RPSEA
FINAL REPORT

RPSEA Document Number: 09121-3500-02.FINAL

SRP SHRINK-FIT CONNECTION
09121-3500-02

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LEGAL NOTICE

ABSTRACT

The Shrink-Fit connection approach to riser fabrication has been successfully designed and developed to enable the manufacture of riser systems from high strength thick walled pipe that are capable of operating with high internal pressures, beyond that which are typically available within the industry today. This technology has already been employed for manufacture of a shallow water drilling riser system in the North Sea.

The objective of this project is to prove that the connector is suitable for deepwater environmental conditions, which would include resonant fatigue testing of a Shrink-Fit connection. As an alternative to welding this technology facilitates the fabrication of riser joints from high and ultra-high strength sour service qualified steel (80 - 130 ksi). Through qualifying such a system that can be manufactured from steel in excess of 80 ksi, the wall thickness of the pipe can be significantly reduced, which in turn will reduce the weight, current loading (due to reduced diameter), tensioner requirements and cost of manufacture of critical deepwater riser systems.

This Final Report is a RPSEA deliverable and describes all stages in the project, including result from testing.

SIGNATURE AND DATE STAMP:

23rd February 2012

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CONTENTS

1 EXECUTIVE SUMMARY

The project under RPSEA to resonant bend fatigue test the SRP shrink-fit coupling was completed in seven months, beginning March 2011, such that it is now 'project ready'. All testing activities were completed on time, within budget. The finished couplings joined sour service qualified API 5CT SM-C110 11-3/4 inch pipe with a 1.1 inch wall thickness. These couplings had a 100 percent hydrotest pass rate at 22,500 psig (15 ksi working pressure). No selective assembly was employed illustrating the insensitivity to machining tolerances of the connector, and therefore its manufacturability.

The fatigue results show a DNV-RP-C203 C1-Class SCF of 1.46 (mean minus 2 standard deviations), equalling 'best in class' welded couplings. It is clear that these results could be improved to around C1, 1.35 by making only very simple changes. Industry partners have made recommendations for further work which include further runs to increase the amount of data-points by 2-4, and work to qualify finite element models as a fatigue life prediction tool.

Failure occurred in all cases by slow leak out of one side of the coupling, the cause of failure was cracking of the pipe where it enters the flange.

2 INTRODUCTION

2.1 Project Scope

The objective of this project is to qualify the shrink-fit technology to 'project ready' status. This involved hydrostatic and resonant fatigue testing of a Shrink-Fit connection which enables the avoidance of welding, and facilitates the fabrication of riser joints from high and ultra-high strength steel (80 - 130 ksi). Through qualifying such a system, the wall thickness of the pipe can be significantly reduced, which in turn will reduce the weight, current loading, tensioner requirements and cost of manufacture of critical deepwater riser systems.

2.2 Narrative

Six large scale specimens were used in place of full bore (21 inch) high pressure shrink-fit coupling in order to demonstrate that:

- Pressure containment is maintained for maximum working and hydro-test pressures
- Target fatigue life is achievable without loss of pressure integrity in the connection

The couplings were fabricated from ASTM A182 Grade F22 [7] modified, 80 ksi forging stock. The 11.75 inch OD, 1.1 inch WT SM-C110 [6] pipe was supplied to the project by BP and machined by SRP.

The Project Management Plan [1], Technology Status Assessment [2], Technology Transfer Plan [3] and Design Report [4] were submitted to RPSEA before any detailed machining of the pipe and flanges. After machining, the two pipes were connected together using a shrink-fit coupling. This occurred as and when pipe and couplings became available, and the resulting assemblies were pressure tested at the designated test pressure of 22,500 psig.

Fatigue testing commenced as soon as fatigue bay, test specimen and availability allowed. The procedure was driven by the qualification test plan [5]; with six specimens comprising 12 shrink-fit connections tested over a period of approximately one month.

3 DESIGN PHASE

3.1 Introduction

The couplings, once thermally expanded, swallow the pipe with the pipe butting against a shoulder, as shown in and Figure 3.2. Very high pressure rated seals are created at the pipe ends. Sealing sufficient to retard seawater ingress is located at the extremities of the coupling.

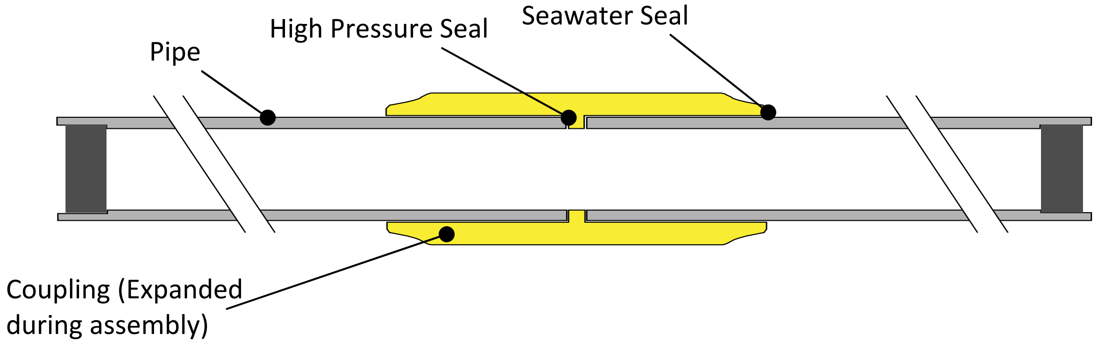


Figure 3.1 – Cross-Sectional Diagram of Shrink-Fit Connection

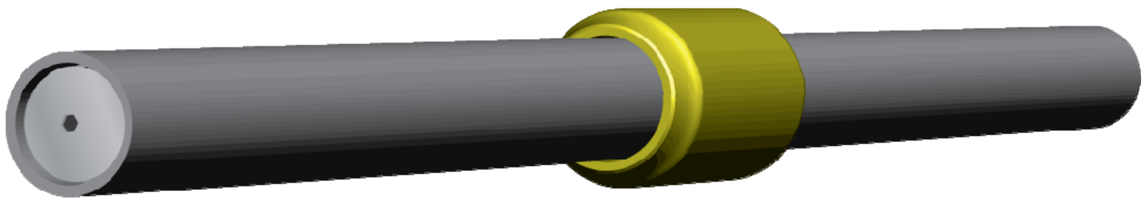


Figure 3.2 – Isometric View of Fatigue Test Specimen

The design phase, fully documented in the RPSEA Design Report [4], addressed the following topics:

- Residual Shrink-Fit stresses
- Safe hydrotest pressure
- Predicted connection fatigue response
- Choice of internal pressure for fatigue testing

Section 3.2 is an extract from the design report which focuses on the fatigue predictions.

3.2 FEA Fatigue Predictions

In deepwater drilling and production riser connections, the component of load which causes fatigue is generally cyclic bending stresses. This is what the resonant bending test aims to simulate. Varying bending transforms to varying axial stress, which can be reported from finite element analyses. These axial stress ranges are compared to the nominal pipe stress ranges, to give an SCF (Stress Concentration Factor). Stress ranges are obtained by analyzing load cases with bending in equal and opposite directions.

Stress ranges are modified according to DNV-RP-C203 [8], since the parent material can have stress ranges which are partly in compression. The compressive contribution to the range is multiplied by 0.6. The pressurized fatigue samples have less of their stress range in compression; therefore exhibit higher modified stress ranges and associated SCF's. The pipe fatigue is worse under internal pressure, since at most severe stress concentration 'B', there is no stress range reduction due to compression (see Table 3.1 and Figure 3.3).

The worst fatigue location (at design phase) was hypothesized to be near fatigue location 'B' on the pipe, on the outer diameter (OD) of the pipe as it enters the coupling. At this location slight rubbing 'fretting' between the coupling and pipe could reduce the fatigue life. A detailed discussion of the causes and severity of this effect is beyond the scope of this report.

It is considered that a 5 ksi internal pressure would be unrealistic since there are no drilling or production riser connections which would be expected to be below this pressure during the majority of fatigue motions. Therefore a 3 ksi internal pressure was selected for the fatigue testing.

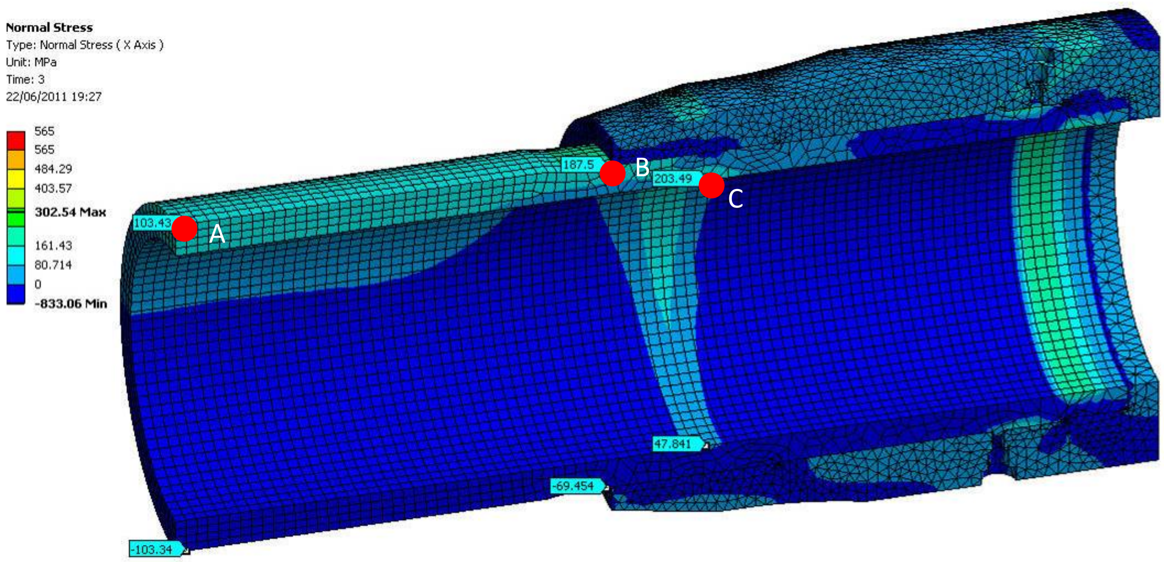


Figure 3.3 – Pipe Stress Range Investigation, Ambient Internal Pressure

Internal Pressure	Location	Dir1 (ksi)	Dir2 (ksi)	Basic Stress Range (ksi)	Modified Stress Range* (ksi)	Basic SCF	Modified SCF*
0 ksi	A	15.0	-15.0	30.0	24.0	1.00	0.80
	B	27.2	-10.1	37.3	33.2	1.24	1.11
	C	29.5	6.9	22.6	22.6	0.75	0.75
5 ksi	A	24.7	-5.3	30.0	27.9	1.00	0.93
	B	48.9	11.8	37.2	37.2	1.24	1.24
	C	40.0	20.8	19.3	19.3	0.64	0.64
**'Modified' is the reduction of the compressive section of the stress range by a factor of 0.6 [8].*							

Table 3.1 – Stress Ranges & SCF Values at Three Key Pipe Locations

4 MANUFACTURE

This section documents the steps taken to produce the Shrink-Fit coupling samples.

4.1 Pipe Information

The API 5CT SM-C110 11-3/4 inch pipe with a nominal 1.1 inch wall thickness were provided by BP for the purposes of destructive testing. Initially, the pipe was supplied in 39 foot lengths, which were then cut to size through our machining contractor. The pipe had been 100 percent volumetrically inspected at the pipe mill.

Figure 4.1 – API 5CT SM-C110 Pipe, Before & After Cut to Length

Further information was supplied regarding the pipe wall thickness variation based on a survey previously carried out by a specialist company (see Appendix A); the average wall thickness of the pipes was around 1.085in.

The detailed machining was carried out on a manual lathe; the internal diameter (ID) of the pipe was left un-machined. Around 0.2 inch was removed from diameter to ensure that the pipe could be made cylindrical, this proved to be unnecessary – and it is proposed that only 0.08 inch would have been required. This means that the thinning of the wall thickness could be reduced to a fraction of what it currently is; reducing the SCF of the connection by 10 percent (i.e., an SCF of 1.46 becomes 1.33).

Figure 4.2 – Machining Of Pipe Ends

4.2 Coupling Information

The SRP stress joint forgings were cut to produce the ASTM A182 Grade F22 coupling stock in the UK. There were seven pieces, of which six would be machined into project couplings (the last was for assembly test only). The pieces were crated and shipped to the selected machining contractor in Houston; clearing customs (see Figure 4.3). Further tests were carried out to confirm the material strength.

Figure 4.3 – Crated Coupling Forgings Arrive at Machining Contractor in Houston

The coupling stock was 100 percent ultrasonically inspected to API 6A PSL3/ASTM 388 requirements by a local NDT subcontractor, no relevant indications were found, and so detailed machining could begin.

4.3 Assembly

The shrink-fit assembly process works by expanding the female coupling or flange through the application of heat, after which the pipe is carefully inserted. The heat is provided in this instance by portable induction heating equipment.

Figure 4.4 – Pre-Assembly Test

Since the connection is a coupling, the assembly is carried out in two steps. First the pipe is lowered into the coupling which rests on an alignment plate on the ground, and after it cools, the entire connection is up-ended into the assembly tower. Then the second shrink-fit operation is performed and the entire sample is lowered down to cool.

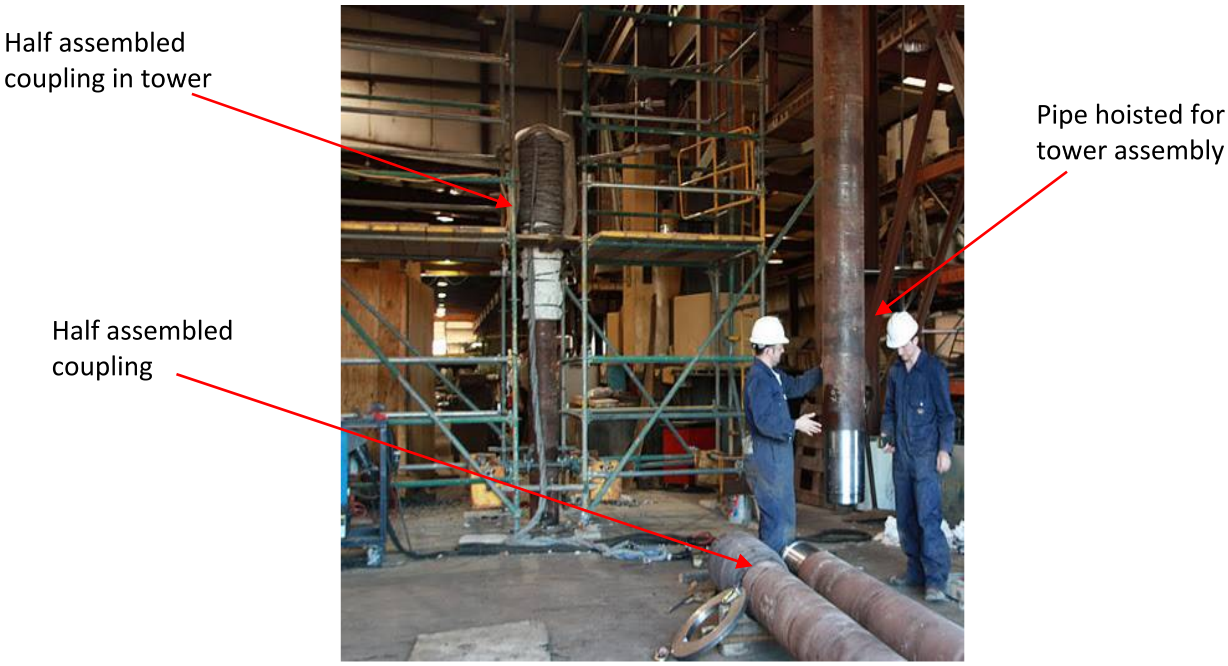


Figure 4.5 – Preparation for Second Shrink-Fit in Assembly Tower

It is possible to conduct the assembly horizontally and SRP has experience doing this for 21 inch shrink-fit flanges; however, this requires a more elaborate assembly rig which was not included within this project.

4.4 End-Cap Fabrication

Once assembly is complete, end-cap plates were welded inside the ends of the pipe for pressure containment. A large fillet weld was laid down, which was then stress relieved by post weld heat treatment (PWHT). This was carried out at Stress Engineering Services (SES), to SES pre-qualified weld procedures.

Figure 4.6 – End-Cap Fillet-Weld Into Pipe Bore

5 TESTING

5.1 Hydrotest

All joints were statically hydro-tested to 22,500 psig and then held for a minimum of 15 minutes using water as the pressure medium. This qualifies the joints to a 15 ksi working pressure, and is carried out prior to fatigue testing.

All six specimens passed the hydrotest, providing good evidence of consistent sealing independent of machining tolerances. Selective assembly was not employed, which underlines the manufacturability of the connection.

5.2 Resonant Bending Fatigue Test

The resonant bending fatigue tests were carried out at SES facilities in Houston. Six couplings (total of 12 connections) were subjected to constant amplitude resonant bending fatigue at three nominal stress ranges (two per connection) – for final results see Table 5.1.

A standard SES resonant fatigue machine is used, which consists of two supports, a variable speed electric motor, drive housing, and dead weight housing. The variable speed motor rotates an eccentric mass in the drive housing clamped to one end of the sample and loads the pipe. The rotational velocity of the motor is adjusted to load the sample near its natural frequency. The dead weight housing is clamped to the other end of the sample to balance the assembly (See Figure 5.1).

The stress was measured using 8off axial strain gauges on the outer diameter of the pipe (4off each side of the connector, 90-degree spacing). Maximum and minimum strain gauge readings were averaged for one minute intervals and the averages written to a results file. This forms the basis for calculating the stress ranges. Additional data recorded is the mean and standard deviation of the one minute averages, along with the cycle count.

Figure 5.1 – Resonant Bending Fatigue Test Pit, With Sample Installed

Fatigue testing was carried out filled with water, with an internal pressure of 3000 psig in order to check for leakage, and to provide an element of mean axial stress. 3000 psig is regarded as a test pressure which is reasonably representative of application for both drilling and production scenarios, and tests the connection fatigue beyond a nominal 'near-ambient' pressure.

