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Full Scale Fatigue Tests for Stay Cable Systems

Essais d'endurance en grandeur réelle sur des systèmes à haubans

Ermüdungstests in vollem Massstab für Schrägseilsysteme

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SUMMARY

Full-scale axial and flexural fatigue tests were implemented for a large capacity site assembly stay cable systems. It was confirmed that the system fulfils every requirement of the PTI recommendation. Through the test, parametric data was acquired to evaluate the system's behaviour during service. In the flexural fatigue test, the bending angle, which represents the worst conditions induced by the wind, was determined; the test confirmed that this system could cater for all possible vibrations arising on the actual cables with the combined use of external passive damping devices.

RÉSUMÉ

Des essais d'endurance en flexion et à l'effort normal ont été exécutés sur des systèmes à haubans utilisés lors de montage sur de grands chantiers. Les essais ont confirmé que le système répondait à toutes les conditions requises dans les recommandations PTI. Pendant l'essai, différentes données paramétriques ont été recueillies afin d'évaluer le comportement des systèmes en service. Dans l'essai d'endurance en flexions répétées, l'angle de flexion a été déterminé; l'essai a confirmé la capacité du système à résister à toutes les flexions alternées que peuvent subir les câbles réels grâce à l'utilisation combinée d'amortisseurs passifs externes.

ZUSAMMENFASSUNG

Axiale und Biegungs-Ermüdungstests wurden in vollem Massstab für ein Schrägseilsystem an einer grossen Anlage durchgeführt. Es wurde bestätigt, dass das System alle Anforderungen der PTI-Empfehlungen erfüllt. Während des gesamten Tests wurden verschiedene parametrische Daten gesammelt, um das Systemverhalten bei der Arbeit zu beobachten. Beim Biege-Ermüdungstest wurde der Biegewinkel, der die schlechteste Bedingung darstellt, bestimmt: es wurde bestätigt, dass das System allen möglichen Biege-Vibrationen entsprach, die an den Kabeln mit der kombinierten Verwendung von externen passiven Dämpfungsvorrichtungen auftraten.

1. INTRODUCTION

The cables of cable stayed bridges are exposed to high intensity fluctuating loads, in axial and transverse directions, arising from the traffic loads and wind forces. A number of large scale cable stayed bridges have been constructed in recent years and full scale axial and felexual fatigue tests on the stay system are becoming important. Specification of axial fatigue test already exists such as PTI recommendations [1]. But the tester to investigate large scale cable systems conveniently did not exist so much.
A great deal of research on wind excited cable vaibration is reported in Japan. However, there exist no specifications for the flexural fatigue test at present.
The authors developed a large axial fatigue tester and implemented an axial fatigue test on a large scale cable system, Dywidag stay cable system. For the full scale flexural faitigue test, a test bending angle was assumed and loaded with continuous alternate bending on the system.

2. TEST SPECIMEN

The test specimen was the site assembly type system which was locally manufactured using JIS standard materials throughout. 15.2mm diameter strands were anchored at the wedge plate individually at both ends. The system provides a series of cable capacities up to 28,173KN nominal strength (Pu). Cable tension is transfered to the bearing plate through the ring nut and the shims (Fig.1). To obtain advanced fatigue resistance at the wedge, high strength grout is injected to minimize the fluctuating stresses reaching the wedge portion. Also, to avoid the sencondary bending stresses caused by the repetitive cable bending motions, an elastic damper is provided at the exit of the system. From the series of cable capacity, C61(Pu=15,912KN) cable system for the axial fatigue test and C37(Pu=9,652KN) for the flexural fatigue test were adopted respectively in consideration of the capacity of the cable and its frequency of actual application.

