Inservice Inspection Forces Measured in Retensioned Tendons

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ABSTRACT

Predicted tendon forces are compared with those measured at lift-off for a group of sample tendons in the R. E. Ginna containment structure. Most of the tendons in the containment had been retensioned approximately 11 years after their original stressing, and the sample tendon forces were measured approximately three (3) years after the retensioning. In calculating the losses to arrive at the predicted forces, it was necessary to account for the effect of retensioning on the stress relaxation property of the tendon wires. A prediction technique was developed using relaxation test data from wire samples that were retensioned after they had relaxed for specified time periods. The agreement between measured and predicted tendon forces was good.

1.0 INTRODUCTION

The R. E. Ginna containment structure is post tensioned by 160 vertical tendons. The tendons were originally stressed in March and April 1969, and lift-off tests were performed on six occasions subsequent to this date over a period of 11 years. From these tests, it was found that the measure tendon lift-off forces were generally lower than the predicted values. Also, the average force of the tendons was marginally above the design requirement of 636 kips. As a result, Gilbert/Commonwealth, Inc. was requested to investigate the possible causes for the lower-than-predicted tendon forces. Reference 1 summarizes this investigation, from which it was concluded that a larger-than-expected stress relaxation of the tendon wires was the cause of the lower-than-predicted tendon forces.

In June 1980, nominally 100,000 hrs. after the original stressing in 1969, the force in 137 of the 160 tendons was restored to 70% of the Ultimate Tensile Strength (UTS) by installing additional shims beneath the anchorhead. The remaining 23 tendons had been retensioned in May 1969, approximately 1,000 hrs. after their original stressing. As a result of the retensioning at 1,000 hrs., the stress relaxation of the 23 tendons was lowered, and the forces in the tendons were found to be acceptable. Therefore, another retensioning was not needed for these 23 tendons.

For future tendon force loss calculations, it was necessary to account for the effect of retensioning on the stress relaxation property of the tendon wires. Using the virgin

(Base) stress relaxation property of a tendon wire to predict stress relaxation loss leads to an over-estimation of the stress loss for tendons that have been retensioned. As a result, the force predicted for the tendon based on this loss will be artifically low, which is unconservative for purposes of comparison with tendon forces measured at future scheduled inspections.

In an effort to obtain the retensioned stress relaxation property, a method of applying superposition principles to the Base stress relaxation property curve (Stress Relaxation versus Time) was developed in Reference 1. However, this approach underestimated the amount of stress relaxation that the retensioned wires experienced. Therefore, the need for a more accurate representation of the retensioned stress relaxation property prompted a direct use of long-term retensioned wire test data, which is described below.

2.0 STRESS RELAXATION PROPERTIES OF RETENSIONED WIRES

2.1 Test Conditions

Each tendon has 90, 1/4 inch diameter wires, plus an extra wire, 115 ft. long, which was originally left unstressed. Three of these extra wires were pulled from tendons and shipped to the Fritz Engineering Laboratory at Lehigh University. These wires were cut into 16 ft. and 21 ft. lengths for the stress relaxation tests. The wires were tested in environmental chambers at 68° F and 104° F and maintained at constant strain over a 10 ft. gage length. The force in each wire was measured at specified time intervals using a 20 kip BLA load cell.

Seven retensioned wire specimens were tested. Each specimen was initially stressed to 0.70 UTS and allowed to relax for a specified duration. During this time, forces were measured periodically. Then the force in the wire was increased back to 0.70 UTS (retensioned) and force measurements were continued. Table I indicates the test condition for each specimen, including the duration of the initial relaxation (Time at Retensioning) and the duration that the wire specimen was allowed to relax after it was retensioned (Retensioned Duration). As seen from the table, retensioning times covering three decades (100 hrs, 1,000 hrs, and 10,000 hrs) were achieved.

2.2 Test Results

An example of the basic test results is shown in Figure 1 for wire specimen #3. The "Base" curve represents the stress relaxation of the specimen prior to its retensioning at 6,000 hrs. The stress relaxation occuring subsequent to retensioning is the "Retensioned" curve. The horizontal time scale refers to either the time after initial stressing (Base curve) or the time after retensioning (Retensioned curve). From the figure, the stress relaxation of a retensioned wire would appear to eventually equal that of an unretensioned wire. However, the time at which this occurs is probably beyond any practical time of interest, considering that at 40 years (350,000 hrs.) there is still a significant difference in relaxation (17% vs. 12%).

Using the results in Figure 1 and similar curves from the other six specimens, Retensioned-to-Base stress relaxation ratios were obtained at various "times after retensioning", which ranged from 10 hrs. to 350,000 hrs. At each such time after retensioning, curves similar to those in Figure 2 were constructed. This figure represents the stress relaxation in a wire (expressed as a fraction of its Base value) 1,000 hrs. after retensioning, having retensioned the wire from 100 hrs. to 350,000 hrs. after its original stressing. In the figure, the 90° F curve is a linear interpolation of the 68° F and 104° F data curves. The 90° F condition is considered to be more applicable to the actual tendons.

