Technical Brief

Viper™ Connector

Fatigue Test Summary

Viper weld-on connectors are perhaps the most analyzed and tested large bore connectors on the market today. XL Systems incorporated extensive full-scale fatigue testing in the Viper connector development program to accurately characterize connector fatigue performance.

The Viper connector development plan included full-scale physical tests of over fifty Viper connector samples in a range of sizes and grades. This document provides a summary of the Viper connector fatigue testing program with statistical analysis of the test data to generate connector fatigue design curves. The Viper connector is manufactured in two thread geometries. The Viper-1ST connector uses a single-start thread and makes-up in 1.68 turns. The Viper-3ST connector uses a triple-start thread and makes-up in 0.56 turns. Dimensions and capacities are the same for both thread geometries. The Viper fatigue testing program included both Viper-1ST and Viper-3ST connectors. Viper connectors are available in sizes from 16-inch to 38-inch diameter.

Family of Parts Design and Fatigue Testing Plan

The Viper connector line is unique in that it was designed as a true 'family of parts'. Consistent design methods and design parameters from size to size ensure consistency of performance across the product line. This design consistency also allows for meaningful extrapolation of physical test data from size to size. XL Systems took advantage of this family of parts design and selected representative connector sizes for extensive fatigue testing. Finite element analysis (FEA) is used as the tool to interpolate and extrapolate connector fatigue performance to non-tested sizes. Certain connector sizes such as 36-inch were explicitly tested to remove uncertainty in the connector fatigue prediction model for sizes often used in fatigue-critical applications such as subsea well conductors.

