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NEW PRESTRESSING FORCE MEASUREMENT SYSTEM FOR PRESTRESSED CONCRETE CONTAINMENT VESSELS

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ABSTRACT

In Japanese PWR type nuclear power plants, periodic measurement of prestressing force at tendon anchorages (anchored load) in prestressed concrete containment vessels (PCCV) has been carried out as a part of in-service inspection. In the anchored load measurement, two filler gages are inserted between the shim and the anchorhead at each selected tendon end. Next, the tendon is pulled by the hydraulic jack gradually. When the filler gages are pulled out because of anchorhead movement, the jacking load at the moment (lift-off load) is regarded as anchored load. The measurement work has been required to be carried out more rationally from the viewpoint of time and cost. Considering these present conditions, we developed new prestressing force measuring system using hydraulic type load cells.

KEY WORDS: PCCV, anchored load, lift-off load, in-service inspection

INTRODUCTION

In the nuclear power plants, periodic measurement of prestressing force at tendon anchorages (anchored load) in prestressed concrete containment vessels (PCCV) has been carried out to verify that they have required ability after completion as shown in references [1] to [4].

VSL unbonded prestressing system is used for Ohi power station unit 3, 4. In the anchored load measurement in each periodic inspection, two filler gages (0.3 mm thick, stainless steel) are inserted between the bearing plate and the anchorhead at each selected tendon end by pulling the tendon with a hydraulic jack. Each of the gages is anchorhead-center-symmetrically set on the opposite side from each other. The jack is specially designed for the lift-off work (lift-off jack), and the weight is 1.3 t. Next, the tendon is pulled again by the jack gradually. When the filler gages are pulled out because of anchorhead movement, the jacking load at the moment (lift-off load) is regarded as anchored load. Schematic drawing is shown in Fig. 1.

The measuring work by this method is troublesome, and especially measurement for hoop tendons is outdoor work, therefore the work efficiency is influenced by weather condition. On the other hand, shortening the periodic inspection time of the plants is required at present. The measurement work is also required to be carried out more rationally from the viewpoint of time and cost.

Considering these present conditions, we developed simpler and easier method for the measurement.

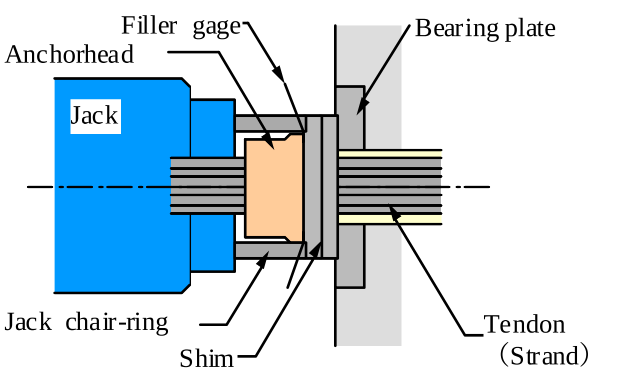

Fig. 1 Lift-off load measurement by filler gage

OUR RESEARCH AND DEVELOPMENT

Our purpose is to develop new measuring method under following conditions.
1) The load cells can be left at the anchor ends during total plant life.
2) The size of the load cell is same as the shims, which can be replaced without detension.
3) The measuring work can be carried out without end cap removal, which is filled with grease.
4) The measuring work can be carried out with only portable devices.
5) The system can keep the same measuring accuracy as existing filler gage method.

We, for our purpose, utilized hydraulic type load cells, which were used for prestressing force measurement of permanent anchors in sloped soil and others.

This measurement system is composed of a hydraulic type load cell (shim-type load cell, hereafter), a hydraulic pump, an amplifying cylinder, and other measuring devices. The load cell is permanently set between the bearing plate and the anchorhead. The amplifying cylinder is used to increase the oil pressure made by portable low pressure pump.

The anchor load is obtained in the manner that the oil pressure is measured at the time the rams of the load cell move.

The measuring work can be rationalized by the system that has the following merits using these devices.

We carried out a series of experiments to verify the applicability and reliability of the system, They are reduced-scale model test and full-scale model test. In the full scale model, not only the simulation work of the measurement, but also long-term measuring test and heating test were executed.

