March 27, 2015
07.031727

DRAFT

State of the Art in 2015 for Calculating the Remaining Strength of Corroded Pipe

Contents

Development of the B31G/RSTRENG and Other Models

B31G

The need for a valid model to assess the remaining strength of corroded pipe became sufficiently urgent in the late 1960s that the pipeline industry through the American Gas Association (AGA) sponsored an effort at Battelle to study the bursting behavior of corroded pipe. Forty-seven full scale burst tests were conducted on samples of pipe containing actual corrosion-caused metal loss, and a variation of Maxey's surface flaw equation[i] that embodied the "Folias factor"[ii] to account for bulging of the corrosion-weakened pipe and "flow stress"[iii] to account for the failure strength of the pipe material was found to give reasonable predictions of the failure stresses[iv].

The advent of in-line inspection (ILI) tools in the 1970s that could locate and characterize the sizes of areas of corrosion-caused metal loss in a buried pipeline encouraged the industry to standardize a method for calculating the remaining strength of corroded pipe based on the dimensions of the metal missing. The model developed previously at Battelle for AGA was embodied in a new standard in 1984: ASME B31G[v].

Modified B31G and RSTRENG

While the B31G model served the purpose for ranking ILI anomalies, its highly simplified and over-conservative treatment of long corrosion on the basis of minimum remaining thickness resulted in large numbers of unneeded excavations. Therefore, AGA once again funded a project at Battelle in 1988 that involved developing a less conservative approach to predicting the remaining strength of corroded pipe. This project[vi] resulted in the development of the Modified B31G model that considers the axial length and depth of the anomaly with no limit on length and an iterative model named RSTRENG that considers the detailed depths of the corrosion within an "effective" length. Additional burst test data acquired mostly from pipeline operators' in-house tests of corroded pipe were added to the database[vii] bringing the total number of tests in the database to 124 not all of which were suitable for analysis by the B31G/RSTRENG approaches (e.g., tests involving brittle fracture initiation, defects aligned in the transverse or diagonal directions, multiple interacting defects, etc. were not used in the evaluation of the models). At this point the B31G-Modified B31G-RSTRENG suite of models had been validated by 86 full scale burst tests.

The Pipeline Research Council International (PRCI) funded additional work in the mid-1990s at Kiefner and Associates, Inc., the objective of which was to enhance the database of corroded pipe tests by including newly acquired data from burst tests on pipes with machined defects[viii]. The total number of burst test results in the database had grown to 216 by this time. However, the highest grade of material in the database at this time was X65. No data were available to assess the applicability of the B31G/RSTRENG models to higher grades of pipe such as X80 and X100.

In 2009 ASME B31G was revised to include the Modified B31G equation and provisions for more sophisticated analysis of metal loss effects including a description of the "effective area" approach. RSTRENG is an example of an effective area approach. The latest ASME B31G document is a slightly revised version issued in 2012[ix]

Models Other than B31G/RSTRENG

In the meantime other models for assessing the remaining strength of corroded pipe had evolved and were being used by some pipeline operators in place of or in addition to the B31G/RSTRENG models. One of these, LPC-1[x] was embodied in the standard DNV RP-F101[xi]. A second, called PCORR[xii] was developed at Battelle, and the third was called SHELL92[xiii]. The latter is identical to the Level 1 assessment model for locally-thinned areas embodied in API RP 579[xiv]. Along with the development of these models, additional burst test data were acquired. In many cases the additional data were generated by testing pipes containing corrosion-simulating machined defects.

Comparisons of the Models to Burst Test Results (the "Advantica" study)

In 2005, the U.S. Department of Transportation (DOT) funded a project with GL Industrial Services UK Ltd (known as Advantica at the outset of the project) to evaluate ASME B31G, Modified B31G, RSTRENG, LPC-1, SHELL92, and PCORR and compare them to the burst test results in the AGA/PRCI database and the additional burst test results acquired in conjunction with the development of the newer models. The results of these evaluations were presented in Reference XIV (the Advantica study)[xv]. Failure pressures predicted by each of the six models (denoted as P_f) were compared to actual failure pressures determined in the burst tests (denoted as P_A). The degree of scatter and the bias of the parameter, P_A/P_f, were used to assess the accuracy and inherent conservatism of each model. A database of 313 burst tests was compiled consisting of data from tests conducted by AGA/PRCI tests, GL, Petrobras, the

Korean Gas Corporation, the University of Waterloo, and a couple of pipeline operators. Of these 313 results, 133 were obtained through tests of actually corroded pipe, and 180 were obtained through tests of pipe or ring specimens containing machined corrosion-simulating defects. In the case of the pipe specimens, the machined defects had uniform depths and various lengths. In the cases of most of the ring specimens, the machined defects had uniform depths clear across the width of each ring.