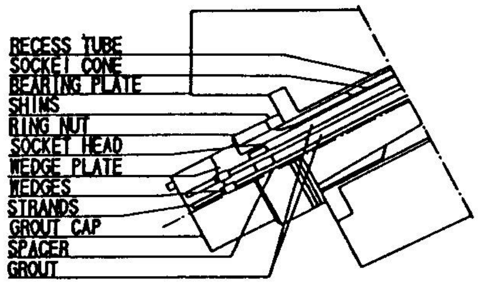

Fig.1 Cable anchorage system

3. AXIAL FATIGUE TEST

3.1 Tester

KASC (Kajima Stay Cable) Tester has the world's largest capacity at present, with a possible static load of 29.4MN and dynamic load of 17.6MN (Fig.2).

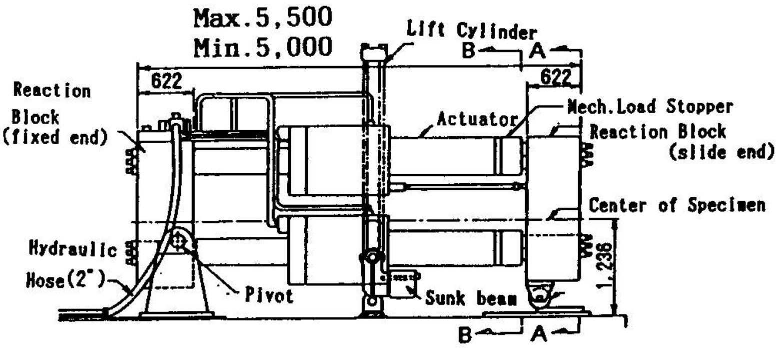

Fig.2 KASC Tester

This tester incorporates a pair of reaction blocks and three electrohydraulic actuators in between, and is designed to fulfill the requirements of the PTI recommendations. The tester can be inclined up to 60 degrees to enable to grout test specimen at the same inclination of actual cables (photo.1).

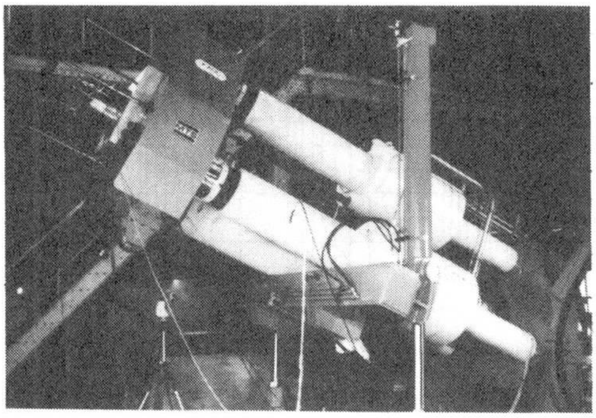

Photo.1 Inclined KASC Tester

Bridge Name	Max.Span	Fluctu.Stress
Shiraya Bridge	125 m	43 N/mm^2
Aomori Bridge	240 m	129 N/mm^2
Yobuko Bridge	250 m	119 N/mm^2
Usui Bridge	111 m	62 N/mm^2
Chichibu Bridge	196 m	104 N/mm^2
Tajiri Bridge	169 m	88 N/mm^2

Table 1 Typical fluctuating stress of P.C.Cable-Stayed bridge

3.2 IMPLEMENTATION AND EVALUATION

The axial fatigue test was implemented according to the PTI recommendations. The tension of the axial fatigue was set to 0.45Pu for the upper load and 160N/mm2 for the amplitude of fluctuating stress. After 2 million cyclic loadings, the load was statically increased to more than 0.95Pu as the PTI. In Japan the upper load is usually 0.40Pu which is 10% less than the PTI [2]. Fluctuating stress level for the test is also adequately safe even compared to stress caused by lane loading that is higher than actual (Table 1). According to the PTI, strand wire breakage after completing the test shall be less than 2% of total number and the system shall be safe at any portion during and after the 0.95Pu static loading.

