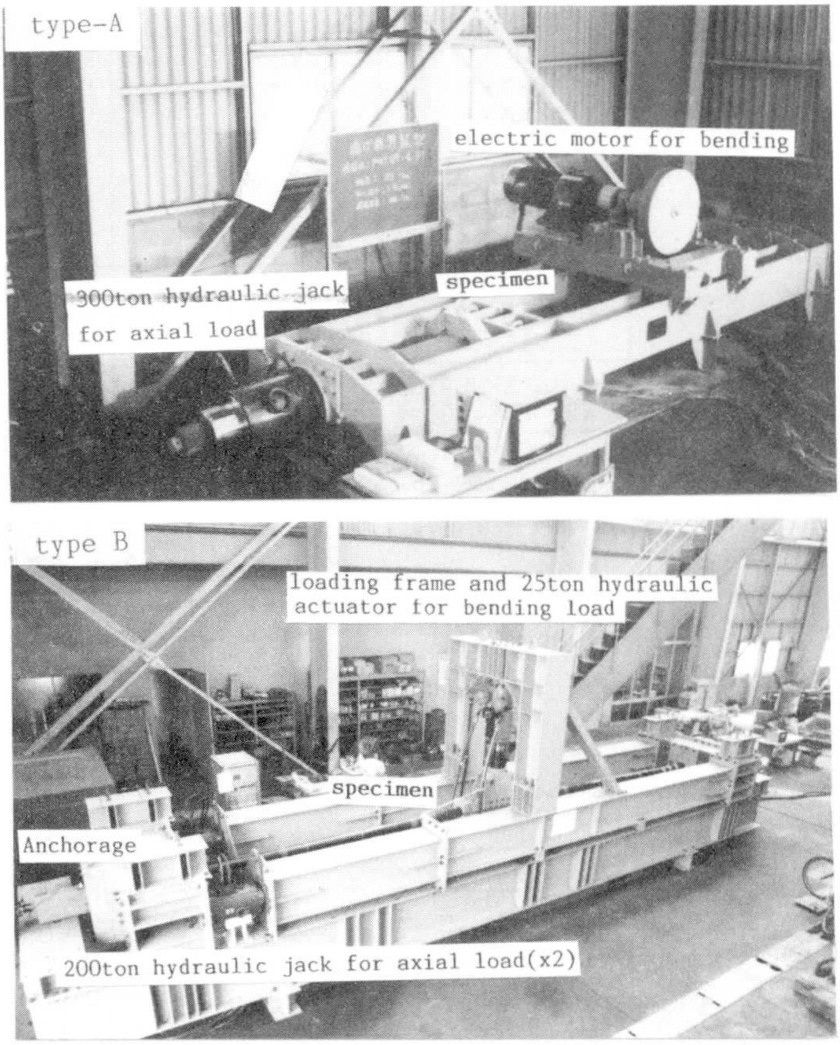



Fig. 2 Bending fatigue test systems

Detection of cable snapping during testing was accomplished by accelerometers fixed at both ends of specimens in tensile fatigue tests and in bending fatigue tests of Series I. In bending fatigue tests of Series II, detecting was done with a total of 6 AE sensors attached at the two ends of a socket and 4 locations at the middle part of the cable.

## 4. TENSILE FATIGUE TEST RESULTS

The state of progress in failure of element wires in CFRC rope is shown in Fig. 3. Breaking of wires progressed comparatively slowly from the first breakage up to 5 or 6 wires, after which it was gradually speeded up, and when the ratio of breakage exceeded the range of 10 to 20%, breakage began to occur consecutively.

The result of investigating the failure locations on taking apart the rope after tests indicates that with CFRC 60 , breaking occurred in large number inside sockets, while with CFRC 85 , breaking occurred more at general portions of rope. Cases of breaking at a multiple number of locations in a single wire were

