QUARTERLY REPORT
Project WP#339: Structural Significance of Mechanical Damage

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Project Title Project WP#339: Structural Significance of Mechanical Damage

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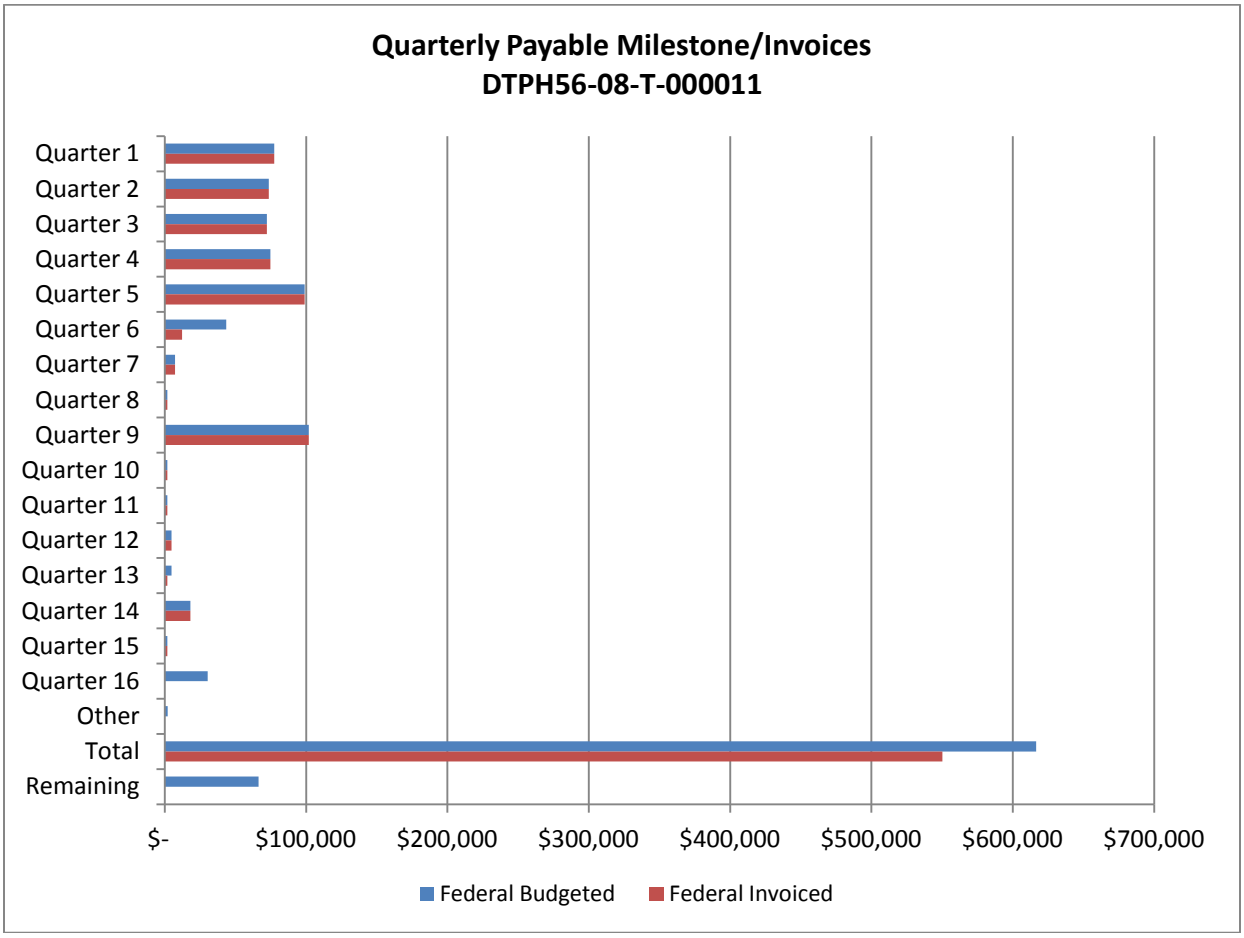
Funds and Work Completed During this Quarterly Period



Technical Status

Technical activities undertaken through this reporting period focused on the following tasks:

- Task 2—Purchase & Characterize Pipe Material
- Task 3—Literature Review
- Task 4—Testing of Dents on Welds and Corrosion Features
- Task 5—Testing of Dents with Gouges
- Task 6--Demonstration of Mechanical Damage Model Performance
- Task 8 – Project Management and Reporting

A summary of the technical status and results to date are presented below for each tasks.

