SUBJECT CODE 305	SOUTH CAROLINA ELECTRIC AND GAS COMPANY CALCULATION RECORD	PAGE 1 of 46

CALC TITLE	CALC NO.	REV	STAT
RB VERTICAL TENDON FORCE LOSS AND 5TH PERIOD SURV. ACCEPTANCE CRITERIA CALCULATION	DC03050-002	0	I

PARENT DOCUMENT	SYSTEM	SAFETY CLASS	CALC. CLASS
STP0160.001	BS	NN QR [SR]	[I] II III IV V VI

ORIGINATOR	DISC	ORGANIZATION	DATE	XREF NO.
KRASUE, D.	CS		10/13/95	NONE

A. CALCULATION INFORMATION

CONTENT DESCRIPTION:

THIS CALCULATION IDENTIFIES THE RB TENDON FORCE LOSSES AND THE 5TH PERIOD SURVEILLANCE ACCPTANCE CRITERIA FOR THE VERTICAL TENDONS.

AFFECTED COMPONENTS/ANALYSIS:

RB TENDONS V7, V8, V9, V39, V40, V41, V89, V90, V91

FOR INFORMATION ONLY

CONTAINS PRELIMINARY DATA/ASSUMPTIONS:

☒ NO ☐ YES, PAGES

COMPUTER PROGRAM USED: ☒ NO

☐ YES, VALIDATION NOT REQ'D. [REF. 3.5] ☐ YES, VALIDATED [OTHERS]

☐ YES, VALIDATED [ES-412] ☐ PROGRAM VALIDATION CALCULATION

B. VERIFICATION

VERIFICATION SCOPE

VERIFY CACLUATION METHODOLOGY, INPUT AND ASSUMPTIONS. PERFORM SPOT CHECK OF MATH.

VERIFIER: PARSONS, G. P.

ASSIGN BY: WHORTON, R. B.

Greg Parsons FOR DALE KRAUSE 1/8/96
LEAD ENGINEER (DESIGNEE)/DATE

VERIFIER / DATE	APPROVAL / DATE
Greg Parsons 1/8/96	RBWhorton 1-8-96

C. RECORDS

TO PRS: ____________
INIT/DATE

REEL NUMBER:

FRAME NUMBER:

ORIGINAL MAINTAINED BY:

DISTRIBUTION: CALC FILE [ORIGINAL]
DSE ____________ /SYSTEM ENG ____________ /DE FILE 20.6602 [ATTACH. 1 ONLY, COPY]

SOUTH CAROLINA ELECTRIC & GAS COMPANY REVISION SUMMARY	PAGE 2 OF 96
CALCULATION NO. DC03050-002	

REV NO.	SUMMARY DESCRIPTION
0	This calculation identifies the predicted forces and acceptance criteria for the retentioned vertical RB tendons that were selected for the fifth period surveillance and the associated adjacent tendons.

☐ CONTINUES ON PAGE

ENGINEERS
TECHNICAL WORK RECORD

Serial 10606
Engineer G. Parsons
Date 1/8/96

Project Title RB Vertical Tendon Force Calculations

Page 1 of_

VERIFIER'S COMMENTS

The purpose of this TWR is to document the verification performed on DC03050-002 Rev. 0. The verifier has reviewed the calculation methodology, the inputs and the assumptions. A spot check of the math was also performed. This calculation identifies the predicted forces and acceptance criteria for the retentioned vertical RB tendons that were selected for the fifth period surveillance and the associated adjacent tendons.

Previous tendon force predictions were based on subtracting a series of estimated force loss factors from the original lock-off force value. This calculation replaces the original calculations because the re-tensioning which occurred after the last surveillance significantly changed the tendon forces. This calculation uses the same approach and many of the same inputs as the original tendon force predictions. Each component of the calculation is examined for the affect of the tendon re-tensioning. The previous calculations are verified documents and are reasonable and accurate for this application.

1.0 OBJECTIVES

(1) Develop general methodology for predicted liftoff force for the retensioned vertical tendons.

(2) Develop the predicted liftoff forces for the vertical tendons for Surveillance Period 5 (15th year after SIT).

1.1 DESIGN INPUTS

1.1.1 The design inputs consist primarily of previous V.C.Summer Station structural calculations. these are clearly listed when they are referenced in the body of the calculation.

1.1.2 Other documents referred to in the calculations include:

(1) SP 228 Surveillance of the Reactor Building Post Tensioning System.

(2) Reactor Building Containment Fourth Period Surveillance Tendon Forces Report, May 1990.

(3) Vertical Tendon Retensioning of the V.C.Summer Unit 1 Reactor Building Report by Precision Surveillance Corp.

1.2 ASSUMPTIONS

Assumptions are identified in the calculation where used. There are no assumptions requiring future confirmation.

1.3 COMPUTER USE

No computer software was used to perform calculations.

1.4 CALCULATION

The prestress losses addressed in this calculation are those identified in R.G. 1.35.1 and include:

(1) Elastic shortening.

(2) Concrete creep.

(3) Concrete shrinkage.

(4) Wire stress relaxation.

1.4.1 Elastic Shortening

Ref.: Calc. Book Z-4J, 1:18.6, p. 1 and 1:18.7, p.8

All of the vertical tendons were retensioned during the 4th tendon surveillance in 1990. Therefore, the elastic shortening losses for the vertical tendons are relative to the additional increment of vertical force consisting of the difference between the lockoff force at retensioning and the force previously existing in the tendons just prior to retensioning.

Liftoff forces were measured for all vertical tendons prior to retensioning. While the liftoff measurements for the last tendons retensioned would have been affected by the elastic shortening due to the tendons previously retensioned as the work proceeded, the effect is minor and disregarded in this work. The average of the liftoff measurements taken for all the vertical tendons is 1195.8 kips as calculated from the lockoff force data included as the next pages in this calc. The average force in the vertical tendons at the time of the 4th surveillance based on the average of the normalized liftoff forces ***for the surveyed vertical tendons*** is 1190 kips (Table 2-1 of the 4th Period Surveillance Report).

From 1:18.7, p.8,

$\Delta\sigma_{ci}$ = increment of compressive stress in concrete resulting from the retensioning.

F_r = average retensioned tendon force = 1372 kips (calculated from data on following pages)

F_{4th} = average tendon force at 4th surveillance = 1195.8 kips (see following pages)

Ac = Average area of concrete per vertical tendon = 2210 sq. in. (Calc. Book Z-3D,1:18.3, p. 185)

$\Delta\sigma_{ci} = (F_r - F_{4th}) \div Ac = (1372 - 1195.8) \div 2210 = 0.07973$ ksi

F_{les} = Maximum elastic shortening loss for first vertical tendon retensioned.

$F_{les} = \Delta\sigma_{ci} \times Ec/Es \times At$

At = Area of tendon = 8.3453 sq. in.

$F_{les} = 0.07973$ ksi $\times$ 29/4 $\times$ 8.3453 sq. in. = 4.8 kips **Use F_{les} = 5 kips**

Calculate The Individual Tendon Elastic Shortening Loss

The expression for the elastic shortening for each tendon is:

$F_{les}{}^{n} = n_r / N \times F_{les}$

$F_{les} = 5$ kips

n = stressing sequence for the individual tendon. For this calculation it is sufficiently accurate to assume all tendons restressed in a single day comprise one sequence.

$n_r = N - n$

N = Total number of sequences

ENGINEERS

TECHNICAL WORK RECORD

Serial

Engineer D. KRAUSE

Date

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REF.: PRECISION SURVEILLANCE CORP. REPORT "VERTICAL TENDON RETENSIONING OF THE V.C. SUMMER UNIT 1 REACTOR BUILDING."

VERTICAL TENDON RETENSIONING OF THE
V.C.SUMMER UNIT 1 REACTOR BUILDING

TABLE V: SUMMARY OF DATA SHEETS 3, 21, A & WORK SHEET B
LIFT OFFS BEFORE AND AFTER RETENSIONING, TOP (SHOP END) ONLY

TENDON	JACK			NO.OF EFFECTIVE WIRES	BEFORE RETENSIONING			AFTER RETENSIONING		
	ID.	AREA (IN2)	CONSTANT (KIP)		LIFT OFF		SHIM THCKNS (IN)	LIFT OFF		SHIM THCKNS (IN)
					PRESS. (PSI)	FORCE (KIP)		PRESS. (PSI)	FORCE (KIP)	
V1	9362	210.999	-9.479	170 !	5590	1170	14.10	6560	1375	15.90
V2	9362	210.999	-9.479	170	5548	1161	13.55	6535	1369	15.60
V3	9362	210.999	-9.479	170	5670	1187	13.80	6520	1366	15.30
V4 **	9362	210.999	-9.479	170	5678	1189	13.90	6573	1380	15.60
V5	9362	210.999	-9.479	170	5700	1193	14.40	6500	1362	15.90
V6 **	9362	210.999	-9.479	170	5477	1146	14.10	6447	1353	16.00
V7	9362	210.999	-9.479	170 *	5720	1197	15.90	6453	1352	17.25
V8	9363	211.033	-7.500	170	5493	1152	14.65	6620	1390	16.65
V9	9363	211.033	-7.500	170	5647	1184	13.95	6590	1383	15.70
V10	9363	211.033	-7.500	170	5710	1197	13.30	6600	1385	15.00
V11	9363	211.033	-7.500	170	5713	1198	14.10	6592	1384	15.75
V12	9365	209.970	-4.664	170	5663	1184	13.35	6503	1361	14.95
V13	9363	211.033	-7.500	170	5653	1185	13.10	6558	1376	14.90
V14	9363	211.033	-7.500	170	5677	1191	13.40	6580	1381	15.20
V15	9363	211.033	-7.500	170	5590	1172	13.75	6530	1371	15.60
V16	9365	209.970	-4.664	170	5710	1194	14.00	6550	1371	15.60
V17	9363	211.033	-7.500	170	5830	1223	13.85	6507	1366	15.10
V18	9363	211.033	-7.500	170	5713	1198	14.40	6510	1366	15.85
						Σ 21,321			Σ 24,691	

Verification

Type of Verification	Verifier Signature/Date

Approval

Signature/Date

ENGINEERS

TECHNICAL WORK RECORD

Serial ______

Engineer D. Krause

Date ______

Project Title ______ Tab ___ Page 5 of ___

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VERTICAL TENDON RETENSIONING OF THE
V.C.SUMMER UNIT 1 REACTOR BUILDING

TABLE V: (CONTINUE)

TENDON	JACK			NO.OF EFFE-CTIVE WIRES	BEFORE RETENSIONING			AFTER RETENSIONING		
	ID.	AREA (IN2)	CONSTANT (KIP)		LIFT OFF		SHIM THCKNS (IN)	LIFT OFF		SHIM THCKNS (IN)
					PRESS. (PSI)	FORCE (KIP)		PRESS. (PSI)	FORCE (KIP)	
V19	9363	211.033	-7.500	170	5772	1211	14.10	6582	1382	15.60
V20	9365	209.970	-4.664	170	5870	1228	14.30	6510	1362	15.30
V21	9363	211.033	-7.500	170	5777	1212	13.70	6563	1378	15.25
V22	9363	211.033	-7.500	170	5690	1193	13.80	6610	1387	15.70
V23	9363	211.033	-7.500	170	5983	1255	14.90	6570	1379	15.60
V24	9365	209.970	-4.664	170	6087	1273	15.00	6550	1371	15.90
V25	9363	211.033	-7.500	170	5666	1188	14.05	6560	1377	15.55
V26	9363	211.033	-7.500	170	5632	1181	13.60	6517	1368	15.05
V27	9363	211.033	-7.500	170 *	5790	1214	14.20	6590	1383	15.60
V28	9365	209.970	-4.664	170	5720	1196	13.60	6500	1360	15.10
V29	9363	211.033	-7.500	170	5713	1198	13.60	6490	1362	15.10
V30	9363	211.033	-7.500	170	5533	1160	14.90	6510	1366	16.65
V31	9362	210.999	-9.479	170	5777	1209	13.00	6478	1357	14.20
V32 ##	9365 9362	209.970 210.999	-4.664 -9.479	170	5800	1213	12.40	6600 6553	1381 1373	14.10
V33	9362	210.999	-9.479	170	5730	1200	13.05	6518	1366	13.95
V34	9363	211.033	-7.500	170	5637	1182	11.60	6510	1366	12.95
V35	9362	210.999	-9.479	170	5565	1165	14.40	6460	1354	15.40

