R.11-02-019: Hearings on PG&E's Implementation Plan

City and County of San Francisco
Proposed Exhibit 156:
PG&E Response to TURN Data Request 030-06, and Attachment

PACIFIC GAS AND ELECTRIC COMPANY
Gas Pipeline Safety OIR
Rulemaking 11-02-019
Data Response

PG&E Data Request No.:	TURN_030-06		
PG&E File Name:	GasPipelineSafetyOIR_DR_TURN_030-Q06		
Request Date:	March 13, 2012	Requester DR No.:	030
Date Sent:	March 20, 2012	Requesting Party:	The Utility Reform Network (TURN)
PG&E Witnesses:	Todd Hogenson Mike Rosenfeld	Requester:	Marcel Hawiger

QUESTION 6

Has PG&E done a pressure cycle analysis for one of its local transmission lines of 20-inch or greater? If yes, please provide the analysis.

ANSWER 6

Yes. GasPipelineSafetyOIR_DR_TURN_030-Q06Atch01 is a "Pressure-Cycle Induced Fatigue Analysis Report" for pipelines L-101, L-109 and L-132 located on the San Francisco Peninsula. This report was prepared by Kiefner & Associates for PG&E. Please note that, although it is marked as such, PG&E does not consider this document to be covered by the attorney-client privilege.

Gas Transmission Systems Inc. on Behalf of PG&E

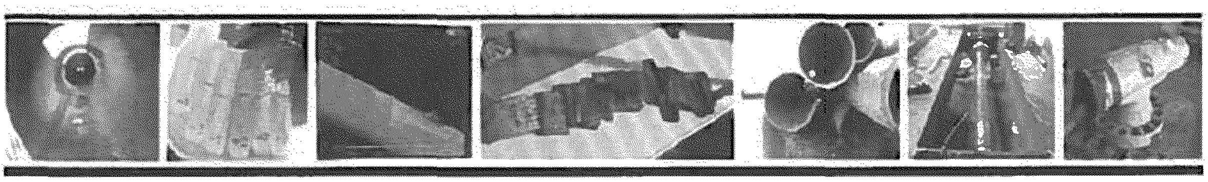
Final Report No. 12-024

Final Report

Analysis of the Effects of Pressure-Cycle-Induced Fatigue-Crack Growth on the Peninsula Pipeline

Privileged and Confidential

Michael J. Rosenfeld, P.E. and Kolin M. Kolovich, P.E.
March 19, 2012



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on

ANALYSIS OF THE EFFECTS OF PRESSURE-CYCLE-INDUCED FATIGUE-CRACK GROWTH ON THE PENINSULA PIPELINE

Privileged and Confidential

GAS TRANSMISSION SYSTEMS INC. ON BEHALF OF PG&E

March 19, 2012

by

Michael J. Rosenfeld, P.E. and Kolin M. Kolovich, P.E.

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Analysis of the Effects of Pressure-Cycle-Induced Fatigue-Crack Growth on the Peninsula Pipeline

Michael J. Rosenfeld, P.E. and Kolin M. Kolovich, P.E.

INTRODUCTION

Fluctuations in the operating pressure of pipelines, due to the non-steady demand for the product transported or as a result of day-to-day operation and maintenance, can cause subcritical defects to enlarge over time. This threat has been realized on many liquid pipelines and is less common in gas pipelines for the simple reason that gas pipelines tend to operate with less-frequent significant changes in internal pressure. The following describes our analysis of the effects of pressure-cycle-induced fatigue-crack growth on the Peninsula Pipelines.

SUMMARY AND CONCLUSIONS

The evaluation of the operational pressure of L101, L109, and L132 recorded over the ten years prior to the September 9, 2010 incident suggest that for a defect to enlarge to the point of failure by pressure-cycle-induced fatigue-crack growth, it would have to have been initially very large. It has been demonstrated herein that if a pipe was tested to the minimum required API 5LX pressure at the mill, then the fatigue threat is very low. Lower-grade pipe (i.e. Grade A and Grade B) that was not required to be tested to as high a pressure as API 5LX grades would be at a higher risk for seam-weld fatigue. Finally, if it cannot be reliably established that a hydrostatic test was ever performed then a pressure reduction can slow potential crack growth and allow time to plan for an integrity assessment. If a pressure reduction is taken, then for it to effectively mitigate the fatigue threat, protection against overpressure events is important.

