A Delayed Phenomena Evaluation of Prestressed Concrete Containment Vessel at Tsuruga Unit No.2 Power Station

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ABSTRACT

The structural integrity test (SIT) of the prestressed concrete containment vessel(PCCV) of Tsuruga Unit No.2 Power Station was carried out in February 1986. Since then strain measurements and the lift-off test to investigate reduction in tensile force of tendons, as an in-service inspections (ISI) of the PCCV, have been made periodically.

This paper summarizes the results of analysis of data on changes in strains of concrete and tensile forces of the tendons used, in connection with the long-term behavior of the PCCV. Measured values of strain changes due to creep and shrinkage of concrete agreed comparatively well with calculated ones. The tensile force reductions of tendons obtained in the lift-off tests also corresponded to the calculated values.

As a result of the above, it was ascertained that the long-term behavior of the PCCV agrees more or less with the one predicted at the design stage.

1. INTRODUCTION

The prestressed concrete containment vessel (PCCV) of Tsuruga Unit No.2 Power Station is made up of hemispherical dome, cylindrical wall with three-buttresses, and unbonded tendon system. Fig. 1 gives its cross-sectional view and outline of the arrangement of tendons.

A number of sensors, such as strain gauges put on reinforcing bars and thermometers, are embeded in this PCCV (as shown in Figs. 1-(1) and 1-(2), these sensors being installed at typical locations consisting of 10 vertical sections and 12 horizontal sections). These sensors were used in the structural integrity test (SIT) [1], and have been used effectively for the strain measurements for this study.

Figs.1-(3) and 1-(4) show the arrangement of the inverted-U-shaped tendons, cylinder hoop tendons and dome hoop tendons, and the numbers assigned to these tendons. Construction and test process of the PCCV were as follows :

(1) Placement of cylinder base concrete : July 1983
(2) Placement of dome's spring line concrete :May 1984
(3) Placement of dome top concrete : June 1985
(4) Commencement of tendon tensioning : October 1985
(5) Completion of tendon tensioning : January 1986
(6) SIT : February 1986
(7) First lift-off test of ISI : December 1987
(8) Seond lift-off test of ISI : September 1990

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2. EVALUATION METHOD OF LONG-TERM BEHAVIOR OF THE PCCV

Because a sufficient amount of the strain measurement data have been accumulated after SIT was commenced, properties of the long-term behavior of concrete strains measured after the SIT were evaluated. Thermal strains due to temperature variation within the cross sections were calculated from measured temperature data and subtracted accordingly from the measured strains.

Effective age t ($=\sum[(T_i + 10)\cdot\Delta t_i] / 30$; T_i = atmosphere temperature ℃ , Δt_i =days under T_i , and $\sum\Delta t_i$ = age of concrete), creep and shrinkage strains of concrete can be calculated by the method [2)] used at the design stage.

Changes in tensile forces of the tendons could be evaluated here as follows. The measured values of the tensile force reductions obtained from the lift-off tests include the elastic losses due to elastic shortening of the structure. These elastic losses may greatly affect the evaluation of some tendon reduction forces. In evaluating the elastic loss, therefore, the simplified method used at the design stage was not adopted. Instead, a detalied analysis using the finite element method (FEM) was carried out, and its results were used for evalution of elastic loss this time.

In the FEM analysis, the entire structure of the PCCV was modelled, and tendons placed in the structure were also modelled as precisely as possible.

Factors affecting the tensile force reduction of the tendons include losses due to the relaxation of the tendons, creep and shrinkage of concrete, as well as the elastic losses. These factors were evaluated in accordance with the standard criteria described in the JSCE Standard Specifications [2)] .

3. RESULTS OF STRAIN MEASUREMENT

Fig. 2 shows measured strains at the typical sections. The measured values shown in the figure, where t is the effective age and ε ($\times 10^{-6}$) is the strain, are compared with calculated ones. In the creep and shrinkage calculation, temperatures before the tensioning of the tendons and thereafter were assumed to be 20℃ and 25 ℃ , respectively, and relative humidity was assumed to be 70%.

As shown in this figure, the measured and calculated values indicated relatively good agreement, both qualitatively and quantitatively. Changes in strains of the dome were about 200 μ at the effective age of 2,400 days. Changes in the circumferential and longitudinal strains in the 3H section of the cylindrical wall were about 200μ and 100μ , respectively. The strains showed a tendency to fall in summer and rise in winter. This is considered to have something to do with seasonal changes in the shrinkage of concrete.