Reduced-scale model test

Prior to full-scale model test, a 1/10 reduced-scale model of the system was made and tested to verify the applicability on the measuring work and to obtain fundamental data.

Following subjects were investigated.

1) Does the system have the same measurement accuracy as existing method?
2) Is there any fundamental problem in the measuring work by the system, for example, work efficiency ?

Full-scale model test

A full-scale model which simulated 10 MN class prestressing anchorage of PCCVs was made, and tested under the equivalent load condition to actual plants.

Following subjects were investigated.

1) Efficiency of replace work of shims and the shim-type load cells without detensioning in existing PCCVs.
2) Reliability and measurement accuracy of the shim-type load cell at actual prestressing level in PCCVs.

REDUCED-SCALE MODEL TEST

Outline of the test

The reduced-scale model of the load cell of which capacity is 1 MN is shown in Fig. 2. The load cell is a ring-shaped block made of chromium molybdenum steel (JIS-G4105) which is divided in two like shims to be installed to the prestressing system without detension. Each part has six oil cells.

The load cell is set between the bearing plate and anchorhead and functions as shims usually does. When the prestressing force is measured, the oil is injected by hydraulic pump and hose into the load cell, and the prestressing force is obtained by measuring the oil pressure in the load cell by a pressure gage. Outline of this system is shown in Fig.3.

The test was carried out using rigid cylindrical steel beam which has bearing plates at both ends (Photo 1). The prestressing force was measured at 300, 600, 800 kN to investigate the influence of the load level on measurement accuracy. The lift-off load measurement using filler gages was also carried out for comparison.

The following items were measured in the test. The projection length of the amplifying cylinder was in proportion to injected oil quantity to the load cell, therefore it can be said that the change of the length shows the change of the oil quantity.

1) Projection length of the amplifying cylinder

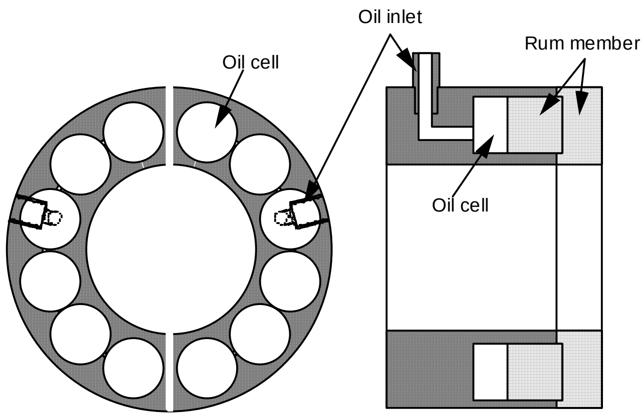

Fig. 2 1 MN class shim-type load cell

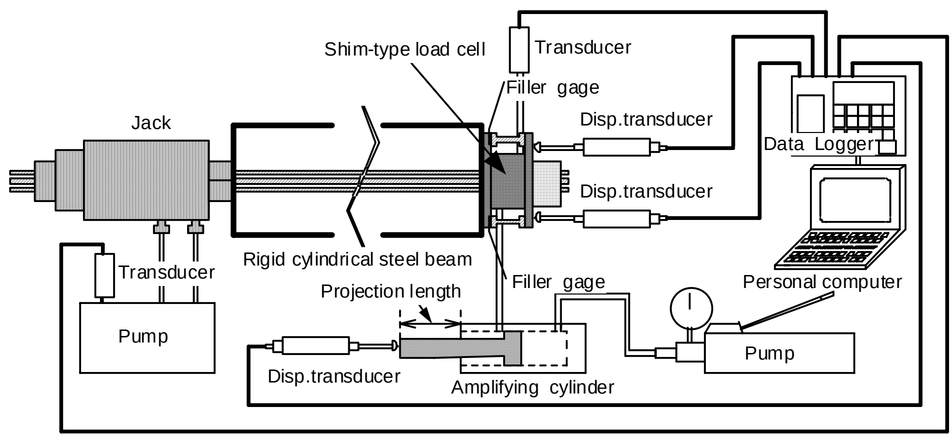

Fig. 3 Outline of measuring system (1 MN class)

2) Uplift displacement of the anchorhead
3) Load value of the load cell
4) Load value of the jack

Test results

The relation between the load cell load and the projection length of the amplifying cylinder is shown in Fig. 4 as an example. The relation between the load cell load and the uplift displacement of the anchorhead and lift-off load obtained by filler gage method are also plotted in the figures.