Task 2: Purchase & Characterize Pipe Material

There are currently four different pipe steels in this program:

- Pipe 1 and 2 are modern IPSCO pipes manufactured between 2005 and 2006. All material characterization has been completed for these pipes.

- Pipes 3 are older steel to represent the majority of the pipelines in-service. It was initially intended to provide a manufactured pipe that replicates vintage pipe properties for Pipe 3. Due to challenges identified with this initial approach, the project is now using vintage pipe from former in-service pipelines provided by PRCI member companies. This has resulted in the need to use several different pipes retrieved from service: one vintage material for the full-scale testing program for dents, designated Pipe 3, and;

- Pipe 3DG for the Dent and Gouge tests left Houston at the end of January 2012 and reached the GDF SUEZ lab at the end of March. Material characterization is underway and first characterization results are presented here:

Chemical Content

As shown in Table 1, the percentages of carbon and sulfur are high and the carbon equivalent deduced from this chemical composition is 0.44%. In addition, knowing the sulfur and manganese percentages, the volume ratio of manganese sulfur inclusions is approaching a high level of $2\ 10^{-3}$, as indicated by Franklin's formula. This initial information shows that Pipe 3DG may have a low toughness level.

Table 1: Chemical analysis of Pipe 3DG (%)

C	S	P	Si	Cr	Mn	Ni	Cu	Other
0.23	0.036	0.019	0.06	0.02	1.10	0.06	0.16	<0.01

Microstructure

The microstructure was observed with and without etching on longitudinal and transverse polished cuts by optical microscope with X200 and X500 magnifications. Figure 1 shows the presence of numerous elongated inclusions (observation without etching).

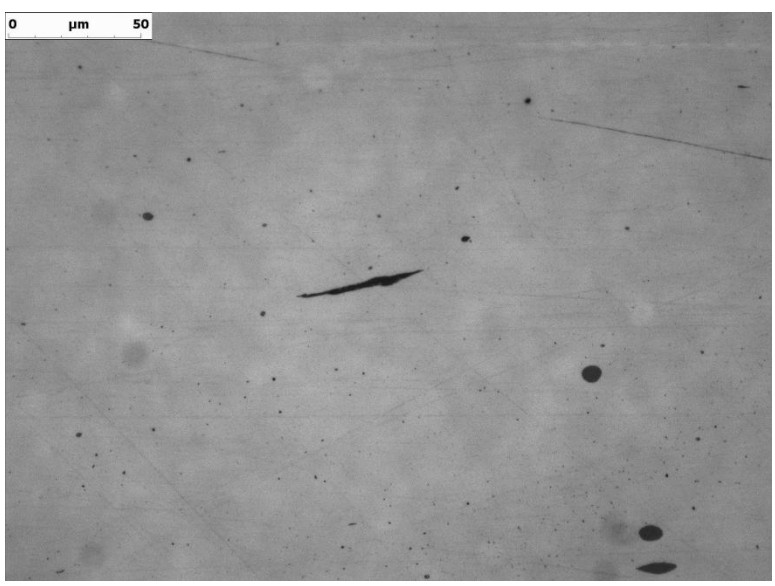


Figure 1: Manganese sulfur inclusions

The observation with etching reveals a high density of pearlitic phase (black and grey areas) due to the high quantity of carbon in the chemical content (See Figure 2).