4. RESULTS OF THE LIFT-OFF TESTS OF TENDONS

Table 1 summarizes results of the lift-off tests of the tendons during the first and second ISIs.

As shown in the table, the maximum value of reduction force, ΔT, in the tendons was 62 tons (H37 tendon), which accounted for about 9% of lock-off load T_0 (initial tensile force). Comparison of the results of the first and second tests reveals that the latter tend to show smaller decreases than the former do. It is thought that the tendency observed in the measured strains appeared in the results of the lift-off tests, too, because the first and second tests were conducted in winter and summer, respectively.

Let us consider the correspondence between the results of the lift-off tests and those of the strain measurement. In considering the correspondence between these results, it is necessary to standardize individual conditions. That is, the amount of change in the tensile force of a tendon includes the elastic loss ΔF_1, the relaxation loss ΔF_2 and the losses $\Delta F_3{}^*$ and ΔF_3 due to the strains of creep and shrinkage before and after SIT, respectively. On the other hand, the change in the measured strain consist of the strain due to the creep and shrinkage after SIT, corresponding to the loss ΔF_3. Therefore, these values of ΔF_1, ΔF_2, $\Delta F_3{}^*$ and ΔF_3 were calculated individually. Results concerning the typical tendons could then, be examined.

As shown in Table 2, hoop tendons in the dome (H141, H161) and hoop tendons in the middle section of the cylinder (H37, H102, H119) were examined. Reduction force ΔT_i in these tendons was compared with $\sum \Delta F_i$, which is the sum of totalized values of the calculated losses and the values of ΔF_3 converted from the measured strains. The ratios of ⑧／① as shown in Table 2 were within the range of 0.76～ 0.86, showing good agreement. The good agreement between the measured and calculated strains indicates that those calculated values are reliable to some extent. Hence, it can be thought that decrease in the tensile forces of the tendons also correspond so much with increase of the measured strains.

5. DISCUSSION

The values obtained from both the strain measurement and the lift-off tests agreed relatively well with their calculated values, approximating the predicted results.

It can be expected, therefore, that changes in the prestresses of PCCV can be evaluated with considerable accuracy.

Judging from the results of the lift-off tests and the strain measurement, it can be said that the reduction in the prestress is, at most, 9% or so, and that the PCCV of Tsuruga Unit No.2 Power Station well satisfies its prestress requirements.

6. CONCLUSION

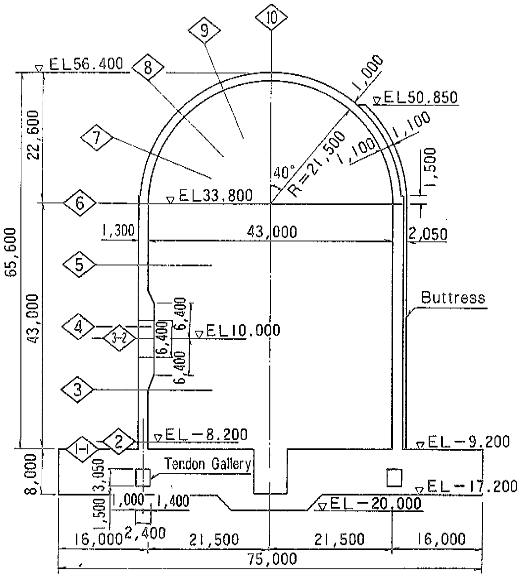
(1)Measured values of strain, although corresponding loads were not obtained directly, seem to be useful in the evaluation of residual prestress.

(2)The results of the lift-off tests showed relatively good agreement with the measured strains. Therefore, the lift-off tests are useful, in roughly evaluating prestressing loads.

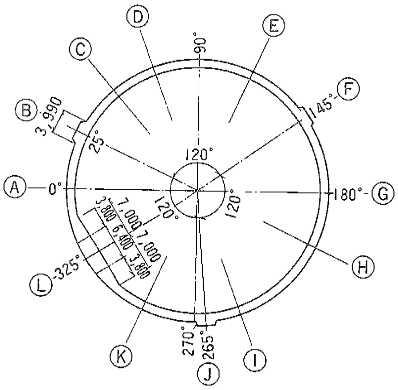
REFERENCES

1)Tamura, S., Nagata, K., Takeda, T., Yamaguchi, T., and Nakayama, T. (1987). Structural Integrity Test of Prestressed Concrete Containment Vessel for Tsuruga Unit No.2 Nuclear Power Station, Transactions of the 9th SMiRT, Vol.J, pp.135-140.