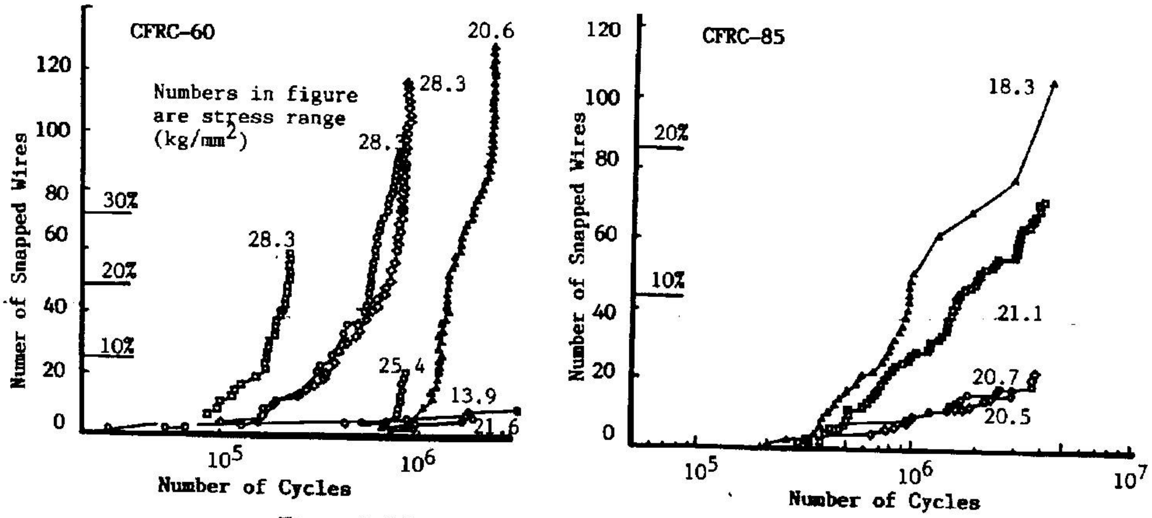



Fig. 3 The state of wire snapping of CFRC cable

more numerous with CFRC 85 . It is considered that such trends of failure occurred due to differences in compositional structures and methods of winding of rope.

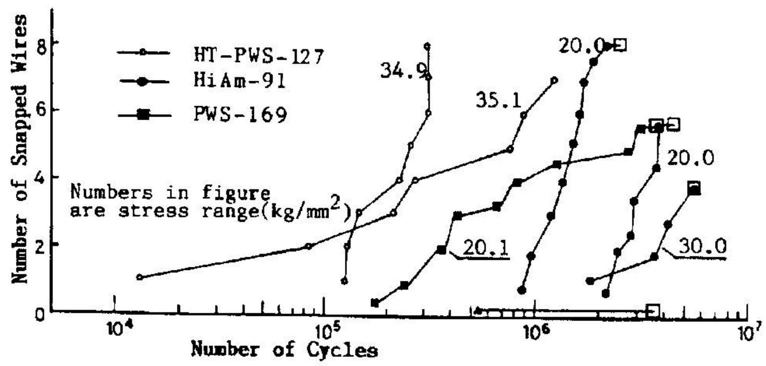



Fig. 4 The state of wire snapping

Fig. 4 shows the states of progress in breaking of element wires of PWS, HT-PWS, and HiAm, and all specimens indicate roughly linear relationships on semi-logarithmic axes. The results of investigations of wire breakage locations indicates that snapping occurred in a concentrated matter in wires at the outermost layers in the vicinities of socket mouths with PWS. With HT-PWS, snapping occurred in wires at the inner layers at locations 30 to 50 mm inside the sockets in case of specimens which had high fatigue strength. With HT-PWS and specimens that had fatigue strength which were comparatively low, snappings were concentrated at wires of the outermost layers at the socket mouth. These trends are thought to have been produced dependent on bending of element wires and condition of casting of zinc when attaching sockets.

The ratios of breakage locations of wires in the longitudinal direction of HiAm specimens are shown in Fig. 5. Snapping occurred only at anchorages in case of stresses being in a low range. Fig. 6 shows the locations inside cables of element wires which had broken, and it can be seen that almost all were wires of the outermost layer. That is, even though a socket of high fatigue strength, its fatigue strength was greatly affected by stress concentration produced accompanying anchorching, and it is thought breaking occurred from element wires at the outermost layer where the degree of stress concentration was highest.

The fatigue test results of CFRC 60 , CFRC 85 , and LCR in the relations with initial breakage, 2% breakage, and 5% breakage are shown in Fig. 7. With the time of 5% breakage as the reference, even though a correction is made for the difference with stress ratio, a tendency is seen for CFRC rope of 85 to be slightly lower in strength than CFRC 60 . Also, it can be seen that the fatigue strength of LCR is slightly higher than that of CFRC.

The fatigue test results of PWS, HT-PWS, and HiAm are shown in Fig. 8. Many of the specimens were finished testing before their breakage ratios reached 5%, but from a comparison of PWS and HiAm, the effect of having made sockets to be of high fatigue strength is quite clear. Further, from the comparison of PWS and HT-PWS, it can be seen that fatigue strength is increased with increase in static tensile strength of element wires. However, the fatigue strengths of these cable systems are fairly low compared with the fatigue strengths of element wires, and it may be said that the influence of secondary stress due to the compositions and anchorage structures of cables is dominant in fatigue strengths of cable systems. Further, the life up to initial breakage becomes shorter