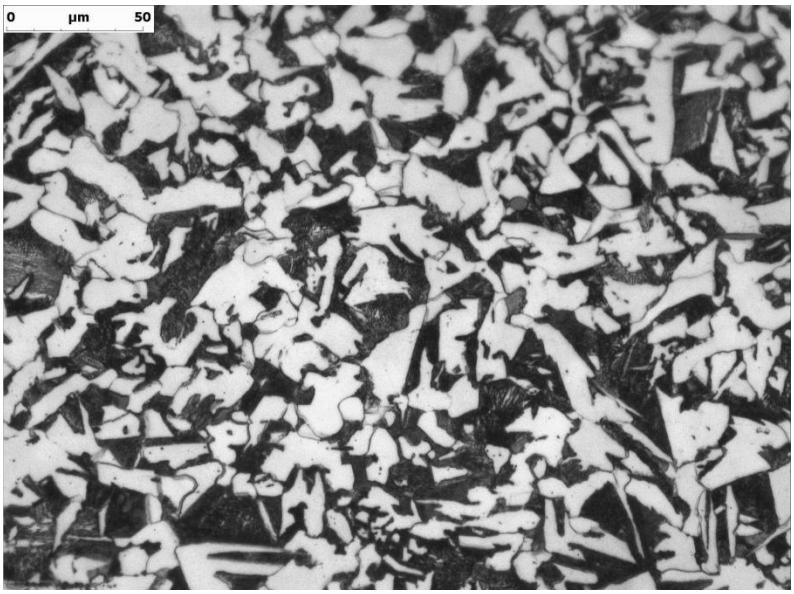


Figure 2: Ferritic-Pearlitic microstructure

Three transverse tensile tests were performed on cylindrical specimens under quasi- static loading at room temperature. Results are given in Table 2 below.

Table 2: Results on tensile transverse properties for Pipe 3DG

Test number	YS (MPa ksi)	UTS (MPa ksi)	YS/UTS	Elongation at rupture (%)	Section area reduction at rupture (%)
1	488 71	599 87	0.81	26	57
2	486 70	607 88	0.80	26	58
3	496 71	612 89	0.81	26	58
Average	490 71	606 88	0.81	26	58

Tensile test results show steel properties close to those of an API 5L X70 grade.

Task 3: Literature Review

The team has completed the literature review regarding cyclic fatigue dent assessment techniques. They will submit a report summarizing the findings and demonstrating the performance of the identified assessment techniques following the completion of the testing.

Task 4: Testing of Dents on Welds and Corrosion Features

BMT Fleet has submitted their recommendation for the final series of four full-scale test specimens to the project team for review and approval. Table 3 below shows the last batch of recommended test matrix, for the vintage pipe full scale dent fatigue tests. The test matrix includes three indenter sizes and three indenter displacements. All four tests incorporate dents interacting with welds. The location of the dents with respect to the girth welds were chosen based on the likely location of fatigue crack initiation with the objective of determining the affect on the fatigue life due to the dent interacting with the weld.

Table 3: Test Matrix for Dents Interacting with Girth Welds for Vintage Pipe 3

Specimen #	Nominal Indenter Diameter	Indenter Travel	Dent Depth	Dent Restraint	Interacting with	GW Location wrt Dent	Initial Pressure Cycle	Cyclic Pressure Range
	(in)	(%)	(%)				(%SMYS)	(%SMYS)
58	2	15	~2	U	GW	Shoulder	100%	10%-80%
59	12	20	~2	U	GW	Center	80%	10%-80%
60	2	7.5	7.5	R	GW	Shoulder	100%	10%-80%
61	8	7.5	7.5	R	GW	Shoulder	100%	10%-80%

BMT Fleet has selected two tests from the last series of full scale tests, Specimen 53 and 55 for detailed investigation. In both cases, the fatigue crack leading to the pipe failure (leak) occurred on the transverse shoulder of the dent away from the axial center line of the pipe (see Figures 3 and 4, below). The dents in both the cases were unrestrained and created using the 12 in. indenter while the pipe was pressurized. The researchers will report on the detailed results of the metallurgical investigation in the next quarterly report.