The connection was resonated at high frequency (24Hz), and it was possible that heating of the connection may occur as an artefact of the testing. This was monitored with a thermocouple or hand-held IR device, and it was decided after some heating occurred (<120°F) to use a water spray to cool the OD of the connection. This was carried out for all samples except joint B, which was the first to be tested. Sample B was monitored and allowed to cool when its heat exceeded a threshold. See Appendix C for graphs of temperature over time and maximum temperature reached per sample.

Since the performance of the connection is unknown, the highest stress range was tested first, to establish a baseline of performance. As a result, the values of the medium and low stress ranges were adjusted in order to give confidence in the connection at a wide variety of stress ranges. Each sample was tested to failure.

SRP was interested to ascertain whether the order of assembly played any part in the failure mode. The assembly sequence described in Section 4.3, means that one pipe/coupling connection will be exposed to high temperatures twice (i.e., it is 'reheated'). By tracing through the assembly records, it is clear that there is no link between reheating and failure (see Table 5.1). In addition, there was no relationship between the sample orientation in the fatigue test rig (drive end or dead end), and failure.

Joint	A	B	C	D	E	F
Average Stress Range (PSIG)	31,538	31,878	21,600	21,921	14,272	13,500
Cycles to Leakage	569,532	1,205,874	1,631,135	1,045,711	2,603,934	2,956,179
Leaked Pipe Number	10	5	12	3	7	11
Connection Reheated?	Yes	Yes	Yes	No	No	No
Drive End or Dead End?	Drive	Drive	Drive	Dead	Dead	Drive

Table 5.1 – Fatigue Test Results

The failure mode of every coupling was by slow leakage, detected where the pipe enters the coupling (see Section 5.3 for in-depth analysis). For a standard statistical analysis of the fatigue results by Stress Engineering Services, please see Appendix C.

5.3 Post Fatigue Examination

After hydrotest and fatigue test, it was evident that the secondary locking was not engaged and this is evidence that the hydrotest did not overcome the friction fit of the connection, nor did the repeated action of the resonant fatigue test, combined with the tension due to end-cap load, cause the coupling to 'walk' along the pipe and engage the secondary locking.

After fatigue failures at SES, the mechanical locking chambers were opened and examined to determine whether hydrotest fluid had entered the chambers. All ports were found to be dry on post-failure inspection. This indicates that leakage was not due to failure of the main pressure seal, since it would have to fill the chambers in order to continue to the coupling neck and final leak.

Figure 5.2 – Cutting Samples for Post-Test Examination

The samples were then dissected in order to better ascertain the failure mode and location, and to direct possible design modifications. As shown in Figure 5.3, three girth cuts were made with a gas axe (red lines), and then the samples were split lengthwise (green line).

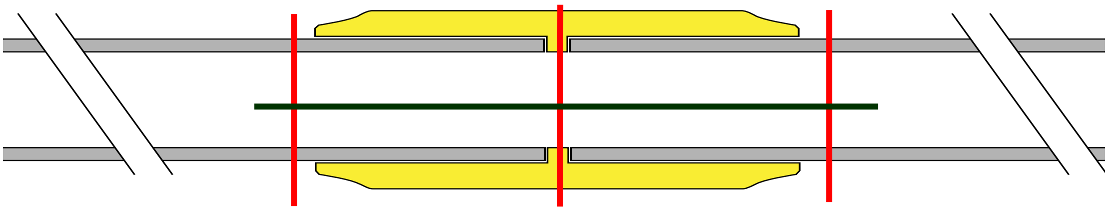


Figure **5.3 –** Sample Dissection

The bores and outer diameters of the pipes inside the couplings were examined for fatigue cracks using dye-penetrant inspection techniques. Cracks were found at the entry point of the pipe to the flange. The main seal remained intact, with the pressure escaping through the cracked pipe. A typical example of cracking picked up by dye penetrant testing is shown in Figure 5.4.

A summary of the non-destructive testing carried out on the samples is to be found in Appendix B, five out of the six failure points were identified as circumferential fatigue cracking of the pipe. It is considered that the remaining failure point failed in the same manner, but that the NDT investigation failed to detect it, possibly due to the dissection intersecting the indication.

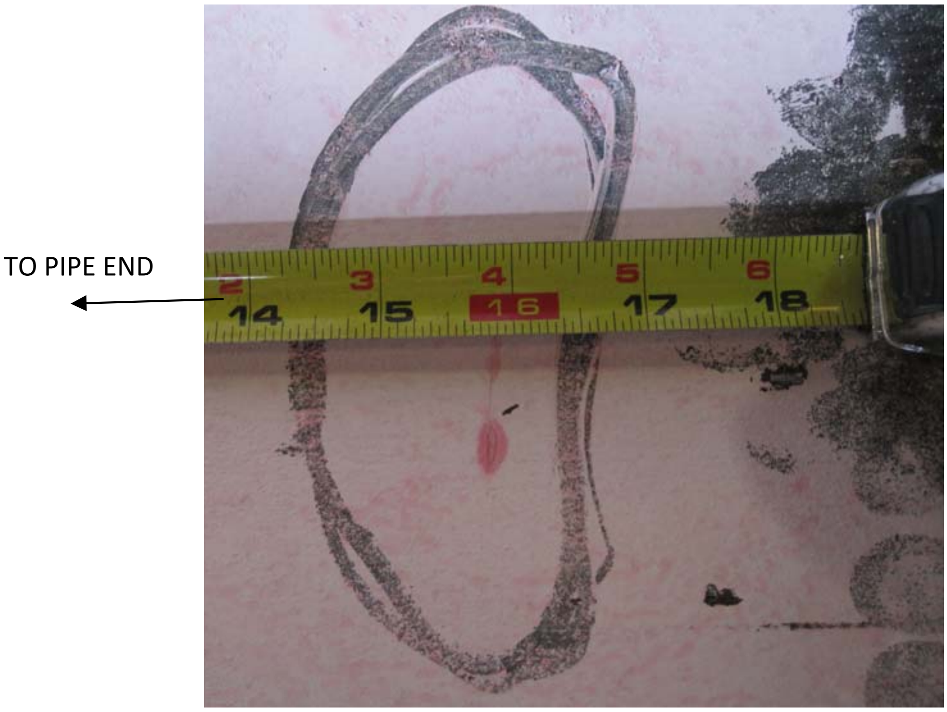


Figure 5.4 – Pipe Bore Cracking, Measurement Taken From Pipe End

5.4 Results Reception & Recommendations

After reviewing the results, industry partners present at the TAC meeting indicated that the fatigue and hydrotest results of the project were very favourable. Recommendations were made for further work, including:

- Additional 12-15 data points at various stress ranges, with some in the region 10^7-10^8 cycles.
- Experimentation with taper neck area geometry at pipe-coupling transition.
- Recommendation to qualify a finite element model for fatigue life prediction.

6 REFERENCES

[1] Subsea Riser Products Ltd., "Project Management Plan" RPSEA Report 09121-3500-02.01

[2] Subsea Riser Products Ltd., "Technology Status Assessment" RPSEA Report 09121-3500-02.02

[3] Subsea Riser Products Ltd., "Technology Transfer Plan" RPSEA Report 09121-3500-02.03

[4] Subsea Riser Products Ltd., "Design Report" RPSEA Report 09121-3500-02.04

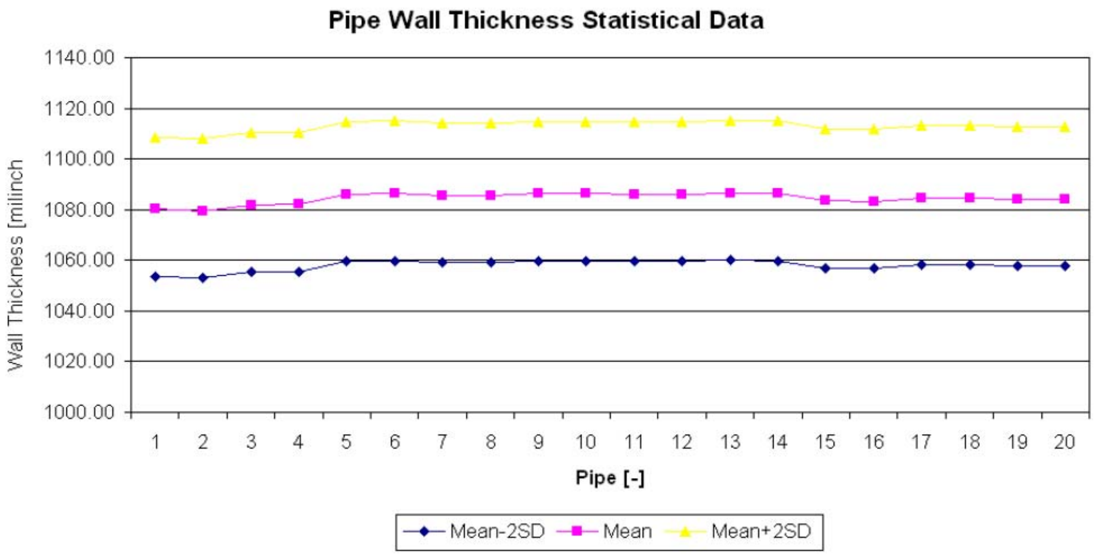
[5] Subsea Riser Products Ltd., "Qualification Procedure & Test Plan" RPSEA Report 09121-3500-02.05

[6] Sumitomo Tubulars, TGP-2517 Proprietary SM-C110 Casing Material.

[7] ASTM A182/A182M-11a "Standard Specification for Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High Temperature Service"

[8] DNV RP C203, "Fatigue Design of Offshore Steel Structures" 2010.

Appendix A


Pipe Wall Thickness Statistical Data
Wall Thickness [milinch
1140.00
1120.00
1100.00
1080.00
1060.00
1040.00
1020.00
1000.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Pipe [-]
Mean-2SD
Mean
Mean+2SD

Appendix B – NDT REPORT, POST FAILURE EXAMINATION

RADIOGRAPHIC SPECIALISTS, INC.

4110 MOHAWK
HOUSTON TX 77093

Ph. 281-449-1634
Fax 281-449-1640

TO: Camec Fab.

DATE: 1-4-12
P. O. NO. 5838
JOB NO.
DEL SLIP

LOCATION: RSI

MAGNETIC PARTICLE INSPECTION REPORT

ITEM NO.	DESCRIPTION	REJ	ACC	COMMENTS
1	D3 A	X		Crack I.D. & O.D.
	B		✓	
1	B5 A	X		Crack I.D. & O.D.
	B		✓	
1	F11 A		✓	
	B		✓	
1	E7 A		✓	
	B		✓	
1	A11 A	X		Crack I.D.
	B		✓	

Materials Used 3Gals 8SCA
APPLICABLE SPECIFICATION E709
ACCEPTANCE STANDARD AWS D1.1
SCOPE OF EXAMINATION 100% split Rings - 2 halves
PROCEDURE NO. MT-5 ✓
METHOD: WET ______ DRY ______
INSTRUMENT USED Electromagnet
MODEL: ES-X S/N 17550
AMPERES: 6 amps - 10 lb. Lift
CURRENT: AC ✓ DC ______

FLUORESCENT
BLACK LIGHT:
CALIBRATION:
LIGHT METER:
PREPARED BATH Circle Safe
TYPE: 8SCA
BATCH NO.: 16116
LEVEL II

TECHNICIAN J C Mitchell
WITNESSED BY
CUSTOMER
TIME LEFT RSI:
TIME ARRIVED RSI:

Radiographic Specialists, Inc.

4110 Mohawk
Houston, Tx 77093

Ph.281-449-1634
Fax.281-449-1640

To: Camec Fab

Date: 1-4-12
P.O.No. 5838
Job No.
Del.Slip

Location: RSI

Liquid Penetrant Inspection

Item No. # Of Pc's	Description	Rej.	Acc.	Comments
1	D3 A		✓	
	B		✓	
1	B5 A	X		crack OD & I.D
	B		✓	
1	F11 A		✓	
	B		✓	
1	E7 A		✓	
	B		✓	
1	A10 A		✓	
	B		✓	

Materials: 2 cans dye, 2 cans dev

Applicable Specification: E165

Acceptance Standard: AWS D1.1

Scope Of Examination: 100% split Ring - 2 halves

Procedure No. PT-6
Type Met-L-Check
Penetrant VP-30
Application: Spray X
Developer D-70
Application: Spray X
Examination: Visual X

Visible ✓
Batch No. 1561
Dip
Batch No. 2207
Dip

Fluorescent
Dwell Time: 30 Min.
Other
Dwell Time 30 Min.
Other

Blacklight

Technician: J Mitchell

Level: II

Witnessed By:

Date:

Customer:

Depart R.S.I

Arrive R.S.I

Radiographic Specialists, Inc.

4110 Mohawk
Houston, Tx. 77093

Ph.281-449-1634
Fax.281-449-1640

To: CAMEO FABRICATION

Date: 12-7-11
P.O.No
Job No. 5838
Del.Slip

Location: R.S.I.

Liquid Penetrant Inspection

Item No. # Of PC's	Description	Acc.	Rej.	Comments
22	10" PIPE SPLIT IN TWO PC'S	X		
2	10" PIPE SPLIT IN TWO PC'S		X	

Materials 6 CANS CLEANER,3 CANS PEN. , 3 CANS DEV.

Applicable Specification SE165

Acceptance Standard ASME SEC. VIII DIV. I APP. 6 PARG. 6.4

Scope Of Examination 100%ACCESSIBLE AREAS

Procedure No. PT-6
Type Met-L-Check
Penetrant VP-30
Application: Spray X
Developer D-70
Application: Spray X
Examination: Visual X

Visible
Batch No. 15655
Dip
Batch No 6316F10
Dip

Fluorescent
Dwell Time: 30 Min.
Other
Dwell Time 30 Min.
Other
Blacklight

Technician: TIM BRADLEY

Level: III

Witnessed By:

Date:

Customer:

Depart R.S.1

Arrive R.S.1

Appendix C – STRESS ENGINEERING SERVICES FATIGUE TESTING REPORT

RPSEA DEEPWATER

11.75” OD x 1.1” WALL SHRINK FIT CONNECTOR

HYDROTEST AND FATIGUE TEST

Prepared For

SUBSEA RISER PRODUCTS

Houston, Texas

OCTOBER 2011

RPSEA DEEPWATER

11.75" OD x 1.1" WALL SHRINK FIT CONNECTOR

HYDROTEST AND FATIGUE TEST

PN1201286SAF-0

Prepared for
SUBSEA RISER PRODUCTS
Houston, Texas

Prepared By:____________________________
S. Allen Fox, P.E.

Reviewed By:____________________________
Andreas Katsounas, P.E.

Stress Engineering Services, Inc.
13800 Westfair East Drive
Houston, Texas 77041-1101
Texas Registered Engineering Firm F-195

OCTOBER 2011

EXECUTIVE SUMMARY

Six Subsea Riser Products 11.75" OD x 1.1" wall shrink-fit connector samples were hydro tested then fatigue tested to failure, where failure was a leak due to either seal failure or a through-wall crack. The samples were fatigue tested to failure at three stress ranges with two samples at each stress range.

Prior to the fatigue tests the samples were hydrotested to 15 ksi, 18.75 ksi and 22.5 ksi with 15 minute holds at each pressure. All six samples passed the hydrotest. None of the samples leaked during the hydrotest.

Stress Engineering Service's resonant fatigue test machines were used to fatigue test the samples at a frequency of about 24 Hz. The samples were filled with water and pressured to 3000 psi. during the fatigue tests. All of the samples failed by leaking out one end of the coupling. Table 1 and Figures 1 and 2 summarize the fatigue test results.

Test stress factors for the connectors were determined using both the target and the survival methods with a 97.5% probability survival. As discussed in Section 4.0, the test stress factors were based on the DNV C203 B1 and C1 S-N curves. Based on the six samples tested to failure, the test stress factors for the 11.75" OD x 1.1" wall shrink-fit connector are:

Target Method

Test Stress Factor B1 = 2.151 based on 97.5% Target Limit and 2005 DNV C203 B1 Curve

Test Stress Factor C1 = 1.624 based on 97.5% Target Limit and 2005 DNV C203 C1 Curve

Survival Method

Test Stress Factor B1 = 2.22 based on 97.5% Target Limit and 2005 DNV C203 B1 Curve

Test Stress Factor C1 = 1.46 based on 97.5% Target Limit and 2005 DNV C203 C1 Curve

The test stress factor is only valid when the curve used to derive it is used to evaluate the fatigue performance. If another curve is to be used, a new factor must be derived, since the stress factor is dependent on the fatigue curve used.

Although only six samples have been tested, the data indicated that the slope of the data is steeper than either the B1 or C1 curved. That is “m” for the data is lower than 3 and the use of the test stress factors is not recommended for stress ranges below the lowest test stress range of 14,000 psi.

The test stress factor derived from tests is a good way to evaluate a "nominal" connector. However, if the connector fatigue performance is affected by variation in dimensions and the connectors tested do not represent the “worst case” tolerances, the test values may not be conservative. It may be very difficult to machine connectors to the worst case, thus, it may not be practical to investigate the extremes in tolerances during testing. Therefore, it may be necessary to use FEA for a "worst case" connector and a "nominal" case connector to obtain a correction to adjust test results to account for the worst tolerance case.