The projection length increased linearly and gradually up to the first pull out of the filler gage, and after the pull out, the length increased rapidly. The reason is that when the load cell load exceeded the prestressing force, the load cell lifted the anchorhead, and injected oil to the load cell increased rapidly (Fig. 5). The relation between the load and the projection length was not changed at the load level of the pull out of the second gage. This tendency was observed in every load level.

The relation between the load cell load and the uplift displacement of the anchorhead showed similar tendency.

The prestressing force and lift-off load are shown in Table 1 and Table 2. The prestressing force and the average value of the lift-off load (a) and (b) agreed well. The difference was within 2% at maximum.

As shown above, it became obvious that the lift-off load and the change of amplifying cylinder displacement have close relation to each other. Therefore, we concluded that we could obtain accurate value of lift-off load by the system instead of existing filler gage method.

We tried calculating the accurate anchored load by the following two evaluation methods (Fig. 6).

CASE 1: The correlation coefficient of the load cell load and the projection length are calculated successively from initial load level to increasing load level. When the correlation coefficient falls below 0.99, the load is defined as anchored load.

CASE 2: The correlation coefficient of the load cell load and the projection length are calculated successively from initial load level to increasing load level. The data in which the correlation coefficient exceeds 0.99 is defined as first inclination data. Similarly the coefficient is calculated successively from last load level to decreasing load level. The data in which the correlation coefficient exceeds 0.99 is defined as second inclination data. Two lines are calculated by least squares method using first and second inclination data. The anchored load is defined as a crossing point of the lines.

The obtained loads by the two methods and prestressing forces are also shown in Table 1 and Table 2. The difference between prestressing force and evaluated load is approximately 2% at maximum at each load level by Case 2 method.