To summarize the results of the fatigue analysis presented in the following sections, the level of hydrostatic test pressure is very important for estimating a specific pipe segment's susceptibility to pressure-cycle-induced fatigue-crack growth. Figure 1 shows that for pipe tested to levels corresponding to 1.75 x the MAOP or more, the calculated fatigue life is in excess of 500 years. Pipe tested to a level of 1.5 x MAOP has a fatigue life of 200 years or more, and pipe tested to 1.25 x MAOP has a fatigue life of at least 100 years. Pipe that was not tested to at least 1.25 x MAOP has a limited calculated fatigue life.

Background

Pipe manufactured to API 5L Line Pipe Specifications was required to have been tested to a minimum hydrostatic pressure before leaving the pipe mill. The test pressure level varied based on pipe diameter and grade however large-diameter (NPS 20 and greater) API 5LX pipe was required to have been tested to a pressure corresponding to 90% of SMYS starting in 1956. API 5LX grades were introduced in 1949 and were required to have been tested to a minimum of 85% SMYS prior to 1956.

The level of a hydrostatic pressure test has been shown to directly relate to the size of defects that can remain in the pipe following the test. The higher the test pressure, the smaller is the flaw that can survive the test. Using a suitable remaining strength criterion such as the Modified Ln-Sec equation, a distribution of sub-critical flaws varying in length and depth from short-and-deep to long-and-shallow can be developed based on a given test pressure level. The remaining life of such flaws can be predicted using a fatigue-crack-growth model and actual pressure data.

Analysis Results

An analysis of initial flaw distributions in terms of fatigue-crack growth in response to the L101, L109, and L132 pressure fluctuations suggests that any pipe tested to API 5LX pressures could be expected to have a fatigue life on the order of hundreds of years (see Table 1). The extremely long predicted fatigue lives result from the high test-pressure-to-operating-pressure ratio (90% SMYS to less than 40% SMYS), as well as from the fact that the gas pressure fluctuations are relatively small and infrequent. For API 5L Grade A and Grade B pipe, the minimum required test pressure was lower (60% SMYS) so the calculated fatigue life in some cases is on the order of 50 years. Note that in these cases in Table 1 the pipe was either tested by PG&E to a higher pressure resulting in a long fatigue life (so in essence the fatigue life predicted by the mill test does not apply), or the pipe is seamless so the threat of seam-weld fatigue does not apply.

L109 contains segments of a PG&E-specified pipe grade (33 ksi yield strength) and Grade B pipe. Since this pipe was not required to have been tested to as high a pressure at the pipe mill, the calculated fatigue life is on the order of 100 years. A safety factor of two (2) has generally been recommended for determining reassessment intervals for the seam-fatigue threat in liquid pipelines for analyses based on test pressure. In other words, reassessment is recommended at half of the predicted time to failure and the reassessment interval begins at the time of hydrostatic test used in the fatigue calculation. Applying the safety factor to the L109 fatigue predictions and beginning at the time the pipe was installed, the PG&E-grade pipe reassessment interval would be expired (the pipe was tested in 1936 and the recommended interval as half of the 139-year fatigue life, 70 years, would place reassesment in the year 2006), and the Grade B-pipe reassessment interval would expire in 2019 (the 120-year fatigue life divided by two then added to the test year, 1959, places reassessment in the year 2019). Therefore an integrity assessment of these segments may be warranted sometime in the future although the fatigue threat is not considered to be imminent in the short term.

A conclusion drawn from the fatigue analyses is that any flaw that could enlarge in response to the pressure cycles such that it could threaten the integrity of the pipeline at the MAOP would have to be initially very large. It also follows that lower grades of pipe (such as Grades A and B) that were not required to be tested to as high a pressure, or pipe that was not tested at all, could conceivably contain very large defects.