The P_A/P_f comparisons for each of the six models were done in six ways called "cases". Case 1 comparisons involved using actual wall thicknesses and material properties and the definitions of flow stress normally associated with each model. Case 1 comparisons served as the measurement of the accuracy of each model. Case 2 comparisons were intended to show model performance in terms of reliably predicting a given factor of safety when used as a means of ranking ILI-detected anomalies. In Case 2 comparisons, nominal wall thickness and specified minimum material properties and the definitions of flow stress for each model were used. Cases 3-6 involved calculations based on various definitions of flow stress and are not as useful for assessing the performance of the models as the Case 1 and Case 2 comparisons.

The Advantica study provides many details on the performance of the six models making it the most thorough compilation of comparisons to date. While it is impractical to discuss all of them in this review document, the essence of the findings can be summarized as follows. In terms of scatter the following table shows the frequency distributions of the ratios of actual failure pressures in the 313 burst tests to model-predicted failure pressures for the six models. For Case 1 analyses, RSTRENG predictions exhibit the least scatter.

Model	P_A/P_f Distribution	
	Mean	Standard Deviation
ASME B31G	1.330	0.468
Modified ASME B31G	1.184	0.285
RSTRENG	1.170	0.177
LPC-1	1.178	0.318
PCORRC	1.191	0.310
SHELL92	1.436	0.407

The original ASME B31G model performed least well in terms of scatter, but Modified ASME B31G exhibited less scatter than four other models.

Models such as B31G and Modified B31G are inappropriate for predicting failure pressures for uniform-depth defects, but as the Case 2 comparisons show, they provide conservative predictions of safe operating pressures when applied with a safety factor of 1.25 or 1.39 to real corrosion defects in materials with specified minimum yield strengths of 70,000 psi or less.

The authors of the Advantica study suggest that further evaluations of the models should be made by conducting burst tests on higher-grade materials (i.e., X80 and X100) using defects that are designed to simulate actual corrosion-caused metal loss rather than uniform-depth machined defects.

The Effects of High Strength on the Performance of Corrosion Assessment Models

With the increasing use of, Concern has arisen over possible inadequacies of the current corrosion assessment models (i.e., B31G, Modified B31G, RSTRENG) for analysis of corrosion-caused metal loss in higher grades (X80 and X100) of line pipe materials. These materials, particularly X100 materials, tend to have yield-strength/tensile-strength (Y/T) ratios in the range 0.93-0.97, low strain hardening capacity and low strain to failure. The high Y/T ratios make the use of the common definitions of flow stress (1.1SMYS for B31G, SMYS + 10,000 psi, for Modified B31G and RSTRENG) for models questionable. Also, the effects of low-strain to failure is thought to be a factor that could affect the applicability of the models.

GL Phase 1 Work: Assessment of Corrosion in Higher Strength Pipe

GL Industrial Services undertook additional work for DOT aimed at reviewing the effectiveness of current corrosion assessment models for evaluating corrosion-caused metal loss in higher strength line pipe materials. The objectives of Phase 1 of this work[xvi] were to review existing burst test data on higher strength materials to see how well the current models had predicted the actual failure pressures and to see how well a finite-element (FE) model would predict the actual failure pressures.

These FE methods are still being reviewed and additional input will be provided for the final report on this task.

Within the database of corroded pipe burst tests reviewed in Reference XV were eight burst tests of X80 pipe samples, four burst tests of X100 pipe samples, and 37 ring tests. In Phase 1 of the actual failure pressures obtained in these tests were compared to the failure pressures predicted by the current models and by the FE analysis.

