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Long Term Relaxation Characteristics of CFRP Cables

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ABSTRACT:
The highly non-corrosive continuous fiber reinforcing polymer (CFRP) cables are effective to use as prestressed concrete tendons, ground anchors and construction cables. In the maintenance of structures, these special characters are to be utilized to its fullest capacity. Until now, only a few researches on this important characteristic of relaxation and moreover there are no reports on relaxation study under various environment temperatures.
Here, the authors have carried out an experimental study on relaxation of CFRP cables having various carbon fiber strengths and changing ambient temperatures by using the standard method specified by the Japan Society of Civil Engineers (JSCE).
From the results, it was found that regardless of the varying strength and ambient temperature, the relationship showed the straight line nature between relaxation rate and logarithm of passing time. Therefore, the effective and reliable data have been obtained for practical design purpose of structures.

Keywords: CFRP, relaxation, prestressed concrete, ground anchor, tendon

1. INTRODUCTION

The CFRP cables are highly non-corrosive and have a similar strength and modulus of elasticity of prestressed concrete tendons. These CFRP cables can be used as; prestressed concrete tendons, ground anchors and cables for construction in the highly corrosive environment. For the application of CFRP cables, the information on the relaxation characters is necessary. At present, research reports on relaxation characteristics on CFRP are not available. Moreover, study on relaxation with respect to environment temperature on CFRP cables is almost non-existence status.
In this study, 7 wire strand CFRP cables are used to investigate the relaxation for prestressed concrete tendons and ground anchors. The results obtained are verified and investigate its contribution to structural design.

2. TESTING METHOD AND APPARATUS

The 200kN capacity automatic data recording machine for relaxation is used. The outline of relaxation testing machine is shown in Fig.1.The leverage can exert the mechanical advantage of 200 times its capacity on the specimen. To prevent the elongation at the required portion of specimen, device with the signals from extensometer that will activates the transfer spindle and adjust the load. The testing machine is installed in temperature controlled room at 20±2°C. The furnace used has vertical door and electric heating system.

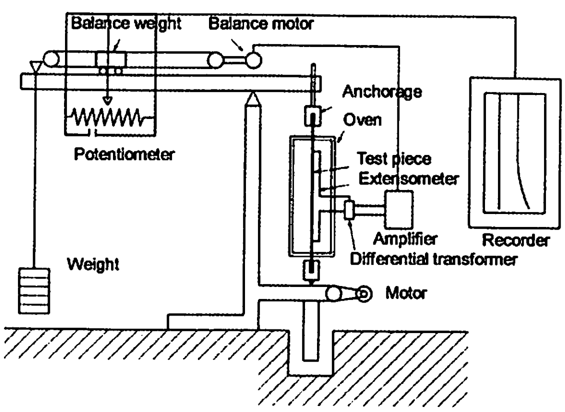

Fig.1 Relaxation testing machine

The testing methods are, JIS G 3536[2] "Steel wires and strands for prestressed concrete" and JIS Z 2276 "Method of tensile stress relaxation test for metallic materials". In 1988, the time required for the relaxation test is 10 hours but according to the revised testing method in 1994, the duration becomes 1000 hours. Therefore, the present tests are carried out with the revised method for CFRP cables and Continuous Fiber Reinforcing Materials (CFRM).

3. RESEARCH AND DEVELOPMENT FOR CFRP CABLES

When CFRP cables are developed in1988, the criteria is necessary to grasp the specific characters to use as prestressed concrete tendons. The JIS G 3536 "Steel wires and strands for prestressed concrete" is used for the relaxation experiment for CFRP cables. The CFRP strand is made of 7 wires and making 12.5mm diameter with the epoxy resin matrix.

For comparison with CFRP cable, a steel strand having 12.4mm diameter and follows with the same test procedures. The experiments are carried out with initial starting loads ranging from 50%, 65% and 80% of the standard tensile strength. The room temperature for experiments is 20±2°C. For 100 hours the load decrement is measured and taken as corresponding relaxation values. The standard load for CFRP cables are made as not to exceed the values taken from the average failure load less three times the standard deviation. Referring to the steam curing of precast members at factories, this relaxation experiment follows the process with maximum temperature of 80±2°C.