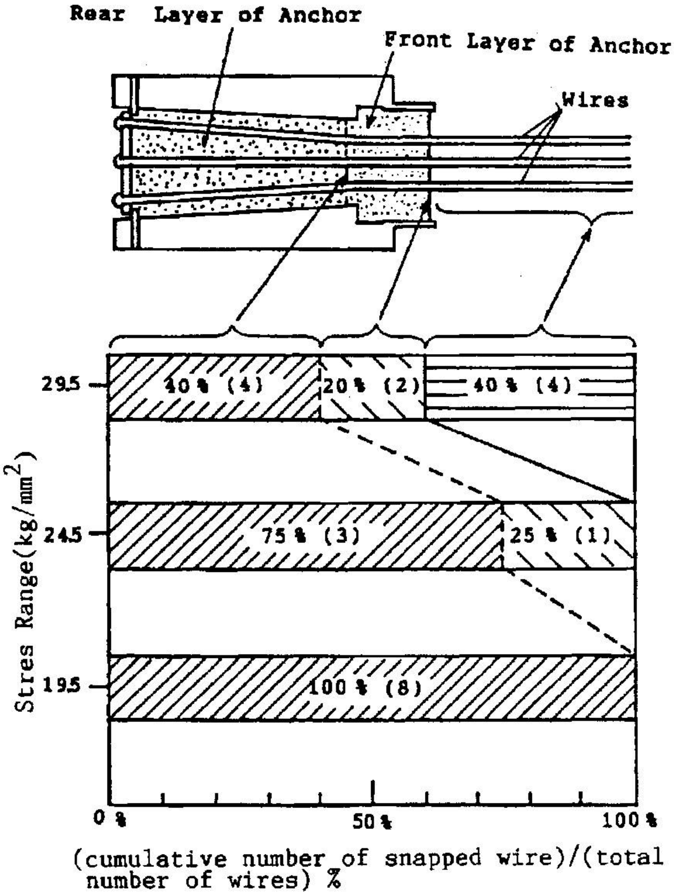



Fig. 5 Locations of wire breakage in HiAm cable systems

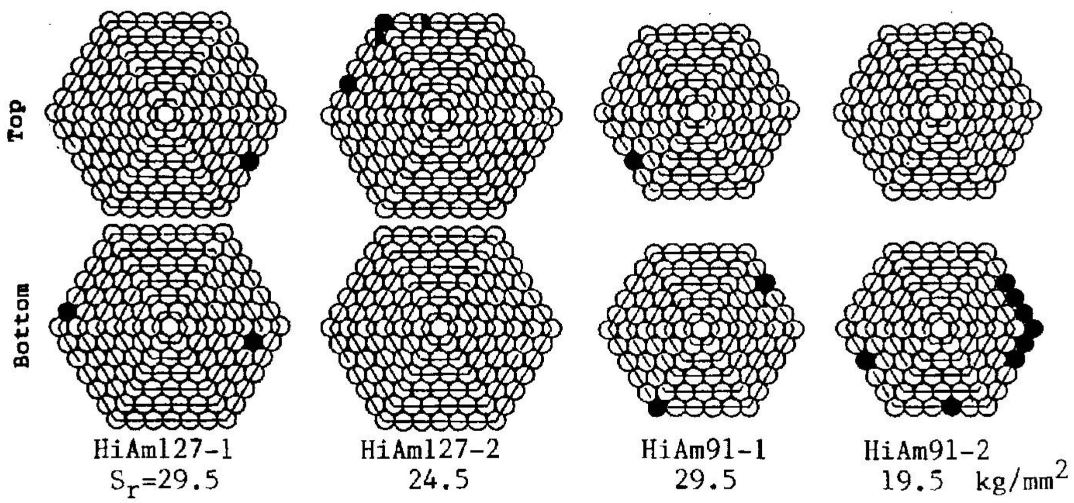



Fig. 6 Positions of snapped wire in HiAm cables

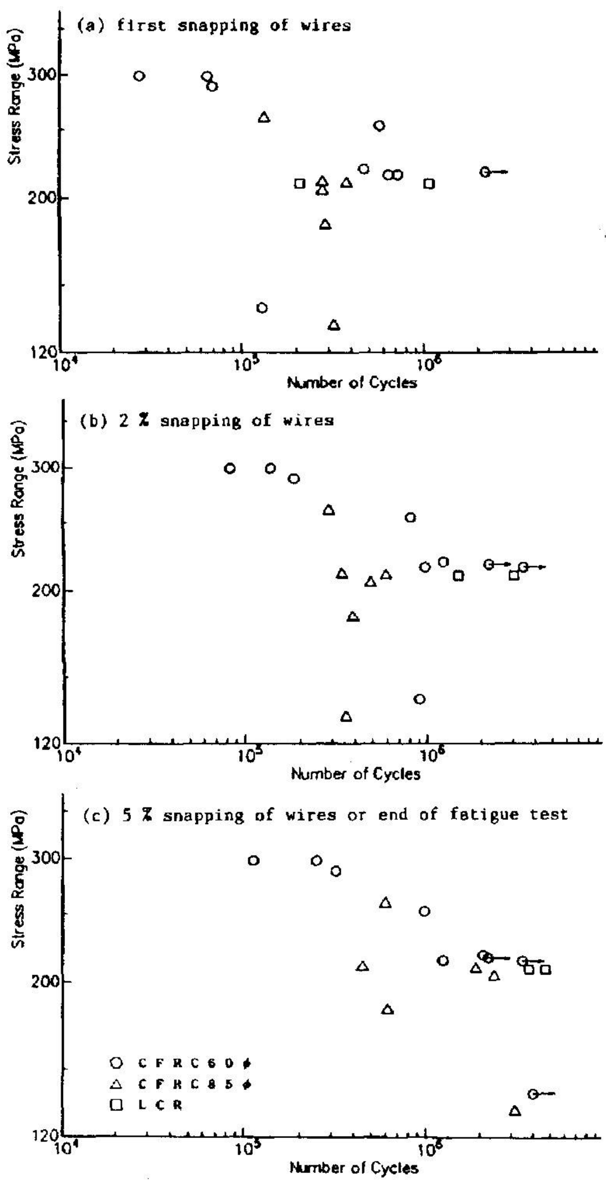



Fig. 7 S-N relationship of CFRC60, CFRC85 and LCR

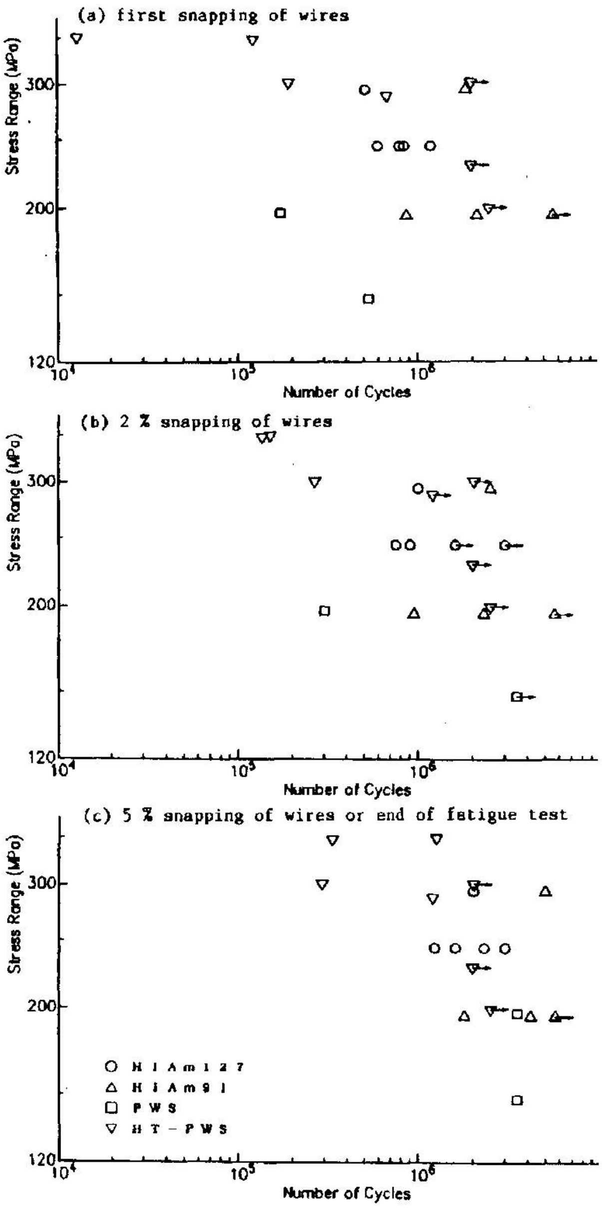



Fig. 8 S-N relationship of PWS, HT-PWS and HiAm

as diameter becomes larger, and it is shown that the degree of stress concentration becomes higher with increase in diameter.

## 5. BENDING FATIGUE TEST RESULTS

### 5.1 Series I:CFRC and LCR Cables

The stress occurring in the element wire is the combination of stress due to axial tension variation accompanying variation in cable length and stress due to bending deformation of the cable. Therefore, stress and fatigue behavior of a wire depends greatly on the composition and anchorage structure of the cable.

With CFRC specimens, two out of five specimens had axial tension of 200 tons and three had 150 tons induced. The stress occurring when axial tension was induced was 50 kg/mm$^2$ in calculated value and 48 kg/mm$^2$ in measured value for 200 tons, and 37 kg/mm$^2$ in calculated value and 35 kg/mm$^2$ in measured value for 150 tons. The forced displacement applied at the central drive section was 15 mm in all cases, corresponding to 0.57 deg in terms of angle. Fig. 9 shows the stress behavior of element wire due to bending of cable close to the collar at the fixed side of CFRC 85. It can be comprehended that rope which is an assemblage of element wires behave as a whole as a single elastic body possessing a certain bending rigidity.

Failures of element wires were concentrated at the collars at both ends and the drive section collar. The location of the wires broken are shown in Fig. 10, and wires that broke were all at location in contact with other strands. This is considered to have been because in the same strand element wires were wound laid parallel to each other and were in linear contact, whereas contact with a different strand was point contact, and contact pressure therefore became high. As shown in Fig. 11, fatigue cracks were all initiated from impressions occurring due to contact between element wires.