Four of the eight X80 burst tests were conducted on a material with a diameter-to-thickness (D/t) ratio of 62 and a Y/T ratio of 0.81. The other four X80 burst tests were conducted on a material with a D/t ratio of 82 and a Y/T ratio of 0.80. The Y/T ratios of both of these materials do not seem to represent a low-strain-hardening capability, nor does it seem likely that the definitions of flow stress as 1.1 the actual yield strength or the actual yield strength + 10,000 psi would cause inaccurate predictions. In fact the B31G comparisons were made on the basis of flow stress being defined as 1.1 times the actual yield strength, and the MOD B31G and RSTRENG comparisons were made on the basis of flow stress being defined as the actual yield strength plus 10,000 psi. Machined, uniform-depth, axial grooves were used to simulate corrosion-caused metal loss. The lengths of the defects in the tests were either 3.9 or 4.5 times $\sqrt{Dt}$ meaning that they were "long" defects. Defect depth/thickness ratios ranged from 0.089 to 0.782. The ratios of actual failure pressures, P_A, to predicted failure pressures, P_f, were as follows.

	B31G	MOD B31G	RSTRENG	LPC-1
MAX	1.443*	1.195	1.232	1.176
MIN	0.67**	0.745**	1.099	0.993
RANGE	0.773	0.45	0.133	0.183
AVG	1.160625	1.057	1.179625	1.1155

*B31G defaulted to the remaining thickness and infinite length for the 4.5 $\overline{Dt}$ cases.
**These low values result because these models consider metal loss areas that are less than the actual areas.

The results indicate that RSTRENG was able to predict the failure pressures with reasonable accuracy using the average of yield strength and ultimate strength as the flow stress. The predictions based on B31G and MOD B31G show what was already known, namely, that these methods are unsuitable for uniform-depth defects.

Four burst tests of an X100 material with D/t of 58, Y/T of 0.98, two with patch defects and two with axial groove defects were carried out. Machined, uniform-depth, axial grooves or patches were used to simulate corrosion-caused metal loss. The lengths of the defects ranged from 3 $\overline{Dt}$ to 6.3 $\overline{Dt}$. Depths were about 50% of the wall thickness in all four samples. In view of the very high Y/T ratio, one might question whether the normal definitions of flow stress would be adequate. Nevertheless, the B31G comparisons were made on the basis of flow stress being defined as 1.1 times the actual yield strength, and the MOD B31G and RSTRENG comparisons were made on the basis of flow stress being defined as the actual yield strength plus 10,000 psi. The ratios of actual failure pressures, P_A, to predicted failure pressures, P_f, were as follows. Note that the comparisons for FE analysis are included.

	B31G	MOD B31G	RSTRENG	LPC-1	Finite Element
MAX	1.175*	1.021	1.136	1.045	1.299
MIN	0.909**	0.897**	1.012	0.96	1.027
RANGE	0.266	0.124	0.124	0.085	0.272
AVG	1.04	0.95925	1.074	1.00125	1.11525

*B31G defaulted to the remaining thickness and infinite length for the cases where the lengths exceeded 4 $\overline{Dt}$.
**These low values result because these models consider metal loss areas that are less than the actual areas.

The results indicate that RSTRENG was able to predict the failure pressures with reasonable accuracy using the yield strength plus 10,000 psi ultimate strength as the flow stress. The non-linear FE method gave failure predictions exhibiting more scatter than RSTRENG did.

RSTRENG predictions for 28 of the 37 ring tests gave the following comparisons (P_A/P_f) with actual failure pressures (9 of the comparisons were judged invalid by the GL team):

MAX = 1.237 MIN = 0.931 RANGE = 0.306 AVG = 1.167 STDEV = 0.061

The lowest number was associated with a test involving a notch-like groove that may not have represent corrosion-caused metal loss very well.

The authors of Reference XVI concluded that RSTRENG adequately predicts the failure pressures for corrosion-like defects in higher strength materials such as X80 and X100 even when flow stress is defined as the yield strength plus 10,000 psi. However, they show that more conservative results would result from using the average of yield and ultimate strength as the flow stress. They implied that B31G and Modified B31G may also be adequate for higher strength materials, but that cannot be proven one way or another by means of tests on uniform-depth defects. They suggest conducting tests on higher strength materials with defects created by corrosion-like metal removal methods that would result in defects that look more like actual corrosion defects.

GL Phase 2 Work: Assessment of Corrosion in Higher Strength Pipe

Liu, J, Mortimer, L, and Wood, A., "Project #153H Corrosion Assessment Guidance for High Strength Steels (Phase 2)", Report Number: 7930, GL Industrial Services, to: BP Exploration, US DOT PHSMA, Electicore & GL Industrial Services, November, 2009.