The results in Figure 2 in conjunction with other similar figures (each for a specific time after retensioning) were used to construct a series of curves similar to Figure 3, which is for the 90° F condition. These results indicate that the stress relaxation a wire experiences subsequent to its retensioning (as percent of its Base value) decreases as the time of retensioning after initial stressing increases - up to a point. If the wire is retensioned at least 10,000 hrs. after initial stressing, there is no significant difference in retensioned stress relaxation.

The values of retensioning ratio provided by the two curves in Figure 3 for times-of-retensioning of 1,000 hrs. and 100,000 hrs. were applied to a general Base stress relaxation curve established for all the tendons. This, therefore, established stress relaxation property data to be used for future force predictions of the tendons retensioned in May 1969 (RT = 1,000 hrs.) and in June 1980 (RT = 100,000 hrs.). Figure 4 contains these curves along with the Base stress relaxation property curve used. The inservice inspection in July 1983 provided the first opportunity to apply these results.

3.0 JULY 1983 TENDON LIFT-OFF FORCES

3.1 Procedure

Tendon lift-off forces where obtained from two calibrated measurement systems attached to the hydraulic stressing unit. The first system utilized the pressure gauge of stressing ram. Gauge pressures were input into the calibration equation:

$$\text{Force (Kips)} = 0.896 + 0.1274 \times \text{Gauge Pressure (PSIG)} \qquad (1)$$

This equation is derived from a linear regression fit of the force-gauge pressure data obtained during calibration of the pressure gauge and stressing ram as one unit.

The second measurement system involved a strain gage instrumented stressing rod which measured the tendon force directly. The calibration equation for this system is:

$$\text{Force (Kips)} = 0.2004 \times \text{Strain (micro-inches/inch.)} \qquad (2)$$

Tendon forces where measured at their respective lift-off points, which were determined when the tendon anchorhead lifted off the shim stack just enough to allow two pre-inserted feeler gages (1/32 inches thick) on opposite sides to be withdrawn.

The inspection involved the testing of 18 tendons. This included 4 tendons previously retensioned in May of 1969 and 14 tendons retensioned in June 1980.

3.2 Results

The results of the lift-off forces for all 18 sample tendons are shown in column (3) of Table II with an average tendon force of 709 kips. As expected, the four tendons retensioned in May 1969 exhibited lower lift-off forces than the remaining sample tendons retensioned in June 1980.

To correlate the 18 sample tendons to all 160 tendons in the containment, a weighted average was obtained by factoring in the group averages of those tendons retensioned in June 1980 and May 1969. This resulted in an average tendon force of 713 kips, which represents the expected average tendon force in the containment. It exceeds by 12.1% the minimum required value of 636 kips appearing in the Ginna Technical Specifications.

Prior to the start of the inspection, predicted tendon forces were obtained for each sample tendon based on the retensioned stress relaxation curves (RT) in Figure 4. Force-versus-time history curves were constructed. Examples of two of these curves are illustrated in Figures 5 and 6 for tendon nos. 18 and 120. For tendon no. 18, the July 1983 lift-off force was 727 kips, which is only 0.8% above the predicted value of 721 kips. The lift-off force for tendon no. 120 of 680 kips is within 2.9% of its 661 kip predicted value. The predicted forces for all 18 sample tendons are indicated in column (1) of Table II. The percent difference between measured and predicted force appears in column (4). The forces for 13 of the 18 tendons exceed the predicted values, and all of the forces measured in the remaining 5 tendons were well above 95% of their predicted values, which is generally acceptable.

For comparison, column (2) of Table II includes the predicted tendon forces obtained using the Base stress relaxation property curve in Figure 4. The Base curve was applied as if the tendons were tensioned for the first time in May 1969 and June 1980. Thus, the effect on the stress relaxation property due to retensioning is ignored. Comparing column (5) with column (4) in Table II, it is evident that not accounting for the effect of retensioning results in a significantly greater percent difference between measured and predicted forces.

4.0 CONCLUSIONS

The results from the July 1983 inservice inspection indicate that the forces in the retensioned tendons are remaining at or above the expected (predicted) levels and no abnormal force losses have occurred. A prediction technique developed for this application proved successful in determining future forces for retensioned tendons. The predicted tendon forces were obtained using stress relaxation property curves developed from retensioned wire tests, and the agreement with the measured tendon forces was as good or better than that generally experienced on containments that have not undergone retensioning.

ACKNOWLEDGEMENTS

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REFERENCES

(1) FULTON, J. F. and MURRAY, K. H., "Containment Structure Tendon Investigation" Transactions of the 7th International Conference on Structural Mechanics in Reactor Technology, August 1983, Paper D3/7.