3.3 PERFORMANCE AND RESULTS

Strand breakage was monitored by the highly sensitive accelerometers. The breakage, however, was not detected because of the meters monitored cracking of grout, too. After 2 million cyclic loadings, the test specimen was loaded statically up to Pu which is higher than PTI requirement of 0.95Pu (Fig.3). Precise inspection was made on every portion of the specimen and it was confirmed that there were no breakages except for metallic frettings and the system fulfills the PTI recommendations.

3.4 SIGNIFICANCE OF THE FULL SCALE TEST

In spite of the single strand has fatigue limit of 196N/mm2 (Fig.4), two serious metallic frettings arose under the fluctuating stress of 160N/mm2. The fretting location was the exit of the wedge plate where the polyethylene spacer is attached. After consideration of every dimension of the wedge plate and the polyethylene spacer, it was found that the cause of these portinal frettings was geometrical touch of strand with wedge plate, and fretting can be prevented with a small modification to the spacer hole diameter. To obtain advanced fatigue resistance high strength

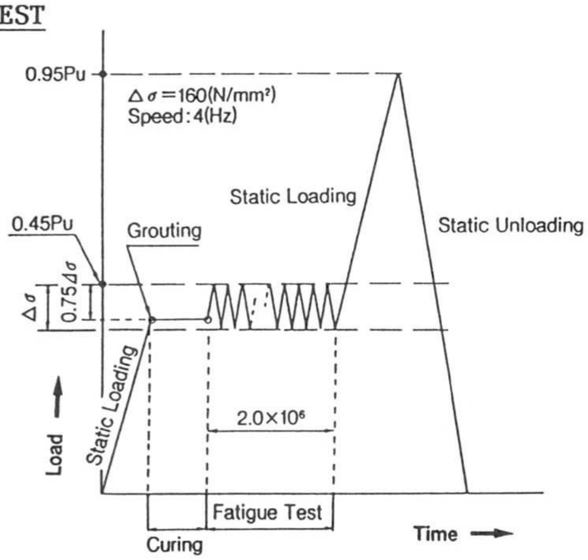

Fig.3 Loading pattern for axial fatigue test

grout is injected into the socket in this system. At the initial stage of cyclic loading, reduction ratio of the transfered fluctuating stress at the wedge was almost 50% and it remained so even after 2 million cycles. Although this bond effect might be affected by the state of the injected grout, for example the existence of air voids inside the anchorage system, it is supposed that the actual stay cables can get same bond effect because of the grouting work of test specimen was performed at nearly actual inclination of 28 degrees with KASC TESTER.

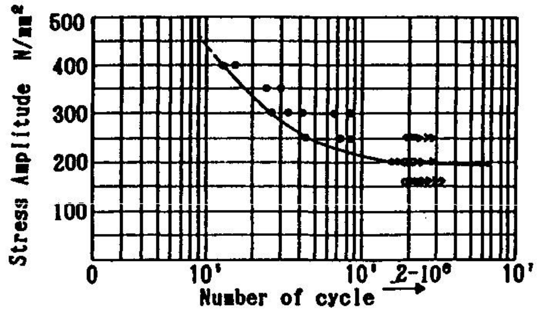

Fig.4 Voehler diagram for single system

4. FLEXURAL FATIGUE TEST

4.1 TEST METHOD

In general, many full scale flexural fatigue tests are performed to obtain an accurate flexural Voehler curve for that specific cable systems [3] and a huge budget is required to complete this. At present, if a certain amount of vibration is induced by wind on the stay cable, it is common practice to provide the cable with damping devices without numerical analysis of fatigue damage degree.

Therefore, in the test at this time it was aimed to investigate the soundness of system under the largest bending angle which can be reached after using general dampers against the possible maximum cable vibrations experienced in practice [4].