Σ 20,478   Σ 23,291

Verification

Type of Verification	Verifier Signature/Date

Approval

Signature/Date

VERTICAL TENDON RETENSIONING OF THE
V.C.SUMMER UNIT 1 REACTOR BUILDING

TABLE V: (CONTINUE)

TENDON	JACK			NO.OF EFFECTIVE WIRES	BEFORE RETENSIONING			AFTER RETENSIONING		
	ID.	AREA (IN2)	CONSTANT (KIP)		LIFT OFF PRESS. (PSI)	LIFT OFF FORCE (KIP)	SHIM THCKNS (IN)	LIFT OFF PRESS. (PSI)	LIFT OFF FORCE (KIP)	SHIM THCKNS (IN)
V36 ##	9365 9362	209.970 210.999	-4.664 -9.479	170	5687	1189	12.70	6573 6547	1375 1372	14.15
V37	9362	210.999	-9.479	170	5700	1193	16.30	6535	1369	17.70
V38	9363	211.033	-7.500	170	5657	1186	14.20	6560	1377	16.00
V39	9362	210.999	-9.479	170	5697	1193	14.00	6555	1374	15.70
V40 ##	9365 9362	209.970 210.999	-4.664 -9.479	170	5587	1168	13.50	6490 6517	1358 1366	15.20
V41	9362	210.999	-9.479	170	5663	1185	13.90	6580	1379	15.70
V42	9363	211.033	-7.500	170	5620	1179	13.50	6580	1381	15.40
V43	9362	210.999	-9.479	169	5855	1226	15.15	6553	1373	16.55
V44 ##	9365 9362	209.970 210.999	-4.664 -9.479	170	5780	1209	13.60	6530 6513	1366 1365	15.10
V45	9362	210.999	-9.479	170	5610	1174	14.30	6560	1375	16.15
V46	9362	210.999	-9.479	169	5913	1238	12.75	6565	1376	13.90
V47	9362	210.999	-9.479	170	5697	1193	14.00	6580	1379	15.60
V48	9362	210.999	-9.479	170	5708	1195	13.35	6560	1375	15.00
V49	9362	210.999	-9.479	170	5693	1192	13.30	6460	1354	15.00
V50	9362	210.999	-9.479	170	5675	1188	16.40	6513	1365	18.10

Σ17,908 Σ20,580

Verification

Type of Verification	Verifier Signature/Date

Approval

Signature/Date

ENGINEERS

TECHNICAL WORK RECORD

Serial________
Engineer D. Krause
Date________

Project Title________ Tab____ Page 7 of____

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VERTICAL TENDON RETENSIONING OF THE
V.C.SUMMER UNIT 1 REACTOR BUILDING

TABLE V: (CONTINUE)

TENDON	JACK			NO.OF EFFE-CTIVE WIRES	BEFORE RETENSIONING			AFTER RETENSIONING		
	ID.	AREA (IN2)	CONSTANT (KIP)		LIFT OFF PRESS. (PSI)	LIFT OFF FORCE (KIP)	SHIM THCKNS (IN)	LIFT OFF PRESS. (PSI)	LIFT OFF FORCE (KIP)	SHIM THCKNS (IN)
V51	9365	209.970	-4.664	169	5733	1199	12.80	6536	1368	14.60
V52	9362	210.999	-9.479	170	5673	1188	14.15	6590	1381	15.95
V53	9362	210.999	-9.479	170	5740	1202	15.40	6500	1362	16.90
V54	9362	210.999	-9.479	170	5600	1172	13.20	6490	1360	14.90
V55	9362	210.999	-9.479	170	5787	1212	14.40	6560	1375	15.90
V56	9362	210.999	-9.479	170	5717	1197	13.55	6570	1377	15.20
V57	9362	210.999	-9.479	170	5820	1219	14.10	6577	1378	15.60
V58	9362	210.999	-9.479	170	5677	1188	13.05	6503	1363	14.60
V59	9362	210.999	-9.479	170	6120	1282	15.30	6550	1373	16.10
V60	9362	210.999	-9.479	170	5973	1251	14.55	6537	1370	15.50
V61	9362	210.999	-9.479	170	6017	1260	15.10	6547	1372	16.10
V62	9362	210.999	-9.479	170	5650	1183	14.00	6456	1353	15.45
V63	9365	209.970	-4.664	170	5813	1216	14.20	6570	1375	15.55
V64	9362	210.999	-9.479	170	5720	1197	14.20	6476	1357	15.70
V65	9362	210.999	-9.479	170 #	5740	1202	14.10	6630	1389	15.75
V66	9362	210.999	-9.479	170	5756	1205	13.75	6596	1382	15.30
V67	9362	210.999	-9.479	170	5680	1189	14.20	6620	1387	16.00
V68	9362	210.999	-9.479	169	5863	1228	15.60	6553	1373	16.70
						Σ21,790			Σ24,695	

Verification

Type of Verification	Verifier Signature/Date

Approval

Signature/Date

VERTICAL TENDON RETENSIONING OF THE
V.C.SUMMER UNIT 1 REACTOR BUILDING

TABLE V: (CONTINUE)

TENDON	JACK			NO.OF EFFE-CTIVE WIRES	BEFORE RETENSIONING			AFTER RETENSIONING		
	ID.	AREA (IN2)	CONSTANT (KIP)		LIFT OFF PRESS. (PSI)	LIFT OFF FORCE (KIP)	SHIM THCKNS (IN)	LIFT OFF PRESS. (PSI)	LIFT OFF FORCE (KIP)	SHIM THCKNS (IN)
V69	9362	210.999	-9.479	170	5733	1200	13.80	6448	1351	15.25
V70	9362	210.999	-9.479	170	5693	1192	13.70	6586	1380	15.15
V71	9362	210.999	-9.479	170	5710	1195	13.90	6460	1354	15.30
V72	9362	210.999	-9.479	170	5686	1190	14.10	6626	1389	15.80
V73	9362	210.999	-9.479	170	5750	1204	14.30	6560	1375	15.90
V74	9362	210.999	-9.479	170	5808	1216	14.20	6510	1364	15.65
V75	9362	210.999	-9.479	170	5733	1200	13.80	6460	1354	15.10
V76	9362	210.999	-9.479	169	5860	1227	14.05	6613	1386	15.45
V77	9362	210.999	-9.479	170	5840	1223	13.75	6630	1389	15.30
V78	9362	210.999	-9.479	170	5630	1178	13.60	6606	1384	15.30
V79	9362	210.999	-9.479	170	5557	1163	13.80	6620	1387	15.80
V80	9362	210.999	-9.479	170	5713	1196	14.10	6470	1356	15.60
V81	9362	210.999	-9.479	170	5687	1190	13.30	6560	1375	15.10
V82	9362	210.999	-9.479	170	5736	1201	14.60	6487	1359	16.10
V83	9365	209.970	-4.664	169	6250	1308	14.85	6460	1352	15.35
V84	9362	210.999	-9.479	170	5686	1190	14.40	6613	1386	16.10
V85	9362	210.999	-9.479	170	5700	1193	14.60	6600	1383	16.40
V86	9362	210.999	-9.479	170	5656	1184	13.10	6550	1373	14.90

Σ 21,650 ✓ Σ 24697 ✓

VERTICAL TENDON RETENSIONING OF THE
V.C.SUMMER UNIT 1 REACTOR BUILDING

TABLE V: (CONTINUE)

TENDON	JACK			NO.OF EFFE-CTIVE WIRES	BEFORE RETENSIONING			AFTER RETENSIONING		
	ID.	AREA (IN2)	CONSTANT (KIP)		LIFT OFF		SHIM THCKNS (IN)	LIFT OFF		SHIM THCKNS (IN)
					PRESS. (PSI)	FORCE (KIP)		PRESS. (PSI)	FORCE (KIP)	
V87	9362	210.999	-9.479	170 *	5603	1173	13.10	6580	1379	14.80
V88	9362	210.999	-9.479	170	5696	1192	14.10	6470	1356	15.60
V89	9362	210.999	-9.479	170	5710	1195	14.10	6600	1383	15.90
V90	9362	210.999	-9.479	170 $	5670	1187	13.80	6503	1363	15.60
V91	9362	210.999	-9.479	170	5720	1197	12.40	6520	1366	13.90
V92	9362	210.999	-9.479	170	5626	1178	13.10	6460	1354	14.70
V93	9362	210.999	-9.479	170	5727	1199	13.90	6520	1366	15.35
V94	9362	210.999	-9.479	170 @	5816	1218	13.80	6580	1379	15.30
V95	9362	210.999	-9.479	170	5700	1193	13.40	6560	1375	15.00
V96	9362	210.999	-9.479	170	5726	1199	13.40	6530	1368	14.80
V97	9362	210.999	-9.479	170	5657	1184	13.80	6590	1381	15.60
V98	9362	210.999	-9.479	170	5516	1154	13.60	6606	1384	15.60
V99	9362	210.999	-9.479	170	5660	1185	13.80	6560	1375	15.60
V100	9362	210.999	-9.479	170	5707	1195	13.70	6603	1384	15.40
V101	9362	210.999	-9.479	170	5613	1175	13.90	6520	1366	15.60
V102	9362	210.999	-9.479	170	5790	1212	14.20	6590	1381	15.75
V103	9363	211.033	-7.500	170	5593	1173	14.10	6600	1385	16.00
V104	9362	210.999	-9.479	170 #	5673	1188	14.10	6597	1382	15.90
						Σ 21,397			Σ 24,729	

Verification	
Type of Verification	Verifier Signature/Date

Approval
Signature/Date

VERTICAL TENDON RETENSIONING OF THE
V.C.SUMMER UNIT 1 REACTOR BUILDING

TABLE V: (CONTINUE)

TENDON	JACK			NO.OF EFFE-CTIVE WIRES	BEFORE RETENSIONING			AFTER RETENSIONING		
	ID.	AREA (IN2)	CONSTANT (KIP)		LIFT OFF		SHIM THCKNS (IN)	LIFT OFF		SHIM THCKNS (IN)
					PRESS. (PSI)	FORCE (KIP)		PRESS. (PSI)	FORCE (KIP)	
V105	9363	211.033	-7.500	170	5623	1179	13.90	6510	1366	15.50
V106	9362	210.999	-9.479	170	5687	1190	13.60	6570	1377	15.20
V107	9363	211.033	-7.500	170	5703	1196	14.30	6473	1359	15.90
V108	9363	211.033	-7.500	170	5505	1154	12.85	6535	1372	14.50
V109	9363	211.033	-7.500	170	5600	1174	14.10	6572	1379	15.90
V110	9363	211.033	-7.500	170	5587	1172	13.65	6590	1383	15.50
V111	9363	211.033	-7.500	170	5660	1187	14.10	6620	1390	15.80
V112	9363	211.033	-7.500	170	5633	1181	14.25	6527	1370	15.90
V113	9363	211.033	-7.500	170	5630	1181	14.10	6550	1375	15.85
V114	9363	211.033	-7.500	170	5630	1181	13.80	6522	1369	15.60
V115	9363	211.033	-7.500	170	5607	1176	14.40	6557	1376	16.10

Σ 12,971 Σ 15,116

$\Sigma\Sigma = \frac{137,515}{115} = 1195.8^K$ AVE

$\Sigma\Sigma = 157,797 / 115$
AVE $= 1372^K$

LEGEND:

* SQ5.1 SHOWS 169 WIRES.
# SQ5.1 SHOWS 168 WIRES.
$ 3 PROTRUDING (1/16") WIRES ON FIELD END.
@ 1 PROTRUDING (1") WIRE ON FIELD END.
! 5 BUTTONHEADS WITH GRINDING MARKS.
** JACK 9363 WAS USED FOR RETENSIONING THESE TENDONS.
PER SQ5.1 LIFT OFFS WERE TAKEN AGAIN FOR THESE TENDONS AFTER ALL VERTICAL TENDONS WERE RETENSIONED.