If pressure-cycle-induced fatigue-crack growth is the suspected cause of a failure, then the benefit of a pressure reduction can be shown through crack-growth modeling using an assumed reduced operating pressure spectrum. Instead of establishing the initial pipe quality based on a previous hydrostatic test, a more conservative approach would be to determine the postulated flaw distribution based on what could survive the recently recorded highest operating pressure. Then by applying reduced operating pressures to the flaws through the fatigue model. times to failure can be predicted. This exercise was performed for the L132 pressure and 30-inch OD, 0.375-inch and 0.312-inch wall thickness Grade API 5LX pipe assuming various material toughness and strength parameters and levels of pressure reduction. The results of the analyses are summarized in Table 2.

The results show that even a small 25-psig pressure reduction results in a remaining fatigue life that would be considered tolerable by liquid pipeline standards with regard to having adequate time to plan for reassessment before the predicted life is met. The results also show that the predicted fatigue life is relatively insensitive to the pipe properties (wall thickness, material strength, and toughness) for a given reduced operating pressure. This result is interesting since it was expected that material properties would have a significant impact on calculated fatigue life. The implications of the insensitivity to pipe strength and toughness are two-fold – the size of the flaw presumed to exist is dominating the fatigue calculations and overpressure events can threaten the benefit of a pressure reduction.

Large flaws accelerate rapidly in size (primarily depth) towards their end-of-life and the initial flaw size presumed to exist at the time of the pressure reduction was very deep in this case (80% wall thickness). The large initial flaw is a result of the assumption that it was just subcritical at 395 psig (a conceivable high pressure that L132 experienced prior to the failure). The lower operating stress at the reduced operating pressure allows this flaw to sustain sub-critical crack growth. Since toughness is not a factor in the crack-growth calculation (and to only a small extent is strength a factor) the time to failure prediction is dominated by the acceleration of the flaw in depth rather than the failure criterion which depends on both the flaw size and the material properties.

From the fatigue analyses performed to examine the sensitivity of the calculations to wall thickness, strength, and toughness, it was observed that different cases had identical or very similar fatigue lives. Further inspection of these cases showed that failure was predicted at the same pressure cycle in the spectrum, namely the cycle that contained the maximum pressure in the spectrum. The maximum pressure in the original L132 spectrum was 404 psig (a 7.7% excursion above the 375 psig MAOP) as shown in Figure 2. Figure 3 shows a similar overpressure event where the pressure at one location exceeded 400 psig. Figure 4 shows a suspected overpressure event that was ruled to be erroneous data since it was a single data point (rather than a gradual increase over hours as observed in the other events) and the other locations on the line did not experience an increase at all, either abruptly or otherwise.

Using a multiplicative factor to scale the actual spectrum to a pseudo reduced operating pressure spectrum, the overpressure events remain as overpressure events at the reduced pressure (although the magnitude of the event is scaled by the same factor). The similar fatigue lives for some cases shown in Table 2 are an indication that the large flaws are sensitive to the overpressure events. In the absence of these events, the flaws could potentially endure more pressure cycles before they became critical.

The fatigue lives shown in Table 2 are predictions that are based on several assumptions, so consideration should be given to the accuracy of the predictions. Two major assumptions (i.e. material strength and toughness) were varied to illustrate the sensitivity of the time-to-failure calculations to the predicted initial and final flaw size. It may seem counterintuitive, but shorter fatigue lives were calculated for higher-strength, higher-toughness pipe. The reason for this is as follows. The method for determining the initial flaw size was based on what size flaw could survive a given pressure – stronger, tougher pipe can tolerate larger flaws and these flaws grow more quickly in response to pressure cycles compared to the smaller flaws that may be presumed to exist in lower-strength, lower-toughness pipe exposed to the same pressure. So from a fatigue standpoint with initial quality based on hydrostatic test pressure, it is less conservative to assume minimum strength and toughness properties than to assume better-than-minimum material properties. Since a 40-ft-lb toughness and a pipe specified as X42 but exhibiting yield strength more similar to X52 is certainly plausible for 1956 vintage pipe, we would recommend that the fatigue lives presented in the last column of Table 2 be used. and that an additional safety factor such as two (2) be considered to account for other uncertainties in the analysis. Therefore if a 20-year fatigue life is desired from the standpoint of a pressure reduction, Table 2 would suggest that a 50-psig reduction from 375 to 325 psig is appropriate.