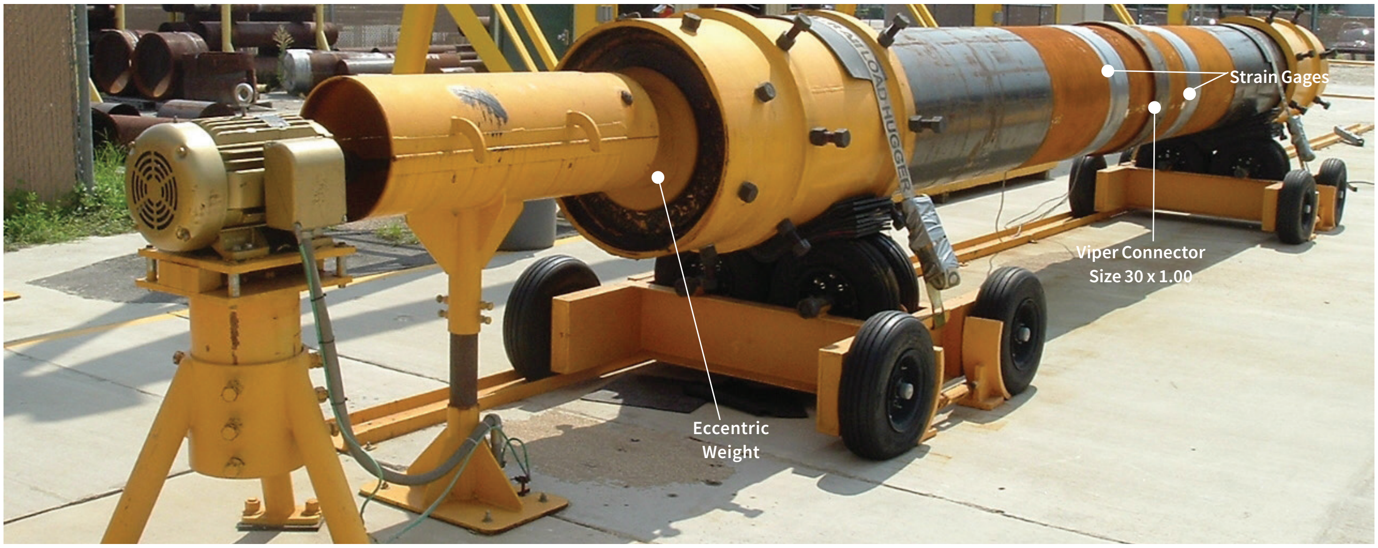


Figure 1: Harmonic Fatigue Testing Assembly

Viper Connectors – Designed for Excellent Fatigue Performance

The complete product line for Viper was designed for use in fatigue-critical applications. The connector design includes such features as stress reduction grooves and large thread root radii to enhance connector fatigue performance. XL Systems also uses an engineered weld neck on all Viper connectors. This longer connector weld neck improves the pipe-to-connector weld fatigue performance by moving the weld away from stress concentrations due to the connector upset geometry, improves weld quality by moving the weld farther away from the connector body 'heat sink' during welding, and provides better access to both sides of the weld for weld inspection. Viper connectors use an industry best practice of shot peening the thread surfaces to enhance connector fatigue performance. To our knowledge this is unique in the large diameter connector industry.

Fatigue Testing Program

Over fifty harmonic fatigue tests on Viper connectors have been performed in a variety of sizes, pipe grades, and forging grades as summarized in Table 1 below.

Table 1

Fatigue Testing Summary

Connector	Pipe Grade	Connector Grade	Tested Samples
20x0.812 Viper-1ST	X56	M70	13
30x1.00 Viper-3ST	X56	M70	9
30x1.00 Viper-1ST	X56	M70	3
36x1.50 Viper-3ST	X56	M70	9
36x1.50 Viper-1ST	X80	M85	6
36x1.50 Viper-3ST	X65	GP-110	11

Furthermore, Table A.1 in Appendix A provides detailed information for each test sample that includes stress range, cycles to failure, and failure location.

Fatigue Test Protocol

XL Systems physical testing of Viper connectors uses a harmonic test machine, a test method that has become the de-facto standard for connector and pipe fatigue testing. The test is a severe test in that the complete circumference of the connector is exposed to cyclic stress.The harmonic test machine uses a rotating eccentric weight to induce vibration in the test sample. The magnitude of cyclic stress in the connector is controlled by changing the speed of the drive motor. Strain gages bonded to the test sample on each side of the connector provide direct measurement of peak stresses in the region of the test sample containing the connector.

The test sample is vibrated at a constant stress range until a through-wall fatigue crack develops in the test sample.

XL Systems goal for Viper fatigue testing was to develop design curves for connector failure modes only. Certain test samples developed fatigue cracks in the pipe-to-connector welds or the pipe body before a connector fatigue crack. Data from these test samples were not included in the statistical analysis used to develop the connector fatigue design S-N curves. There is a significant body of data available in the industry to characterize the fatigue performance of various weld details. It is noted that significant effort was required to achieve pipe-to-connector welds in our test samples with weld fatigue life exceeding connector fatigue life. This is an excellent indicator of the superb fatigue performance of Viper connectors.

Fatigue Test Results

Appendix A provides details on each Viper fatigue test sample and also separates the fatigue test results into four categories: weld cracks, pipe body cracks, connector cracks with incomplete connector preload, and connector cracks with good connector make-up.

Weld cracks occurred on several early test samples. XL Systems modified welding procedures and developed a series of closely controlled post-weld surface treatments to eliminate this failure mode from later test samples. Weld failures were not included in the statistical analysis to generate connector fatigue design curves.

Pipe body cracks occurred in a small number of test samples. A surface treatment process was developed for the pipe body section in the highly stressed region of the test sample near the connector. The fact that pipe body cracks preceded connector cracks in multiple test samples also indicates excellent Viper connector fatigue performance.