Verification

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The stressing dates on the following table are from the Precision Surveillance Corp. Vertical Tendon Retensioning Report Volume 2 of 3.

STRESSING SEQUENCES FOR RETENSIONED VERTICAL TENDONS AND ELASTIC SHORTENING LOSSES FOR INDIVIDUAL TENDONS

SEQUENCE NO.	STRESSING DATE	TENDON I.D.	F_{les} " CALC.	F_{les} " ROUNDOFF
1	2/1	2	4.58	5
2	2/2	5, 63, 83	4.24	5
3	2/5	90, 94	4.15	4.5
4	2/6	51	3.93	4
5	2/8	32,36,40,44,101	3.71	4
6	2/9	93, 97	3.49	3.5
7	2/12	20,24,28,77,81,85,89	3.27	3.5
8	2/13	12,16,57,61,65,69,73,	3.05	3.5
9	2/14	4,8,49,53,103,105, 107,109,111,115	2.84	3
10	2/15	6,10,14,18,22,26,45, 47,55,59,67,71,75,79, 113	2.62	3
11	2/20	87,91,95,99	2.4	2.5
12	2/21	1,3,7, 30, 34, 38,42	2.18	2.5
13	2/23	100,102,104,106	1.96	2
14	2/26	80,82,92,96,98	1.75	2
15	2/27	76,78,84,86,88	1.53	2
16	2/28	25,29,57,70,72,74	1.31	1.5
17	3/1	62,64,66,68	1.09	1.5
18	3/2	60	0.87	1
19	3/5	48,50,52,54,56,58	0.65	1
20	3/6	31,33,35,37,39,41,43,46	0.44	0.5
21	3/7	108,110,112,114	0.22	0.5
22	3/8	15,9	0	0

Elastic shortening losses are rounded up to the nearest 0.5 kips.

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1.4.2 Concrete Shrinkage

Ref.: Calc Book Z-4H, 1:18.4 and Z-4K, 1:18.5.

The concrete shrinkage losses determined previously in calculation 1:18.4 pages C32 through C34 and 1:18.5, page 79 are applicable. Shrinkage losses are relatively minor because most of the shrinkage has occurred in the period after concrete placement before the tendons are tensioned. Shrinkage losses are independent of force in the concrete, and therefore are independent of the restressing. The shrinkage loss for the restressed tendons is the increment that has occurred since the time of restressing.

Shrinkage losses are based on total shrinkage strain of 100×10^{-6} in/in for the 40 year plant life as listed in the original prestress system purchase specification.

F_{lsh} = force loss in kips due to concrete shrinkage

F_{lsh} = shrinkage strain x E_{st} x At = strain x 29×10^3 x 8.345 sq.in. (Ref. 1:18.4, pp.C32 to C34 for shrinkage strains)

The vertical tendons were retensioned at 9 years after the SIT. The strain from the curve on p.C34at 9 years is 91.9×10^{-6}

Therefore, the strain difference, $\Delta\varepsilon$, from prestress to 9 years after SIT is:

$\Delta\varepsilon = 91.9 \times 10^{-6} - 79 \times 10^{-6} = 12.9 \times 10^{-6}$ in/in

F_{lsh} at 9 years = 12.9×10^{-6} in/in x 29×10^3 x 8.345 sq.in. = 3.12 kips

F_{lsh} (Retensioned) = F_{lsh} (At period "x") - F_{lsh} at 9 years

Example:

F_{lsh} at 15 years = 3.87 kips - 3.12 kips = 0.75 kips

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Concrete Shrinkage Loss

Surveillance Period Years After SIT	From Initial Stressing, F_{lsh} kips	From time of Restressing at 9 Years F_{lsh} kips
9	3.12	
10	3.27	0.15
15	3.87	0.75
20	4.24	1.12
25	4.60	1.48
30	4.84	1.72
35	5.08	1.96
40	5.32	2.20

NOTES:

1. F_{lsh} from initial prestressing for periods 10 through 40 years are from calculation 1:18.4 page C32.

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1.4.3 Concrete Creep

Reference: Calc. Book Z-3D, 1:18.3, p. 181 and Book Z-4K, 1:18.5, p. 78.

The ***total creep strain*** from the original tendon purchase specification used to determine the initial prestress levels are:

Vertical 210×10^{-6} in/in

Hoop 390×10^{-6} in/in

Dome 330×10^{-6} in/in

The ***specific creep strain*** at the 40 year design life is defined as:

= Total creep strain ÷ Initial average concrete stress, σ_{ci}

σ_{ci} = 658 psi (Ref. 1:18.3, pp. 183, 185, 159)

Therefore, ***specific creep strain*** in the vertical direction at 40 years is

= 210×10^{-6} in/in ÷ 658 psi = 0.3191×10^{-6} in/in /psi

It is noted that the above approach uses the initial concrete stress and does not take into consideration the elastic shortening losses which occur immediately upon stressing the tendons and prior to the occurrence of creep. The following investigates the effect on creep of accounting for the elastic shortening losses. The 658 psi average initial concrete stress assumed is based on the average initial lockoff force of 1455 kips per tendon (ref. 1:18.3, p. 159).

Average F_{les} = 39.81 kips ÷ 2 = 19.9 kips / tendon (ref. 1:18.4, p.C-6)

The concrete stress due to 19.9 kips per vertical tendon = 19,900 # ÷ 2210 sq.in. = 9.0 psi

Therefore, the concrete stress after elastic shortening loss is 658 psi - 9 psi = 647 psi

Specific creep corresponding to 647 psi = 210×10^{-6} in/in ÷ 647 psi = 0.3245×10^{-6} in/in /psi

The difference in the creep loss when the elastic shortening is accounted for prior to calculating the creep loss is:

Δcr = (.3245-.3191) x 647 psi x (29×10^{-3}) (8.345 sq. in.) = 0.845 kips

This difference of 0.845 kips total for creep loss at 40 years calculated using the initial concrete stress calculated before and after elastic shortening effects is negligible.

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Calculate tendon force loss due to creep for the retensioned vertical tendons:

The predicted creep loss for the remaining surveillances for the retensioned vertical tendons will be calculated by superimposing two components as follows:

F_{cr1} = creep loss that would have occurred had tendons not been retensioned.

F_{cr2} = creep loss corresponding to the additional increment of compressive stress introduced by the retensioning starting at the age of the concrete when the added prestress due to retensioning is introduced.

Calculate F_{cr1}.

Calculate the creep at the time of retensioning, 9 years after the SIT. Creep loss is occurring linearly versus the log of time for the time period of interest as shown on the creep curves that are based on test data (ref. 1:18.4, p. c-28).

Determine the ratio of specific creep between 9 years and 5 years using the curve for creep loss from 1:18.4 p. c-28 included as the next page of this calculation.

$$\text{Ratio} = 0.142 / 0.125 = 1.136$$

Therefore, since F_{cr} is assumed to be linearly proportional to specific creep:

$$F_{cr \text{ at 9 years}} = F_{cr \text{ at 5 years}} \times 1.136 = 29.6 \text{ kips} \times 1.136 = 33.63 \text{ kips}$$

The Total Creep Losses from Initial Stressing listed on the table on the next page for the surveillance periods are calculated using a spreadsheet and the specific creep strains on page 78 of 1:18.5. These creep losses are the same for all of the vertical tendons and are shown on spreadsheets on pp. 160 through 222 of 1:18.5.

Calculate F_{cr1} for the remaining surveillances with respect to the creep loss for the 9th year after the SIT when the vertical tendons were retensioned.

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F_{cr1}
(Creep Loss that would have occurred assuming no retensioning)

Surveillance period Years after SIT	Total Creep Loss from Initial Stressing Kips	Creep Force Loss Starting From Inspection at 9 years Kips
5	29.6	
9	33.6	0
10	34.2	0.6 = (34.2 - 33.6)
15	39.0	5.4 = (39.0 - 33.6)
20	42.5	8.9
25	44.9	11.3
30	47.3	13.7
35	49.2	15.6
40	50.8	17.2

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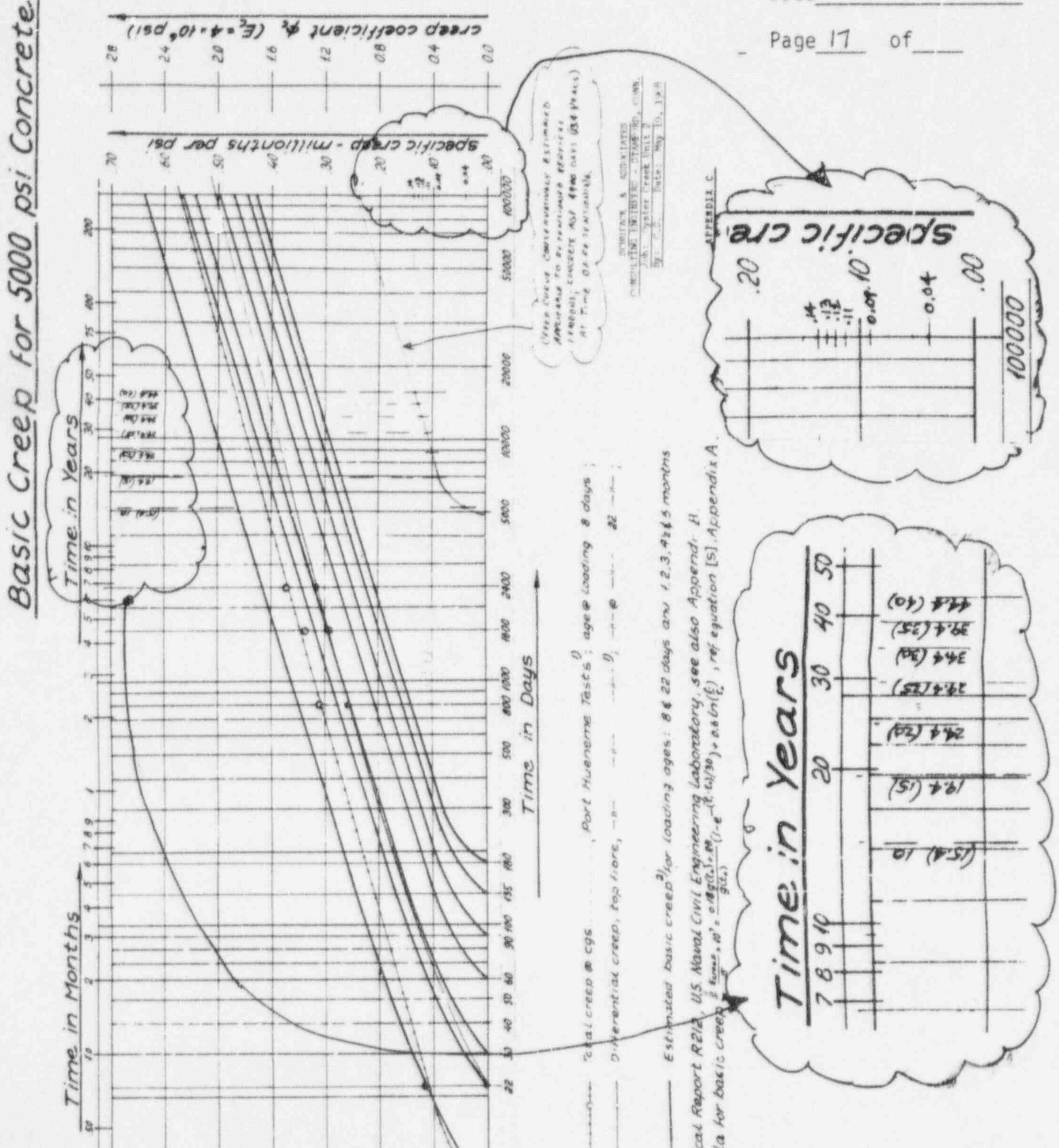

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F_{cr2}

(Concrete Creep Loss Due to the Increment of Vertical Prestress Force Added At Retensioning)

Surveillance Period Years After SIT	Age of Concrete at the Surveillance Years	(1) Specific Creep Coefficient for Concrete at Age 4900 Days x 10^{-6} in/in/psi	(2) Specific Creep Coefficient for Concrete at Age 1000 Days x 10^{-6} in/in/psi	(3) Specific Creep Coefficient Based on Specified Creep Loss x 10^{-6} in/in/psi	(4) Effect. Creep Coef. x 10^{-6} in/in/psi	(5) F_{cr2} (kips)
9	13.4					
10	14.4	0.04	0.145	0.215	0.06	1.2
15	19.4	0.09	0.165	0.245	0.134	2.6
20	24.4	0.10	0.180	0.267	0.148	2.9
25	29.4	0.11	0.190	0.282	0.163	3.2
30	3424	0.12	0.200	0.297	0.178	3.4
35	39.4	0.13	0.208	0.309	0.193	3.7
40	44.4	0.14	0.215	0.3191	0.208	4.0

Notes:

(1) Specific creep coefficients corresponding to the age of the concrete (13.4 years or 4900 days) at the time of vertical tendon retensioning taken from the creep curve included in this calc. on the previous page.