In the experiment, the heating system is controlled as follows; starts with nominal temperature for a duration of two hours, and followed by hourly increment rate of 20°C until maximum temperature of 80°C. Under this maximum temperature, the specimen is kept for 10 hours. This is again followed by gradual decrement taking 5 hours and back to nominal temperature. This whole experiment took a total of 50 hours for a single complete cycle. Results of this experiment are shown in Fig.2 and 3. From the results of experiment on CFRP cables, the following basic facts relating to the relaxation became obvious.

(1) The time versus relaxation values of CFRP cables showed linear logarithmic relationship, similar to that of general steel strands.

(2) At the elapsed time of 100 hours, the pure relaxation values are 50~80% range to that of standard initial loading and this is approximately 0.4~1% lesser.

(3) At the high temperature, the relaxation curves of CFRP cables as well as steel tendon showed instantaneous advancement and these results showed higher values compared to nominal temperature thereafter the relaxation stabilized and showed no advancement.

(4) In the 50 hour cycle test, for 10 hours with 80°C, the relaxations are 3~4% at the load range of 50~80% of the standard load. The relaxation is not influence by the corresponding initial load.

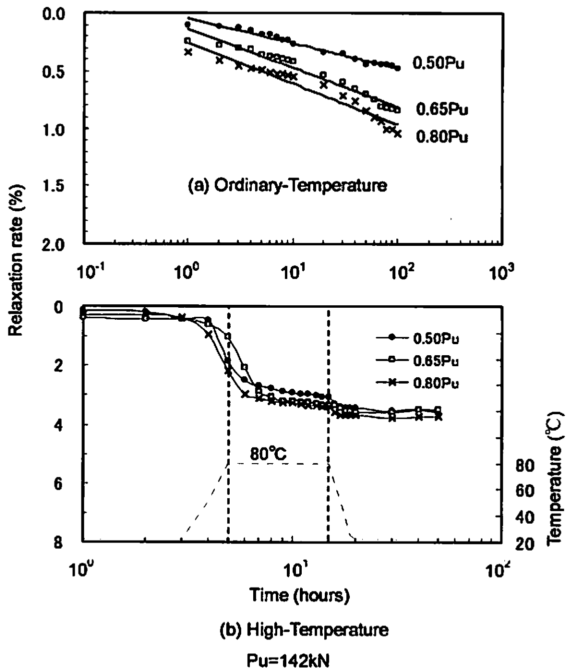

Fig.2 Relaxation curve of CFRP cable

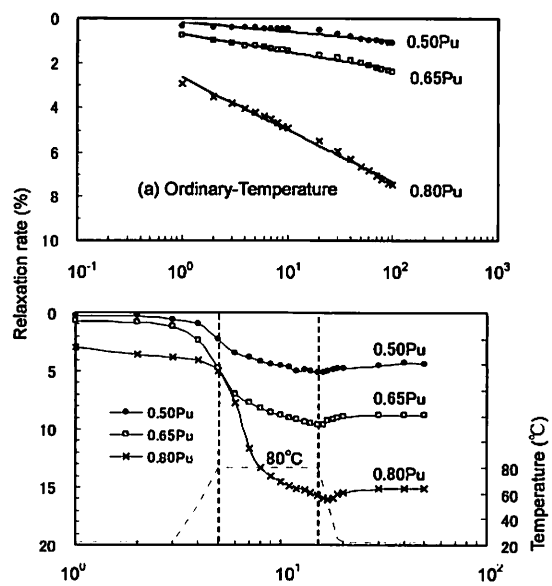

Fig.3 Relaxation curve of Steel strand

4. RELAXATION VALUES DETERMINED BY THE JSCE CRITERIA

In 1996, JSCE proposed a draft specification on "Test method for long-term relaxation of continuous fiber reinforcing materials"[4)5)]. Referring to the data reported in chapter 3, and applying the testing method as explained in chapter 2, along with standard temperature of 20±2°C the experiments are carried out. For the loads, the lesser values are taken from the following two cases.