A small number of test samples produced fatigue cracks in the connector but at cycle counts much less than the large population of test data. Investigation determined that these test connectors were not fully made-up at the start of the test. The key indicator of incomplete make-up was a significant amount of connector make-up rotation during fatigue testing. For a shouldered connector design such as Viper, additional make-up rotation is not physically possible if the connector is properly shouldered during initial make-up. All test samples were made-up in a horizontal orientation. This orientation does not allow the connector to self-center and self-align as easily as the vertical make-up always used in the field. Test sample make-up procedures were developed and continually refined to achieve test connector make-up representative of the connector preload levels achieved in a normal vertical make-up. Data from test samples determined to have inadequate make-up were not included in the statistical analysis of test data.

Appendix A shows that the majority of Viper test samples produced the target failure mode of a fatigue crack in the connector body with good connector make-up. These data were included in the statistical analysis of test data to produce the recommended connector fatigue design curve.

All connector failures initiated in the threaded region between the internal O-ring seal and the external metal-to-metal seal. Connector failures occurred in the critical cross-sections in both the pin and the box connectors. Evenly spread failure data between the pin and the box show a well-balanced Viper connector design.

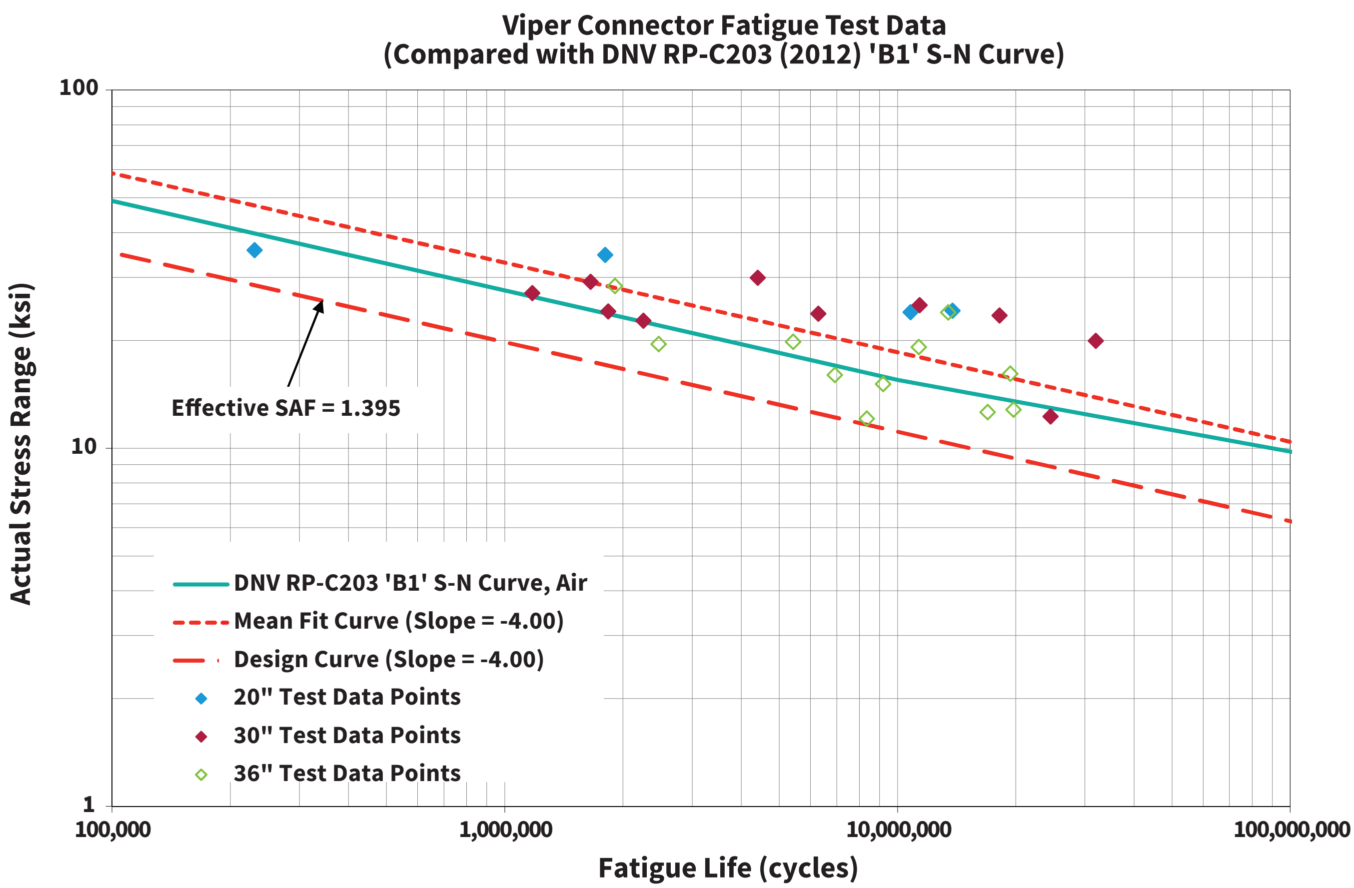


Figure 2: Viper Connector Fatigue Test Data

Statistical Analysis of Test Results

Following testing and data acquisition, each data point was presented as a log-log plot of double-amplitude stress range (S) versus the number of cycles to failure (N), which is known as an S-N curve. As shown in Figure 2, data points for different diameters are designated with different colors for comparison. Statistical analyses were performed to calculate a least squares regression fit 'mean curve' for the test data. The somewhat narrow range of tested stress levels (a limitation of the harmonic fatigue testing apparatus) and the fairly large variability in tested connector fatigue life did not produce a reasonable slope for the mean S-N curve. XL Systems opted to fit our mean curve to a fixed slope of -4.00 to match the slope of the DNV RP-C203 (2012 edition) 'B1' S-N curve. This 'B1' industry standard curve is often used to characterize the base material fatigue performance of machined alloy steel parts for offshore service. Figure 2 shows the mean curve and the relevant Viper test data.