(2) Specific creep coefficients corresponding to the age of the concrete 1000 days at the time of the initial stressing of the vertical tendons taken from calcs 1:18.4 pages C-21 to C-28 and 1:18.5 page 78. The coefficients are taken from curves based on projections of creep test data.

(3) Specific creep coefficients based on the creep loss in the vertical direction specified for the original design of the initial tendon prestress level taken from calc 1:18.5 page 78.

(4) The effective creep coefficient, (4), is the creep coefficient for the age of the concrete at restressing (1) multiplied by the ratio of (3) to (2) above. The calculation of F_{cr2} is then consistent with the calculation of F_{cr1} and is based on the creep loss specified in the original purchase specification for the tendons and does not include a tolerance. This is in compliance with R.G. 1.35.1. (If the creep losses based on the creep test curves were used , a tolerance on the creep could have been applied when calculating the lower limit as defined in the R.G. 1.35.1.)

(5) F_{cr2} = Specific Creep (4) x Es x $\Delta\sigma_{ci}$ x At

Where: Es = 29 x 10^3 ksi/in/in
$\Delta\sigma_{ci}$ = 79.7 psi
At = 8.345 sq. in. tendon cross section area

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Summary of the Predicted Creep Losses for the Retensioned Vertical Tendons

Surveillance Period Years after SIT	F_{cr1} kips	F_{cr2} kips	Total $F_{cr} = F_{cr1} + F_{cr2}$ kips
10	0.6	1.2	1.8
15	5.4	2.6	8.0
20	8.9	2.9	11.8
25	11.3	3.2	14.5
30	13.7	3.4	17.1
35	15.6	3.7	19.3
40	17.2	4.0	21.2

Investigate Interaction vs Noninteraction Approach for Calculating Creep for the Retensioned Vertical Tendons:

Appendix A in R.G. 1.35.1 defines fc as the average sustained concrete stress. This definition accounts for the interaction between creep loss and the stress in the concrete although the R.G. does not provide specific guidance for calculating fc. It is recognized that the concrete stress does decrease somewhat over time as the force in the tendons decreases due to the losses that are occurring such as wire stress relaxation.

From Calc Book Z-4J, 1:18.7 page 11, the predicted tendon force at 40 years after losses is 1280.7 kips per tendon. Therefore, the concrete compressive stress in the vertical direction at 40 years due to this average force is 580 psi (1280.7 kips ÷ 2210 sq.in.). The initial average concrete compressive stress calculated previously is 658 psi. The average of 658 psi and 580 psi is 619 psi. The average compressive stress in the concrete just after retensioning without considering elastic shortening losses is 621 psi (1372 kips ÷ 2210 sq.in.).

Using direct proportioning, Fcr1 at 40 years calculated for the average concrete stress of 619 psi is 16.2 kips (17.2 kips x 619/658 = 16.2 kips). The difference in Fc1 by the two methods is 17.2 kips minus 16.2 kips or 1 kip.

For Fcr2, the *average* of the incremental stress placed in the concrete between the time of retensioning and 40 years is 79.7 psi divided by 2 or 39.6 psi. The creep force Fcr2 corresponding to 39.6 psi at 40 years is 2 kips. The difference in Fcr2 between the two methods is therefor 2 kips (4 kips - 2 kips). The total difference for Fcr1 and Fcr2 is 3 kips. As a percent of the predicted force in the tendon at 40 yeas, 3 kips represents 0.23% of 1280.7 kips average predicted force. this difference is not significant. As a percentage of the losses predicted at 40 years for the retensioned tendons (99.3 kips from calc 1:18.7 page 11) 3 kips represents 3.2% of the predicted losses. This percentage is also considered not significant because the acceptance criteria for measured liftoff force is in % of the force in the tendon , i.e. 95% Base Value, not in terms of percent of the losses.

Summarizing, the non-interaction method is reasonable and appropriate for predicting the creep losses in the retensioned vertical tendons.

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1.4.4 Wire Stress Relaxation

Ref.: Calc. Book Z-4J, 1:18.10, page 12.
Book Z-3D, 1:18.3
Book Z-4K, 1:18.5

Wire stress relaxation testing discussed in the paper "Inservice Inspection Forces Measured In Retensioned Tendons" by J.F.Fulton and C.A.Forbes has shown that the relaxation of wire decreases for wire that has been retensioned. The magnitude of the decrease is proportional to the length of time that has elapsed from when the wire is initially stressed until it is restressed. The greater the span of time to restressing, the lower % of stress relaxation that will occur for the retensioned wire. This phenomenon occurs up to about retensioning 10,000 hrs. after original stressing when the percent relaxation remains relatively constant. The retensioning ratios determined by testing in the referenced paper are assumed to apply to the V.C.Summer wire. This is a reasonable assumption that does not require further confirmation since the wire for both plants was 0.25" diameter A421 Type BA wire supplied by ARMCO.

Determine time spans necessary to calculate the retensioning ratios:

Surveillance Years After SIT	(1) Concrete Placement to Initial Prestress Hrs	(2) Concrete Placement to Surveillance Hrs	(3) = (2) - (1) Initial Prestress to Surveillance Hrs	(4) Initial Prestress to Retensioning Hrs	(5)= (3) - (4) Retensioning to Surveillance Hrs	Retensioning Ratio at 90 degrees F.
15	23,364	172,344	148,980	94,944	54,036	0.48
20	"	214,032	190,668	"	95,724	0.55
25	"	257,856	234,492,	"	139,548	0.58
30	"	301,680	278,316	"	183,372	0.61
35	"	345,504	322,140	"	227,196	0.63
40	"	389,352	365,988	"	271,044	0.65

Notes:

1. Refer to calc. 1:18.3 page 156 for (1) and (2).

2. Average date of initial stressing of the vertical tendons is April 2, 1979. The time from concrete placement to prestress is calculated as (23,040 + 23,688) ÷ 2 = 23,364 hours.

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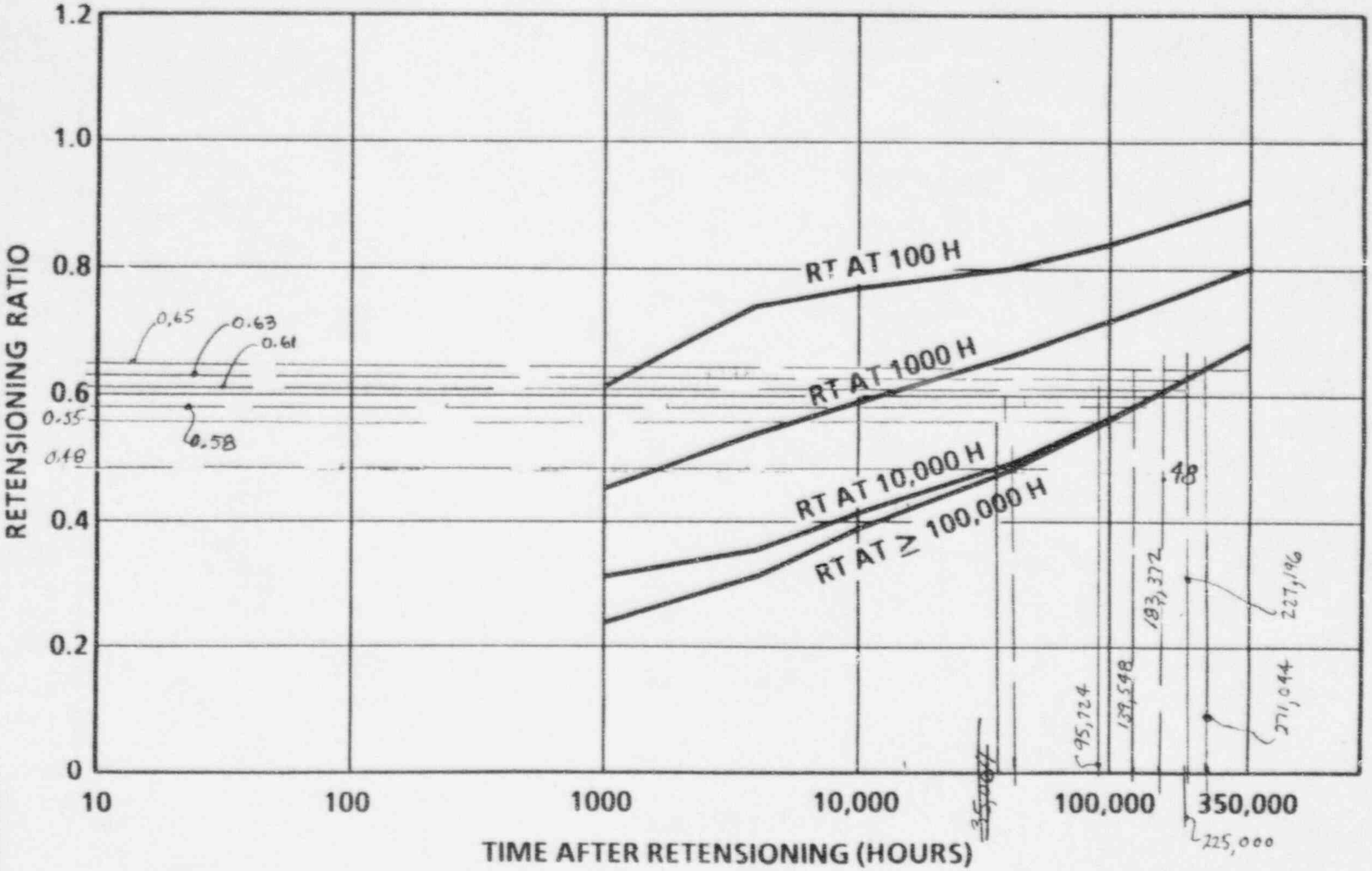

FIGURE 3
RETENSIONING RATIO - 90°F

Notes (cont)

3. Average date of restressing vertical tendons is February 1, 1990.

4. Surveillance at 15 years is planned for April 1, 1996.

Calculation of (4) in table on previous page:

1979 = 9 months from April 1 to end of year = (365 days - 31 - 31 - 28)24 = 6600 hours

1980 through 1989 = 10 years x 365 days/year x 24 hours/day = 87,600 hours (This is sufficiently accurate without considering the extra day in leap years which could add another 96 hours).

1990 = 31 days x 24 hours/day = 744 hours

Total = 6600 + 87,600 + 744 = 94,944 hours

% Wire Relaxation Loss for Retensioned Vertical Tendons

Surveillance Period Years after SIT	(1) Retensioning Ratio	(2) Unretensioned Wire Relaxation %	(3) = (1) x (2) Retensioned Wire Relaxation %
15	0.48	11	5.28
20	0.55	11.5	6.33
25	0.58	11.9	6.90
30	0.61	12.1	7.38
35	0.63	12.4	7.81
40	0.65	12.8	8.32

Notes:

1. Wire relaxation % loss (2) is from calc 1:18.5, page 9.

2 The retensioned wire stress relaxation loss in kips is equal to the individual tendon lockoff force in kips at retensioning times (3) in the table above, the retensioned wire percent relaxation.