Case one, the initial load is taken as 70% of the standard load. Case two, creep failure load at one million hours. Also in this experiment, it is assumed that relaxation and passing time has linear logarithmic relationship. Using this assumption with the experimental data at 1000 hours, one can estimate relaxation at one million hour by best fit line. Now with the million hour relaxation value, applications toward design purpose can be promoted.

5. VERIFICATION ON ESTIMATED RELAXATION VALUES AT ONE MILLION HOURS FOR CFRP CABLES

5.1 Specimen and testing conditions

(1) Specimen

The CFRP cable for this experiment is made up of 7 single CFRP wires into strand of 12.5mm with epoxy resin matrix. They are shown in Table.1

(2) Testing condition

The initial load is 70% of the guarantee strength of 99.5 kN. The speed for loading is 200±50 N/mm^2/min. The testing temperature is 20±2°C.

5.2 Three tests for million hour relaxation value

For million-hour relaxation value test were carried out for the three times. The results are shown in Fig.4.The relaxation values for 1000-hour was found to be 1.17%, 1.2% and 1.54% respectively. Fig.4 shows the best fit curve by the method of least squares from the results of all three tests.

$$Y=0.231+0.345\log T \quad (1)$$

Where,

Y is relaxation rate (%)

T is time (hours)

From the equation (1), relaxation at 1 million hour was found to be Y_{1E6} = 2.30 (%).

On the other hand, results are verified with the approximate relationship laid down by "The Research Committee of JSCE on Continuous Fiber Reinforcing Materials".

$$Y=0.200+0.316\log T \quad (2)$$

From the equation (2), relaxation at 1 million hour was found to be Y_{1E6} = 2.10 (%).

Both the results of equation 1 and 2 showed similarity.

5.3 Verification of relaxation values for long term 1-million hour test

The relaxation values at million-hour are determined by the extrapolation of 1000-hour data. There is almost no existing data for test duration longer than 1000-hour. The authors carried out the 33,000-hour test and verify the results with plotting curves. The results are shown in Fig.5. The approximate relationship between duration and relaxation data can be shown as equation (3).

$$Y=0.0558+0.3956\log T \quad (3)$$

Using the equation (3), the relaxation at million-hour is found to be 2.43%. All the curves drawn using equations 1, 2 and 3 have similar slopes. When relaxations at million-hour is calculated using the above equations, they are, 2.30%, 2.10% and 2.43% respectively. The relaxation at million-hour by using the one at 1000-hour and 33,000-hour showed only 0.13~0.33% difference. The apparent relaxation rate of PC tendon is 6.0%[3]. The relaxation values of CFRP cables are found to be lesser than 10% that of PC tendon.

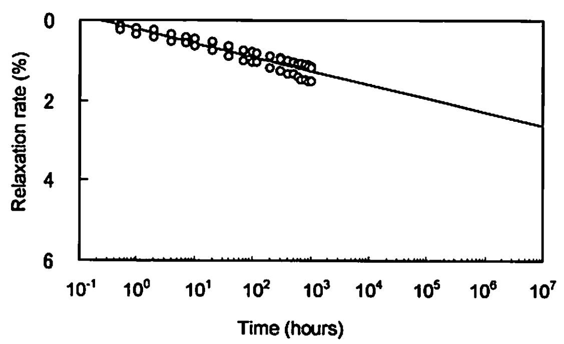

Fig.4 Relaxation curve

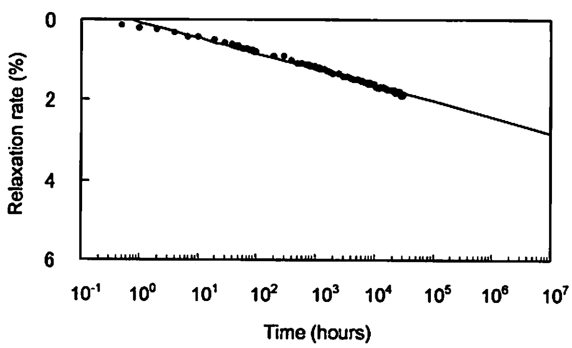

Fig.5 Relaxation curve

6. RELAXATION CHARACTERISTICS AT HIGH TEMPERATURE

The CFRP cables are aimed to use as ground anchor tendons in the severe locations like hot springs and volcanic areas for landslide counter measures. To fulfill there objectives, the experiments for relaxation are carried out at 60, 80 and 100°C environment. The JSCE experimental procedures stated in chapter 4 are used.