TABLE 1
11.75” OD x 1.1” WALL SHRINK-FIT CONNECTOR FATIGUE TEST RESULTS

Sample	Test Strain Range με	Test Pipe Stress Range psi	Test Pipe Stress Range MPa	Cycles at Stress Range	DNV C203 B1 Mean Curve Cycles	DNV C203 C1 Mean Curve Cycles	Failure	Maximum Temperature °F
A	1051	31,538	218	569,532	1,469,399	686,444	Leak Out Drive End Of Coupling at Pipe 10	89
B	1063	31,878	220	1,205,874	1,407,780	664,739	Leak Out Drive End Of Coupling at Pipe 5	119
C	720	21,600	149	1,631,135	6,678,231	2,136,713	Leak Out Drive End Of Coupling at Pipe 12	85
D	731	21,921	151	1,045,711	6,294,985	2,044,071	Leak Out Dead End of Coupling at Pipe 3	88
E	476	14,272	98	2,603,934	35,035,578	7,406,823	Leak Out Dead End of Coupling at Pipe 7	77
F	450	13,500	93	2,956,179	43,760,565	8,751,091	Leak Out Drive End of Coupling Pipe 11	80

Sample Number	Test Internal Pressure psi	Pipe Stress Range psi	Cycles at Stress Range Cycles	Number of Samples For Target Curve	97.5% DNV C203 B1 Target Stress Factor	97.5% DNV C203 C1 Target Stress Factor
A	3000	31,538	569,532	6	1.390	1.204
B	3000	31,878	1,205,874	6	1.140	0.927
C	3000	21,600	1,631,135	6	1.560	1.237
D	3000	21,921	1,045,711	6	1.718	1.414
E	3000	14,272	2,603,934	6	2.101	1.602
F	3000	13,500	2,956,179	6	2.151	1.624

Maximum (highlighted)

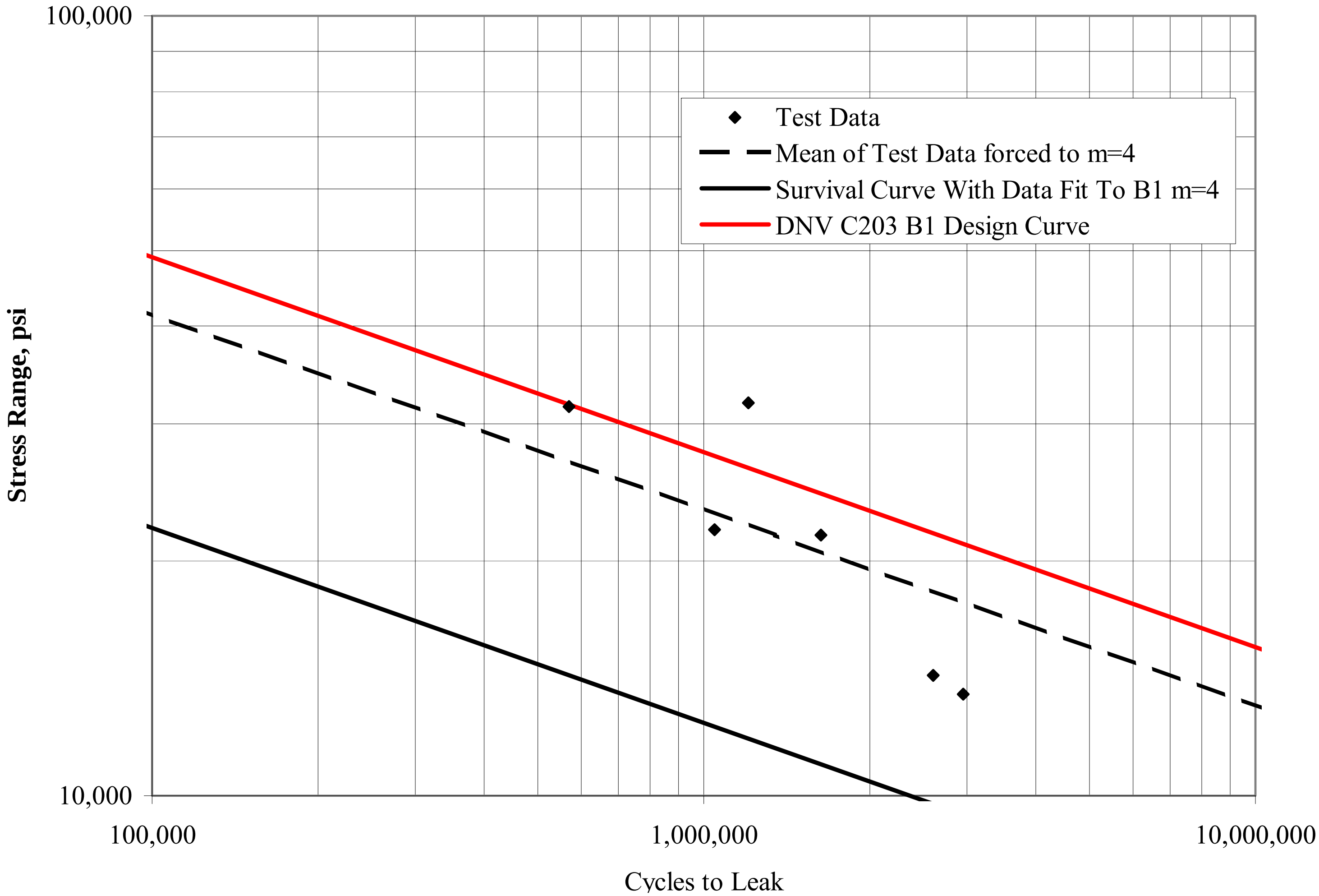


FIGURE 1
11.75” OD x 1.1” WALL SHRINK-FIT CONNECTOR FATIGUE TEST RESULTS COMPARED TO DNV C203 B1 CURVE

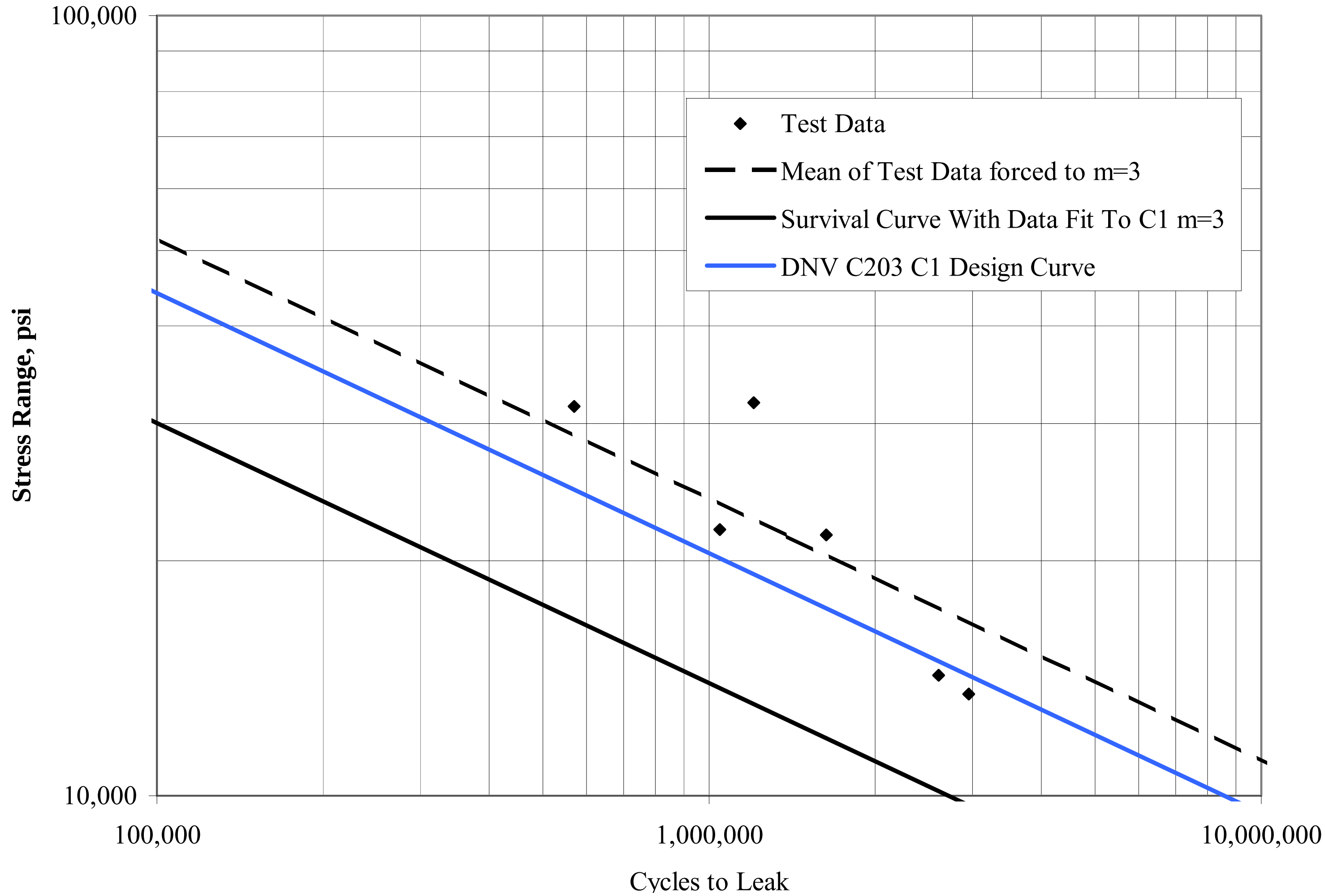


FIGURE 2
11.75” OD x 1.1” WALL SHRINK-FIT CONNECTOR FATIGUE TEST RESULTS COMPARED TO DNV C203 C1 CURVE

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Revision History

Rev. 0 - Initial Release

1.0 INTRODUCTION

Six 11.75” OD x 1.1” wall shrink-fit connector test samples were provided by Subsea Riser Products. Hydro tests followed by fatigue tests were performed on the six 11.75” OD x 1.1” wall shrink-fit connectors. The hydro tests were performed at 15 ksi, 18.75 ksi and 22.5 ksi. The six connectors were fatigue tested to failure, where failure is defined as a leak due to either a through wall crack or a seal leak. All of the the samples were filled with water and the internal pressure of 3000 psi was applied during the fatigue tests. The fatigue tests were performed in a resonant test machine at a frequency of about 24 Hz. The tests were performed per Subsea Riser Products Ltd specification “RPSEA Deepwater Shrink-fit Fatigue Testing HYDROTEST AND RESONANT FATIGUE TEST SPECIFICATION “, September 2011, Rev. 03, 12 Sep 11.

Section 2.0 contains the test details and Section 3.0 contains the results of the test results.

2.0 TEST DETAILS

The samples provided by Subsea Riser Products were identified as shown in Table 2.1.

TABLE 2.1
11.75” OD x 1.1” WALL SHRINK-FIT CONNECTOR TEST SAMPLES

Sample	Pipe Drive End	Pipe Dead End	Coupling
A	10	8	2
B	5	1	3
C	12	6	1
D	9	3	6
E	4	7	5
F	11	2	4

2.1 Hydro Test

The hydro test was performed in three steps. The sample were filled with water and the internal pressure was increased to 15 ksi and held for 15 minutes, then increased to 18.75 ksi and held for 15 minutes, and finally increased to 22.5 kips and held for 15 minutes, as shown table 2.2.

TABLE 2.2
11.75” OD x 1.1” WALL SHRINK-FIT CONNECTOR HYDRO TEST PRESSURES

Internal Pressure psi	Hold min
15,000	15
18,750	15
22,500	15

Table 2.3 shows the stresses the nominal 11.75” OD x 1.1” wall pipe at the three hydro test pressures.

Four and a half inch thick end caps were welded into the samples for the hydro test. The samples were filled with water and placed in a covered pit, as shown in Figure 2.1. A pressure line was connected to one end of the sample and two pressure transducers were attached to the other end. Appendix A contains the pressure transition calibration certificates. A data acquisition system was used to record the pressure history during the test.

Absorbent pads were placed under the coupling during the hydro test to detect leaks. If the sample leaked, the water would drop on the pad and discolor it.

2.2 Fatigue Test

Strain gages were placed on the pipe 10" from the ends of the coupling, far enough from the connector to obtain pipe body stresses without the influence of the connector. A total of eight gages were used, four on each side of the connector every 90º around the circumference of the pipe. Figure 2.2 shows the fatigue test sample strain gage locations. Table 2.3 shows the fatigue test stress ranges along with the stresses and resulting R ratios based on nominal pipe dimensions. The pipe wall thickness and O.D. were recorded at each strain gage location. Appendix B contains the wall and O.D. dimensions for the fatigue samples.

Stress Engineering Service's resonant fatigue test machine was used for the fatigue tests. The resonant fatigue machine consists of two supports, a variable speed electric motor, drive housing, and dead end housing. The variable speed motor rotates an eccentric mass in the drive housing clamped to one end of the sample and loads the pipe. The rpm of the motor is adjusted to load the sample near its natural frequency. The applied load produces the same sinusoidal alternating stress at every point around the circumference of the sample. The dead weight housing is clamped to the other end of the sample to balance the assembly. The test sample length required and the approximate test frequency were determined using a finite element model. Figure 2.3 shows a sample in the fatigue machine.

One of the concerns was heating at the ends of the coupling due to relative motion between the coupling and the pipe. Thus, thermocouples were mounted on the pipe at the ends of the coupling on the first sample tested, Sample B. Figure 2.4 shows the temperature history during the test of Sample B. Based on the temperature results from Sample B, water spray cooling was used on the remainder of the samples. Thermocouples on the second sample tested, Sample A, showed that the temperature did not get above 89° F. Spot checks, on the remainder of the samples using an infrared thermometer, showed a maximum temperature of 85° F.

Axial strain gages on the outer diameter of the pipe body were used to monitor the bending strains during the fatigue test. Both bending strains and number of cycles were monitored and recorded by the fatigue data acquisition system. Each minute the data acquisition software recorded the average maximum and minimum strains for each strain gage along with the number of cycles. All fatigue tests were run with the internal pressure of 3000 psi. Water was used to pressure the samples.

A pressure switch was used to monitor the internal pressure. A pressure drop in the sample triggers the pressure switch and shuts down the machine.

The general steps, involved in the fatigue tests, were:

1. Weld in the end plugs.
2. Fill the samples with water.
3. Measure and record the wall and outer diameter at each strain gage location.
4. Install the strain gages to monitor the fatigue strains.
5. Load the samples in the fatigue test machine.
6. Apply an internal pressure of 3000 psi.
7. Zero and shunt the gages.
8. Apply water spray to the ends of the coupling of samples A, C, D, E and F.
9. Adjust the rpm of the test machine to achieve the desired strain range.

10. Log internal pressure, strain amplitude, frequency, and number of cycles.
11. Cycle the six samples until they leak.
12. Document the test including fatigue test strains and cycles.

TABLE 2.3
11.75" OD x 1.1" WALL SHRINK-FIT CONNECTOR
HYDRO TEST STRESSES AND FATIGUE TEST STRESSES AND R VALUES

Hydrotest

Pipe OD =	11.75 in		b =	5.875
Pipe ID =	9.55 in		a =	4.775
Pipe Wall =	1.1 in		r =	5.325

Internal Pressure psi	Axial Stress psi	Pressure End Load lbs	ID Stress Intensity psi	ID Hoop Stress psi	ID von Mises psi	Mid Wall Hoop Stress psi	Mid Wall Radial Stress psi	Mid Wall Stress Intensity psi	Mid Wall von Mises psi
15,000	29,194	1,074,454	88,388	73,388	76,546	64,730	-6,342	71,073	61,551
18,750	36,493	1,343,068	110,485	91,735	95,683	80,913	-7,928	88,841	76,938
22,500	43,791	1,611,681	132,582	110,082	114,820	97,096	-9,513	106,609	92,326

Fatigue Test

Pipe OD =	11.75 in		b =	5.875
Pipe ID =	9.55 in		a =	4.775
Pipe Wall =	1.1 in		r =	5.325

Stress Range Mpa	Stress Range psi	Internal Pressure psi	Mean Stress psi	Pressure End Load lbs	ID Stress Intensity psi	ID Axial Alternating Stress psi	Mid Wall Axial Alternating Stress psi	Mid Wall Hoop Stress psi	Mid Wall Radial Stress psi	Mid Wall Stress Intensity psi	R
214	31,000	3,000	5,839	214,891	17,678	12,598	14,049	12,946	-1,268	14,215	-0.453
145	21,000	3,000	5,839	214,891	17,678	8,534	9,517	12,946	-1,268	14,215	-0.285
97	14,000	3,000	5,839	214,891	17,678	5,689	6,345	12,946	-1,268	14,215	-0.090