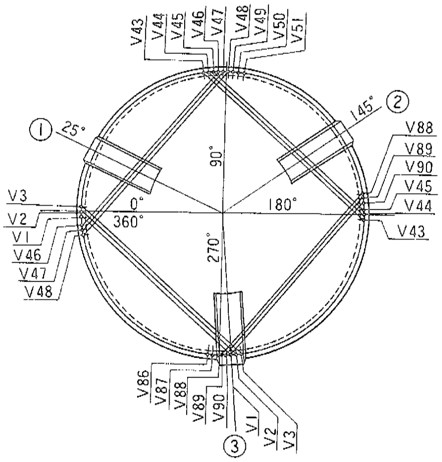
2)Japan Society of Civil Engineers (1978). Standard Specification for Prestressed Concrete, pp.16-24.



(1) Vertical Section



(2) Horizontal Section



(3) Arrangement of Inverted U Tendons

(4) Arrangement of Hoop Tendons

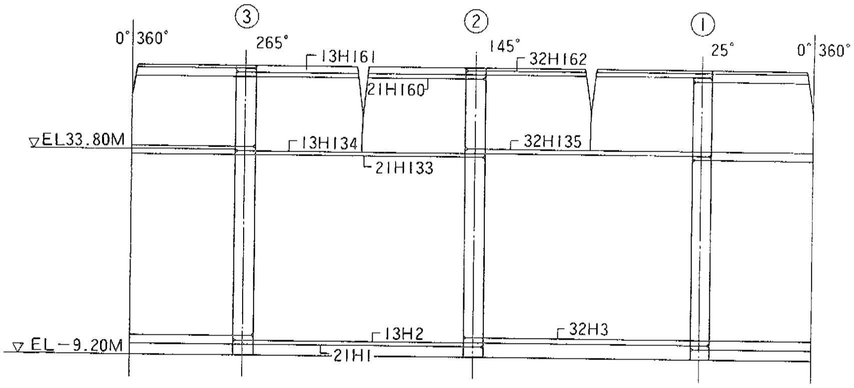


Fig. 1. Out-line of PCCV at Tsuruga No. 2 Power Station

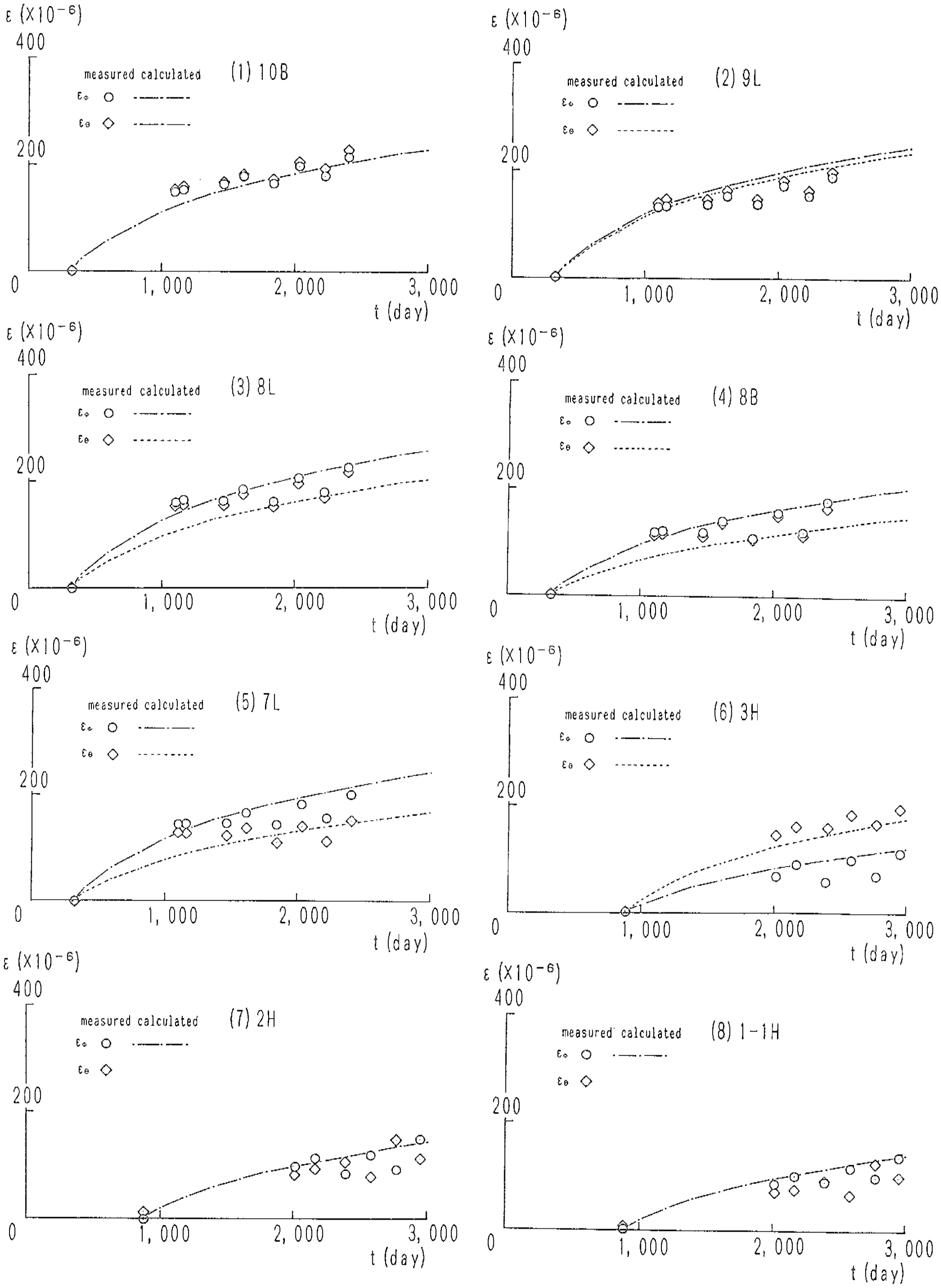


Fig. 2 Comparison with Measured and Calculated Results of Concrete Strains

Table 1. Lift-off Test Results of Tendons

	Tendon No.		ISI No.1			ISI No.2			Tendon No.		ISI No.1			ISI No.2	
			To(t)	T_1(t)	ΔT_1	T_2(t)	ΔT_2				To(t)	T_1(t)	ΔT_1	T_2(t)	ΔT_2
Dome Hoop	H161	S	701	621	60.0	–	–	Cylinder	H25	S	699	643	44.5	–	–
		F	680	640		–				F	698	665		–	
	H150	S	683	–	–	647	48.5		H5	S	685	623	37.5	–	–
		F	675	–		614				F	696	683		–	
	H141	S	698	652	47.5	657	47.0	Inverted U Tendons	V85	S	688	648	30.0	–	–
		F	695	646		642				F	698	678		–	
	H119	S	698	610	56.5	–	–		V82	S	679	–	–	662	13.0
		F	686	661		–				F	700	–		691	