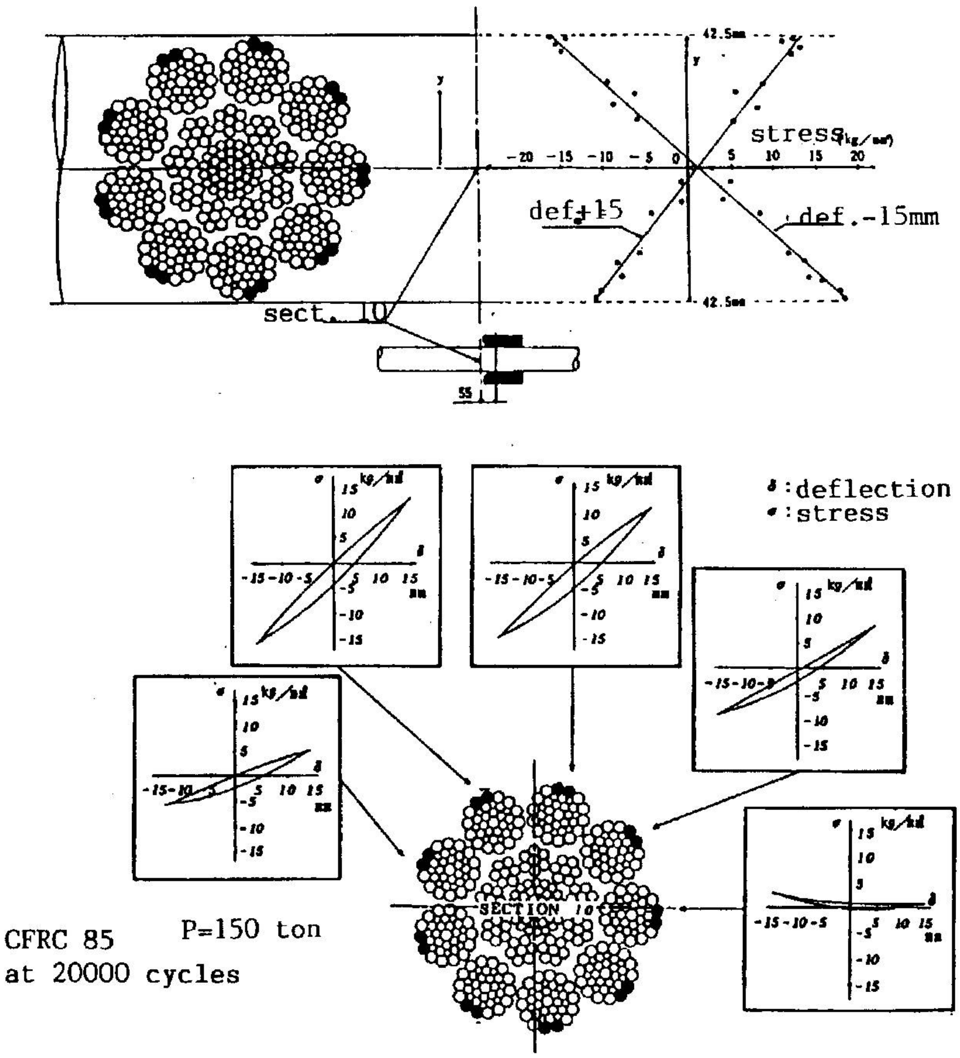
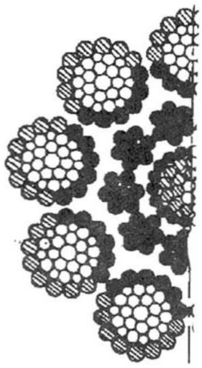



Fig. 9 Stress behavior due to bending



● many failures
⊗ a few failures
○ no failure

Fig. 10 Locations of the wires broken

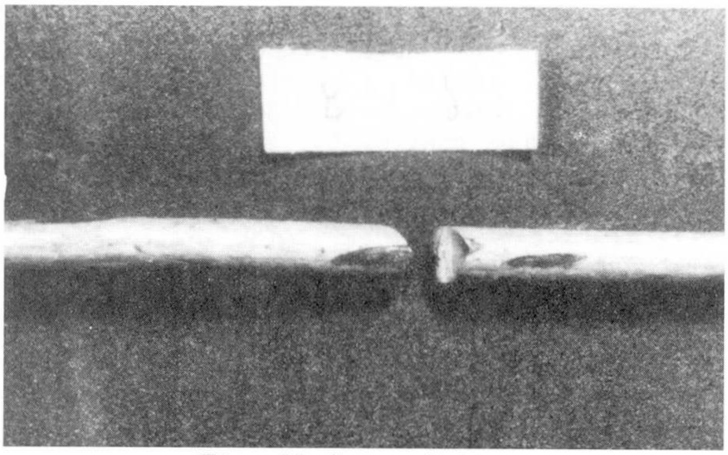


Fig. 11 Snapped wire

With LCR specimens, axial tension of 200 tons was induced. Stresses in an element wire at such time were $23kg/mm^2$ in calculated value and $27kg/mm^2$ in measured value. The forced displacements caused at middle parts were 20mm and 15mm, corresponding respectively with 0.76 deg and 0.57 deg in terms of bending angle. The stress behavior of an element wire in an LCR rope is similarly to CFRC rope, the rope behaved mechanically as single elastic body. Failures of wires were concentrated at collars having occurred mainly in the E3 and E2 layers which were the outermost and second layers.