By the reduced-scaled model test,

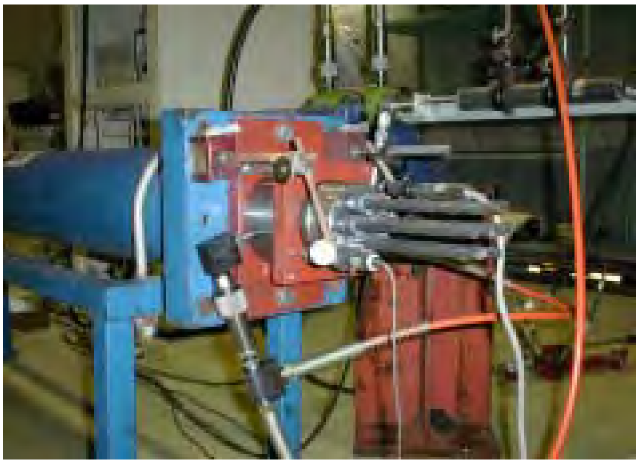

Photo 1 Reduced-scale model test

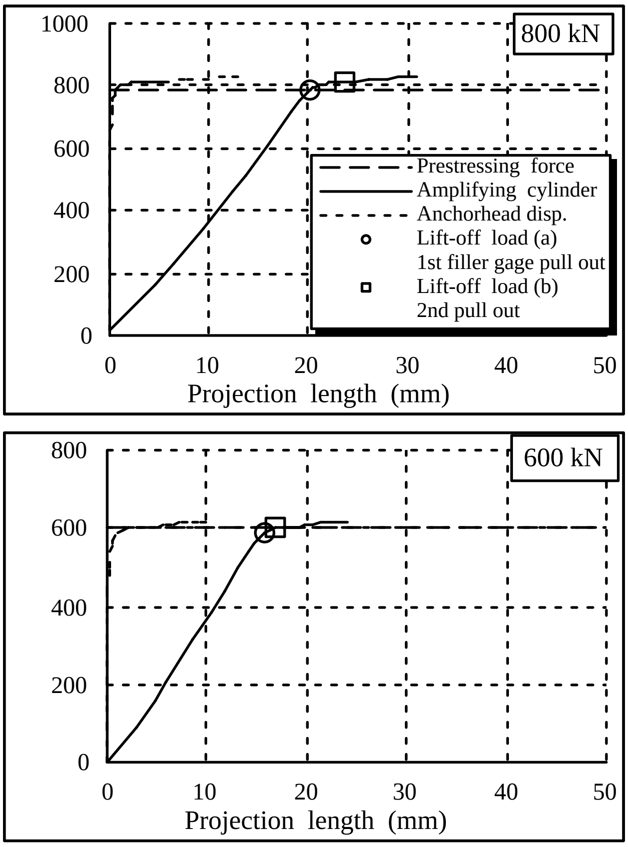

Fig. 4 The relation between the load cell load and the projection length of the amplifying cylinder

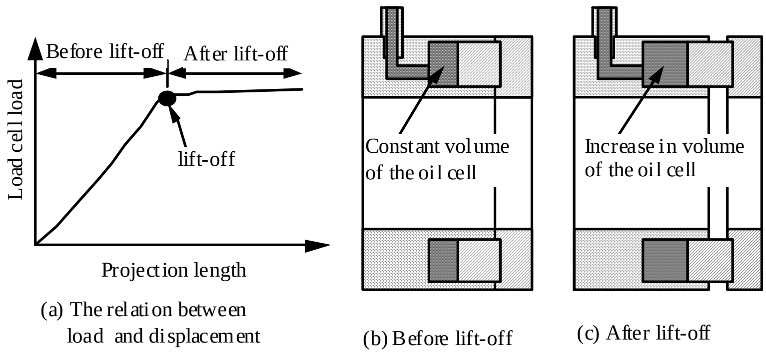

Fig.5 Change of injected oil quantity caused by load cell ram movement

following items were verified.

1) The anchored load can be measured by this system with the same accuracy as filler gage method.
2) There are no fundamental problems in setting the load cell to the anchor end.

It was recognized that further research on the following subjects was needed to utilize the system for existing PCCVs.f

1) Verification of reliability and measuring accuracy in long term.
2) Verification of replacing procedure of the load cell at full scale anchor end.

FULL-SCALE MODEL TEST

Outline of the test

The 10 MN type load cell is shown in Photo 2. The load cell has just the same size and configuration as shims in existing PCCV, because we plan to set the load cells between the bearing plates and the anchorheads by replacing the shims which were set in existing PCCVs. The load cell consists of two parts as 1 MN shim–type load cell does. Each part has seven oil cells. The material of the load cell is nickel chromium molybdenum steel (JIS-G4103).