The same rationale applied to the other seam-welded pipe segments in L132 (assuming 40 ft-lb toughness and yield strength 10 ksi more than the specified minimum) produces similar results for different levels of pressure reduction (Table 3). These results suggest that for a 20-year fatigue life (including a safety factor of two), a pressure reduction to 300 psig might be necessary however it is noted that if these segments were tested to the minimum API 5LX mill pressures then the calculated fatigue lives are on the order of hundreds of years as shown in Table 1. While the benefit of a pressure reduction in terms of extending a calculated fatigue life shown in Table 3 is correct in a relative sense, the actual time to failure would depend on the test pressure that the pipe actually experienced.

If the L132 pressure is reduced, then the L109 pressure is effectively reduced since both lines operate similarly. The effect of a pressure reduction to 300 psig on the PG&E-grade and Grade B pipe segments in L109 was determined in a similar fashion as the L132 pressure-reduction scenario. A toughness of 40 ft-lb and yield strength equivalent to SMYS plus 10 ksi was assumed to establish a conservative postulated flaw distribution based on a pre-pressure-reduction high operating pressure (371 psig in this case). The pressure data representing operation at 375 psig were scaled by a factor of 0.8 (300/375) to represent the pressure reduction. The results of the fatigue analyses are shown in Table 4. The predicted times to failure are 32 and 34 years beginning at the time of the pressure reduction. Incorporating a safety factor of two (2), reassessment would be recommended in 16 years.

Table 1. Comparison of Estimated Times to Failure Based on Test Pressure

Line No.	OD, inch	WT, inch	SMYS	Long Seam	Year Installed	PG&E Hydro Test	PG&E Test Pressure, psig	PG&E Test Time to Failure, years	Mill Hydro Test Pressure, psig*	Mill Test Time to Failure, years
109	22	0.313	33000 psi	SSAW	1936	No	–	–	503	139
109	22	0.313	33000 psi	SSAW	1936	Yes	605	417	503	139
109	22	0.313	X42	ERW	1965	Yes	640	256	1014	500+
109	24	0.312	GRB	ERW	1959	No	–	–	501	120
109	30	0.313	X52	ERW	1965	Yes	No data	–	921	500+
101	20	0.250	33000 psi**	Smith	1949	Yes	600	212	454	51.2
101	20	0.250	GRB	SMLS	–	Yes	650	500+	481	131
101	20	0.250	GRA	DSAW	1948	Yes	650	500+	413	55.4
101	20	0.250	GRA	SSAW	1949	Yes	650	500+	413	55.4
101	30	0.312	X42	DSAW	1959	Yes	800	500+	743	500+
101	36	0.350	X52	DSAW	1965	Yes	970	500+	859	500+
132	24	0.313	33000 psi	SSAW	1948	No	–	–	430	60.7
132	24	0.281	GRB	SMLS	1944	No	–	–	451	53.4
132	24	0.313	X42	ERW	1957	No	–	–	930	500+
132	30	0.375	X52	DSAW	1948	No	–	–	1105	500+
132	36	0.313	X52	DSAW	1964	Yes	887	500+	767	500+
132A	24	0.281	40000 psi	SMLS	1944	No	–	–	515	171

*The API 5L or 5LX minimum required mill test pressure was reduced by 5% SMYS to account for the short duration of the test (typically 10 seconds long).

**Field hardness testing indicated that the yield strength could actually meet requirements for grade X46 pipe, so the X46 pipe grade was used in the fatigue analysis for conservatism.