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VERTICAL TENDON PREDICTED WIRE RELAXATION FORCE LOSSES 5TH SURVEILLANCE PERIOD

VERTICAL TENDON NO.	(1) RETENSIONED VERTICAL TENDON LOCKOFF FORCE KIPS	(2) PREDICTED WIRE STRESS RELAX. AT 5TH SURVEILLANCE %	(3) PREDICTED WIRE STRESS RELAXATION FORCE LOSS KIPS
V7	1352	5.28	71.4
V8	1390	"	~~73.04~~ 73.4 MAA 4/8/96
V9	1383	"	73.0
V39	1374	"	72.5
V40	1358	"	71.7
V41	1379	"	72.8
V89	1383	"	73.0
V90	1363	"	72.0
V91	1366	"	72.1

NOTES:

1. The retensioned vertical tendon lockoff forces are from PSC Corp. Vertical Tendon Retensioning Report Volume 1, Section 2, Table V.

Determine Feasibility of Using One Set of Losses Applicable to all Retensioned Vertical Tendons:

The following study is performed to determine the feasibility of establishing a single loss for predicted force versus time applicable to all of the vertical tendons. In this case all of the vertical tendons is considered as one subgroup. To determine the feasibility, the two causes of losses that depend on variables which change from tendon to tendon will be reviewed, i.e. the wire relaxation loss which depends on the lockoff force at retensioning and the elastic shortening which depends on the sequence of stressing.

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Wire Stress Relaxation Effect:

The range of lockoff forces for the retensioned vertical tendons (from the reference in Note 1 above) is 1351 kips for V69 at the low end and 1390 kips for V8 at the high end.

The maximum wire relaxation losses at 40 years corresponding to this range of lockoff forces are:

Tendon V69: Wire Relax. Loss = 0.0832 (relax. @ 40 yrs) x 1351 kips = 112.4 kips

Tendon V8 : Wire Relax. Loss = 0.0832 x 1390 kips = 115.6 kips

Difference between high and low = 115.6 kips - 112.4 kips = 3.2 kips

Assuming in the best case an accuracy in the liftoff force measurement of 1%, the actual force in the tendon could vary by 13.9 kips at the high end and 13.5 kips at the low end. For an accuracy of 2% on the liftoff force measurement (which is permitted by the specification), the actual tendon force could vary by double the above forces or, 27.8 kips to 27 kips per tendon. Since the potential variation in tendon force due to wire relaxation for the highest restressed tendon at 1390 kips and the lowest restressed tendon at 1351 kips of 3.2 kips at 40 years is much less that the accuracy of the force measurements and represents less than 0.5% of the tendon force, it is reasonable to use the higher predicted wire stress relaxation loss corresponding to the highest stressed tendon at 1390 kips for predicting the losses for all the restressed vertical tendons.

In addition to the foregoing justification, R.G. 1.35.1 permits a variation of ±15 % on the predicted wire stress relaxation loss when calculating the lower limit. The following calculation applies the ±15 % variation to the high and low lockoff force tendons for the case of the maximum predicted wire relaxation loss of 8.32% at 40 years.

V69: 0.0832 x 1351 kips = 112.4 kips

V69 Lower Bound Loss = (1+ 0.15) x 112.4 = 129.3 kips

V69 Upper Bound Loss = (1- 0.15) x 112.4 = 95.54 kips

V8: 0.0832 x 1390 kips = 115.6 kips

V8 Lower Bound Loss = (1+ 0.15) x 115.4 = 132.9 kips

V8 Upper Bound Loss = (1 - 0.15) x 115.4 = 98.1 kips

The difference between the predicted range of 112.4 kips to 115.6 kips wire relaxation loss and the lower bound loss range of 129.3 kips to 132.9 kips is 16.9 kips to 17.3 kips. This range of force loss (16.9 kips to 17.3 kips) due to the R.G.

Wire Relaxation Effect (cont)

permitted tolerance on wire relaxation is significantly greater than the maximum predicted difference of 3.2 kips between tendons V8 and V69. Although the calculation of the lower bound losses approach in accordance with R.G. 1.35.1 is not being used to develop the predicted force vs time curve for the retensioned vertical tendons, it is clear that using the wire relaxation loss for the highest restressed tendon, V8, as applicable to all the restressed vertical tendons for the purpose of predicting force loss in the tendons is reasonable.

Elastic Shortening Effect:

From calc page 2 the maximum elastic shortening loss for an individual retensioned tendon is 5 kips. The calculation table on page 3 indicates the elastic shortening losses to the nearest 0.5 kips for each vertical tendon depending on the stressing sequence. The average lockoff force for the retensioned tendons is 1372 kips. The 5 kips maximum elastic shortening loss of 5 kips is 0.36% of the lockoff force. The permitted measurement accuracy of the force in the tendons is 2% (27.4 kips). Therefore, for the purpose of grouping the tendons into subgroups for checking individual tendons, all of the vertical tendons can be placed in one subgroup based on consideration of the elastic shortening losses because the elastic shortening losses are much lower than the liftoff measurement accuracy. Use 5 kips as the predicted elastic shortening loss for all of the vertical tendons.

Predicted Force Loss Due to Wire Stress Relaxation

Surveillance Number Years after SIT	(1) Wire Stress Relaxation %	(2) Maximum Lockoff Force Retensioned Vertical Tendons Kips	(3) = (1) x (2) Predicted Wire Stress Relaxation Loss Kips
15	5.28	1390	73.4
20	6.33	"	88.0
25	6.90	"	95.9
30	7.38	"	102.6
35	7.81	"	108.6
40	8.32	"	115.6

1.4.5 Normalization Factor

Ref.: Calc Book Z-4K, 1:18.5, page 98.

A normalization factor is added algebraically to the measured liftoff force to adjust the particular tendon liftoff force to an average tendon by accounting for the difference in elastic shortening and wire stress relaxation losses between individual tendons due to the position in the overall stressing sequence for the particular tendon. As one of the required surveillance activities, the average of the normalized individual tendon forces for each group of tendons is compared with the minimum required average prestress for that group of tendons to assure the design conditions for the containment are accounted for in the period up to the next scheduled surveillance. The normalization factors for the vertical tendons included in the 5th period tendon surveillance are calculated and shown on the table on the next page. The same methodology can be used for the vertical tendons for the remaining surveillances.

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NORMALIZATION FACTOR

VERTICAL TENDON NO.	(1) $Fave_o$, KIPS	(2) Fl_o KIPS	(3) SR(t) %	(4) $Fave_o$ - Fl_o KIPS	(5) (4) X [1 - SR(t)/100]	(6) ΔFles KIPS	N	n	(7) ΔFles x [(N-2n+1)/2N]	(5) + (7)	NF
7	1372	1352	8.32	20	18.34	5	22	12	-0.114	18.22	18
8	1372	1390	8.32	-18	-17.08	5	22	9	0.57	-16.51	-17
9	1372	1383	8.32	-11	-10.08	5	22	22	-2.4	-12.48	-13
39	1372	1374	8.32	-2	-1.08	5	22	20	-1.93	-3.01	-3
40	1372	1358	8.32	14	12.83	5	22	5	1.48	14.31	14
41	1372	1379	8.32	-5	-4.08	5	22	20	-1.93	-6.01	-6
89	1372	1383	8.32	-11	-10.08	5	22	7	1.02	-9.06	-9
90	1372	1363	8.32	9	8.25	5	22	3	1.93	10.18	10
91	1372	1366	8.32	6	5.5	5	22	11	0.114	5.61	6

NOTES:

1. Normalization Factor (NF) = [$Fave_o$ - Fl_o] [1 - SR(t)/100] + ΔFles [(N-2n+1) / 2N]

2. $Fave_o$ = average pf the retensioned lockoff force for all vertical tendons = 1372 kips

Fl_o = lockoff force for individual retensioned vertical tendon

SR(t) = % wire stress relaxation at time t. For the retensioned vertical tendons use the relaxation at 40 years for all surveillance tendons = 8.32%

ΔFles = maximum total elastic shortening loss for the first vertical tendon retensioned = 5 kips

N = total number of stressing sequences = 22

n = stressing sequence for the individual tendon

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1.5 RESULTS

The following Table lists the total predicted loss, F_{total}, applicable to all of the individual retensioned vertical tendons for the remaining surveillances.

SUMMARY OF PREDICTED LOSSES FOR RETENSIONED VERTICAL TENDONS

Surveillance Period Years after SIT	F_{les} Elastic Shortening Kips	F_{lsh} Concrete Shrinkage Kips	F_{lcr} Concrete Creep Kips	F_{lsr} Wire Stress Relaxation Kips	F_{total} Total Losses Kips
15	5	0.75	8.0	73.4	88
20	5	1.12	11.8	88.0	106
25	5	1.48	14.5	95.9	117
30	5	1.72	17.1	102.6	127
35	5	1.96	19.3	108.6	135
40	5	2.20	21.2	115.6	144

Notes:

1. The sum of the individual losses , F_{total}, is rounded upward to the next higher kip.

1.5 RESULTS (CONTINUED)

The following Table lists the Base Value, 0.95 Base Value, and 0.90 Base Value for the tendons in the 5th surveillance. The Base Values for tendons for the other remaining surveillances are calculated in the same manner, i.e. F_{total} for the particular surveillance is subtracted from the retensioned tendon lockoff force to obtain the Base Value.

PREDICTED LIFTOFF FORCES FOR RETENSIONED VERTICAL TENDONS

SURVEIL. PERIOD YEARS AFTER SIT	VERTICAL TENDON NUMBER	(1) RETENSION LOCKOFF FORCE KIPS	(2) TOTAL LOSSES KIPS	(1) - (2) PREDICTED BASE VALUE KIPS	0.95 X BASE VALUE KIPS	0.90 X BASE VALUE KIPS
15	7	1352	88	1264	1200	1137
15	8	1390	88	1302	1236	1171
15	9	1383	88	1295	1230	1165
15	39	1374	88	1286	1221	1157
15	40	1358	88	1270	1206	1143
15	41	1379	88	1291	1226	1161
15	89	1383	88	1295	1230	1165
15	90	1363	88	1275	1211	1147
15	91	1366	88	1278	1214	1150

NOTES:

1. When calculating 0.95 Base Value and 0.90 Base Value, decimal fractions are rounded downward to the nearest kip.

2/15/89

XC: J. LISNEY
D KRAUSE

P.30

Gilbert/Commonwealth engineers and consultants

GILBERT/COMMONWEALTH, INC., P.O. Box 1498, Reading, PA 19603/Tel. 215 775-2600/Cable Gilasoc/Telex 836-431

February 7, 1985

Commission of the European Communities
DG XIII - A-3 - Groupe de Liaison
(Attn: Mme J. Stalpaert)
MDB 4/28
200, rue de La Loi
B-1049, Brussels, Belgium

Dear Mrs. Stalpaert:

Please find the enclosed manuscript "INSERVICE INSPECTION OF RETENTIONED TENDONS," Paper D8/5 for the 8th SMiRT Conference. I believe that the requirement of a 6 page limit has been met. The text is 4 pages; and the 2 tables, when reduced, will comprise another page. The 6 figures will stand reduction fo 1/4 scale, thus allowing all figures to be set on one page.

Thank you.

Very truly yours,

J. F. Fulton

J. F. Fulton

JFF:flg
Enclosure

cc: C. A. Forbes (RG&E)
J. C. Herr
D. R. Campbell

INSERVICE INSPECTION FORCES MEASURED IN RETENSIONED TENDONS

by

J. F. Fulton - Gilbert/Commonwealth, Inc.
P.O. Box 1498
Reading, PA 19603, U.S.A.

C. A. Forbes - Rochester Gas and Electric Corporation
89 East Avenue
Rochester, New York 14649, U.S.A.

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

Appreciation is expressed to Rochester Gas and Electric Corporation for permission to publish this paper. The stress relaxation tests at Lehigh University were conducted by Professor R. G. Slutter, and his cooperation is also appreciated.