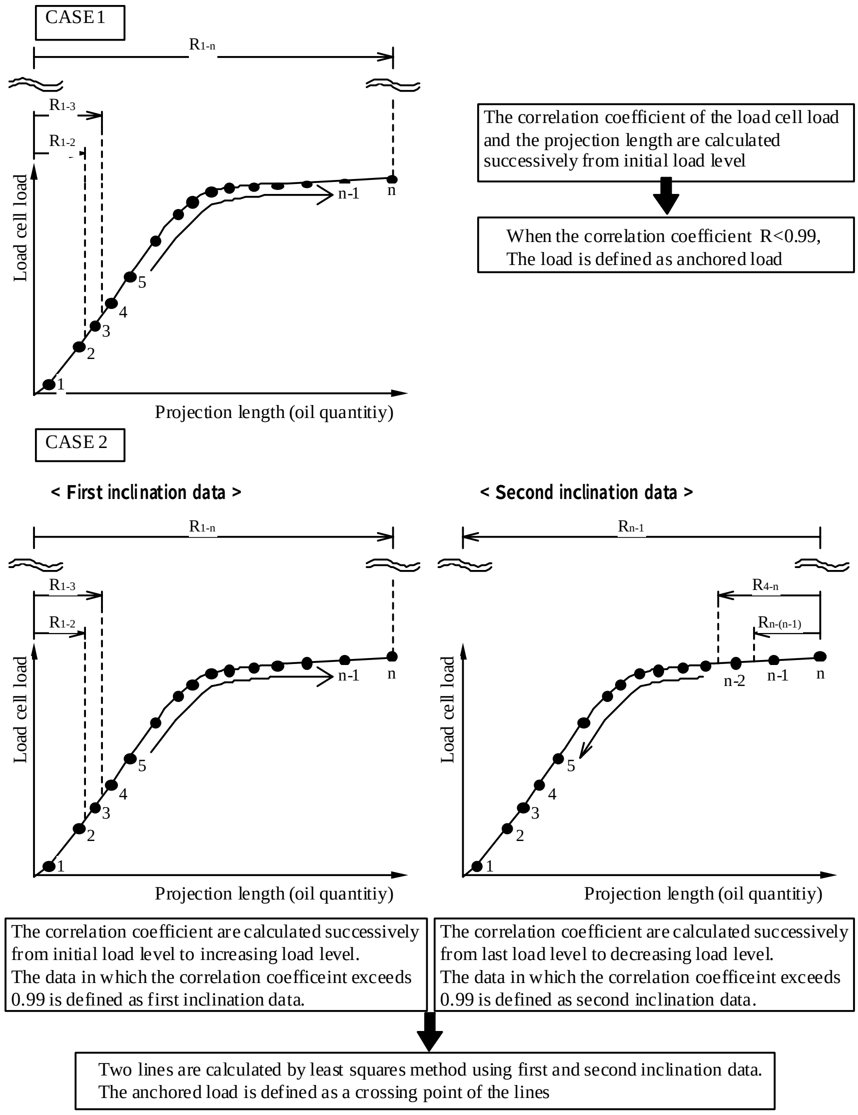

Fig.6 Evaluation method of anchored load

VSL system 10 MN class tendon anchorage was modeled in concrete block (W:1.1 m, H:1.1 m, L:1.6 m). 10 MN shim-type load cell was set at the end (Fig. 7).

We carried out prestressing force measuring test to measure the change of the load cell load and injected oil quantity to set up more rational measuring method of the anchored load. The lift-off load measurement by filler gage method is also carried out to compare the system with existing measuring method. The measuring system in the test is basically same as that of the reduced-scale model test shown in Fig. 3.

We also executed long term verification test to investigate the influence of weather condition and time dependent factor on the reliability and measuring accuracy of the system. In the test, the force measurement was carried out approximately every three months during one year. In each measurement, the force was

Table 1. List of test results (800kN)

	Prestressing force A (kN)	Lift-off load ave.of(a),(b) B (kN)	B／A	Evaluated load CASE 1 C (kN)	Evaluated load CASE 2 D (kN)	C／A	D／A
No.1	760	757	1.00	779	762	1.03	1.00
No.2	760	763	1.00	780	766	1.03	1.01
No.3	787	795	1.01	808	794	1.03	1.01
No.4	785	799	1.02	812	798	1.03	1.02
No.5	787	784	1.00	807	797	1.03	1.01

Table 2. List of test results (600kN)

	Prestressing force A (kN)	Lift-off load ave.of(a),(b) B (kN)	B／A	Evaluated load CASE 1 C (kN)	Evaluated load CASE 2 D (kN)	C／A	D／A
No.1	594	588	0.99	605	593	1.02	1.00
No.2	594	592	1.00	602	589	1.01	0.99
No.3	594	592	1.00	598	589	1.01	0.99
No.4	595	591	0.99	607	591	1.02	0.99
No.5	600	591	0.98	603	598	1.01	1.00

measured in the morning, daytime, and evening when temperature and humidity were different. The test model was left in the condition that the load cell was subjected to prestressing force (6.5 MN) during the test period. The lift-off load measurement by filler gage method was also conducted to observe the anchored load.