C37 cable system had been fixed on the reaction blocks on both sides and the alternate vertical deformation (up and down displacement) was given at the center of the cable (Fig.5). Considering the vibrations during construction period, the primary construction phase was implemented 2 million cycles with an average cable tension of 0.55Pu without the grout injection. After completing the primary construction phase, cable tension was reduced to 0.4Pu by adjusting the shims and subsequently the grout was injected. This completed phase was also continued with the alternating loads until 2 million cycles.

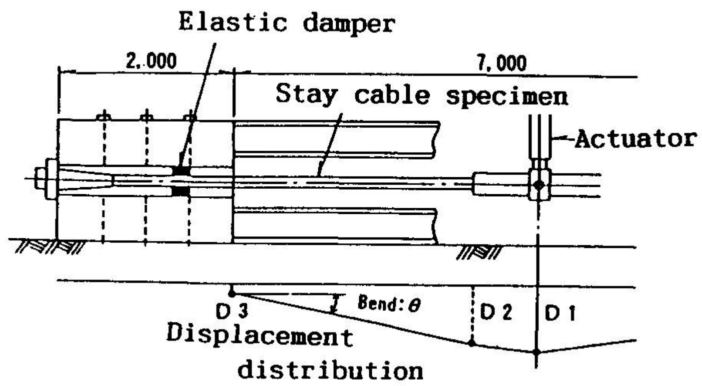

Fig.5 Half drawing of flexural fatigue test

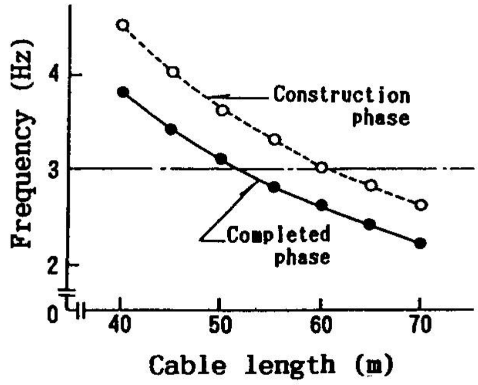

Fig.6 Cable length - frequency relationship

4.2 BENDING ANGLE

The major vibrations of stay cable are rain-vibration and wake-galloping. For large capacity cables, every individual stay is not bundled but is composed with a single stay. If multiple cables are aligned in parallel configuration with small spacing(within 2 ~ 5 times the cable diameter), wake-galloping would be the predominant cause of vibration [5]. Therefore, most of the non-bundled cable exibits rain-vibration, not wake-galloping. According to past site records, rain-vibration is said to be observed on cables whose frequency are less than 3.0 Hz. Preventive devices frequently applied in Japan for cable vibration are high viscous dampers, high energy dissipating rubbers, and diagonal connection ropes between cables. These devices are adopted selectively considering the mode, amplitude, type of vibration, appearance of the structure, etc, but it is reported that highly viscous dampers can reduce the rain-vibration to 0.3D or less in the case of a cable span 200m (where, D is the diameter of the stay cable) [4]. Therefore, for the C37 cable system, rain-vibration is thought to appear when the length exceeds 50 ~ 60m (Fig.6), and the bending angle at the entrance of the anchorage can be reduced to ±0.3D, namely less than ±0.1° when applied the damping device (Fig.7). In the test, considering the uncertainty of the preventive devices, test bending angle was determined to ±0.3° against the primary construction phase and ±0.27° against the subsequent completed phase.

4.3 TEST RESULTS

The specimen was removed from the tester and investigated after 4 million cycles of total loadings for the primary construction phase and the completed phase. Minute compression deformations were observed on the surface of strand wires at the elastic damper location. These compression deformations were apparently due to the mutual contact of the strands. There were no breakages or deformations in any other components. From the strain data, it was found that the strand behaviour was independent during the non-grouted condition and composite with mortar and other strands after the grout was injected (Fig.8). As predicted in the pre-testing analysis, maximum stress appered at the elastic damper location at the completed phase. It was also confirmed that only a little fluctuating stress reached to the end wedges at the completed phase (Fig.9). All strands positioned at the elastic damper, which were exposed to the most severe cyclic bending, were investigated those final static strength. Every strand had