Cylinder Hoop	H115	S	687	–	–	626	45.0		V63	S	697	–	–	689	5.0
		F	684	–		655				F	675	–		673	
	H102	S	701	651	54.5	648	52.5		V56	S	678	623	29.0	–	–
		F	676	617		624				F	698	686		–	
	H58	S	677	631	38.5	–	–		V31	S	686	–	–	661	33.5
		F	687	656		–				F	690	–		648	
	H44	S	687	–	–	606	58.5		V23	S	685	653	30.5	657	28.5
		F	690	–		656				F	697	668		668	
	H37	S	680	617	62.0	615	57.0		V16	S	692	666	32.0	–	–
		F	698	637		649				F	682	644		–	

To : Lock-off T_1 : Lift-off $\Delta Ti = (To-Ti)_{av.}$

Table 2. Tendon Reduction Forces

Tendon No.		measured			calculated					⑧ / ①	⑦ / ③
		① ΔT_1	②[*1] $\Delta \varepsilon$	③ ΔF_3	④ ΔF_1	⑤ ΔF_2	⑥ * ΔF_3	⑦ ΔF_3	⑧ $\Sigma \Delta F_1$		
Dome	H161	60.0	131	16.4	14.0	8.0	9.3	16.9	48.2	0.80	1.03
	H141	47.5	131	16.4	5.7	8.0	9.3	16.9	40.0	0.84	1.03
Cylinder	H119	56.5	125	15.7	10.9	8.3	12.0	15.2	46.4	0.83	0.97
	H102	54.5	125	15.7	6.1	8.3	12.0	15.2	41.6	0.76	0.97
	H 37	62.0	125	15.7	17.7	8.3	12.0	15.2	53.2	0.86	0.97

[*1.)] mean values of measured strain
(8B, 8H, 8L, 7L & 3H, 3L)