In existing PCCVs, tendon anchorages are covered with end caps filled with grease for corrosion prevention, and the load cells are subjected to the temperature of 90℃ at maximum when the hot grease is injected into end caps. Therefore, the reliability of the load cell was also verified under high temperature condition. After completing the long term verification test, the load cell was heated in an oil bowl up to 90℃. The influence of the heat on the reliability of the lad cell was investigated in the manner that the calibration coefficient was compared before and after heating.

Photo 2. 10MN class shim-type load cell

The anchor end load measurement by the load cell is carried out in the manner that the load is judged by the change of injected oil quantity to the load cell instead of filler gage pull out.

In existing lift-off load measurement, lift-off jack pulls tendons by its oil pressure. This basic mechanism,

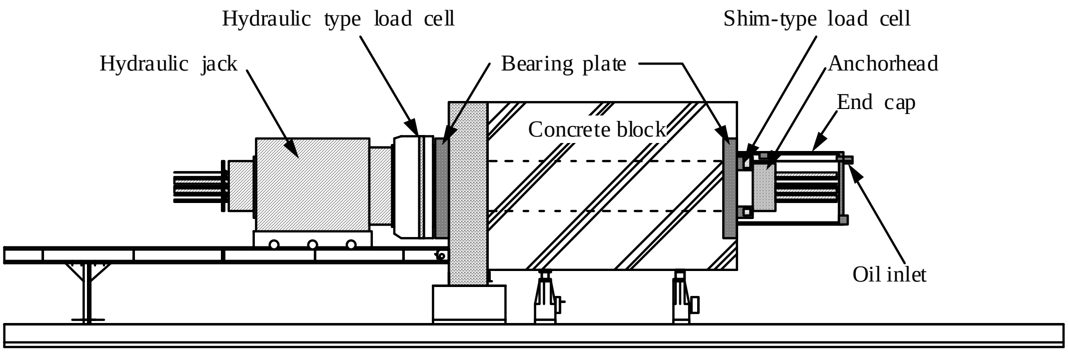

Fig.7 Full-scale model test

tensioning of tendons by oil pressure, is similar to the mechanism of the load cell that we are developing. Then we supposed that change of injected oil quantity at lift-off load level can be observed in the lift-off jack also. We tried to observe this behavior in the in-service inspection in existing PCCV, Ohi unit No. 3, in September 2001.

Test results

Following two kinds of measurement were carried out in the prestressing force measuring test.

1) Test 1: Lift-off load measurement by the filler gage method. Applied load is 6.5 MN.
2) Test 2: Load measurement by the load cell. Applied load is 5.5 MN, 6.5 MN, and 7.3 MN

The test results are shown in Table 3 and Table 4.

The measured load by filler gage method showed 4% error at maximum to the anchored load in TEST 1.

The obtained loads by the load cell showed 2% and 4% error at maximum by CASE 1 and CASE 2 respectively. It was verified that CASE 1 was more accurate method comparing with CASE 2.

The time dependent behavior of the measured loads by the shim-type load cell obtained by the long

Table 3. Test results of the Test1

	Prestressing force A (MN)	Load (a) *1 (MN)	Load (a) *2 (MN)	Ave. of (a), (b) B (MN)	B／A
No.1	6.50	6.23	6.36	6.30	0.97
No.2	6.52	6.25	6.34	6.30	0.97
No.3	6.53	6.23	6.35	6.29	0.96

＊1 ：first filler gage pull out
＊2 ：second filler gage pull out

Table 4. Test results of the Test2

		Prestressing force A (MN)	Evaluated load CASE 1 B (MN)	Evaluated load CASE 2 C (MN)	B／A	C／A
5.5 MN	No.1	5.52	5.62	5.73	1.02	1.04
	No.2	5.55	5.53	5.72	1.00	1.03
	No.3	5.58	5.68	5.79	1.02	1.04
6.5 MN	No.1	6.42	6.56	6.64	1.02	1.03
	No.2	6.37	6.42	6.59	1.01	1.03
	No.3	6.38	6.40	6.62	1.00	1.04
7.3 MN	No.1	7.34	7.40	7.37	1.01	1.00
	No.2	7.38	7.22	7.33	0.98	0.99
	No.3	7.38	7.21	7.56	0.98	1.02