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) PREDICTED WITH RT (1)	PREDICTED BASE (2)	MEASURED (3)		MEAS.-PRED./PREDICTED (%) WITH RT (4)	BASE (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

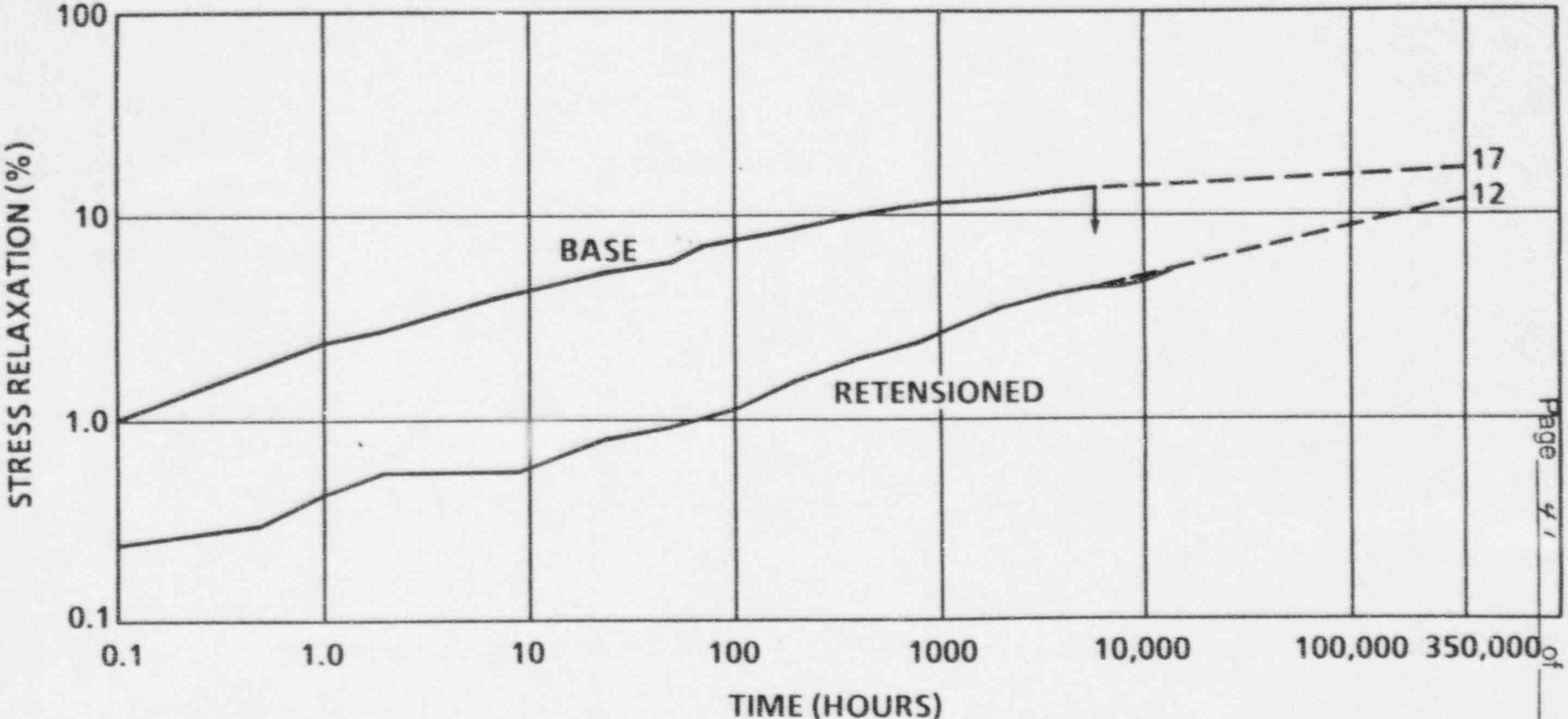

FIGURE 1
BASE AND RETENSIONED STRESS RELAXATION FOR WIRE NO. 3

Calc: DC0 2050-002 Rev. 0
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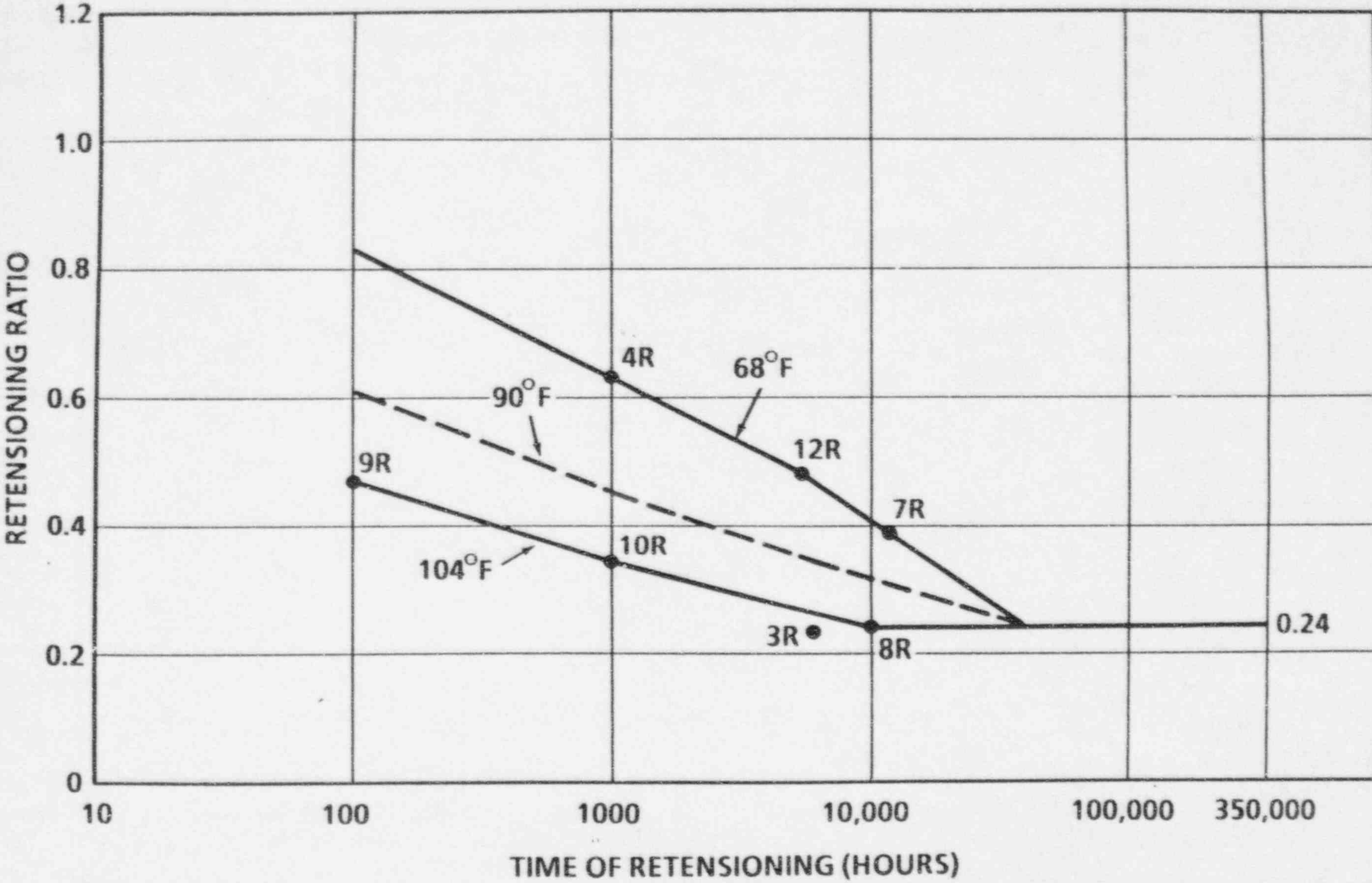

FIGURE 2
RETENSIONING RATIO -
1000 HRS. AFTER RETENSIONING

Calc: DC0 3050-002 Rev. 0
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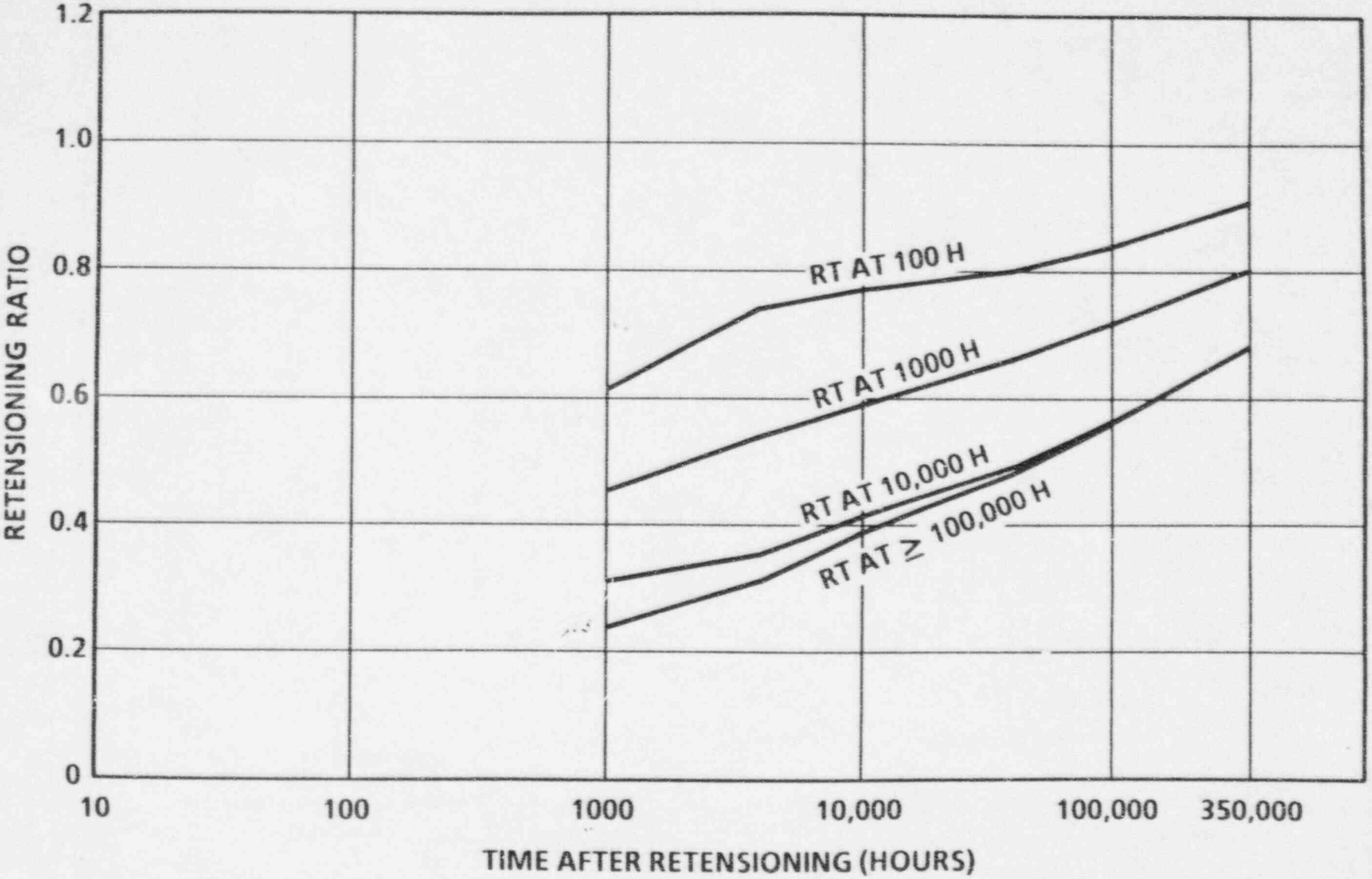