Absorbent Pad Under Coupling To Monitor for Leaks

Sample in Pit View 1

Sample in Pit View 2

FIGURE 2.1
HYDRO TEST SAMPLE IN PIT

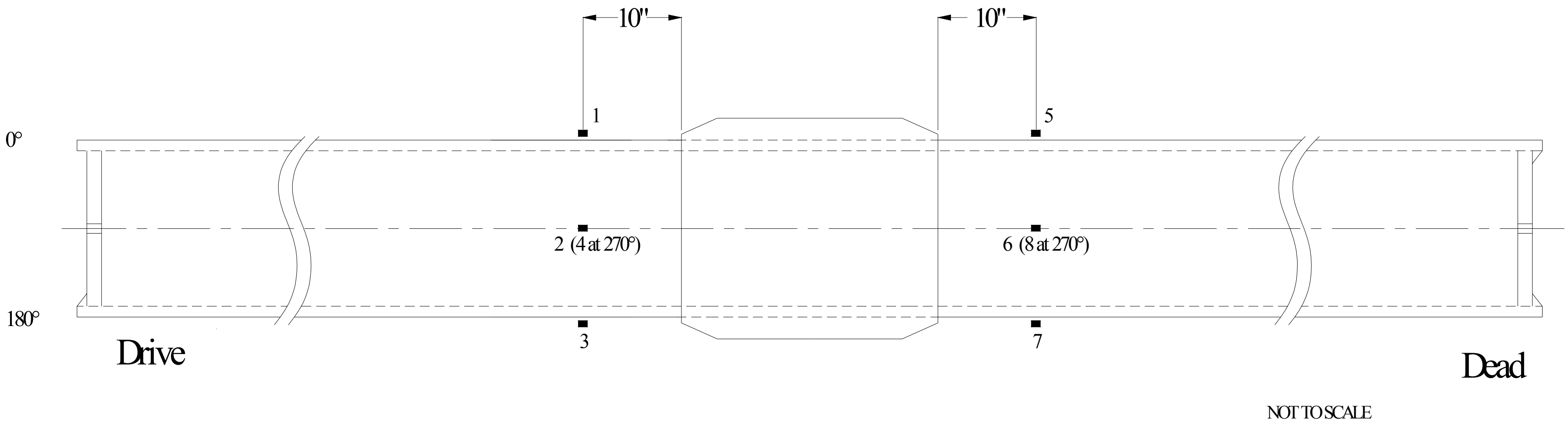


FIGURE 2.2
LOCATION OF STRAIN GAGES ON FATIGUE SAMPLE

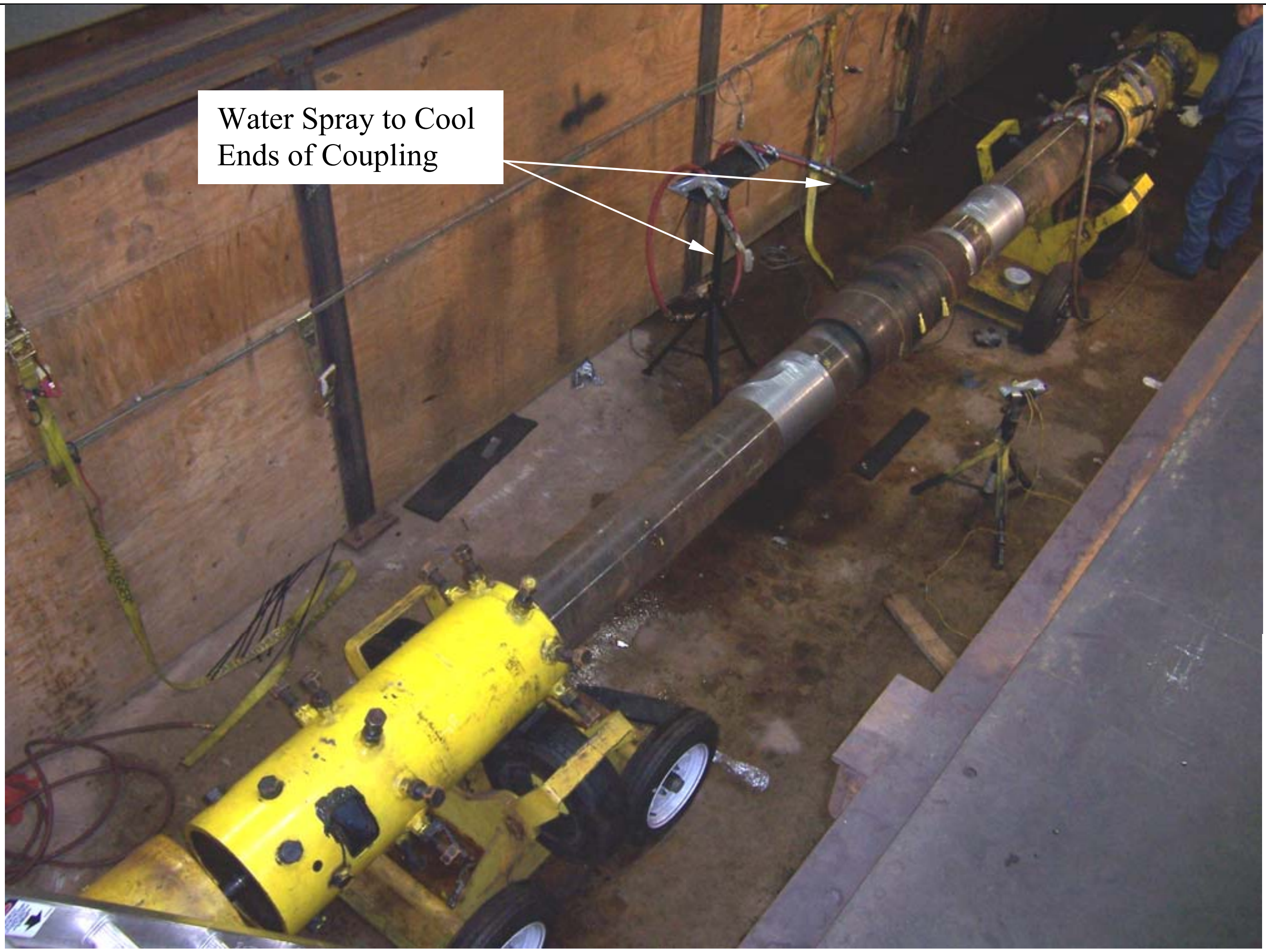


FIGURE 2.3
SAMPLE IN FATIGUE TEST MACHINE

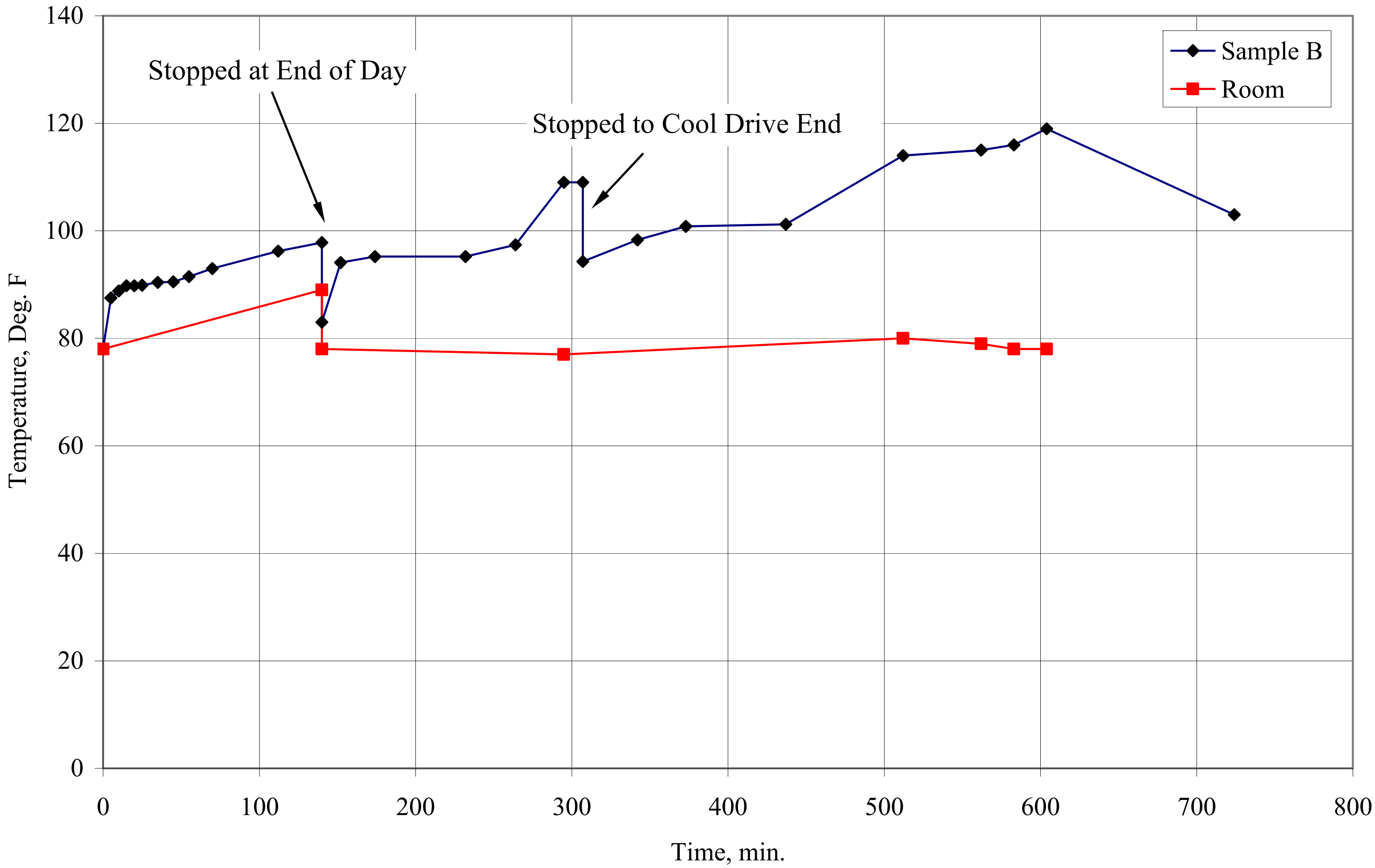


FIGURE 2.4
PIPE TEMPERATURE AT ENDS OF SAMPLE B COUPLING (NO COOLING) DURING FATIGUE TEST

3.0 TEST RESULTS

3.1 Hydro Test Results

Figures 3.1-3.6 show the pressure history plots for the hydro test samples. Table 3.1 shows the hydro test results. As shown in Table 3.1, the pressure change during each pressure step test was negotiable. No leaks were observed during any of the hydro tests. Table 3.2 summarizes OD readings recorded before and after the hydro tests.

3.2 Fatigue Test Results

The bending strains and number of cycles were monitored and recorded by the fatigue data acquisition system. Maximum and minimum strains for each strain gage were averaged for one-minute intervals and the average was written to a results file. The test stress ranges were calculated using the maximum and minimum strains. The mean and standard deviation of the one-minute averages were determined. In addition, the cycle count was determined at each gage and the cumulative cycle count was written to the results file every minute.

Table 3.3 contains the average strain ranges and standard deviations for each gage for each sample. The strains from the eight strain gages near the connectors were averaged and multiplied by the modulus (30,000,000 psi) to get the pipe stress range for each test. Table 3.4 summarizes the test results including the nominal pipe stress ranges and test duration in cycles.

All of the samples leaked out one end of the coupling. Table 3.4 along with Figures 3.7 and 3.8 summarize the fatigue test results.

Two methods were used to calculate test stress factors for the connectors from the test results; target method and the survival method.

A test stress factor was calculated directly from the test results using the target method. The DNV C203 B1 and C1 curves were used. The target stress factor was calculated by setting the equation for the target number of cycles equal to the test duration then solving for the stress factor. A target test stress factor is determined for each sample and the maximum factor must be used to calculate damage for the connectors. The target test stress factor was based on a 97.5% probability of survival, as shown below.

$N_{target} = (N_{mean})10^{1.965(\sigma/\sqrt{n})}$

N_{target} = target life, cycles

N_{mean} = life based on the stress range and the mean S-N curve, cycles

n = number of test samples = 6

σ = the standard deviation of $\log_{10}N$

For the DNV C203 B1 S-N curve, σ = 0.2

For the DNV C203 C1 S-N Curve, σ = 0.2

1.96 = Normal probability function for 97.5% probability of survival

For the DNV C203 B1 S-N curve:

$N_{mean} = A\,(S^{-m})$

A = Mean S-N curve constant = 3.288516×10^{15}

m = S-N curve exponent = 4

S = connector stress range, Mpa

For the DNV C203 C1 S-N curve:

$N_{mean} = A\,(S^{-m})$

A = Mean S-N curve constant = 7.063176×10^{12}

m = S-N curve exponent = 3

S = connector stress range, Mpa

The test stress factor is:

Test Stress Factor = $(\{[A[10^{1.965(\sigma/\sqrt{n})}]/N_{test}\}^{1/m})/(\text{Pipe Stress Range})$

N_{test} = Number of cycles to fail connector

Pipe Stress Range = Pipe Stress Range that resulted in failure at N_{test} cycles

The test stress factor was also calculated using the survival method by determining the mean of the data forced to the slope of the published fatigue curve (the DNV C203 B1 and C1 curves in this case). The mean curve was shifted down by the t-distribution factor for the number of samples tested to obtain a survival curve. The test stress factor is calculated by determining the factor that must be multiplied times the pipe test stress ranges to result in a survival curve that equals the desired design curve. Tables 3.5 and 3.6 show the calculation of the survival test stress factors for the DNV C203 B1 and C1 curves, respectively.

The test stress factors for the connector with 97.5% probability of survival (Target Method) and with 97.5% confidence on the survival limit (Survival Method) are:

Target Method

Test Stress Factor B1 = 2.151 based on 97.5% Target Limit and 2005 DNV C203 B1 Curve

Test Stress Factor C1 = 1.624 based on 97.5% Target Limit and 2005 DNV C203 C1 Curve

Survival Method

Test Stress Factor B1 = 2.22 based on 97.5% Target Limit and 2005 DNV C203 B1 Curve

Test Stress Factor C1 = 1.46 based on 97.5% Target Limit and 2005 DNV C203 C1 Curve

The test stress factor is only valid when the curve used to derive it is used to evaluate the fatigue performance. If another curve is to be used, a new factor must be derived, since the stress factor is dependent on the fatigue curve used. Although only six samples have been tested, the data indicated that the slope of the data is steeper than either the B1 or C1 curved. That is m for the data is lower than 3 and the use of the test stress factors is not recommended for stress ranges below the lowest test stress range of 14,000 psi.

The plugs for the ball ports were removed and the balls were examined to determine if they were dry. Three was a very small release of air from three of the ports when they were opened. All of the ball and grooves were dry. The balls in some ports were covered with black powder. Table 3.7 summarizes the port inspection.

FIGURE 3.1
11.75" OD x 1.1" WALL SHRINK-FIT CONNECTOR
HYDRO TEST SUMMARY

Sample	Internal Pressure psi		Pressure Change psi
	Start of Hold	End of Hold	
A	15,108	15,075	33
	18,810	18,780	30
	22,558	22,504	54
B	15,263	15,235	28
	18,792	18,765	27
	22,554	22,510	44
C	15,100	15,068	32
	18,873	18,846	27
	22,654	22,611	43
D	15,107	15,075	32
	18,631	18,599	32
	22,610	22,550	60
E	15,128	15,106	22
	18,652	18,625	27
	22,645	22,596	49
F	15,116	15,083	33
	18,889	18,874	15
	22,588	22,555	33

No leaks were observed.

TABLE 3.2
11.75” OD x 1.1” WALL SHRINK-FIT CONNECTOR DIAMETERS BEFORE AND AFTER HYDRO TEST

Location	Sample A Diameter, in.		Sample B Diameter, in.		Sample C Diameter, in.		Sample D Diameter, in.		Sample E Diameter, in.		Sample F Diameter, in.	
	Before Hydro	After Hydro	Before Hydro	After Hydro	Before Hydro	After Hydro	Before Hydro	After Hydro	Before Hydro	After Hydro	Before Hydro	After Hydro
D1	na	11.806	na	11.79	11.769	11.772	11.79	11.795	11.787	11.786	11.807	11.809
D2	na	11.794	na	11.775	11.783	11.783	11.813	11.817	11.811	11.807	11.783	11.782
D3	na	15.117	na	15.122	15.122	15.126	15.02	15.022	15.056	15.054	15.068	15.069
D4	na	15.115	na	15.12	15.123	15.127	15.021	15.022	15.052	15.051	15.062	15.062
D5	na	15.12	na	15.123	15.125	15.125	15.02	15.021	15.053	15.052	15.069	15.07
D6	na	15.119	na	15.119	15.121	15.122	15.023	15.024	15.053	15.054	15.068	15.068
D7	na	11.804	na	11.786	11.775	11.779	1.813	11.816	11.813	11.811	11.786	11.788
D8	na	11.79	na	11.802	11.767	11.77	11.767	11.771	11.789	11.787	11.806	11.805

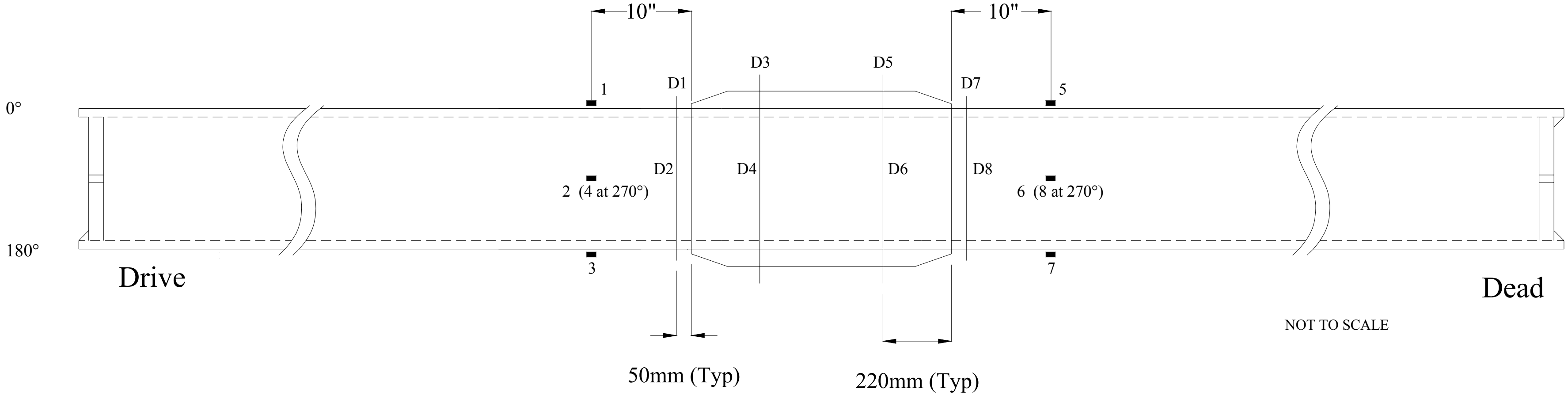
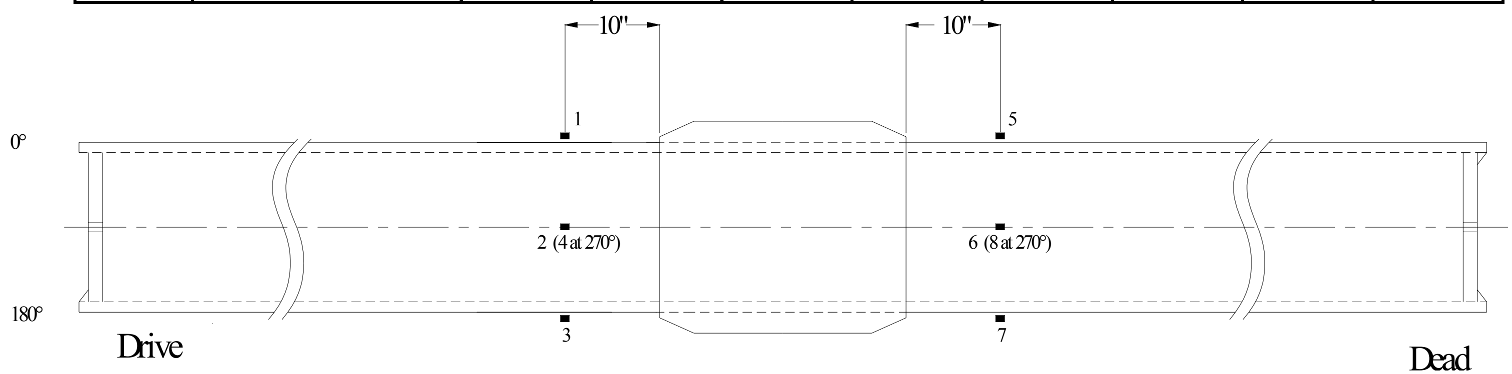