Quotes of the conclusions and recommendations:
"Conclusions
1. Miniature flat tensile (MFT) testing was able to provide the relative change in tensile properties through the pipe wall thickness. Stress versus strain curves from the MFT tests have to be calibrated using results obtained from standard ST tests.
2. From the standard tensile (ST) test results, it was concluded that tensile properties in the longitudinal direction tended to be lower than those in the transverse direction.
3. Scatter in tensile properties was observed from X100 grade line pipe material obtained from three different manufacturers. No identifiable trends in tensile properties through the pipe wall thickness could be determined from the three different manufacturers. It was, however, concluded that in general lower tensile strengths were obtained towards the inner surface of the pipe.
4. Two full scale vessel burst tests were successfully conducted with relatively long axially orientated groove defects that were machined onto the external surface of the pipe. Both defects were targeted to have a depth of 50% of the pipe wall with lengths of 29.3 inch (745mm) and 78.7 inch (2000mm). Failure pressures predicted using ASME B31G and SHELL92 methods were lower than the actual burst pressures recorded from tests. The RSTRENG and LPC-1 methods predicted failure pressure very close (within 3%) to the recorded burst pressures. However, the predicted failure pressures were marginally higher the recorded burst pressures. For both burst tests, the Modified ASME B31G method predicted failure pressures higher than the recorded burst pressures.
5. Normalized failure locus diagrams have been derived for assessing corrosion damage in pipelines of strength grade up to X100 subject to combined internal pressure and external loading.

Recommendations
1. Validation of the assessment methods described in this report should be undertaken on completion of the BP X100 Operational Trial.
2. The normalized failure locus diagrams derived in this report should be incorporated into the PRCI Guidance Document for assessing corrosion damage in pipelines."

These work by Zhu-Leis and their Z-L criteria are still being reviewed and additional input will be provided for the final report on this task.

Summary of Findings on B31G/Mod B31G/RSTRENG

The bottom line is that the B31G/Mod B31G/RSTRENG models have been thoroughly validated for assessing the ductile failure behavior of corrosion-caused metal loss in line pipe materials up through Grade X65. Some caveats are in order. The original B31G equation can give excessively conservative predictions of failure pressure for long defects. The Modified B31G equation can be applied just as easily, and does not give excessively conservative predictions of failure pressure for long defects as is the case with the original B31G equation. It is noted however, that both B31G for shorter defects and Modified B31G may give un-conservative predictions for the failure pressure levels of uniform-depth defects. This is usually not a problem when predicting failure pressure levels of actual corrosion anomalies because they are non-uniform in depth. It has been shown that the RSTRENG model gives accurate predictions for uniform-depth defects for material grades of X80 and X100. However, it may be desirable to modify the definition of flow stress when using RSTRENG or Modified B31G for failure stress predictions with these higher-grade materials. Lastly, it is desirable to evaluate the suitability of the B31G and MOD B31G models for higher grade materials (i.e., X80 and X100) by comparing predictions to burst test data on samples of these materials that contain non-uniform depth defects that simulated corrosion-cause metal loss.

Additional literature below are being considered for review as part of this task is noted below and if found relevant will be summarized in the final report on this task.

Liu, J., Chauhan, V., Ng, P., Wheat, S., and Hughes, C., "REMAINING STRENGTH OF CORRODED PIPE UNDER SECONDARY (BIAXIAL) LOADING", PROJECT #153J, GL Industrial Services, Report Number: R9068, to U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration, August 2009

Quotes of the conclusions and recommendations:

"Conclusions

1. The remaining strength of corroded pipelines subject to internal pressure and external loading cannot be explicitly assessed using the ASME B31G, RSTRENG and LPC assessment methods. However, these assessment methods have been validated using pipe with real corrosion and simulated (machined) defects welded to dome ends to form a pressure vessel and subsequently failed under internal pressure loading. Consequently, existing methods include some inherent biaxial loading and the remaining strength of corroded pipelines can be assessed with a limited amount of external loading.
2. Ground movement due to landslides can impose significant external loading to transmission pipelines. Stresses in pipelines due to landslides can be greater than the stresses due to internal pressure loading.
3. Methods developed by the nuclear industry for assessing corroded pipework are given in ASME Code Case N-597-2 and based on ASME B31G when the axial extent of wall thinning is limited. For more extensive corrosion, the assessment methods are based on branch reinforcement and local membrane stress limits. Strictly the methods given in ASME Code Case