The standard deviation of the test data was calculated with respect to the mean curve with a slope of -4.00. A design curve was calculated as the mean minus two standard deviations as is standard practice for nearly all weld fatigue design curves for offshore welded components. An effective stress amplification factor (SAF) was calculated to relate the Viper connector fatigue design curve to the DNV 'B1' curve. The effective SAF for the current full population of Viper test data is 1.395 as shown in Figure 2. This is the recommended design curve for Viper connectors of all sizes. It is noted that the very low effective SAF of 1.395 represents exceptionally good fatigue performance for a large diameter weld-on connector.

Statistical Analysis of Individual Diameters

Close analysis of the data in Figure 2 suggests a bias in the connector fatigue life with size. This behavior is not entirely unexpected since the larger connectors are known to have lower preload stress at make-up. Higher preload during make-up typically means better connector fatigue performance. It is noted that this bias could also be a function of increasing difficulty of achieving proper test sample make-up in the horizontal orientation as the test samples get larger and heavier.

XL Systems separated the full population of test data into smaller data sets for only 20-inch connectors, only 30-inch connectors, and only 36-inch connectors. Each data set was analyzed independently for a new mean curve, a new standard deviation, and a new effective SAF for the design curve. Table 2 summarizes the effective SAFs generated for each individual diameter.

Table 2

Viper Effective SAFs

Fatigue Data Set	**Effective SAF**
20-inch Viper Connectors	1.299
30-inch Viper Connectors	1.242
36-inch Viper Connectors	1.467

The individual design curves for each diameter data set are shown in Figures B.1, B.2, and B.3 in Appendix B.

Summary

XL Systems has extensively fatigue tested the Viper connector so that the end user can better calculate and manage risks of today's deepwater wells. The result is a weld-on connector that has become the industry leader in demanding applications around the world where connector performance is most critical.