Axial tension of 175 tons was induced in PWS specimens and fatigue tests were performed at forced displacement of 15mm (0.57 deg). Of the three specimens, two were flat top and one was pointed top. The calculated stress when 175 tons was induced was $70kg/mm^2$ and the measured stress $72kg/mm^2$. Two PWS ropes were tested and breaking of element wires was only one wire at the parallel part and one wire at the middle of the drive collar part.

The bending fatigue tests in Series I are shown in relation to bending angle in Fig. 12. Of the three types, PWS possessed the highest fatigue strength.

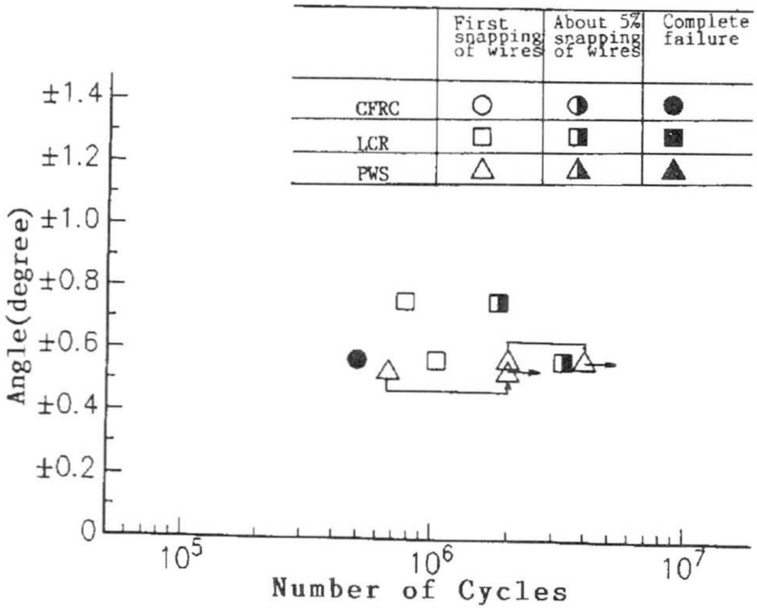



Fig. 12 Results of bending fatigue test (I)

### 5.2 Series II:NEW-PWS 163 and HiAm SWPC 163

Two each of NEW-PWS 163 and HiAm SWPC 163 which are PWS cables of non-grouted type for cable stayed bridges were tested. After inducing axial tension of 350 tons, displacement control fatigue tests were performed imparting the required forced displacements to the middle part. The relationships of bending angle and bending load with incremental stress in the axial direction are shown in Fig. 13. HiAm and NEW-PWS indicated similar behaviors.

The condition of bending stress occurrence is shown in Fig. 14. For all specimens, where bending stresses occurred were in the neighborhoods of the ends of sockets. From the results of measurements by stress concentration gauges attached connecting with sockets(Fig. 15), it is estimated that stresses of 20.0kg/mm$^2$ occurred at bending angle of 0.9 deg at the socket end with NEW PWS, and 21.0kg/mm$^2$ at bending angle of 1.0 deg with HiAm.

Two strain gauges were attached to a single element wire at the A and C cross section of HiAm cables with the purpose of investigating stress behaviors of individual element wires when flexure acts on a cable. As a cable was bent, bending stress acted on element wires also, but there were differences in stresses between locations in the vertical direction on the element wire and locations in the transverse direction. Fig. 16 shows the stresses measured at Cross Section A at 1.0 deg. compiled according to offset from the middle of the cable. Stresses were not uniform even in the same element wire, and this indicates that all of the element wires in the cable were not deformed as one.