FIGURE 3
RETENSIONING RATIO - 90°F

Calc: DC0 3050-002 Rev. 0
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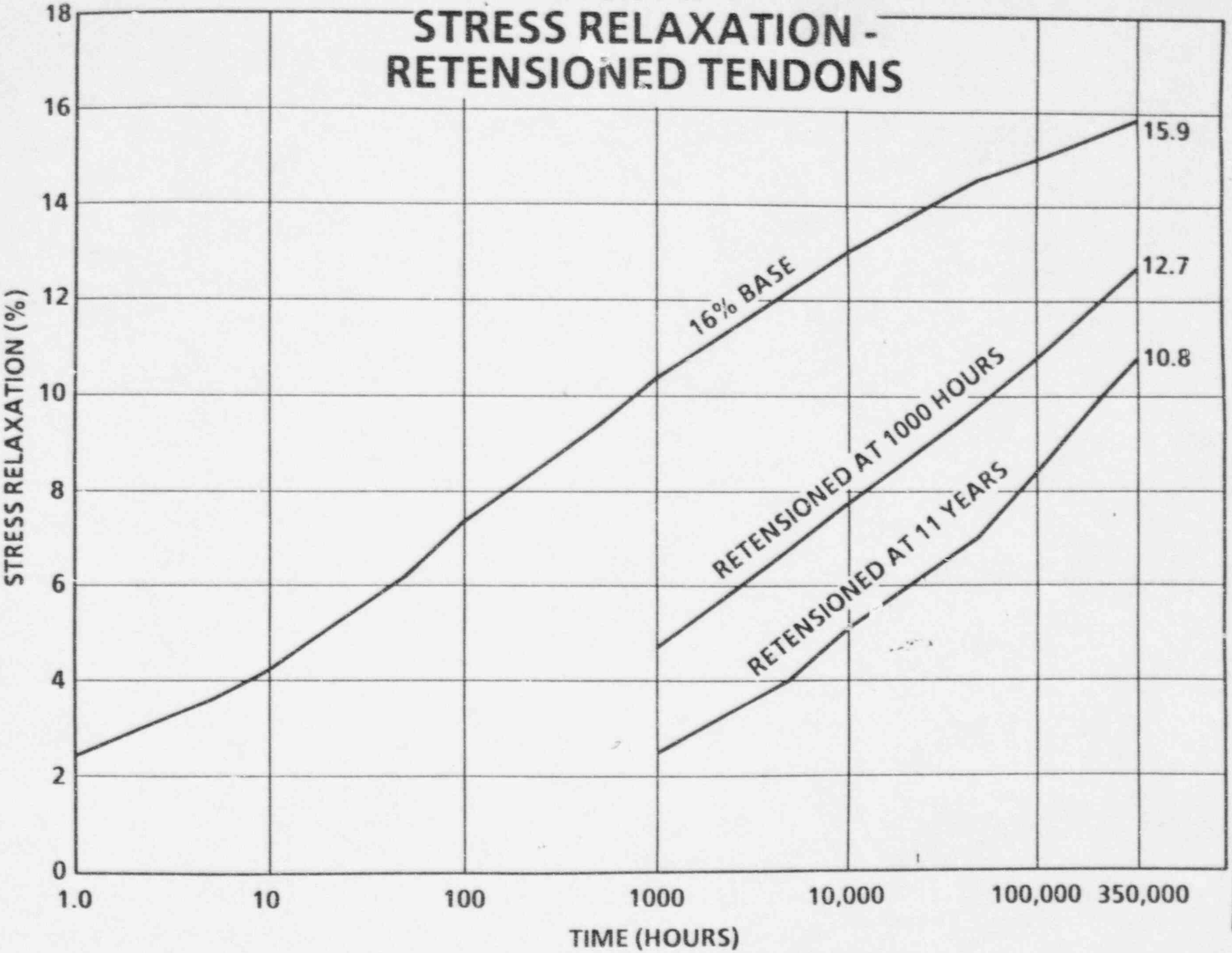
FIGURE 4
STRESS RELAXATION - RETENSIONED TENDONS



Calc: DC0 3050-002 Rev. 0
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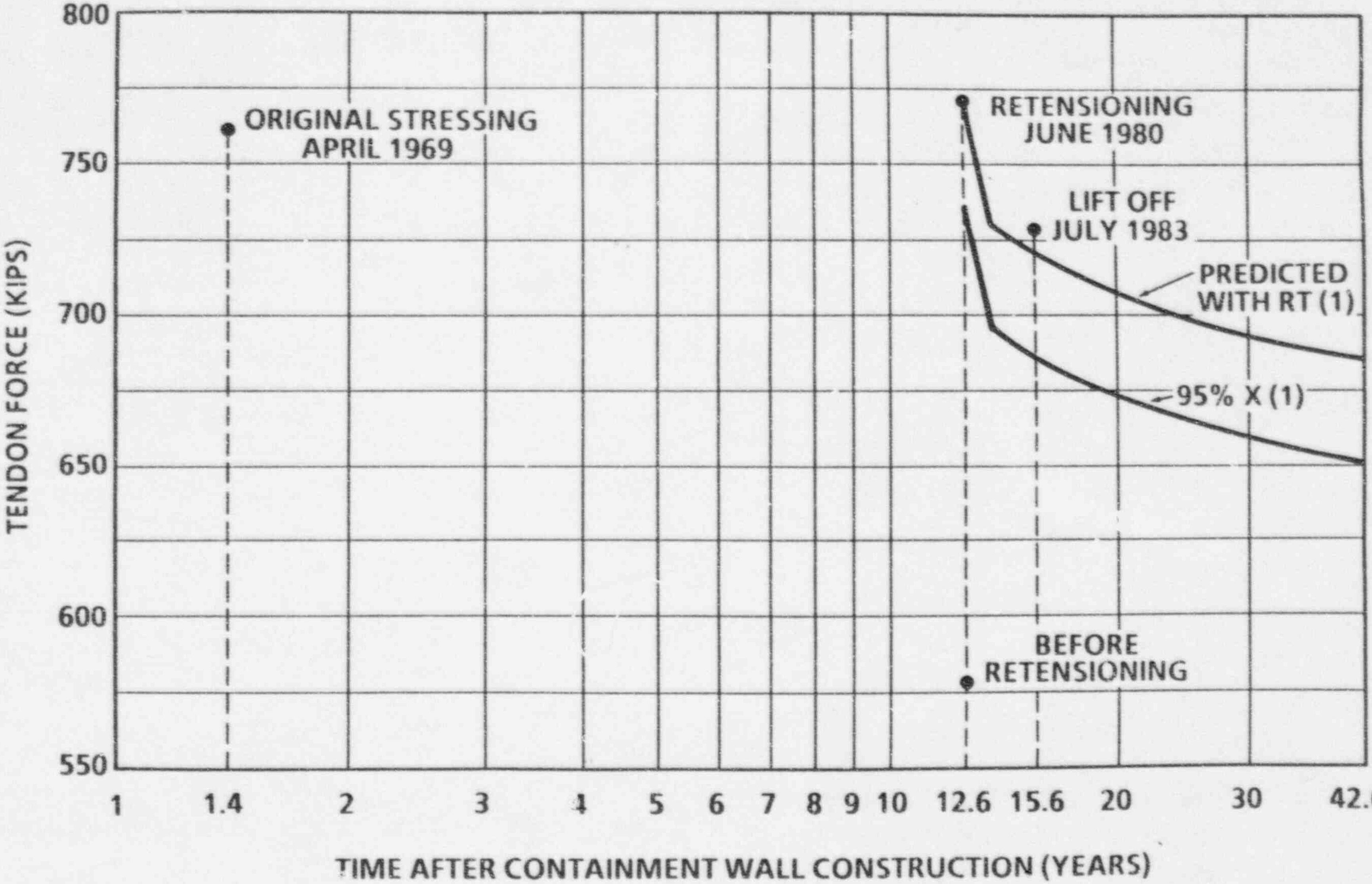
P.4

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



Calc: DC0 3050-002 Rev. 0
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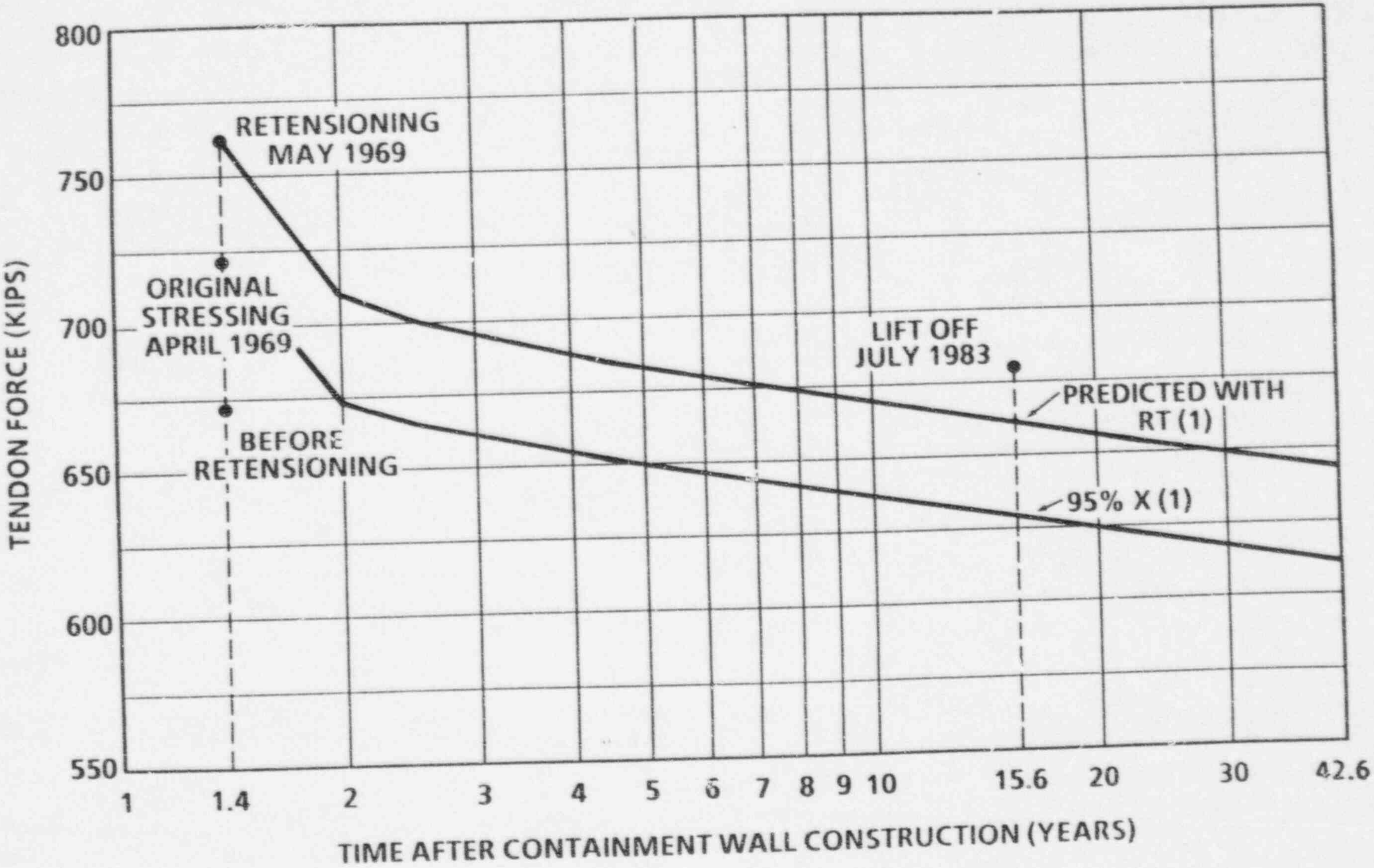
FIGURE 6
COMPARISON OF PREDICTED AND MEASURED FORCES FOR TENDON NO. 120



Calc: DC03060-002 Rev. 0
Page 46 of 46

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SUBJECT CODE 305	SOUTH CAROLINA ELECTRIC AND GAS COMPANY CALCULATION RECORD	PAGE 1 OF 7

CALC TITLE	CALC NO.	REV	STAT
CORRECTED FORCE PREDICTION FOR V40	DC03050-002	1	A RBW 1/17/96

PARENT DOCUMENT	SYSTEM	SAFETY CLASS
STP0160.001	BS	NN QR [SR]

ORIGINATOR	DISC	ORGANIZATION	DATE	XREF NO.
PARSONS, G. P.	CS	SCE&G DE	1/16/96	DC03050-002

A. CALCULATION INFORMATION

CONTENT DESCRIPTION:

THIS CALCULATION REVISION CORRECTS THE PREDICTED TENDON FORCE FOR TENDON V40 FOR THE FIFTH PERIOD TENDON SURVEILLANCE.