Appendix A

Table A.1

Viper Fatigue Testing - Detailed Sample Summary with Failure Locations

Test Sample	Sample ID	Actual Stress Range		Cycles to Failure & Failure Location			
		(ksi)	(MPa)	Pipe-to-Connector Weld Crack	Pipe Body Crack	Connector Crack, Low Pre-Load	Connector Crack
	Sample 1	21.98	151.52	2,499,010			
	Sample 2	24.08	166.00			2,836,011	
	Sample 3	24.03	165.66			520,048	
	Sample 4	35.73	246.31				230,757
20x0.812 Viper-1ST	Sample 5	35.71	246.18		159,735		
X56 Pipe Grade	Sample 6	35.06	241.69	140,816			
M70 Connector Grade	Sample 7	23.96	165.17				10,801,233
	Sample 8	34.65	238.87				1,802,960
	Sample 9	35.84	247.07	668,580			
	Sample 10	23.94	165.04			4,080,667	
	Sample 11	24.13	166.35	3,967,929			
	Sample 12	24.21	166.90				13,803,471
	Sample 13	32.12	221.43	534,944			
	Sample 1	22.69	156.42				2,253,515
	Sample 2	23.76	163.80				6,288,297
30x1.00 Viper-3ST	Sample 35	29.89	206.05				4,404,355
X56 Pipe Grade	Sample 4	12.26	84.52				24,526,736*
M70 Connector Grade	Sample 53	29.16	201.02				1,653,978
	Sample 69	27.09	186.75				1,174,868
	Sample 78	19.94	137.46				31,960,753*
	Sample 87	19.96	137.60			4,391,123	
	Sample 96	24.08	166.00				1,832,799
30x1.00 Viper-1ST	Sample 1	25.10	173.03				11,379,590
X56 Pipe Grade	Sample 2	23.47	161.80				18,179,287
M70 Connector Grade	Sample 3	24.15	166.48			751,100	
	Sample 1	19.52	134.57				2,466,335
	Sample 2	12.08	83.28				8,357,513
36x1.50 Viper-3ST	Sample 3	19.16	132.08			1,089,807	
X56 Pipe Grade	Sample 4	18.32	126.29			597,437	
M70 Connector Grade	Sample 5	12.02	82.86		15,283,190		
	Sample 6	16.02	110.44				6,924,731
	Sample 7	16.13	111.20				19,376,693
	Sample 8	23.94	165.04				13,471,558
	Sample 9	28.35	195.44				1,907,492
	Sample 2	15.2	104.79	10,716,078			
36x1.50 Viper-1ST	Sample 3	12.6	86.86				16,970,307
X80 Pipe Grade	Sample 4	12.8	88.24				19,737,638
M110 Connector Grade	Sample 5	19.8	136.50				5,421,729
	Sample 6	19.9	137.19	7,701,635			
	Sample 7	15.1	104.10				9,197,608
	Sample 1	12.0	82.73	400,062			
	Sample 2	12.0	82.73	1,800,000			
	Sample 3	12.0	82.73			123,926	
36x2.00 Viper-3ST	Sample 4	8.22	56.67			2,102,728	
X65 Pipe Grade	Sample 5	7.93	54.67	1,876,905			
M110 Connector Grade	Sample 6	12.0	82.73			2,810,941	
	Sample 7	7.90	54.46		11,071,882		
	Sample 13	18.83	129.81	1,731,841			
	Sample 14	19.14	131.95				11,338,871
	Sample 15	12.16	83.83			5,344,419	
	Sample 16	19.05	131.33	3,385,180			