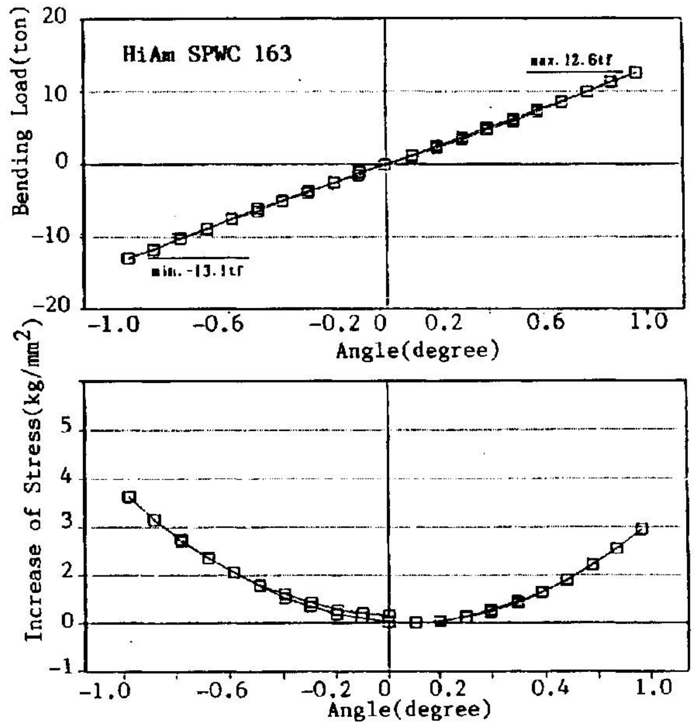



Fig. 13 Bending load, change of angle and increase of stress

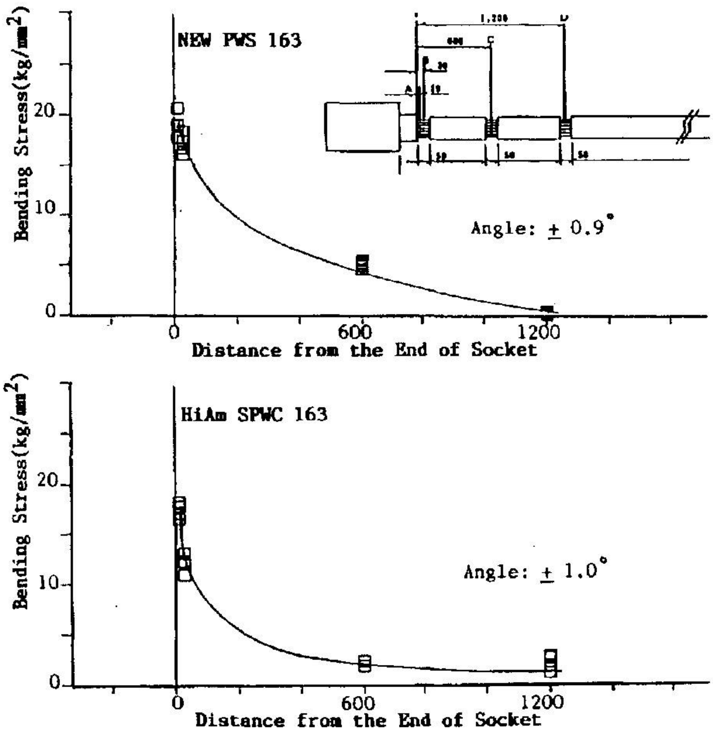



Fig. 14 Occurrence of bending stress

Repetitions of 0.9 deg for NEW-PWS were carried out for $10^7$ cycles, but failure of element wires was not detected. The results of these experiments are shown in Fig. 17 together with results with NEW-PWS 139 tested under conditions close to those of these experiments. It can be seen that the two PWS cable systems used for these experiments possessed high fatigue strengths.

## 6. CONCLUSION

Fatigue tests of models with diameters of actual sizes were carried out on various cable systems for bridges. The results obtained may be summarized as follows:

(1) Extremely characteristic processes of fatigue failure process are indicated depending on the composition and method anchoring of the cable,and strength also differs greatly. Accordingly, scale effect on fatigue strength of a cable cannot be discussed ignoring the methods of composition and anchoring of the cable.

(2) The fatigue strength in the axial direction of cable system including the anchorage is much lower compared with that of an element wire. Even in a cable system having an anchorage structure considered to be high in fatigue strength, breaking of element wires is concentrated at the