6.1 Experiment condition (temperature)

The ambient temperature for the specimen is controlled by the enclosing in high temperature hearth. The following procedure is made to adjust the temperature. From the nominal temperature of 20±2°C to target temperature, a duration of 30 minutes is set. At that temperature, the specimen is kept for an hour and then initial loading took place. During the experiment the temperature fluctuation is kept at ±2°C. The target temperatures for experiments are 60°C, 80°C and 100°C respectively. The experimental data are compared with 20°C data curve.

6.2 Results and considerations

The experimental results are shown in Fig.6.The relaxation values for 1000-hour with three levels of temperature is 1.02%, 1.32% and 1.91% respectively.

at 60°C :

$$Y=0.2618+0.2493\log T \quad (4)$$

at 80°C :

$$Y=0.4660+0.2816\log T \quad (5)$$

at 100°C :

$$Y=0.5954+0.4633\log T \quad (6)$$

Using the above equations, 4, 5 and 6, the relaxation values calculated at million-hour are 1.76%, 2.16% and 3.38% respectively. The relationship between temperature and relaxation is shown in Fig.7. Also in the same figure, the results of relaxation at 20°C are superimposed. The relaxation value for 20°C~80°C at million-hour is within the range of 2%. When the relaxation values of CFRP cables at 100°C are compared with the PC tendon having 6%, there will be problem for practical usage. Above the 80°C the estimated relaxation value may rise up sharply. This case is thought to be the softening of epoxy resin and require further investigations in the future.

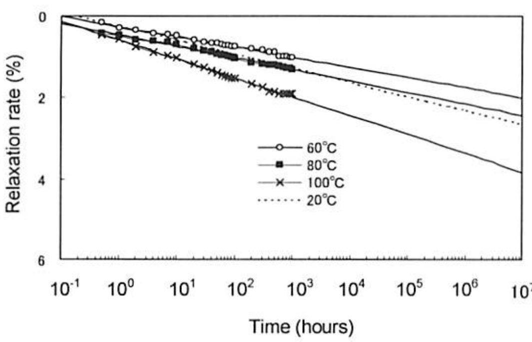

Fig.6 Relaxation curve

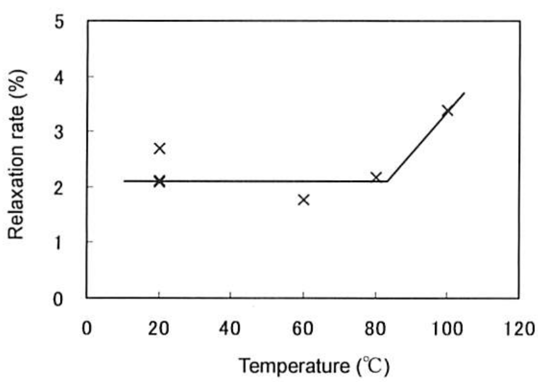

Fig.7 Relationship between temperature and relaxation

7. RELAXATION CHARACTERISTICS OF CFRP CABLES AT VARIOUS MATERIAL STRENGTHS

Recently, the stronger fiber and advanced production technologies have upgraded the tensile failure strength of CFRP cables. The frequency distribution of tensile failure load is shown in Fig.8. From the results, the standard failure loads have risen from 142 kN to 184 kN. The relaxation values and curves are examined with 70% of the failure load as initial loading. The experimental procedure is the same as JSCE standard stated in chapter 4.