TABLE 3.3
11.75” OD x 1.1” WALL SHRINK-FIT CONNECTOR FATIGUE TEST STRAIN GAGE RESULTS

Sample		Pipe Strain Range, με							
		SG 1	SG 2	SG 3	SG 4	SG 5	SG 6	SG 7	SG 8
A	Average	1101	1062	1091	1080	1038	1017	1027	994
	Standard Deviation	58	53	58	53	54	51	54	51
B	Average	1092	1097	1088	1086	1030	1048	1019	1041
	Standard Deviation	15	15	15	15	14	15	14	13
C	Average	734	743	732	738	710	707	709	687
	Standard Deviation	12	11	11	11	11	11	11	11
D	Average	756	769	745	757	696	707	702	714
	Standard Deviation	10	8	10	8	9	8	11	9
E	Average	488	496	478	500	461	469	450	463
	Standard Deviation	14	14	13	14	18	14	13	14
F	Average	479	461	469	480	425	438	424	424
	Standard Deviation	11	10	11	8	9	9	9	12



Location of Strain Gages

TABLE 3.4
11.75" OD x 11" WALL SHRINK-FIT CONNECTOR FATIGUE TEST RESULTS

Sample	Test Strain Range με	Test Pipe Stress Range psi	Test Pipe Stress Range MPa	Cycles at Stress Range	DNV C203 B1 Mean Curve Cycles	DNV C203 C1 Mean Curve Cycles	Failure	Maximum Temperature °F
A	1051	31,538	218	569,532	1,469,399	686,444	Leak Out Drive End Of Coupling at Pipe 10	89
B	1063	31,878	220	1,205,874	1,407,780	664,739	Leak Out Drive End Of Coupling at Pipe 5	119
C	720	21,600	149	1,631,135	6,678,231	2,136,713	Leak Out Drive End Of Coupling at Pipe 12	85
D	731	21,921	151	1,045,711	6,294,985	2,044,071	Leak Out Dead End of Coupling at Pipe 3	88
E	476	14,272	98	2,603,934	35,035,578	7,406,823	Leak Out Dead End of Coupling at Pipe 7	77
F	450	13,500	93	2,956,179	43,760,565	8,751,091	Leak Out Drive End of Coupling Pipe 11	80

Sample Number	Test Internal Pressure psi	Pipe Stress Range psi	Cycles at Stress Range Cycles	Number of Samples For Target Curve	97.5% DNV C203 B1 Target Stress Factor	97.5% DNV C203 C1 Target Stress Factor
A	3000	31,538	569,532	6	1.390	1.204
B	3000	31,878	1,205,874	6	1.140	0.927
C	3000	21,600	1,631,135	6	1.560	1.237
D	3000	21,921	1,045,711	6	1.718	1.414
E	3000	14,272	2,603,934	6	2.101	1.602
F	3000	13,500	2,956,179	6	2.151	1.624

Maximum

TABLE 3.5
11.75" OD x 1.1" WALL SHRINK-FIT CONNECTOR FATIGUE TEST
DNV C203 B1 SURVIVAL CURVE RESULTS

N = A (S^-m)		Basic form of the S-N curve
S = stress range, mpa		
m =	-4	exponent of "B1'" curve
n =	6	number of failures
t dof =	2.571	"t" Didtribution Factor for 6 tests for 97.5% Survivability
A "B1" design =	1.31E+15	for the DNV C203 "B1" Design Curve used to calculate Damage

Sample Number	Pipe Stress Range psi	Stress Range MPa	Test Duration Cycles	log Si	log Ni	N fit	log N fit	(log Ni - log N fit)^2
A	31538	217.44	569,532	2.337	5.756	296597	5.4722	0.08028812
B	31878	219.78	1,205,874	2.342	6.081	284159	5.4536	0.394058546
C	21600	148.92	1,631,135	2.173	6.212	1347994	6.1297	0.006856134
D	21921	151.14	1,045,711	2.179	6.019	1270636	6.1040	0.007158793
E	14272	98.40	2,603,934	1.993	6.416	7071895	6.8495	0.188274266
F	13500	93.08	2,956,179	1.969	6.471	8833025	6.9461	0.225984913
Summation				12.993	36.955			0.902620772

log A data=	14.82148749
A data mean =	6.6296E+14
se =	0.424881342
A survival =	5.35942E+13
A design B1 =	1.31E+15

Test Stress Factor to get the Survival Curve to fall on the B1 Design Curve = 2.223

TABLE 3.6
11.75” OD x 1.1” WALL SHRINK-FIT CONNECTOR FATIGUE TEST
DNV C203 C1 SURVIVAL CURVE RESULTS

N = A (S^-m)		Basic form of the S-N curve
S = stress range, mpa		
m =	-3	exponent of "C1'" curve
n =	6	number of failures
t dof =	2.571	"t" Didtribution Factor for 6 tests for 97.5% Survivability
A "C1" design =	2.81E+12	for the DNV C203 "C1" Design Curve used to calculate Damage

Sample Number	Pipe Stress Range psi	Stress Range MPa	Test Duration Cycles	log Si	log Ni	N fit	log N fit	(log Ni - log N fit)^2
A	31538	217.44	569,532	2.337	5.756	440473	5.6439	0.012454128
B	31878	219.78	1,205,874	2.342	6.081	426546	5.6300	0.203704234
C	21600	148.92	1,631,135	2.173	6.212	1371075	6.1371	0.005689487
D	21921	151.14	1,045,711	2.179	6.019	1311629	6.1178	0.009682448
E	14272	98.40	2,603,934	1.993	6.416	4752772	6.6769	0.06828655
F	13500	93.08	2,956,179	1.969	6.471	5615354	6.7494	0.07764383
Summation				12.993	36.955			0.377460678

log A data=	12.6559107
A data mean =	4.5280E+12
se =	0.274758322
A survival =	8.90240E+11
A design C1 =	2.81E+12

Test Stress Factor to get the Survival Curve to fall on the B1 Design Curve = 1.462

TABLE 3.7
11.75" OD x 1.1" WALL SHRINK-FIT CONNECTOR
PORT INSPECTION RESULTS

Port	Condition of Balls	Notes
Joint A, Pipe 10, Coupling Port	Dry	
Joint A, Pipe 10, Pipe Port	Dry	
Joint A, Pipe 8, Coupling Port	Dry	
Joint A, Pipe 8, Pipe Port	Dry	
Joint B, Pipe 5, Coupling Port	Dry	
Joint B, Pipe 5, Pipe Port	Dry	Balls were black
Joint B, Pipe 1, Coupling Port	Dry	Balls were black
Joint B, Pipe 1, Pipe Port	Dry	Balls were black
Joint C, Pipe 6, Coupling Port	Dry	Balls were shiny
Joint C, Pipe 6, Pipe Port	Dry	Balls were shiny
Joint C, Pipe 12, Coupling Port	Dry	Ball were Gray
Joint C, Pipe 12, Pipe Port	Dry	Balls were shiny
Joint D, Pipe 9, Coupling Port	Dry	
Joint D, Pipe 9, Pipe Port	Dry	Very small release of air when 1st turned fitting
Joint D, Pipe 3, Coupling Port	Dry	Very small release of air when 1st turned fitting
Joint D, Pipe 3, Pipe Port	Dry	Very small release of air when 1st turned fitting
Joint E, Pipe 4, Coupling Port	Dry	Balls were black
Joint E, Pipe 4, Pipe Port	Dry	Balls were black
Joint E, Pipe 7, Coupling Port	Dry	Balls were shiny
Joint E, Pipe 7, Pipe Port	Dry	Balls were black
Joint F, Pipe 2, Coupling Port	Dry	Balls were gray
Joint F, Pipe 2, Pipe Port	Dry	Balls were black
Joint F, Pipe 11, Coupling Port	Dry	Balls were black
Joint F, Pipe 11, Pipe Port	Dry	Balls were black