Table 2. L132 Estimated Years to Failure Based on a Pressure Reduction

Reduced MAOP	Wall Thickness	15 ft-lb		25 ft-lb		40 ft-lb	
		X42	X52	X42	X52	X42	X52
350 psig	0.375 inch	32	29	29	18	21	18
	0.312 inch	29	21	29	18	21	18
325 psig	0.375 inch	93	75	71	50	61	39
	0.312 inch	82	61	71	50	61	39
300 psig	0.375 inch	182	146	136	93	114	71
	0.312 inch	160	118	128	82	104	71

Table 3. Estimated Years to Failure for other Segments of L132 Based on a Pressure Reduction

OD, inch	WT, inch	Grade	Seam	Reduced MAOP		
				300 psig	325 psig	350 psig
24	0.313	PG&E	SSAW	107	60.7	18.0
24	0.313	X42	ERW	71.4	39.4	18.0
30	0.375	X52	DSAW	53.4	28.7	10.7
36	0.313	X52	DSAW	50.1	28.7	7.3

Table 4. Effect of a Pressure Reduction to 300 psig on the PG&E-grade and Grade B Pipe Segments on L109

Diameter, inch	WT, inch	SMYS	Seam Type	Year Installed and Tested	Fatigue Life after Pressure Reduction
22	0.313	33000 psi	SSAW	1936	34.0
24	0.312	GRB	ERW	1959	32.6

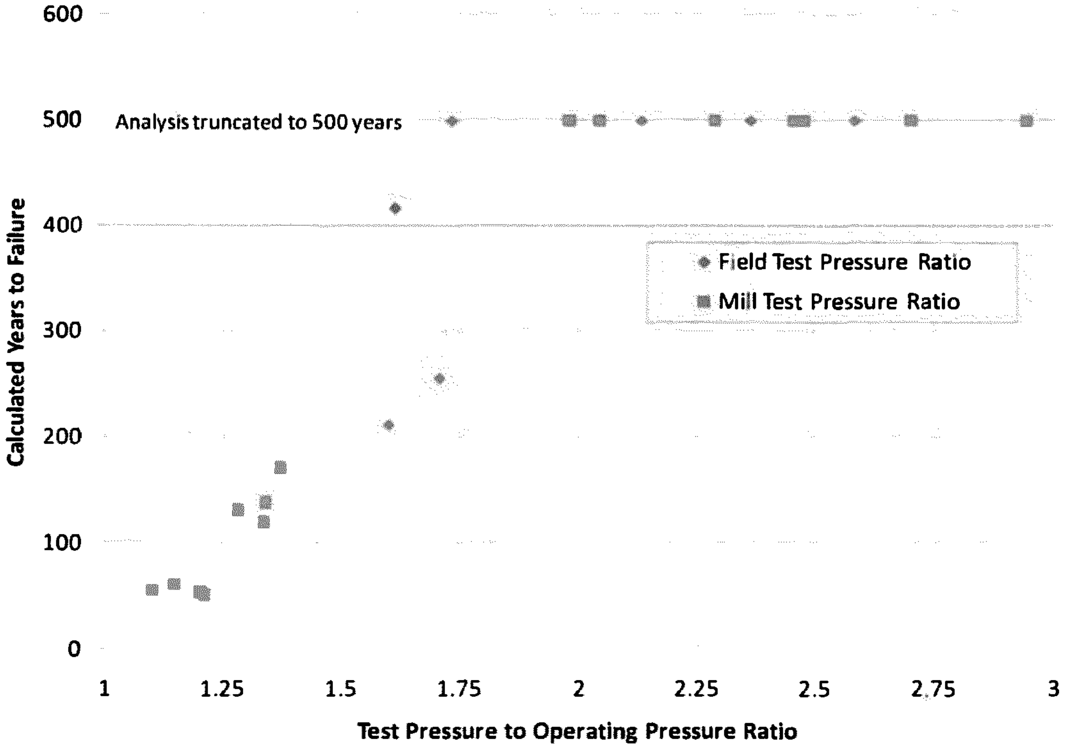


Figure 1. Summary of Predicted Fatigue Lives for Lines 101, 109, and 132 and the Test Pressure to Operating Pressure Ratio