* Sample never failed - testing stopped

Appendix B: 20-inch, 30-inch, and 36-inch Fatigue plots

Figure B.1

20-inch Viper Connector Fatigue Test Data

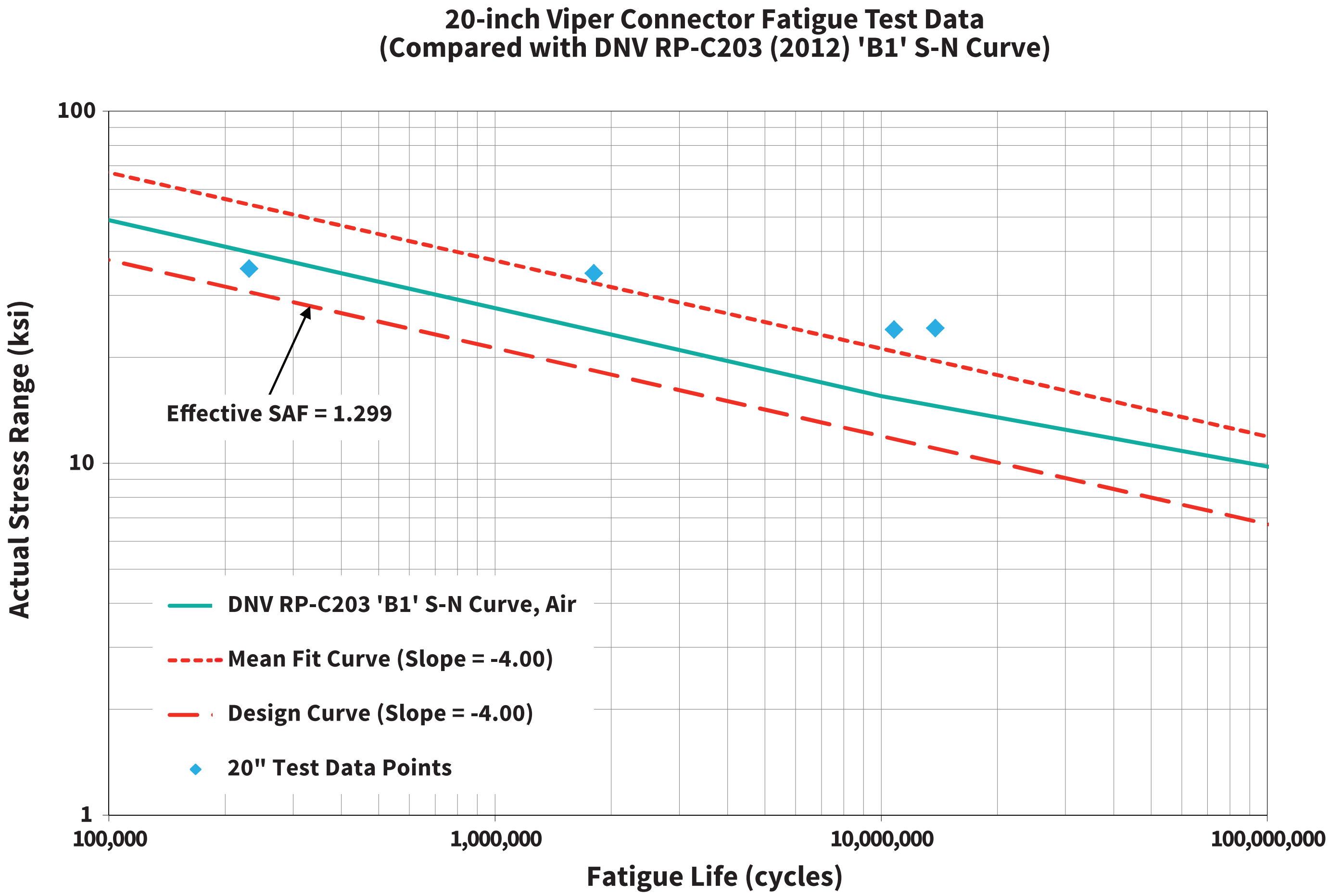


Figure B.2

30-inch Viper Connector Fatigue Test Data