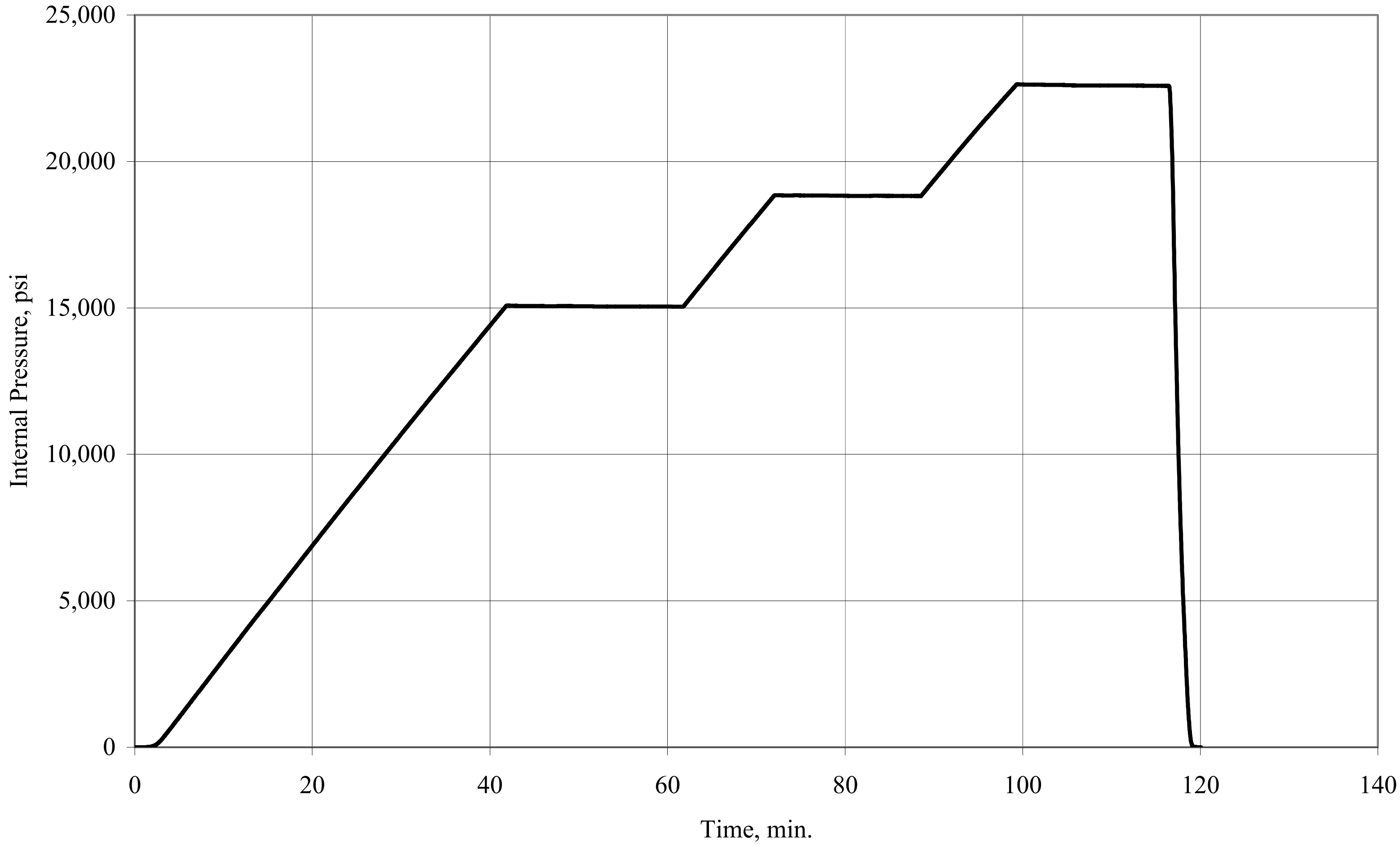


FIGURE 3.1
11.75" OD x 1.1" WALL SHRINK-FIT CONNECTOR SAMPLE A HYDRO TEST HISTORY

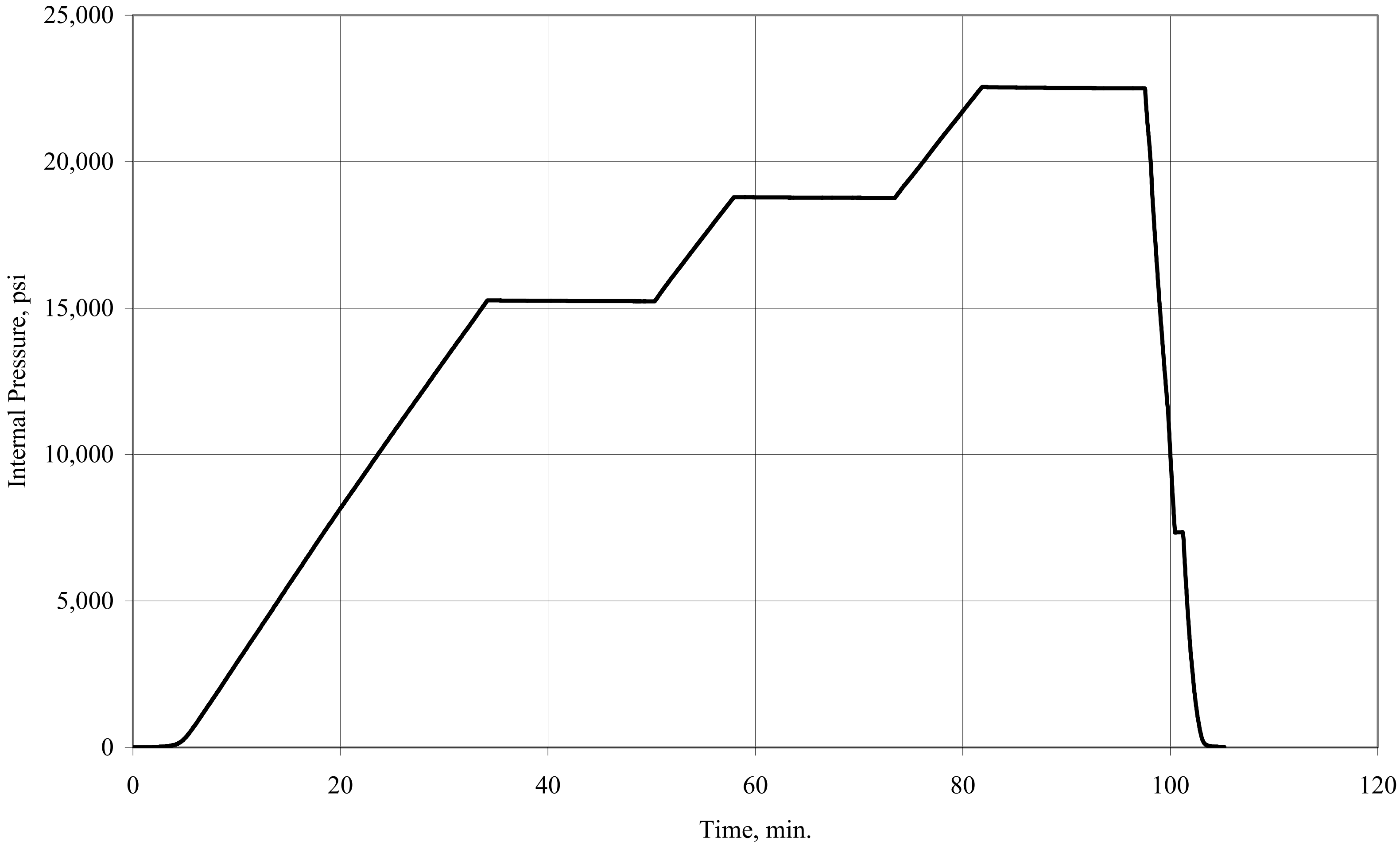


FIGURE 3.2
11.75" OD x 1.1" WALL SHRINK-FIT CONNECTOR SAMPLE B HYDRO TEST HISTORY

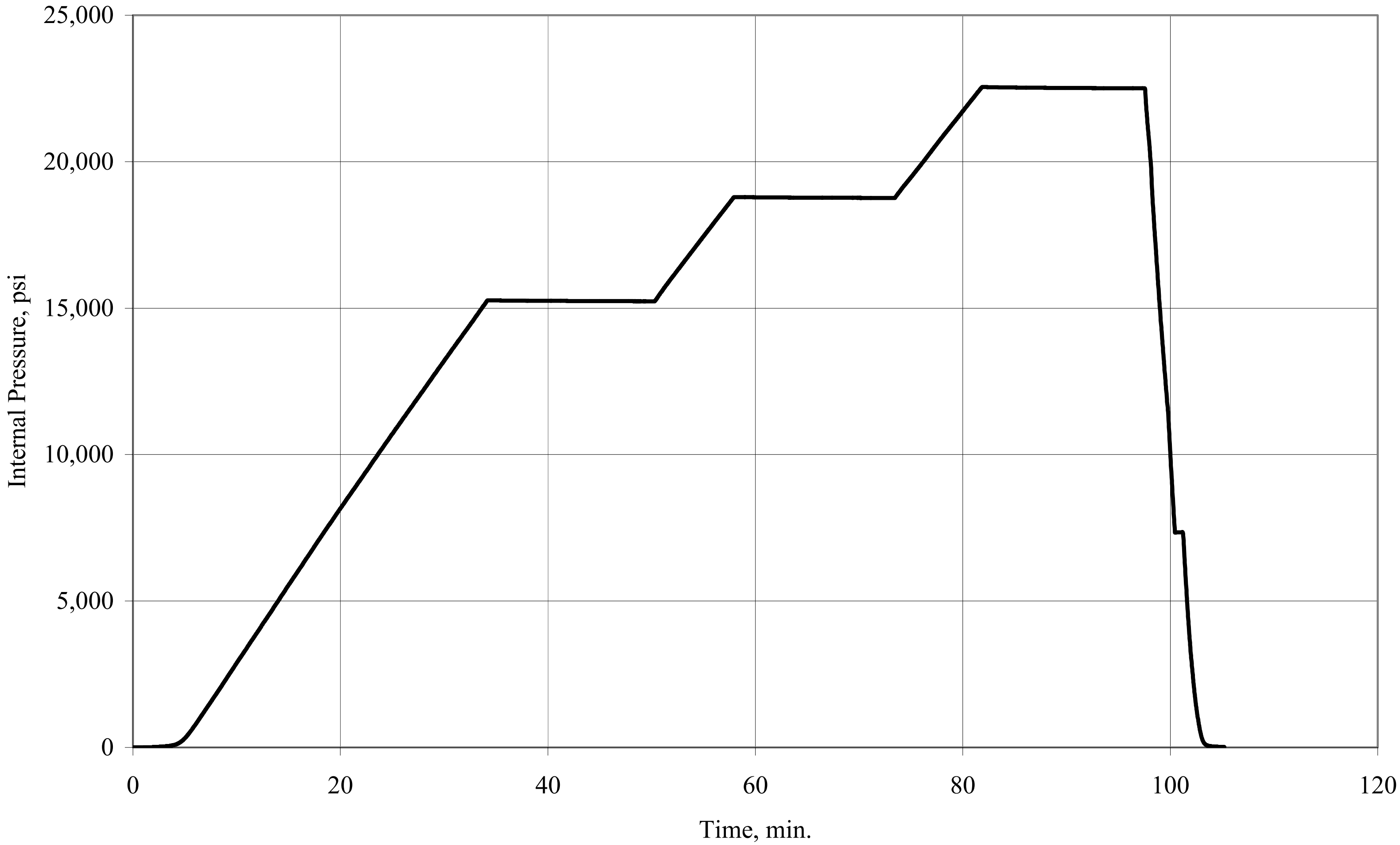


FIGURE 3.3
11.75" OD x 1.1" WALL SHRINK-FIT CONNECTOR SAMPLE C HYDRO TEST HISTORY

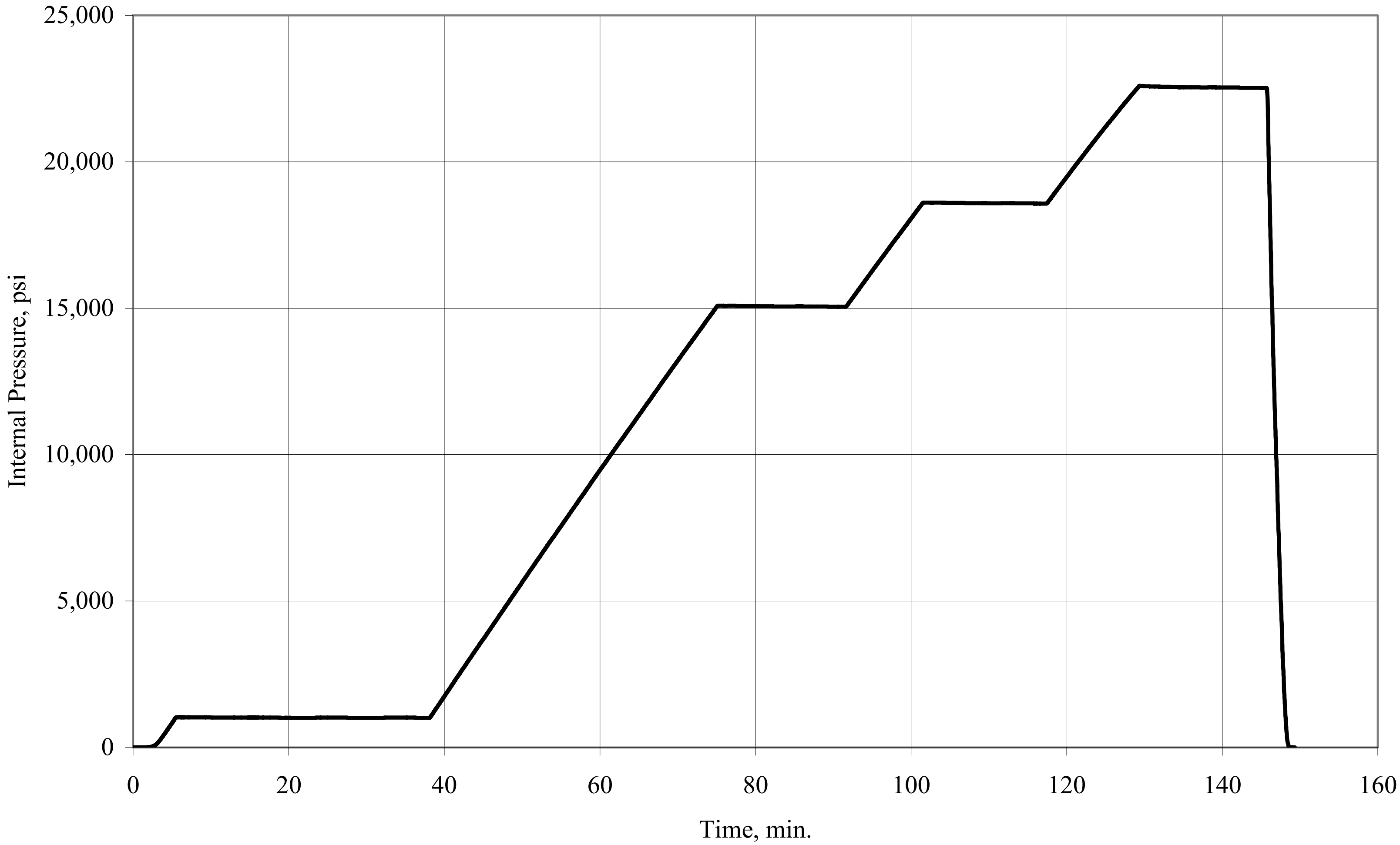


FIGURE 3.4
11.75” OD x 1.1” WALL SHRINK-FIT CONNECTOR SAMPLE D HYDRO TEST HISTORY

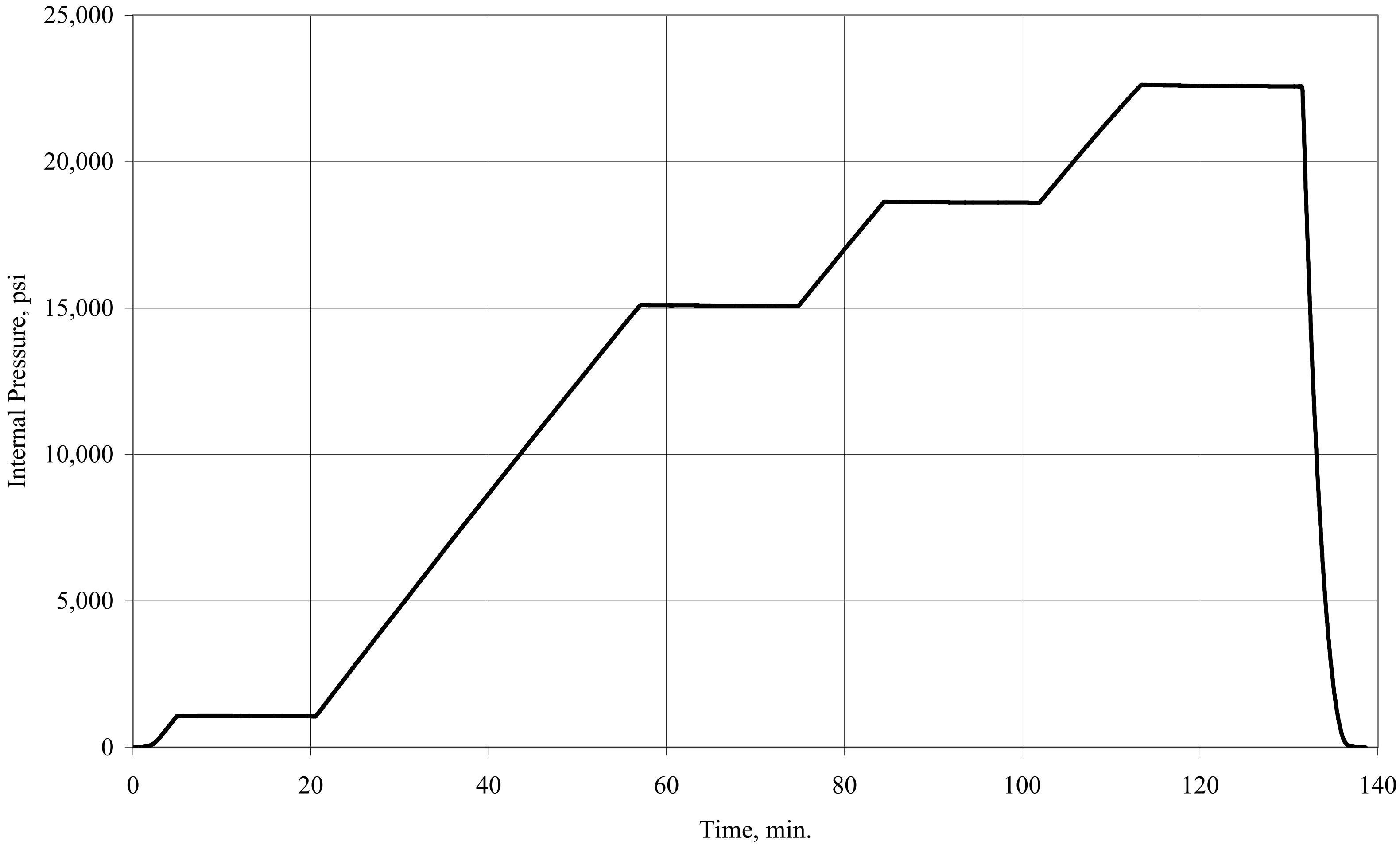


FIGURE 3.5
11.75" OD x 1.1" WALL SHRINK-FIT CONNECTOR SAMPLE E HYDRO TEST HISTORY

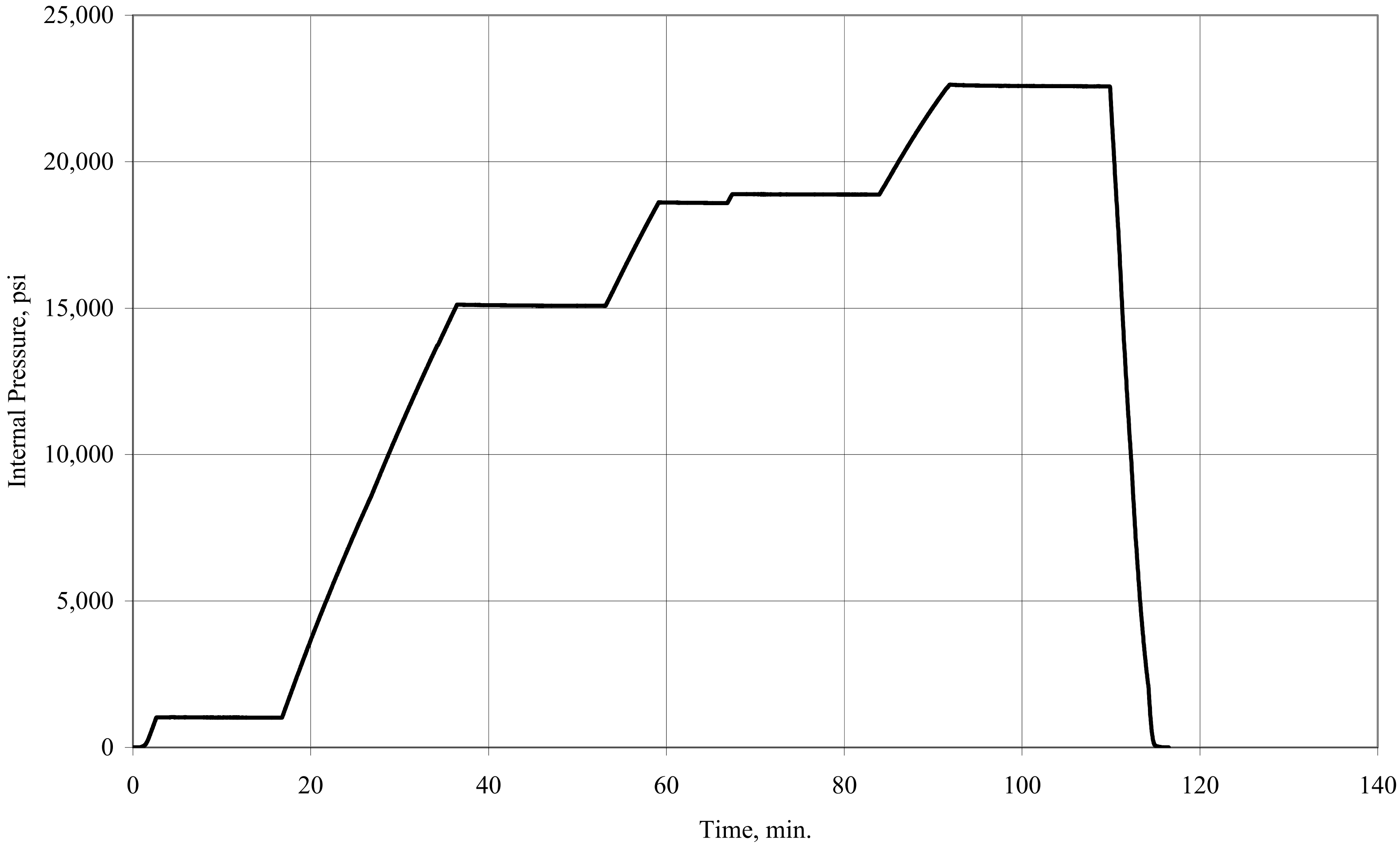


FIGURE 3.6
11.75" OD x 1.1" WALL SHRINK-FIT CONNECTOR SAMPLE F HYDRO TEST HISTORY

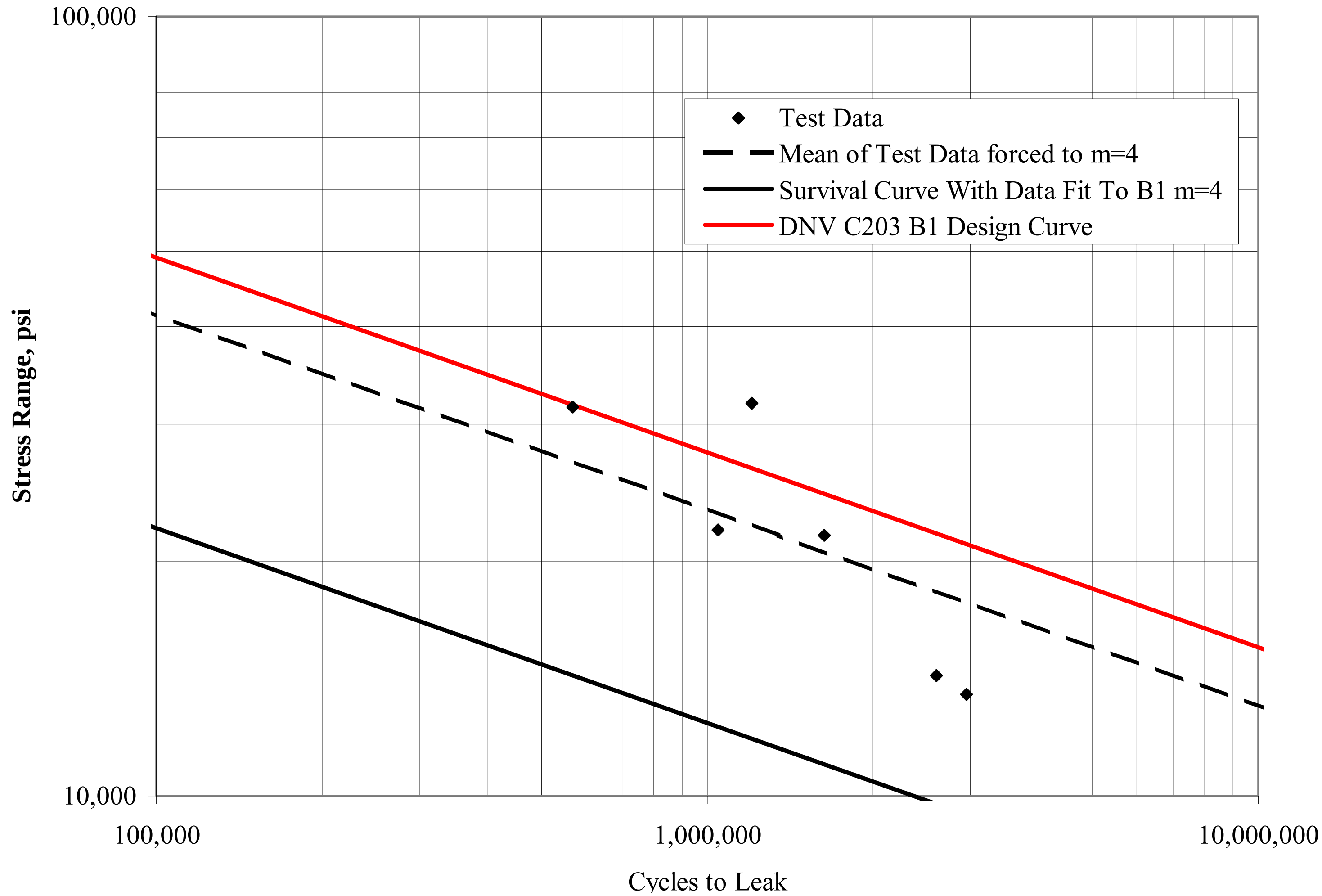


FIGURE 3.7
11.75" OD x 1.1" WALL SHRINK-FIT CONNECTOR FATIGUE TEST RESULTS COMPARED TO DNV C203 B1 CURVE

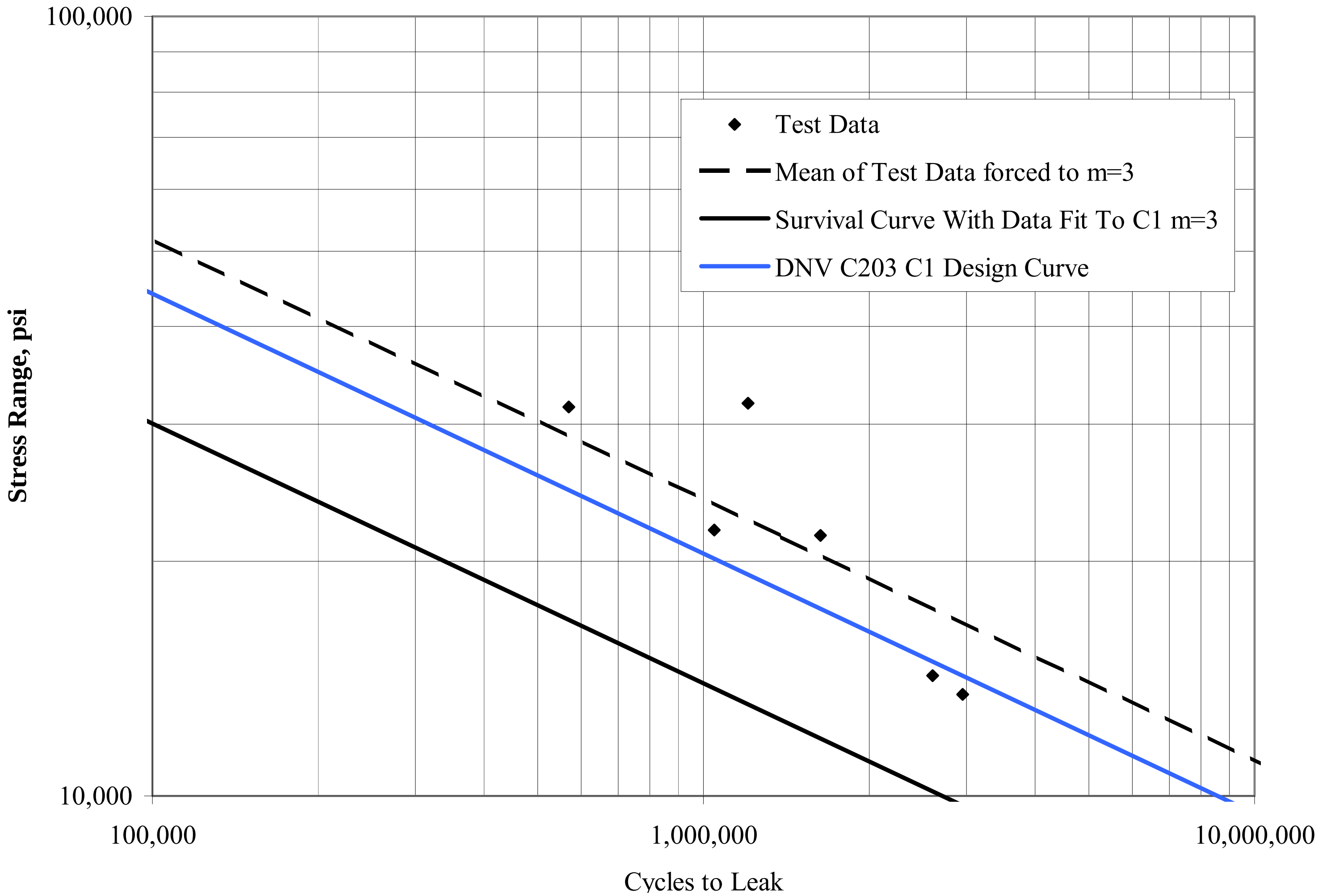


FIGURE 3.8
11.75" OD x 1.1" WALL SHRINK-FIT CONNECTOR FATIGUE TEST RESULTS COMPARED TO DNV C203 C1 CURVE

APPENDIX A

HYDRO TEST PRESSUER TRANSDUCER CALIBRATION CERTIFICATES AND HYDRO TEST LOGS

PRESS 1

A & B

28694 Denn Rd. Montgomery, Tx 77356
Phone - 713-515-3619

Specialized Tech Services

CALIBRATION CERTIFICATE

CUSTOMER: **Stress Engineering Services**

13800 WESTFAIR EAST DR

Transducer Make:	Honeywell	Transducer Model:	TJE
Transducer S/N:	1028256	Transducer Range:	0 - 30000 psi
Reference and testing conditions:		979.312 gals	20°C +/- 1.5 deg
		Excitation	5.0017 volts

CALIBRATION READINGS (as left)

ACTUAL (psi)	READING 1 (mv)	CONVERTED (psi)	PERCENT ERROR % of FS
0	-0.019	0	0.00
500	0.234	500	0.00
1000	0.488	1001	0.00
3000	1.502	3003	0.01
6000	3.024	6008	0.02
12001	6.065	12012	0.04
18001	9.105	18014	0.04
24002	12.141	24008	0.02
30002	15.174	29996	-0.02

All readings within manufacturer tolerence (+/- .5% F.S.)

CONVERSION FACTORS (Reading - Offset)*gain

Shunt Reading (millivolts)	Shunt Reading (psi)	Offset (millivolts)	Gain (psi/mv)
7.652	**15145**	-0.019	1,974.33

Calibration performed per STS document PTC1002 and traceable to N.I.S.T.

Equipment used: Pressurements model M3800 SN:61205, HP Model 34401A Sn: MY47007060

Technician L. Wilson — DATE: January 6, 2011

SIGNED: — RECALL: January 6, 2012

Sample A and B

PRESS 2

#2 #3 B

28694 Denn Rd. Montgomery, Tx 77356
Phone - 713-515-3619

Specialized Tech Services

CALIBRATION CERTIFICATE

CUSTOMER: **MOHR ENGINEERING**

13602 WESTLAND EAST BLVD

Transducer Make:	Dynisco	Transducer Model:	G830-300-30M-K73
Transducer S/N:	200948949	Transducer Range:	0 - 30000 psi
Reference and testing conditions:		979.312 gals	28°C +/- 1.5 deg
		Excitation	5.052 volts

CALIBRATION READINGS (as found as left)

ACTUAL (psi)	READING 1 (mv)	CONVERTED (psi)	PERCENT ERROR % of FS
0	0.001	0	0.00
500	0.253	502	0.01
1000	0.505	1003	0.01
3000	1.515	3013	0.04
6000	3.032	6032	0.11
12000	6.056	12050	0.17
18000	9.073	18054	0.18
24000	12.089	24056	0.19
30000	15.107	30062	0.21

All readings within manufacturer tolerence (+/- .5% F.S.)

CONVERSION FACTORS (Reading - Offset)*gain

Shunt Reading (millivolts)	Shunt Reading (psi)	Offset (millivolts)	Gain (psi/mv)
12.028	**23935**	0.001	1,990.10

Calibration performed per STS document PTC1001 and traceable to N.I.S.T.

Equipment used: Pressurements model M3800 SN:61205, Agilent model 34401A SN: MY47007060

Technician L. Wilson DATE: June 12, 2011

SIGNED: [signature] RECALL: June 12, 2012

Sample A and B

Specialized Tech Services

28694 Denn Rd. Montgomery, Tx 77356
Phone - 713-515-3619

CALIBRATION CERTIFICATE

CUSTOMER: **Stress Engineering Services**

13800 WESTFAIR EAST DR

Transducer Make:	Dynisco	Transducer Model:	G830-300-30M-K73
Transducer S/N:	12-10-987608	Transducer Range:	0 - 30000 psi
Reference and testing conditions:		979.312 gals	19°C +/- 1.5 deg
		Excitation	5.051 volts

CALIBRATION READINGS (as left)

ACTUAL (psi)	READING 1 (mv)	CONVERTED (psi)	PERCENT ERROR % of FS
0	-0.208	0	0.00
500	0.044	500	0.00
1000	0.296	1000	0.00
3000	1.306	3005	0.02
6000	2.825	6019	0.06
12000	5.855	12032	0.11
18000	8.875	18025	0.08
24000	11.890	24009	0.03
30000	14.903	29988	-0.04

All readings within manufacturer tolerence (+/- .5% F.S.)

CONVERSION FACTORS (Reading - Offset)*gain

Shunt Reading (millivolts)	Shunt Reading (psi)	Offset (millivolts)	Gain (psi/mv)
11.918	**24064**	-0.208	1,984.52

Calibration performed per STS document PTC1002 and tracable to N.I.S.T.

Equipment used: Pressurements model M3800 SN:61205, HP Model 34401A Sn: MY47007060

Technician L. Wilson

DATE: January 9, 2011

SIGNED:

RECALL: January 9, 2012

Samples C, D and E

28694 Denn Rd. Montgomery, Tx 77356
Phone - 713-515-3619

Specialized Tech Services

CALIBRATION CERTIFICATE

CUSTOMER: **Stress Engineering Services**

13800 WESTFAIR EAST DR

Transducer Make:	Dynisco	Transducer Model:	G830-300-30M-K73
Transducer S/N:	21962862	Transducer Range:	0 - 30000 psi
Reference and testing conditions:		979.312 gals	24°C +/- 1.5 deg
		Excitation	5.052 volts

CALIBRATION READINGS (as found as left)

ACTUAL (psi)	READING 1 (mv)	CONVERTED (psi)	PERCENT ERROR % of FS
0	0.001	0	0.00
500	0.252	503	0.01
1000	0.501	1002	0.01
3000	1.500	3005	0.02
6000	2.998	6007	0.02
12000	5.994	12012	0.04
18000	8.987	18012	0.04
24000	11.978	24007	0.02
30000	14.966	29996	-0.01

All readings within manufacturer tolerence (+/- .5% F.S.)

CONVERSION FACTORS (Reading - Offset)*gain