Figure 3: Un-restrained dent created using 12 in. indenter at 40% SMYS pressure in Pipe 53

Figure 4: Un-restrained dent created using 12in. indenter at 80% SMYS pressure in Pipe 55

Task 5: Testing of Dents with Gouges

GDF SUEZ is in charge of the creation, characterization, burst test, and fatigue test of realistic combined defects, i.e., dent+gouge, and their program is described in the Table 4:

The defects are identified by three characters **X.Y.Z.** which are numbers:

- **X.**Y.Z.—**X** identifies the **Pipe X** material which is noted by 1, 2, or 3 in this program;

- X.**Y.**Z.—**Y** defines the **type of dent+gouge defect** characterized by its geometry notably in terms of dent depth and length, and gouge depth and length. This program is considering a maximum of three different kinds of defects per pipe material, and therefore, the value of Y can range from 1 to 3; two extreme aggression conditions are considered in this study: highly dynamic and slower aggression. The former corresponds to defect Types 1 and 2 for Pipe 1 (two different excavator teeth used) and Type 1 for Pipe 2, while the latter corresponds to Type 3 for Pipe 1 and Type 2 for Pipe 2.

- X.Y.**Z.**—**Z** is the **number of defect in the defined type of defect**. There are three similar defects per type of defect. The number 1 is for a detailed geometrical, mechanical and metallurgical in-depth defect characterization after its creation. Number 2 is a similar defect for the burst test to evaluate the defect behavior of under monotonic pressure load and number 3 is a similar defect for the fatigue test to evaluate the defect behavior under cyclic variation of the internal pressure.

The background color in the table represents:

- White: Defects not yet created (vintage pipe)
- Yellow: Defects already created but not yet fully characterized (this includes destructive and neutron diffraction testing for characterizing through wall residual strain) or not yet submitted to burst or fatigue tests
- Green: Defects created and all tests completed.

Table 4: Status of dent+gouge defects in Modern Pipes 1 and 2 and vintage pipe 3DG

MD-4-1					DOT	
Pipe 1 (modern steel X52)			Pipe 2 (modern steel X70)		Pipe 3DG (vintage)	
Type 1	Type 2	Type 3	Type 1	Type 2	Type 1	Type 2
Defect 1.1.1.b	Defect 1.2.1.b	Defect 1.3.1	Defect 2.1.1	Defect 2.2.1	Defect 3DG.1.1	Defect 3DG.2.1
Defect 1.1.2	Defect 1.2.2	Defect 1.3.2	Defect 2.1.2	Defect 2.2.2	Defect 3DG.1.2	Defect 3DG.2.2
Defect 1.1.3	Defect 1.2.3	Defect 1.3.3	Defect 2.1.3	Defect 2.2.3	Defect 3DG.1.3	Defect 3DG.2.3

Defect 3DG.1.2 has just been created and the photo is not yet available to fill the yellow cell 3DG.1.2.

GDF SUEZ created the first two defects, 3DG.1.1 and 3DG.1.2, in May 2012 by dynamic impact under an internal pressure of 89 bar (1291 psi). The researchers visually saw cracks at the gouge bottom. The also performed magnetic particle inspection was performed on defect 3DG.1.1 and confirmed the presence of cracks is as shown in the figure below.