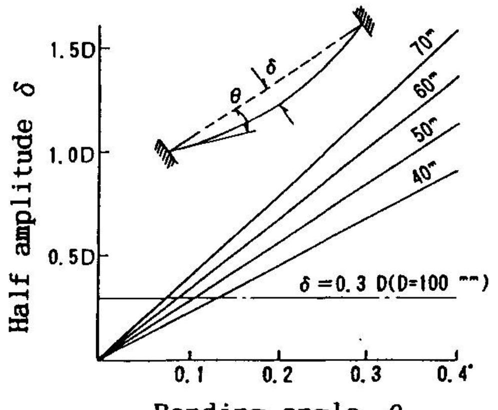

Fig.7 δ − θ relationship

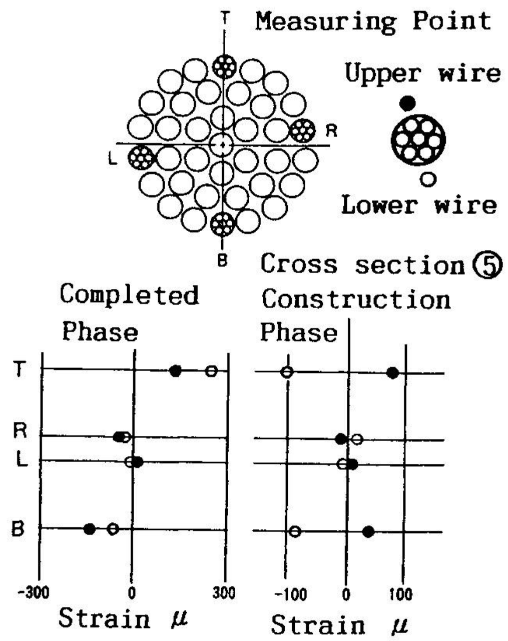

Fig.8 Strain distribution (N=10,000)

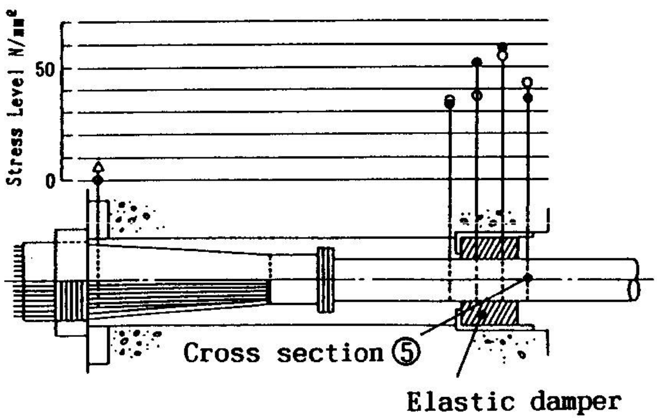

Fig.9 Stress distribution at elastic damper

Nominal Strength	2,550 kN
Max. Tensile Strength	2,610 kN
Min. Tensile Strength	2,560 kN
Average Strength	2,590 kN

Table 2 Tensile strength

retained strength in excess of the nominal strength (Table 2) and ductility was also far above that is required in the standard. Therefore, it could be concluded that this C37 stay cable system was safe for the test bending angle.

5.CONCLUSION

Large capacity stay cable sysytem of site assembly type was examined to find the soundness of the system with respect to axial fatigue and flexural fatigue. Using the world's largest capacity tester, the significance of the full scale test was recognized by the clarifying of the soundness of the individual components of the stay system including the bond effect, and improvement on undesirable factors in the system.
The flexural fatigue test was performed with the assumed bending angle which was introduced based upon the performance of presently existing damping device. Throughout the test, it was found that this stay system was sound and offered an adequate safety with respect to the bending angle.

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