N-597-2 are only applicable to the assessment of piping systems designed to the ASME Boiler and Pressure Vessel Code, Section III.
4. Failure loci of pipelines with isolated corrosion defects and subjected to combined loads have been derived for common pipeline geometries and materials. The failure loci have been validated using tests performed on 457.2mm (18-inch) and 1219.2mm (48-inch) diameter pipe under combined bending/pressure loading. These failure loci can be used to assess the limit of acceptability of existing assessment methods such as ASME B31G and RSTRENG under combined loading conditions.
Recommendations 1. The methods developed in this report should be extended to cover the assessment of higher strength pipelines up to grade X100 pipelines.

Swankie, T., Robinson, M., Liu, J., Crossley, J., and Morgan, G., GL Noble Denton, Project #153K: "The Assessment of Corrosion Damage in Pipelines Subjected to Cyclic Pressure Loading", R8928 Issue 2, to U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration, February 2010.

This was primarily an analytical study where predictions of fatigue life of corroded pipe was estimated from a calculated stress concentration factor using an S-N relationship. Some small scale tests were run, the results of which had been conservatively estimated by the analytical model.

Martin, M., Andrews, R.M., and Chauhan, V., "THE REMAINING STRENGTH OF CORRODED LOW TOUGHNESS PIPE", Project #153K, Report Number: R9247, to U.S. Department of Transportation, February, 2009

Quotes of the conclusions and recommendations:
"Conclusions:
1. This report presents an approach for removing the uncertainty in the use of existing methods for assessing corrosion defects in older, low toughness pipelines based on the Beremin approach to brittle cleavage fracture.
2. Use of the Beremin approach in conjunction with the results from ring expansion tests, vessel tests and non-linear finite element analysis has provided a method of establishing the brittle failure probability as a function of hoop stress and temperature for a variety of corrosion defects including notches, grooves and patches.
3. Effective transition temperatures have been defined as the temperature below which existing assessment criteria such as Modified ASME B31G and LPC-1 are no longer conservative. Effective transition temperatures have been evaluated for both the Modified ASME B31G and LPC-1 methods.
4. Based on typical buried pipeline operating temperatures of around 0 °C, existing assessment criteria are considered to be valid for pipelines with transition temperatures up to +40 °C.
5. It is considered that the results from ongoing investigations into the failure behavior of corrosion defects subjected to biaxial loading in modern high strength pipeline materials will remain valid for older low toughness pipelines. Similarly, rules now being developed for defect interaction are judged likely to remain valid for older low toughness pipelines.

Recommendations:
1. As the pipeline temperatures experienced in the field are unlikely to be below - 20 ºC, it is judged likely that existing assessment methods, such as the Modified ASME B31G and LPC-1, will remain conservative for the assessment of corrosion defects in old, low toughness pipelines.

2. It is considered that the results from ongoing investigations into the failure behaviour of corrosion defects subjected to biaxial loading in modern high strength pipeline materials will remain valid for older low toughness pipelines. Similarly, rules now being developed for defect interaction are judged likely to remain valid for older low toughness pipelines."

Swankie, T., and Chauhan, V., Guidance for Assessing the Remaining Strength of Corroded Pipelines ", Project #153M, GL Noble Denton, Report Number: 9492, to U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration, April, 2010

This is a guidance document. It apparently has no data or analysis in it, but it should be reviewed, nevertheless.

Chauhan, V., and Wood, A., "Experimental Validation of Methods for Assessing Closely Spaced Corrosion Metal Loss Defects in Pipelines", Advantica Final Report, to GRI, March 2005

This report presents some interesting experimental results concerning defect interaction. Quotes of the conclusions and recommendations:
"Conclusions:
1. The finite element analysis reported in PR 273-9803 Phase 4 (L51968) has been validated using the full-scale burst tests.
2. The criterion that defects separated by a distance of 6t or less will interact is over conservative.
3. New rules for interaction, derived using non-linear finite element analyses and validated using full scale burst testing, have been derived for closely spaced metal loss interacting defects in pipelines. The new rules are limited to the following:

- Linepipe of material up to a specified minimum yield strength of 448 N/mm2 (API 5L grade X65) and pipe diameter to thickness (D/t) ratios in the range 42 to 72
- Ductile linepipe that is expected to fail by plastic collapse. The rules are not recommended for pipelines where brittle fracture is likely to occur.
- For corrosion defects in the main body of the pipe, away from seam or girth welds • Flaw depths of up to 80% of the wall thickness; this is including consideration of the measurement uncertainty of flaw dimensions obtained from in-line inspection tools
- Pipelines subject only to internal pressure loading

Recommendations:
1. The PRCI Guidance Document (L51958) and associated software (CORAM) should be revised to incorporate the new and improved defect interaction rules derived in this report.
2. New rules for interacting defects should be extended to provide guidance to cover the following;

- High strength steels (up to API 5L grade X100)
- Older low toughness pipelines
- Pipelines subject to combined internal pressure and external (axial or bending) loading

---

[i] Eiber, R.J., Maxey, W.A.., Duffy, A.R., and Atterbury, T.J., "Investigation of the Initiation and Extent of Ductile Pipe Rupture", Report No. BMI-1866, U.S. Atomic Energy Commission Contract No. w-7405-eng-92, NTIS, July 1969

[ii] Folias, E.S., "The Stresses in a Cylindrical Shell Containing an Axial Crack", Aerospace Research Laboratories, ARL 64-174, (October 1964).

[iii] Hahn, G.T., Sarrate, M., and Rosenfeld, A.R., "Criteria for Crack Extension in Cylindrical Pressure Vessels", International Journal of Fracture Mechanics, Vol. 5, 1969, pp. 187 – 210.

[iv] Kiefner, J.F., and Duffy, A.R., "Summary of Research to Determine the Strength of Corroded Areas in Line Pipe", presented at a Public Hearing at the U.S. Department of Transportation, July 20, 1971.

[v] *Manual for Determining the Remaining Strength of Corroded Pipelines*, A Supplement to ASME B31 Code for Pressure Piping, ASME (1984).

[vi] Kiefner, J.F., and Vieth, P.H., "A Modified Criterion for Evaluating the Remaining Strength of Corroded Pipe", American Gas Association, Catalog No. L51609 (1989).

[vii] Vieth, P. H., and Kiefner, J. F., "Database of Corroded Pipe Tests", American Gas Association (1994).

[viii] Kiefner, J. F., Vieth, P. H., and Roytman, I. "Continued Validation of RSTRENG", PRC International, Catalog No. L51749 (1996).

[ix] *Manual for Determining the Remaining Strength of Corroded Pipelines*, A Supplement to ASME B31 Code for Pressure Piping, ASME (2012).

[x] Fu, B. and Batte, A.D., 'Advanced Methods for the Assessment of Corrosion in Linepipe', UK Health and Safety Executive Summary Report, OTO 1999-051, HSE Books, 1999.

[xi] "Corroded Pipelines", Recommended Practice RP-F101, Det Norske Veritas (1999).

[xii] Stephens, D.R. and Leis, B.N., 'Development of an Alternative Criterion for Residual Strength of Corrosion Defects in Moderate to High Toughness Pipe', Proceedings of the 2000 International Pipeline Conference – Volume 2, Calgary, Alberta, Canada, American Society of Mechanical Engineers, 1-5 October, 2000.

[xiii] Ritchie, D. and Last, S., 'Burst Criteria of Corroded Pipelines – Defect Acceptance Criteria', Paper 32, Proceedings of the EPRG/PRCI 10th Biennial Joint Technical Meeting on Line Pipe Research, Cambridge, UK. 18-21 April 1995.

[xiv] "Fitness-for-Service", American Petroleum Institute Recommended Practice 579, First Edition (January 2000).

[xv] Chauhan, V., and Brister, J., "A Review of Methods for Assessing the Remaining Strength of Corroded Pipelines", GL Industrial Services, Report Number: 6781, Version 6.1 Final Report to U.S. Department of Transportation, November 2009.

References found at: http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=171

[xvi] Chauhan, V., and Crossley, J., GL Industrial Services UK Ltd., Project #153H: "Corrosion Assessment Guidance for High Strength Steels" (Phase 1), Report Number R9017, to U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration, April 2009.