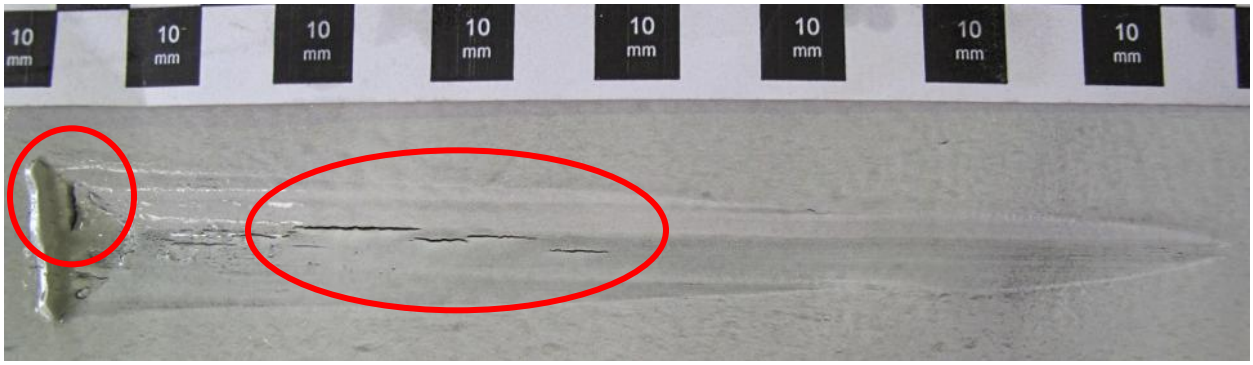


Figure 5: Presence of cracks at the gouge bottom of defect 3DG.1.1.

Technical Results and Conclusions

Task 2: Purchase & Characterize Pipe Material

Material characterization of vintage pipe 3DG has started and the first characterization results indicate the steel has a high percentage of equivalent carbon and sulfur leading to a

microstructure containing a high quantity of pearlitic phase and a significant volume ratio of inclusions of manganese sulfur. This information should indicate a low toughness level, and the team will confirm this through fracture tests in the next few months.

Results of transverse tensile tests provide a level of yield strength close to that of an X70 grade, even if this pipe was specified as an X52 grade. This high value of yield strength can be explained by the content of carbon which reinforces the steel resistance.

Task 4: Testing of Dents on Welds and Corrosion Features

BMT Fleet Technology completed a total of 57 full-scale tests and is analyzing the data. They are subjecting two test samples from the latest batch of vintage pipe tests to detailed evaluation and analysis (samples 53 and 55). Each of the samples failed by fatigue cracking that occurred on the transverse shoulder of the dent away from the axial center line of the pipe. The researchers are currently performing a detailed metallurgical investigation and will report the results next quarter.

Task 5: Testing of Dents with Gouges

GDF SUEZ created two similar "Dent and Gouge" defects, called 3D.1.1 and 3D.1.2, on vintage Pipe 3DG with internal pressure of 89 bar (1290 psi) by dynamic aggression. These defects are pretty similar to those created on modern pipes (Pipe 1 and 2) called 1.1.1b and 2.1.1 defects.

After GDF SUEZ created and re-rounded 3DG.1.1 and 3DG.1.2, they observed cracks at bottom of gouge visually and by magnetic particle inspection analysis. GDF SUEZ will send 3DG.1.1 defect to the SERAM (Société d'Etudes et de Recherches des Arts et Métiers) laboratory for x-ray analysis to determine residual stress in outer and inner surfaces of defect. 3DG.1.2 defect will be instrumented to perform burst test during the summer.

Task 8: Project Management and Reporting

The team completed the required monthly status updates and quarterly reports and also met via teleconference when necessary. The team has prepared two technical papers based in part on the results from this study and submitted them to the 2012 ASME International Pipeline Conference . Both papers have been accepted and are expected to be included in the conference proceedings.

Technical Issues, Problems or Challenges

The team is planning on submitting a 12 month contract, additional cost modification request to DOT PHMSA. The team encountered important delays which were unavoidable for the Dent + Gouge tests on vintage pipes. These delays were due to time spent to locate and select the appropriate vintage pipe material that exhibited sufficiently low toughness (as requested by PHMSA) and for their delivery to GDF SUEZ.

Also, the modification will include changes to the instrumentation and number of the dent fatigue test.

Plans for Future Activity

Task 2: Purchase & Characterize Pipe Material

GDF SUEZ will continue the material characterization, notably Charpy, toughness tests and cyclic behavior tests on vintage pipe 3DG.

Task 4: Testing of Dents on Welds and Corrosion Features

BMT Fleet has submitted their recommendation for the final series of four full-scale test specimens to the project team for review and approval. The test matrix includes three indenter sizes (2, 4, and 12 in cylinders) and three indenter displacements. All four tests incorporate dents interacting with welds. The team had a goal of determining the affect on the fatigue life due to the dent interacting with the weld. They therefore chose the location of the dents, with respect to the girth welds, based on the likely location of fatigue crack initiation. The researchers will initiate testing after confirming the dent matrix with the project team. BMT Fleet will report on the final matrix and any results in the next quarterly report.