Shunt Reading (millivolts)	Shunt Reading (psi)	Offset (millivolts)	Gain (psi/mv)
12.059	**24169**	0.001	2,004.40

Calibration performed per STS document PTC1001 and tracable to N.I.S.T.

Equipment used: Pressurements model M3800 SN:61205, Agilent model 34401A SN: MY47007060

Technician L. Wilson
DATE: May 4, 2011

SIGNED:
RECALL: May 4, 2012

Samples C, D and E

28694 Denn Rd, Montgomery, Tx 77356
Phone - 713-515-3619

Specialized Tech Services

CALIBRATION CERTIFICATE

CUSTOMER: **STRESS ENGINEERING SERVICES**

13800 WESTFAIR EAST DR

Transducer Make:	Dynisco	Transducer Model:	G830-300-30M-K73
Transducer S/N:	47974847	Transducer Range:	0 - 30000 psi
Reference and testing conditions:		979.312 gals	31°C +/- 1.5 deg
		Excitation	5.053 volts

CALIBRATION READINGS (as found as left)

ACTUAL (psi)	READING 1 (mv)	CONVERTED (psi)	PERCENT ERROR % of FS
0	0.856	0	0.00
500	1.108	501	0.00
1000	1.360	1001	0.00
3000	2.369	3005	0.02
6000	3.887	6020	0.07
12000	6.917	12038	0.13
18000	9.934	18031	0.10
24000	12.947	24015	0.05
30000	15.955	29990	-0.03

All readings within manufacturer tolerence (+/- .5% F.S.)

CONVERSION FACTORS (Reading - Offset)*gain

Shunt Reading (millivolts)	Shunt Reading (psi)	Offset (millivolts)	Gain (psi/mv)
13.005	**24130**	0.856	1,986.20

Calibration performed per STS document PTC1001 and tracable to N.I.S.T.

Equipment used: Pressurements model M3800 SN:61205, Agilent model 34401A SN: MY47007060

Technician L. Wilson

DATE: August 6, 2011

SIGNED:

RECALL: August 6, 2012

Sample F

28694 Denn Rd, Montgomery, Tx 77356
Phone - 713-515-3619

Specialized Tech Services

CALIBRATION CERTIFICATE

CUSTOMER: **Stress Engineering Services**

13800 WESTFAIR EAST DR

Transducer Make:	Delta Metrics	Transducer Model:	99-5864-0002
Transducer S/N:	103522	Transducer Range:	0 - 30000 psi
Reference and testing conditions:		979.312 gals	28°C +/- 1.5 deg
		Excitation	5.055 volts

CALIBRATION READINGS (as left)

ACTUAL (psi)	READING 1 (mv)	CONVERTED (psi)	PERCENT ERROR % of FS
0	-0.004	0	0.00
500	0.164	499	0.00
1000	0.332	997	-0.01
3000	1.006	2997	-0.01
6000	2.017	5997	-0.01
12000	4.038	11994	-0.02
18000	6.060	17994	-0.02
24000	8.083	23997	-0.01
30000	10.107	30003	0.01

All readings within manufacturer tolerence (+/- .5% F.S.)

CONVERSION FACTORS (Reading - Offset)*gain

Shunt Reading (millivolts)	Shunt Reading (psi)	Offset (millivolts)	Gain (psi/mv)
5.177	**15374**	-0.004	2967.35905

Calibration performed per STS document PTC1001 and tracable to N.I.S.T.

Equipment used: Pressurements model M3800 SN:61205, Agilent model 34401A SN: MY47007060

Technician L. Wilson

DATE: October 3, 2011

SIGNED:

RECALL: October 3, 2012

Sample F

Shrink Fit Connector Hydro Test   Date 10-3-11
SRP   By Ryan & Mike
PN1201286
Sample A

Time	Scan Number	Internal Pressure psi	Notes
4:09	ϕ	ϕ	START
4:23	761	4933	
4:37	1530	12779	
4:42	1778	15,108	15,000psi 15min Hold START
4:57	2588	15,075	END Hold
5:05	3021	18810	18250 - START Hold
5:21	3867	18780	END Hold
5:29	4307	22558	22.500 - START Hold
5:45	5155	22504	END Hold
5:5			STOP

Shrink Fit Connector Hydro Test Date 10-3-11
SRP By Ryan & Mike
PN1201286
Sample B

Time	Scan Number	Internal Pressure psi	Notes
1:40	Φ	Φ	START
1:45	300	590	
1:53	695	4495	
1:58	965	7155	
2:03	1260	9981	
2:10	1605	13224	
2:15	1873	15,263	15,000 psi 15 min Hold start
2:30	2674	15,235	15,000 psi 15 min Hold Finish
2:38	3105	18,792	18,750 psi 15 min Hold Start
2:53	3915	18,765	" STOP
3:02	4387	22,554	22,500 psi 15 min Hold START
3:17	5205	22,510	" STOP
3:28	5775	20	STOP

Shrink Fit Connector Hydro Test   Date 10-12-11
SRP   By NTH
PN1201286   19 Pressure Trans. SN 1210987608 (24064) 1-9-11
Sample C12 C2 C06   20 Pressure Trans. SN 2196286 2 (24169) 5-4-11

Time	Scan Number	Internal Pressure psi	Notes
4:40 AM	0	0 0	Start Test
5:22	2290	15100 - 15055	Start 18 min Hold
5:41	3325	15068 - 15015	End Hold
		-32	-40 Loss
5:52	3920	18873 - 18816	Start 15 min Hold
6:08	4770	18846 - 18789	End Hold
		-27	-27 Loss
6:20	5414	22654 - 22594	Start 15 min Hold
6:36	6280	22611 - 22551	End Hold
		-43	-43 Loss
6:39	6480	0 0	End Test
7:24	0	0 0	Start Test
8:23	3180	15128 - 15073	Start 15 min Hold
8:39	4030	15106 - 15049	End Hold
		-22	-24 Loss
8:50	4625	18652 - 18595	Start 15 min Hold
9:06	5490	18625 - 18566	End Hold
		-27	-29 Loss
9:19	6190	22645 - 22590	Start 15 min Hold
9:35	7080	22596 - 22534	End Hold
		-49	-56 Loss
9:43	7491	0 0	End Test

Sample
E07-E5-E04
10-13-11

15000
18750
22500

Shrink Fit Connector Hydro Test Date 10-12-11
SRP By NTH
PN1201286 19 Pressure Trans. SN 1210987608(24064) 1-9-11
Sample D09 D6 D03 20 Pressure Trans. SN 2196 2862 (24169) 5-4-11
File Name 1201286-D09-D6-D03

Time	Scan Number	Internal Pressure psi	Notes
13:24	0	0-0	Start Test
13:29	310	1028-1030	check Leaks Close Covers
14:01	2041	1012-1012	Covers Closed
14:39	4080	15107-15056	Start 15 min Hold
14:55	4940	15075-15022	End Hold
		-32 -34	Loss
15:05	5505	18631-18576	Start 15 min Hold
15:21	6340	18599-18543	End Hold
		-32 -33	Loss
15:33	7010	22610-22555	Start 15 min Hold
15:49	7860	22550-22490	End Hold
		-60 -65	Loss
15:53	8075	0 0	End Test

15,000
18,750 } 15 min Hold
22,500

F-02-F9-F11

Shrink Fit Connector Hydro Test
SRP
PN1201286
Sample "F"

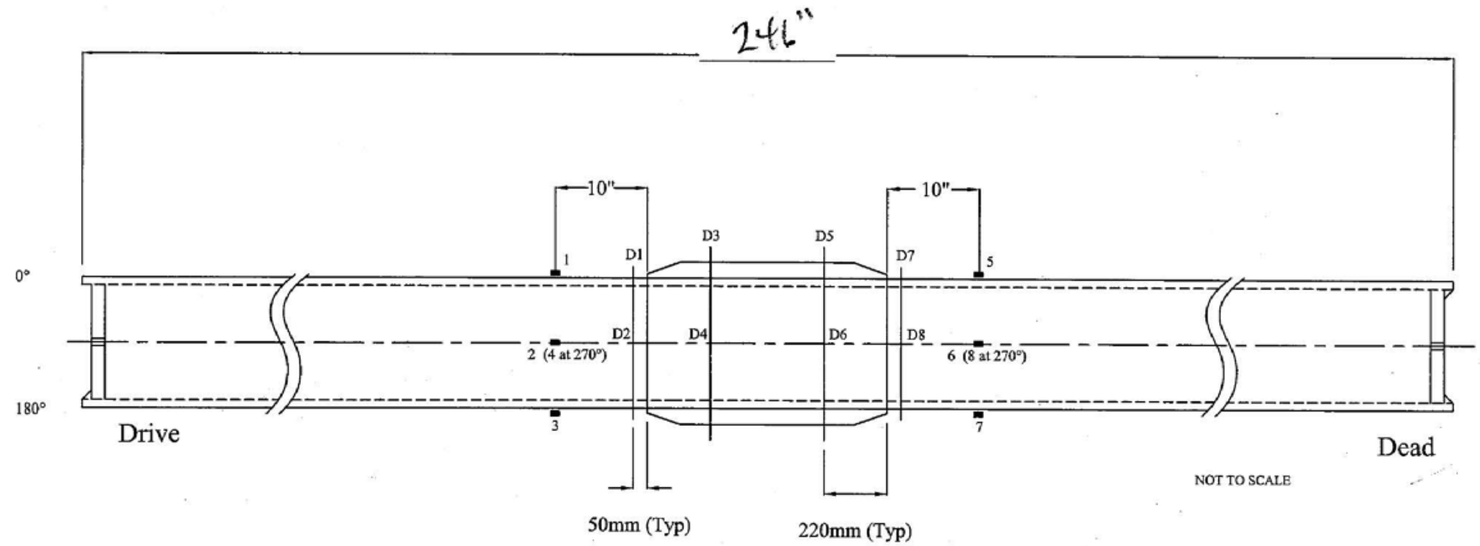
Date 10-20-11
By NTH

	serial	shunt	Due	channel
30K) Pressure Trans. SN	47974847	(24130)	8-6-12	(19)
Pressure Trans. SN	103522	(15374)	10-3-12	(20