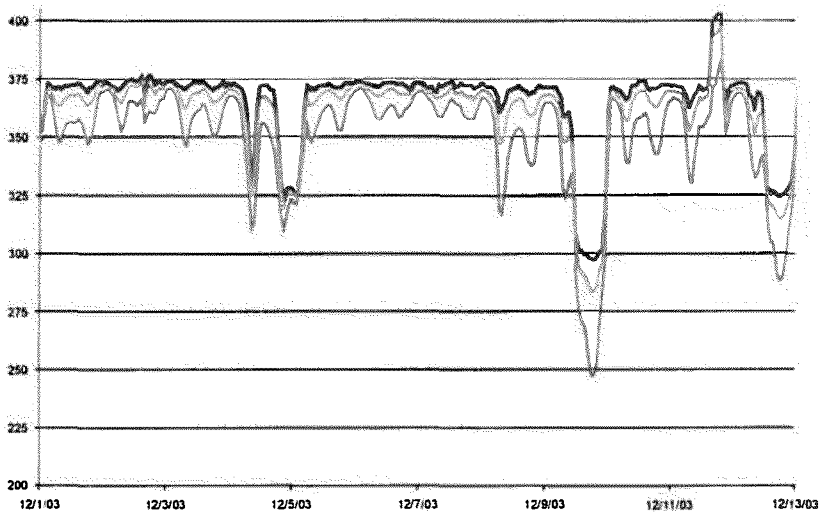
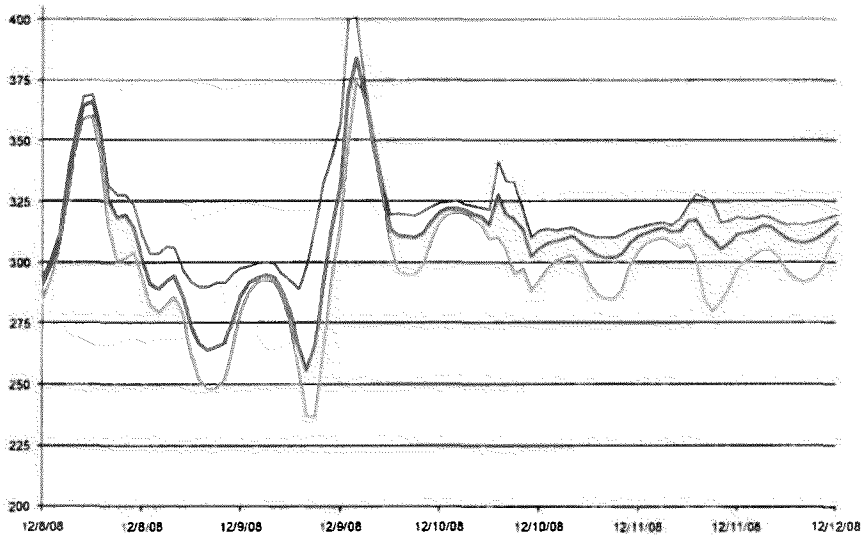


Figure 2. L132 Pressure Data Exhibiting an Excursion above MAOP



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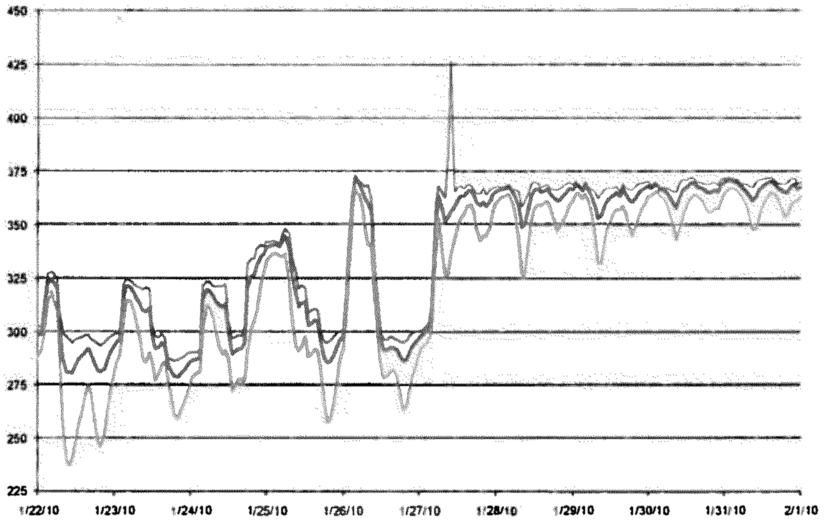

Figure 4. L132 Pressure Excursion Considered to be Erroneous Data