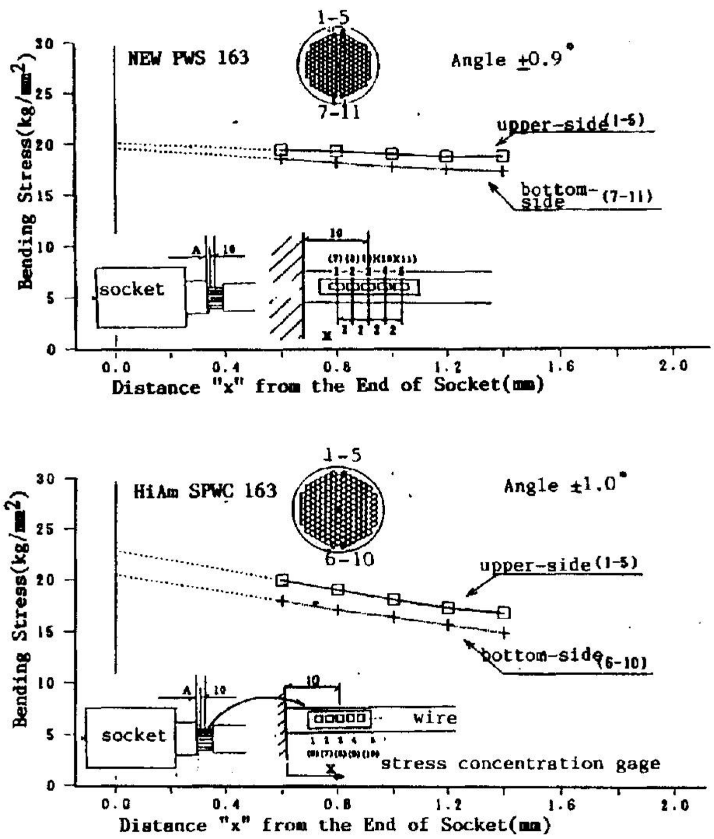



Fig. 15 Bending stress near socket mouth

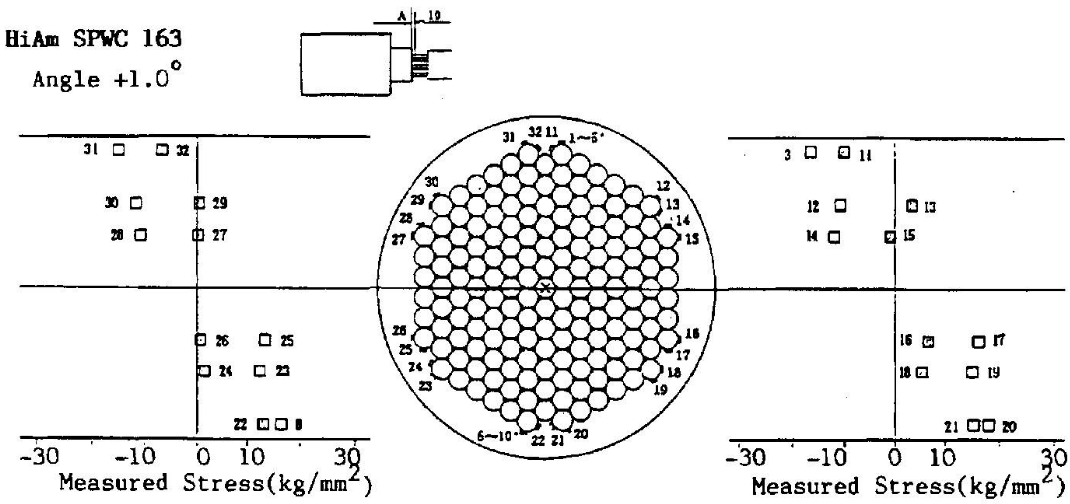



Fig. 16 Stress distributions in a cable

anchorage, and moreover, at the outermost layer, showing that they are subject to the effect of stress concentration due to anchoring.

(3) When forced displacement is applied in the perpendicular direction under a condition of axial tension induced in a cable system, bending stress will be produced in the vicinity of the anchorage. The condition of occurrence of bending stress at such time differs greatly depending on the type of cable (method of composition), and fatigue characteristics also differ greatly according to cable type. With CFRC and LCR, the whole cables show behaviors close to single elastic bodies, while with PWS, NEW-PWS and HiAm, a behavior of considerable slipping between element wires is indicated.

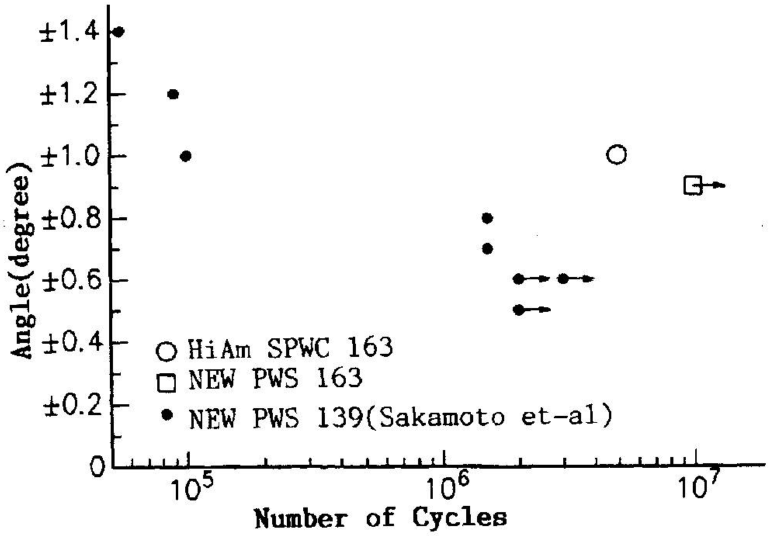



Fig. 17 Results of bending Fatigue test(II)

The experimental work was done by Messrs. H. Takenouchi, Y. Eguchi and S. Tanifuji of the Japan Construction Method and Machinery Research Institute. The authors express their sincerest gratitude to them.

References


(1) A.Okukawa:Tensile and Fatigue Tests of Hanger Ropes. Honshi-Giho, No.5,1978. (in Japanese)

(2) K.Kishimoto et-al:Bending Fatigue Tests of Cables. Honshi-Giho, No.11, 1980. (in Japanese)

(3) K.Takena et-al:Fatigue Resistance of Large Diameter Cable for Cable Stayed Bridges. J.of Structural Engineering,Vol.118,No.3,1992.

(4) Y.Sakamoto et-al:A Study on Secondary Stress and Fatigue Lives in Bending of a Pre-Coating Cable for Cable Stayed Bridge. J.of JSCE,No.446,1992-4. (in Japanese)