Time	Scan Number	Internal Pressure psi		Notes	
9:12AM	0	0	0	Start Test	
9:15	150	1033	1030	check for Leak Take Pic	Covers
9:49	1950	15116	15109	Start 15min Hold	
10:05	2775	15083	15078	End Hold	-33 -31 Loss
10:20	3580	18889	18894	Start 15min Hold	
10:36	4390	18874	18880	End Hold	-15 -14 Loss
10:46	4940	22588	22618	Start 15min Hold	
11:02	5750	22555	22585	End Hold	-33 -33 Loss
11:08	6090	0	0	End Test	

APPENDICX B

OD AND WALL THICKNESS AT STRAIN GAGES ON FATIGUE TEST SAMPLES



Wall Thickness			
Gage 1 (0°)	1.092	Gage 5 (0°)	1.070
Gage 2 (90°)	1.104	Gage 6 (90°)	1.059
Gage 3 (180°)	1.081	Gage 7 (180°)	1.061
Gage 4 (270°)	1.080	Gage 8 (270°)	1.070

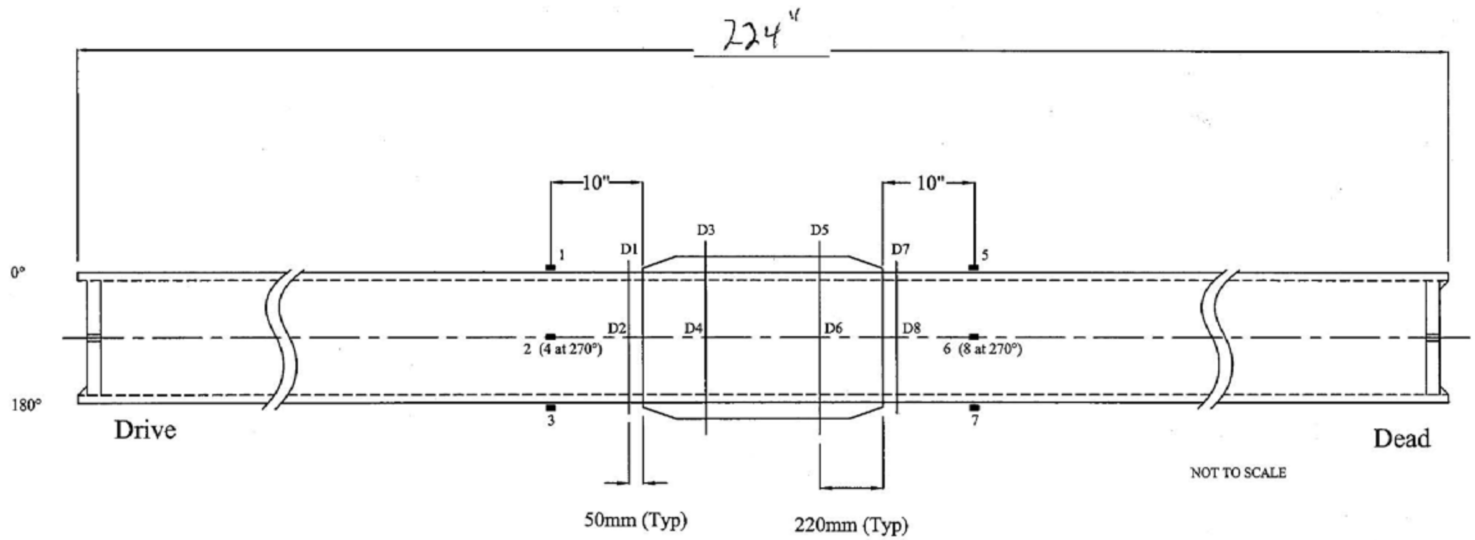
O.D.			
Gage 1-3	11.785	Gage 5-7	11.764
Gage 2-4	11.751	Gage 6-8	11.770

	Before Hydro	After Hydro
D1 (0°)		11.806
D2 (90°)		11.794
D3 (0°)		15.117
D4 (90°)		15.115
D5 (0°)		15.120
D6 (90°)		15.119
D7 (0°)		11.804
D8 (90°)		11.790

By NRTatum
Date 10.28.11

SRP Connector Fatigue Test Sample SRP-A
SRP
PN1201286

10/2/2011



Wall Thickness

Gage 1 (0°)	1.104
Gage 2 (90°)	1.115
Gage 3 (180°)	1.105
Gage 4 (270°)	1.093
Gage 5 (0°)	1.079
Gage 6 (90°)	1.070
Gage 7 (180°)	1.067
Gage 8 (270°)	1.083

O.D.

Gage 1-3	11.795
Gage 2-4	11.755
Gage 5-7	11.793
Gage 6-8	11.764

	Before Hydro	After Hydro
D1 (0°)		11.790
D2 (90°)		11.775
D3 (0°)		15.122
D4 (90°)		15.120
D5 (0°)		15.123
D6 (90°)		15.119
D7 (0°)		11.786
D8 (90°)		11.802

By MTatum

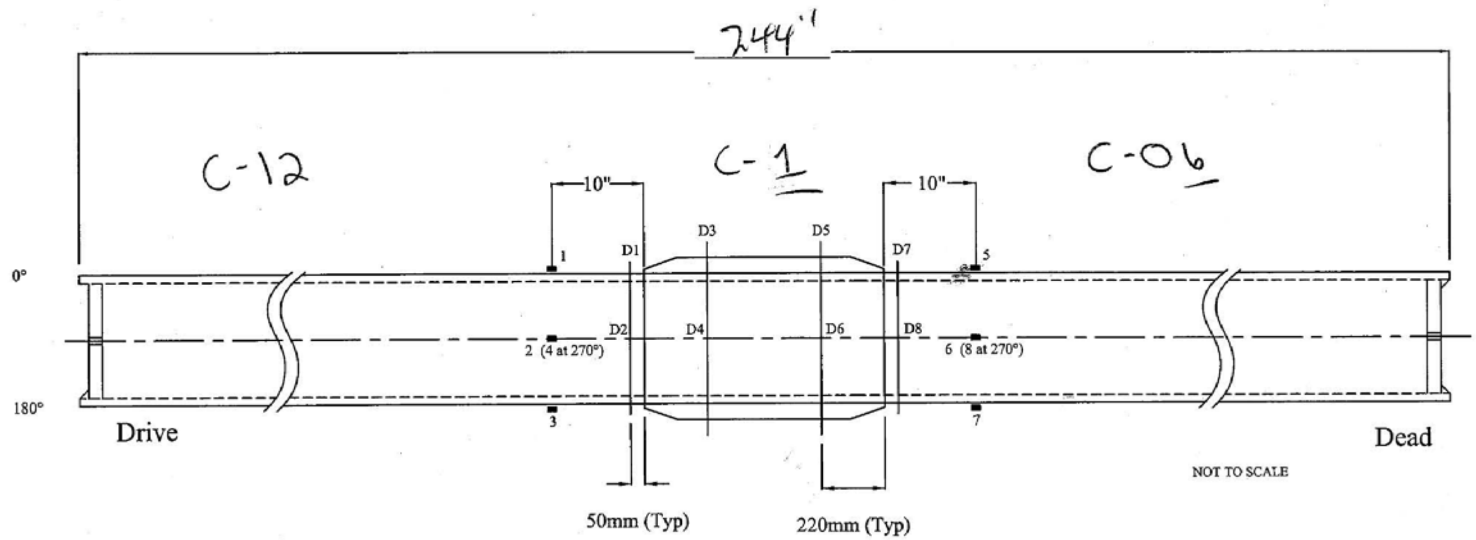
Date 10-4-11

SRP Connector Fatigue Test Sample SAM-B

SRP

PN1201286

10/2/2011



Wall Thickness
Gage 1 (0°) 1.063
Gage 2 (90°) 1.075
Gage 3 (180°) 1.060
Gage 4 (270°) 1.080

Gage 5 (0°) 1.078
Gage 6 (90°) 1.056
Gage 7 (180°) 1.069
Gage 8 (270°) 1.060

O.D.
Gage 1-3 11.745
Gage 2-4 11.767

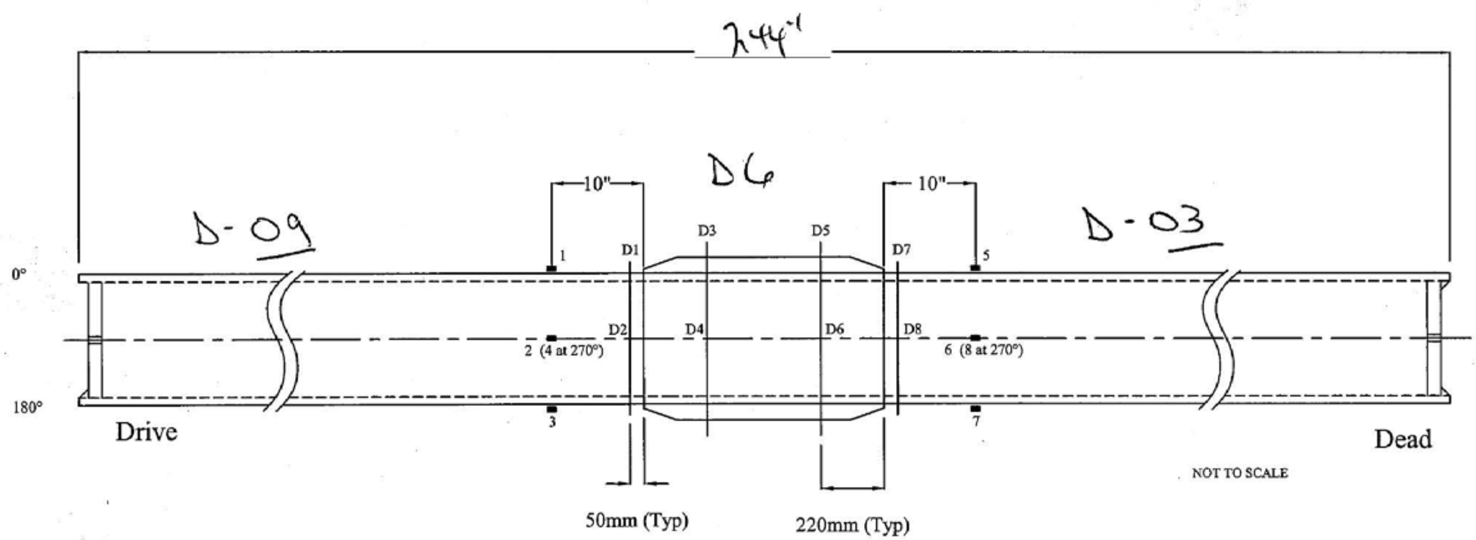
Gage 5-7 11.720
Gage 6-8 11.757

	Before Hydro	After Hydro
D1 (0°)	11.769	11.772
D2 (90°)	11.783	11.783
D3 (0°)	15.122	15.126
D4 (90°)	15.123	15.127
D5 (0°)	15.125	15.125
D6 (90°)	15.121	15.122
D7 (0°)	11.775	11.779
D8 (90°)	11.767	11.770

SRP Connector Fatigue Test Sample C-12 C-1 C-06
SRP
PN1201286

By NTH
Date 10-11-11

10/2/2011



Wall Thickness	
Gage 1 (0°)	1.098
Gage 2 (90°)	1.079
Gage 3 (180°)	1.106
Gage 4 (270°)	1.100
Gage 5 (0°)	1.059
Gage 6 (90°)	1.098
Gage 7 (180°)	1.057
Gage 8 (270°)	1.063

O.D.	
Gage 1-3	11.800
Gage 2-4	11.774
Gage 5-7	11.782
Gage 6-8	11.767

	Before Hydro	After Hydro
D1 (0°)	11.790	11.795
D2 (90°)	11.813	11.817
D3 (0°)	15.020	15.022
D4 (90°)	15.021	15.022
D5 (0°)	15.020	15.021
D6 (90°)	15.023	15.024
D7 (0°)	11.813	11.816
D8 (90°)	11.767	11.771

SRP Connector Fatigue Test Sample D09 D6 D03

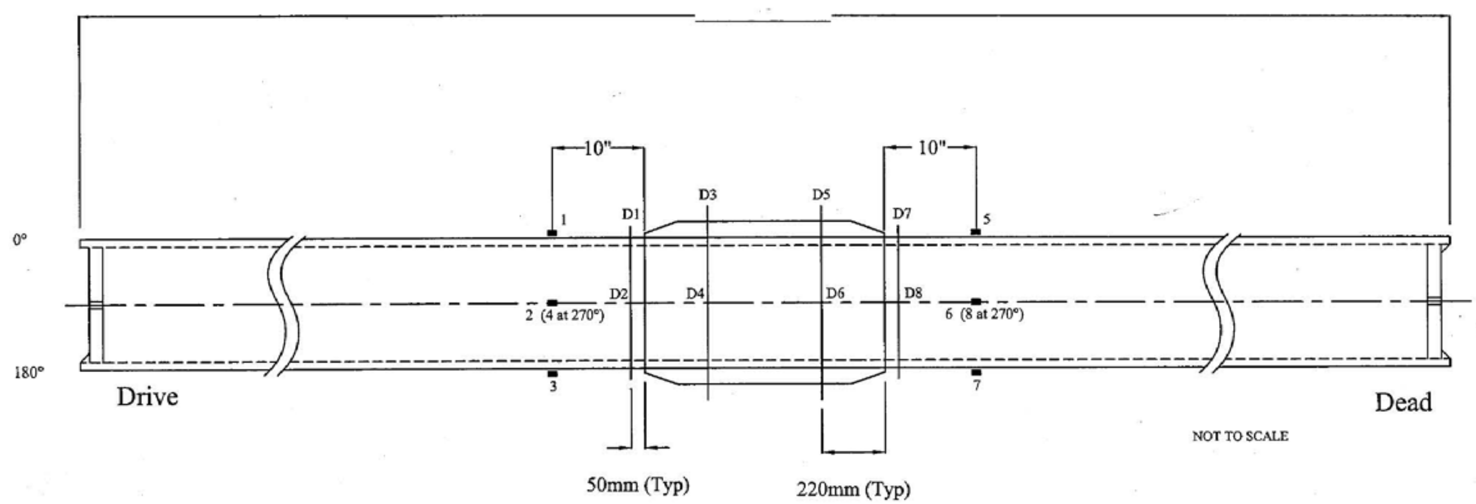
SRP

PN1201286

By NTH

Date 10-11-11

10/2/2011



Wall Thickness	
Gage 1 (0°)	1.042
Gage 2 (90°)	1.068
Gage 3 (180°)	1.052
Gage 4 (270°)	1.042
Gage 5 (0°)	1.099
Gage 6 (90°)	1.091
Gage 7 (180°)	1.129
Gage 8 (270°)	1.074

O.D.	
Gage 1-3	11.772
Gage 2-4	11.753
Gage 5-7	11.790
Gage 6-8	11.791

	Before Hydro	After Hydro
D1 (0°)	11.787	11.786
D2 (90°)	11.811	11.807
D3 (0°)	15.056	15.054
D4 (90°)	15.052	15.051
D5 (0°)	15.053	15.052
D6 (90°)	15.053	15.054
D7 (0°)	11.813	11.811
D8 (90°)	11.789	11.787

By ____________

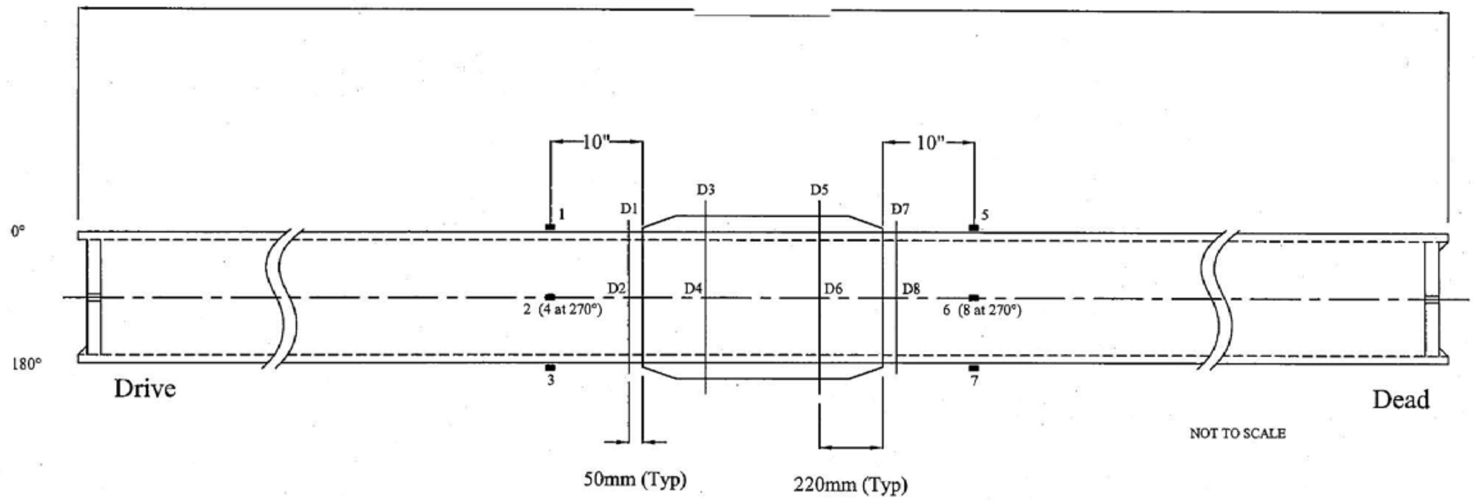
Date ____________

SRP Connector Fatigue Test Sample E

SRP

PN1201286

10/2/2011



Wall Thickness

Gage 1 (0°)	1.080
Gage 2 (90°)	1.091
Gage 3 (180°)	1.075
Gage 4 (270°)	1.081
Gage 5 (0°)	1.062
Gage 6 (90°)	1.039
Gage 7 (180°)	1.052
Gage 8 (270°)	1.048

O.D.

Gage 1-3	11.765
Gage 2-4	11.768
Gage 5-7	11.762
Gage 6-8	11.785

	Before Hydro	After Hydro
D1 (0°)	11.807	11.809
D2 (90°)	11.783	11.782
D3 (0°)	15.068	15.069
D4 (90°)	15.062	15.062
D5 (0°)	15.069	15.070
D6 (90°)	15.068	15.068
D7 (0°)	11.786	11.788
D8 (90°)	11.806	11.805

F02- F04 - F11

SRP Connector Fatigue Test Sample F

SRP

PN1201286

By NTH

Date 10-13-11

10/2/2011