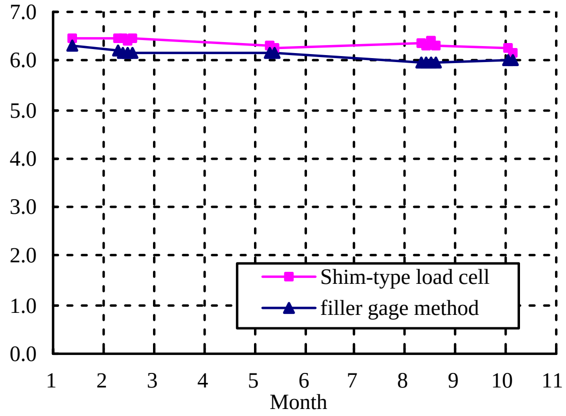

Fig.8 Long term verification test

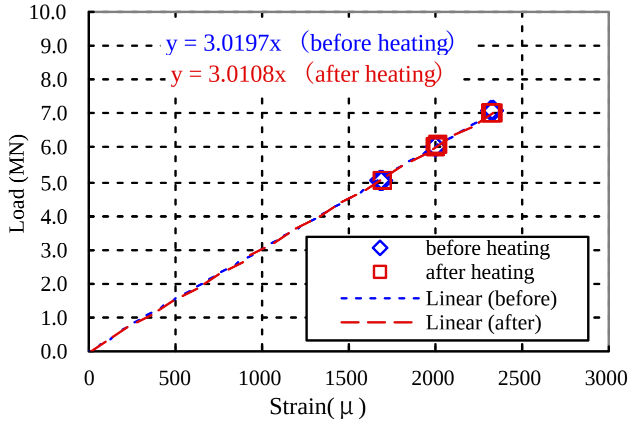

Fig.9 The comparison of the coefficient before and after heating

term verification test are shown in Fig.8 comparing with the load by the filler gage method.

The measured anchored loads by both methods showed kept approximately same deference during long term, and it was verified that they were not affected by temperature and humidity.

The comparison of the calibration coefficient before and after heating is sown in Fig.9. The coefficient was 3.020 before heating, and 3.011 after heating. The difference was only 0.3%. It showed that the reliability of the load cell was not influenced by 90℃ heating.

The relation between the lift-off jack load and the injected oil quantity to the jack expressed by projection length of the cylinder obtained in ISI of Ohi unit 3 PCCV is shown in Fig. 10 as an example.

The anchored load was judged by Case 2 method.

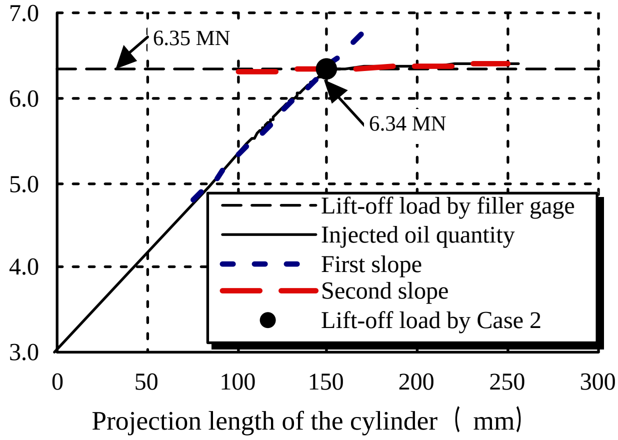

Fig.10 The relation between the lift-off jack load and the injected oil quantity to the jack

The difference between lift-off load by the filler gage method and evaluated load by this method was 1.2% at maximum, and it was verified that the measurement work could be carried out with no technical problems.

CONCLUSION S

The conclusions obtained by the reduced-scale model test and the full-scale model test are as follows:

(1) There are no fundamental technical problems in applying the system we propose here as a measuring system of anchored force measurement of PCCV tendons.

(2) Lift-off load and the change of projection length of the amplifying cylinder which express the change of injected oil quantity to the load cell show close relation to each other.

(3) The difference between anchored load and evaluated load by our method is within 2% in the full-scale model test by Case 1 method.

(4) The shim-type load cell can keep its reliability after 90℃ heating.

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