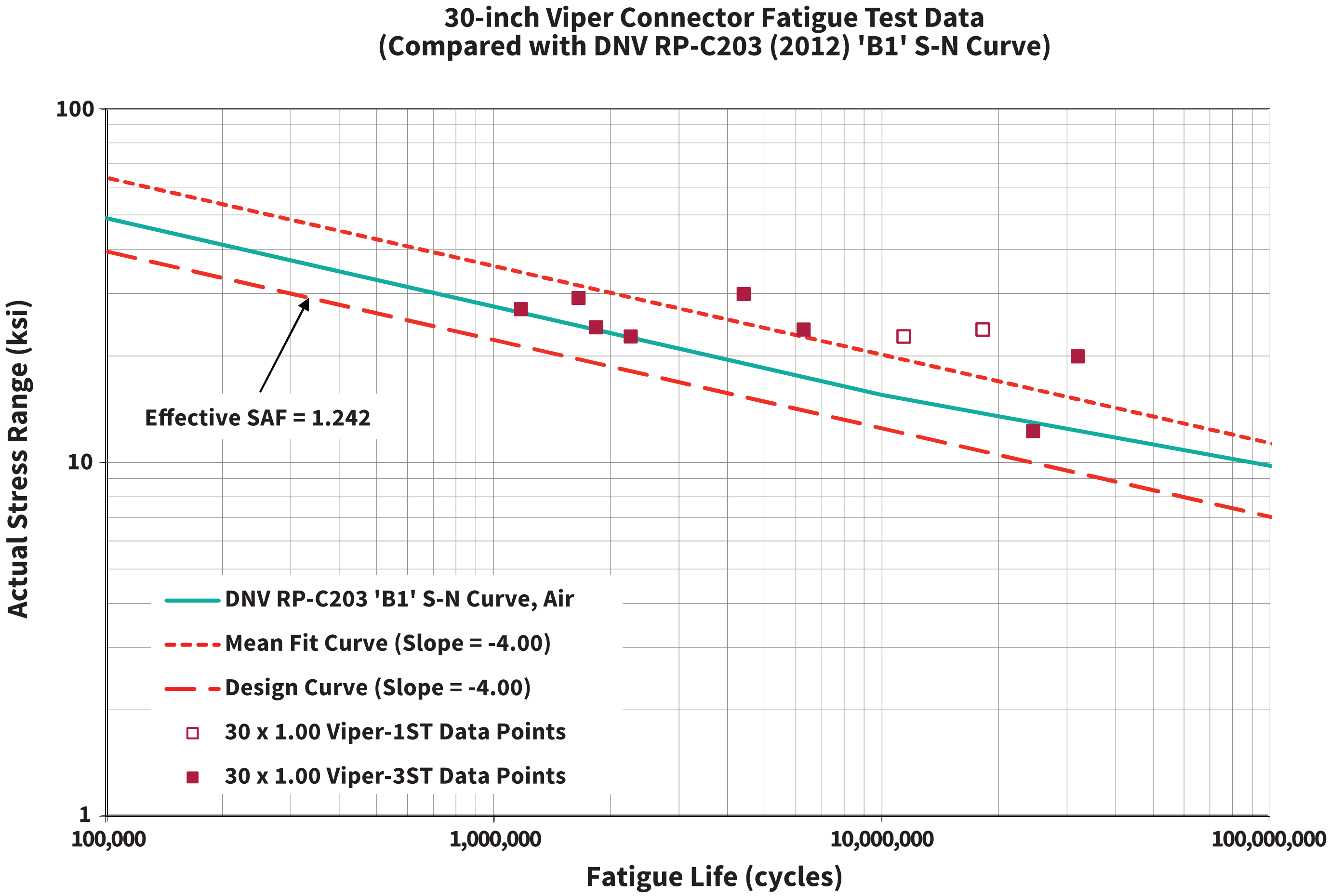
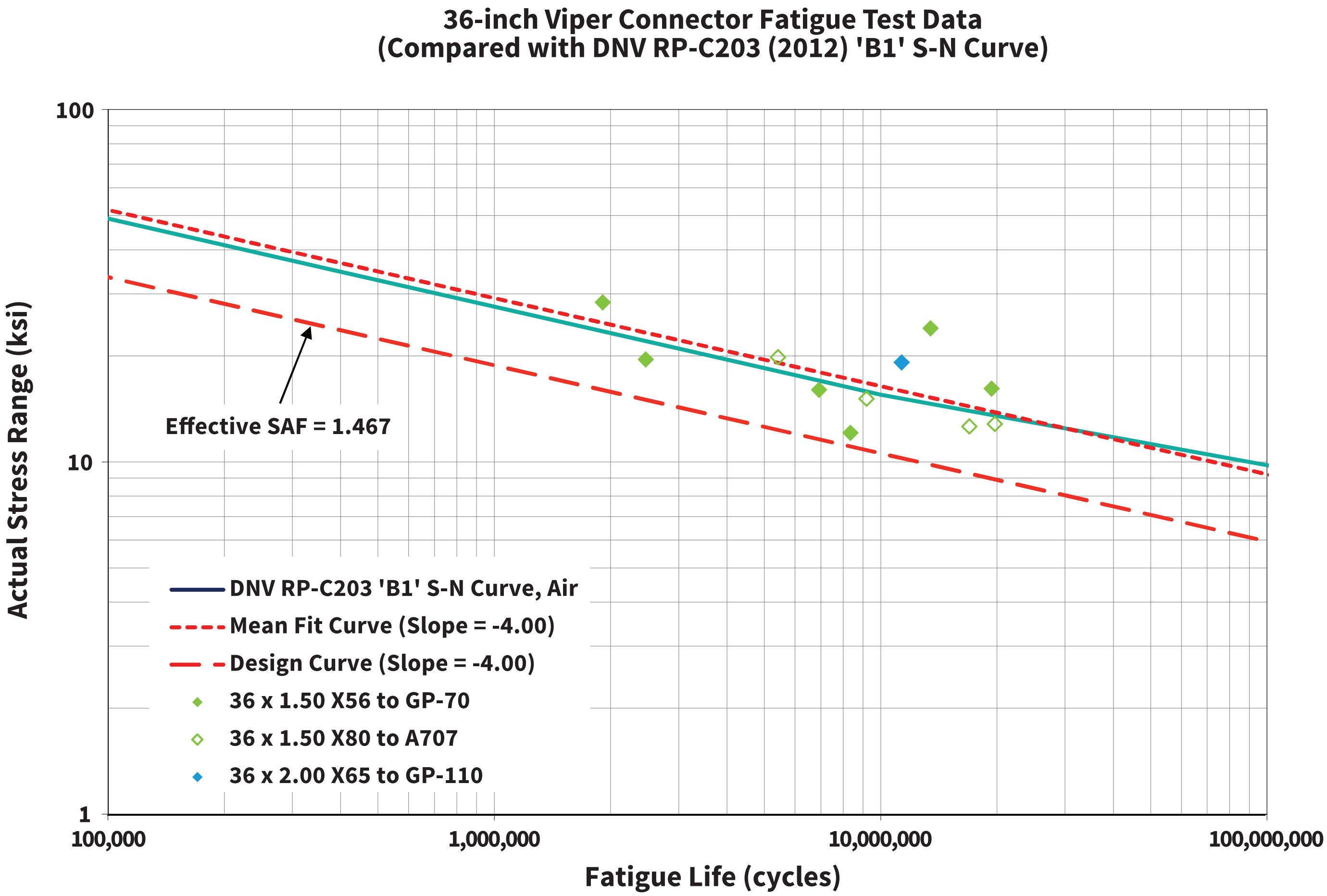


Figure B.3

36-inch Viper Connector Fatigue Test Data



XL Systems develops, produces and markets some of the strongest and most advanced conductor and surface casing systems. XL Systems is a Business Unit in National Oilwell Varco (NYSE:NOV) which supplies customer-focused solutions that best meet the quality, productivity, and environmental requirements of the energy industry.

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