TABEL I. STRESS RELAXATION TEST CONDITIONS OF RETENSIONED WIRES

Tendon I.D.	Specimen No.	Heat No.	Stress (% UTS)	Temperature (°F)	Time at Retensioning (Hours)	Retensioned Duration (Hours)
51-B	3	19477	70	104	6000	18214
51-C	4	19477	70	68	1000	11137
76-C	8	30091	70	104	10190	14229
76-B1	9	30091	70	104	100	8635
76-B2	10	30091	70	104	1000	19229
76-B	7	30091	70	68	11600	3575
150-C2	12	10355	70	68	5500	9720

TABLE II. 1983 SAMPLE TENDON FORCES - MEASURED VERSUS PREDICTED

TENDON NO.	LIFT OFF FORCES (KIPS)				MEAS.-PRED. / PREDICTED (%)	
	PREDICTED					
	WITH RT	BASE	MEASURED		WITH RT	BASE
	(1)	(2)	(3)		(4)	(5)
13	711	653	730		2.7	11.8
18	721	662	727		0.8	9.8
40	711	652	731		2.8	12.1
51	712	653	709		-0.4	8.6
53	711	653	731		2.8	11.9
60	707	649	711		0.6	9.6
62	720	661	715		-0.7	8.2
75	709	651	723	Ave.	2.0	11.1
76	704	646	700	719	-0.6	8.4
93	711	653	706		-0.7	8.1
125	716	657	702		-2.0	6.8
128	703	646	709		0.9	9.8
155	703	645	745		6.0	15.5
160	709	651	721		1.7	10.8
35(1)	650	620	662		1.8	6.8
36(1)	661	630	664	Ave.	0.5	5.4
116(1)	656	626	693	675	5.6	10.7
120(1)	661	630	680		2.9	7.9
AVERAGE	699	647	709		2.0	9.6
WT. AVE.(2)			713			

(1) Retensioned in May 1969

(2) Weighted Average considering 23 tendons retensioned in May 1969

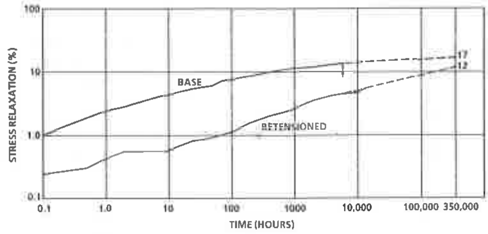

FIGURE 1
BASE AND RETENSIONED STRESS RELAXATION FOR WIRE NO. 3

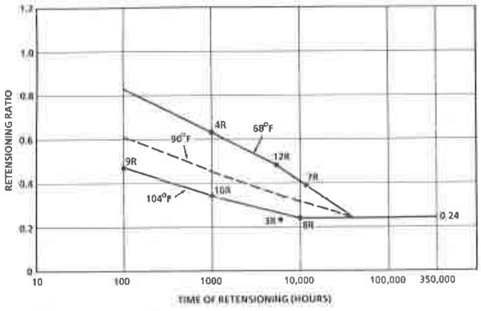

FIGURE 2
RETENSIONING RATIO - 1000 HRS. AFTER RETENSIONING

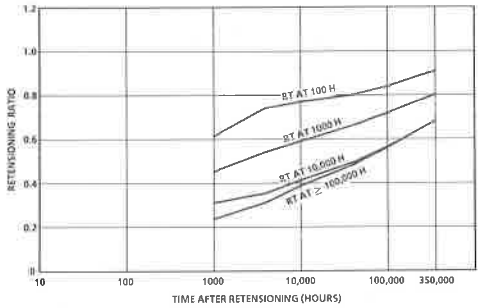

FIGURE 3
RETENSIONING RATIO - 90°F

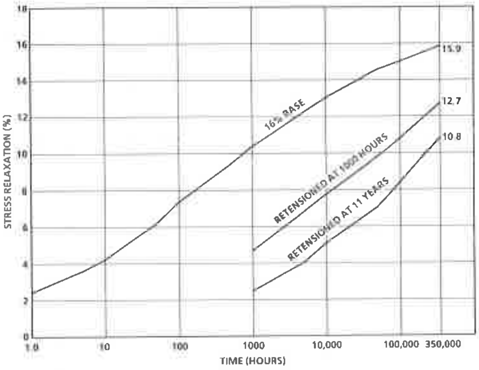

FIGURE 4
STRESS RELAXATION - RETENSIONED TENDONS

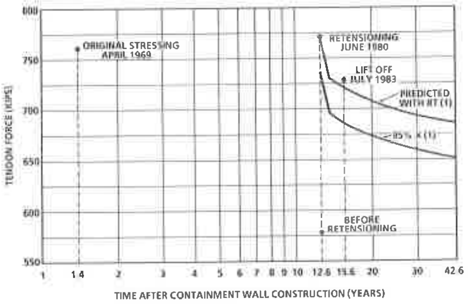

FIGURE 5
COMPARISON OF PREDICTED AND MEASURED FORCES FOR TENDON NO. 18

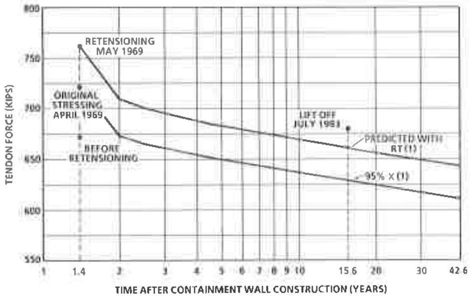

FIGURE 6
COMPARISON OF PREDICTED AND MEASURED FORCES FOR TENDON NO. 120