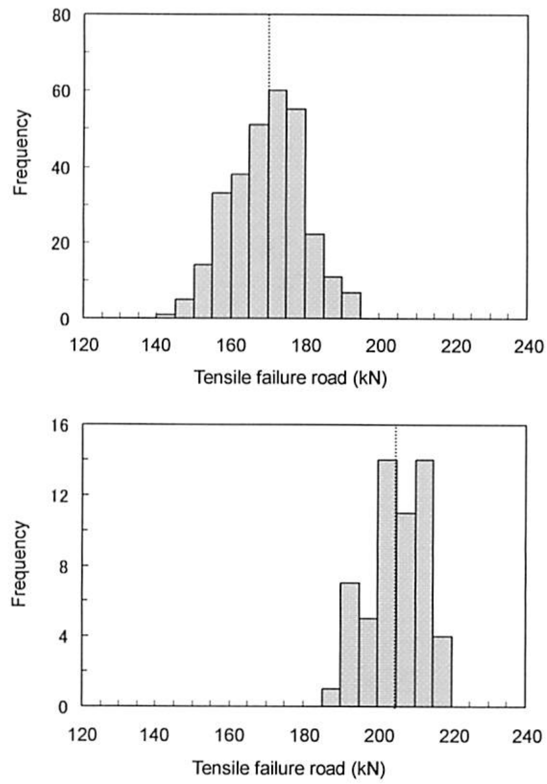

Fig.8 Frequency distribution of tensile failure load

7.1 Material for test (specimen)

The outline of CFRP cables used in this experiment are shown in Table 2. The volumetric contents of carbon fibers in CFRP cables are 70% which is somewhat higher than the previous ones with 65%. The average tensile failure load is 205 kN. The ratio or initial loading weight to actual tensile failure load is 63% which is almost the same with the previous one with 60%.

7.2 Experimental results and considerations

The relaxation curve obtained from this experiment is shown in Fig.9. The approximate line can be shown as the equation (7).

$$Y=0.1367+0.2193\log T \quad (7)$$

Using this equation, the calculated relaxation at million-hour is found to be Y_{1E6} = 1.45 (%). The relaxation value seems to be lesser than previous one. The reason is thought to be addition of 5% of fiber content and strength of individual fibers. The straight line logarithm relationship is observed between relaxation values and passing time. Therefore, the relaxation of 2% obtained at initial load of 70% and million-hour duration in chapter 4, is thought to be non-problematic.

8. CONCLUSIONS

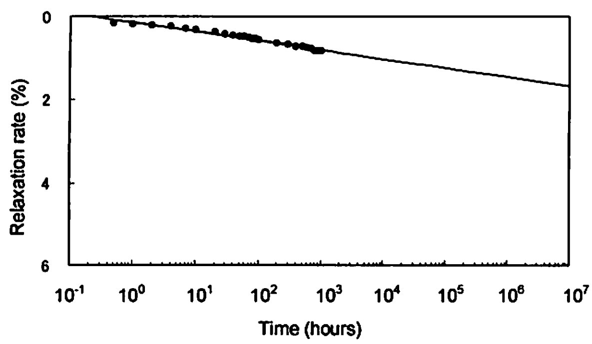

Fig.9 Relaxation curve

(1) The relaxation and logarithm of passing time data of CFRP Cables in nominal temperature showed almost straight line nature. The steel tendons also have the same nature.
(2) The corresponding relaxation data from three test with 1000-hour and one test with million-hour showed no large error.
(3) There is also not much difference in relaxation values for estimated one at million-hour with best fit line of data from 33,000-hour test.
(4) The relaxation values at 20°C~80°C for million-hour test, is around 2% and the differences are quite small. Comparatively the relaxation at 100°C is 3.38% is large, but in the prestressed concrete design using CFRP cables, the approximate relaxation of 6% is on the safe side..
(5) Above the 80°C, the relaxation is estimated as relatively large, therefore it is necessary to investigate furthermore.
(6) The strength of carbon fibers in the CFRP cables becomes stronger and the volume of fiber content also become higher but the relationship between the relaxation and the logarithmic duration is still a straight line. Also at the initial load of 70% of the standard load and with million-hour passing time, the relaxation value is 1.45%. This value is somewhat smaller than the usual value.

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