AFFECTED COMPONENTS/ANALYSIS:

VERTICAL TENDON V40

FOR INFORMATION ONLY

CONTAINS PRELIMINARY DATA/ASSUMPTIONS:

☒ NO ☐ YES, PAGES

COMPUTER PROGRAM USED: ☒ NO

☐ YES, VALIDATION NOT REQ'D. [REF. 3.5]
☐ YES, VALIDATED [ES-412]
☐ YES, VALIDATED [OTHERS]
☐ PROGRAM VALIDATION CALCULATION

B. VERIFICATION

VERIFICATION SCOPE

VERIFY CORRECTED "AS LEFT" VALUE FROM PAGE 9 OF REVISION 0 IS USED AND THAT THE CORRECT VALUE IS CARRIED THROUGH THE CALCULATION. ONLY A SPOT CHECK OF THE MATH IS REQUIRED.

VERIFIER: WHORTON, R. B.

ASSIGN BY: WHORTON, R. B.

Greg Parsons 1/17/96
LEAD ENGINEER (DESIGNEE)/DATE

VERIFIER / DATE	APPROVAL / DATE
RBWhorton 1/17/96	RBWhorton 1/17/96

C. RECORDS

TO PRS: ______ ______________
INIT/DATE

REEL NUMBER:

FRAME NUMBER:

ORIGINAL MAINTAINED BY:

DISTRIBUTION: CALC FILE [ORIGINAL]
PDE ______________ /SYSTEM ENG ______________ /DE FILE 20.6602 [ATTACH. 1 ONLY, COPY]

SOUTH CAROLINA ELECTRIC & GAS COMPANY
REVISION SUMMARY

PAGE
2 OF 7

CALCULATION NO.
DC03050-002

REV NO.	SUMMARY DESCRIPTION
1	The purpose of revision 1 of this calculation is to correct an error in revision 0 of this calculation. The error in the original calculation is contained on pages 23, 27and 32 of 46. The corrected pages follow this page. After all of the vertical tendons were retensioned, a second reading was obtained for the first four tendons to be restressed. Tendon V 40 was the only one of the four to increase in value. Revision 0 of this calculation used the first value. However, upon further review, it was determined that the second "as left" value is the correct value. Therefore, this calculation is being revised.

☐ CONTINUES ON PAGE

ENGINEERS
TECHNICAL WORK RECORD

Serial 10606
Engineer G. Parsons
Date 1/17/96

Project Title RB Vertical Tendon Force Calculations
Page 1 of_

A. PURPOSE:

The purpose of revision 1 of this calculation is to correct an error in revision 0 of this calculation. The error in the original calculation is contained on pages 23, 27and 32 of 46. The corrected pages follow this page.

B. DESIGN INPUTS:

The revision to this calculation is a correction to the previous revision. This revision has no inputs. This revision simply corrects a calculation of the previous revision.

C. COMPUTER CALCULATIONS:

There are no computer calculations in this revision.

D. ASSUMPTIONS:

There are no assumptions in this revision which require future conformation.

E. METHODOLOGY:

The methodology used in making this revision is identical to the methodology used in the base calculation.

F. CALCULATION DOCUMENTATION:

Calculation documentation is contained in the following pages.

G. SUMMARY:

After all the vertical tendons were retensioned, a second reading was obtained for the first four tendons to be re-stressed. Tendon V 40 was the only one of the four to increase in value. Revision 0 of this calculation used the first value. However, upon further review, it was determined that the second "as left" value is the correct value. Therefore, this calculation is being revised. The results are contained on page 7 of 7 of this revision.

ENGINEERS

TECHNICAL WORK RECORD

Serial ______

Engineer D. Krause

Date ______

Project Title ______ Tab ___ Page 6 of ___

Calc: DC03050-002 Rev. 0
Page 9 of 46

Calc: DC03050-002 Rev. 1
Page 4 of 7

VERTICAL TENDON RETENSIONING OF THE
V.C.SUMMER UNIT 1 REACTOR BUILDING

TABLE V: (CONTINUE)

TENDON	JACK			NO.OF EFFE-CTIVE WIRES	BEFORE RETENSIONING			AFTER RETENSIONING		
	ID.	AREA (IN2)	CONSTANT (KIP)		LIFT OFF PRESS. (PSI)	LIFT OFF FORCE (KIP)	SHIM THCKNS (IN)	LIFT OFF PRESS. (PSI)	LIFT OFF FORCE (KIP)	SHIM THCKNS (IN)
V36 ##	9365 9362	209.970 210.999	-4.664 -9.479	170	5687	1189	12.70	6573 6547	1375 1372	14.15
V37	9362	210.999	-9.479	170	5700	1193	16.30	6535	1369	17.70
V38	9363	211.033	-7.500	170	5657	1186	14.20	6560	1377	16.00
V39	9362	210.999	-9.479	170	5697	1193	14.00	6555	1374	15.70
V40 ##	9365 9362	209.970 210.999	-4.664 -9.479	170	5587	1168	13.50	6490 6517	1358 1366	15.20
V41	9362	210.999	-9.479	170	5663	1185	13.90	6580	1379	15.70
V42	9363	211.033	-7.500	170	5620	1179	13.50	6580	1381	15.40
V43	9362	210.999	-9.479	169	5855	1226	15.15	6553	1373	16.55
V44 ##	9365 9362	209.970 210.999	-4.664 -9.479	170	5780	1209	13.60	6530 6513	1366 1365	15.10
V45	9362	210.999	-9.479	170	5610	1174	14.30	6560	1375	16.15
V46	9362	210.999	-9.479	169	5913	1238	12.75	6565	1376	13.90
V47	9362	210.999	-9.479	170	5697	1193	14.00	6580	1379	15.60
V48	9362	210.999	-9.479	170	5708	1195	13.35	6560	1375	15.00
V49	9362	210.999	-9.479	170	5693	1192	13.30	6460	1354	15.00
V50	9362	210.999	-9.479	170	5675	1188	16.40	6513	1365	18.10
						Σ17,908			Σ20,580	

27

CORRECT VALUE

THIS VALUE IS CORRECT. IT USED THE CORRECT VALUE

Verification

Type of Verification	Verifier Signature/Date

Approval

Signature/Date

VERTICAL TENDON PREDICTED WIRE RELAXATION FORCE LOSSES
5TH SURVEILLANCE PERIOD

VERTICAL TENDON NO.	(1) RETENSIONED VERTICAL TENDON LOCKOFF FORCE KIPS	(2) PREDICTED WIRE STRESS RELAX. AT 5TH SURVEILLANCE %	(3) PREDICTED WIRE STRESS RELAXATION FORCE LOSS KIPS
V7	1352	5.28	71.4
V8	1390	"	~~73.04~~ 73.4 MAA 4/8/96
V9	1383	"	73.0
V39	1374	"	72.5
V40	~~1358~~ 1366	"	~~71.7~~ 72.1
V41	1379	"	72.8
V89	1383	"	73.0
V90	1363	"	72.0
V91	1366	"	72.1

REV. 1

NOTES:

1. The retensioned vertical tendon lockoff forces are from PSC Corp. Vertical Tendon Retensioning Report Volume 1, Section 2, Table V.

Determine Feasibility of Using One Set of Losses Applicable to all Retensioned Vertical Tendons:

The following study is performed to determine the feasibility of establishing a single loss for predicted force versus time applicable to all of the vertical tendons. In this case all of the vertical tendons is considered as one subgroup. To determine the feasibility, the two causes of losses that depend on variables which change from tendon to tendon will be reviewed, i.e. the wire relaxation loss which depends on the lockoff force at retensioning and the elastic shortening which depends on the sequence of stressing.

Verification		Approval
Type of Verification	Verifier Signature / Date	Signature / Date

ENGINEERS

TECHNICAL WORK RECORD

Serial ____________

Engineer D. Krause

Date ____________

Project Title ______________________ Tab ___ Page 27 of ___

Calc: DC0 3050-002 Rev. 0
Page 30 of 46

Calc: DC0 3050-002 Rev. 1
Page 6 of 7

NORMALIZATION FACTOR

VERTICAL TENDON NO.	(1) Fave$_o$ KIPS	(2) Fl$_o$ KIPS	(3) SR(t) %	(4) Fave$_o$ - Fl$_o$ KIPS	(5) (4) X [1 - SR(t)/100]	(6) ΔFles KIPS	N	n	(7) ΔFles x [(N-2n+1)/2N]	(5) + (7)	NF
7	1372	1352	8.32	20	18.34	5	22	12	-0.114	18.22	18
8	1372	1390	8.32	-18	-17.08	5	22	9	0.57	-16.51	-17
9	1372	1383	8.32	-11	-10.08	5	22	22	-2.4	-12.48	-13
39	1372	1374	8.32	-2	-1.08	5	22	20	-1.93	-3.01	-3
40	1372	1366 ~~1358~~	8.32	6 ~~14~~	5.5 ~~12.83~~	5	22	5	1.48	6.78 ~~14.31~~	7 ~~14~~
41	1372	1379	8.32	-5	-4.08	5	22	20	-1.93	-6.01	-6
89	1372	1383	8.32	-11	-10.08	5	22	7	1.02	-9.06	-9
90	1372	1363	8.32	9	8.25	5	22	3	1.93	10.18	10
91	1372	1366	8.32	6	5.5	5	22	11	0.114	5.61	6

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NOTES:

1. Normalization Factor (NF) = [Fave$_o$ - Fl$_o$] [1 - SR(t)/100] + ΔFles [(N-2n+1) / 2N]

2. Fave$_o$ = average pf the retensioned lockoff force for all vertical tendons = 1372 kips

Fl$_o$ = lockoff force for individual retensioned vertical tendon

SR(t) = % wire stress relaxation at time t. For the retensioned vertical tendons use the relaxation at 40 years for all surveillance tendons = 8.32%.

ΔFles = maximum total elastic shortening loss for the first vertical tendon retensioned = 5 kips

N = total number of stressing sequences = 22

n = stressing sequence for the individual tendon

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1.5 RESULTS (CONTINUED)

The following Table lists the Base Value, 0.95 Base Value, and 0.90 Base Value for the tendons in the 5th surveillance. The Base Values for tendons for the other remaining surveillances are calculated in the same manner, i.e. F_{total} for the particular surveillance is subtracted from the retensioned tendon lockoff force to obtain the Base Value.

PREDICTED LIFTOFF FORCES FOR RETENSIONED VERTICAL TENDONS

SURVEIL. PERIOD YEARS AFTER SIT	VERTICAL TENDON NUMBER	(1) RETENSION LOCKOFF FORCE KIPS	(2) TOTAL LOSSES KIPS	(1) - (2) PREDICTED BASE VALUE KIPS	0.95 X BASE VALUE KIPS	0.90 X BASE VALUE KIPS
15	7	1352	88	1264	1200	1137
15	8	1390	88	1302	1236	1171
15	9	1383	88	1295	1230	1165
15	39	1374	88	1286	1221	1157
15	40	1366 ~~1358~~	88	1278 ~~1270~~	1214 ~~1206~~	1150 ~~1143~~
15	41	1379	88	1291	1226	1161
15	89	1383	88	1295	1230	1165
15	90	1363	88	1275	1211	1147
15	91	1366	88	1278	1214	1150

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NOTES:

1. When calculating 0.95 Base Value and 0.90 Base Value, decimal fractions are rounded downward to the nearest kip.

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