Task 5: Testing of Dents with Gouges

GDF SUEZ will finalize the interpretation of tests already performed (defects 3DG.1.1 and 3DG.1.2 created) and will continue in the next months to create the third defect 3DG.1.3 for fatigue tests. They will also proceed with burst and fatigue tests of respectively defects 3DG.1.2 and 3DG1.3. The SERAM laboratory will analyze Defect 3DG.1.1 using x-ray diffraction for surface residual stresses. The team will then ship sample 3DG1.1 to Queen's University in Canada, who will then arrange for neutron diffraction evaluation through Chalk River Laboratories to measure residual stresses at the defect surface as well as locations along the thickness under the defect.

GDF SUEZ will create and test three type 2 defects (slower dynamic aggression) in the fall.

Task 8: Project Management and Reporting

The team will complete the required monthly status updates and quarterly reports and also meet via teleconference when necessary. The authors of the IPC papers discussed above will present their results at the conference, scheduled for September 24-28, 2012, in Calgary, Canada.

Business Status

The financial condition of the project is shown in the table below.

		Federal Funding			Cost Share Funding			
Task # per MS	**Task Description**	**Budget**	**Expended (Actuals) This Quarter**	**Expended (Actuals) to Date**	**Budget**	**Expended (Actuals) This Quarter**	**Expended (Actuals) to Date**	**% Complete**
1	Project Kick Off Meeting and Subcontracting	$9,335	$0	$9,335	$831	$0	$831	100%
2	Purchase & Characterize Pipe Material	$134,674	$0	$134,674	$146,108	$0	$146,108	82%
3	Literature Review	$11,549	$0	$11,549	$8,669	$0	$8,669	100%
4	Testing of Dents on Welds & Corrosion Features	$188,507	$0	$157,363	$599,632	$77,800	$753,725	95
5	Testing of Dents with Gouges	$150,020	$0	$150,020	$254,404	$0	$237,711	75%
6	Demonstration of Mechanical Damage Model Performance	$22,008	$0	$19,126	$10,930	$0	$5,530	90%
7	Industry Workshop	$12,030	$0	$0	$4,325	$0	$0	0%
8	Project Management and Reporting	$88,366	$1,834	$66,246	$43,959	$0	$21,692	On-going
	GRAND TOTAL	**$616,490**	**$1834**	**$548,313**	**$1,068,858**	**$93,418**	**$1,174,266**	

Schedule

The project schedule is impacted by the time spent to locate, select, and to transfer pipe 3DG from US to France. Material characterization and defects creation on this pipe started at the beginning of April 2012.

Task No.	Task	Scheduled Completion Date	Completed Date	% Complete	Status (if delayed)
1	Project Kick Off Meeting and Subcontracting	8/31/2008	8/31/2008	100%	
2	Purchase & Characterize Pipe Material	8/31/2010	02/01/2011 for Pipes, 1, 2 and 3	82%	Pipe 1, 2 and 3 complete. This task was extended for Pipe 3DG
3	Literature Review	11/30/2009	11/30/2009	100%	
4	Testing of Dents on Welds and Corrosion Features	2/28/2012	Ongoing	95	
5	Testing of Dents with Gouges	2/28/2012	Ongoing	75%	Testing linked to time needed to locate, secure, and ship for Pipe 3DG
6	Demonstration of Mechanical Damage Model Performance	11/30/2011	Ongoing	90%	
7	Industry Workshop	5/31/2012	Ongoing	0%	
8	Project Management and Reporting	5/31/2012	Ongoing	On-going	

Payable Milestones

Payable milestones for this period are shown in the table below.

		Federal Funding			Cost Share Funding			
Task # per MS	**Task Description**	**Budget**	**Expended (Actuals) This Quarter**	**Expended (Actuals) to Date**	**Budget**	**Expended (Actuals) This Quarter**	**Expended (Actuals) to Date**	**Payable Milestone (Item No)**
1	Project Kick Off Meeting and Subcontracting	$9,335	$0	$9,335	$831	$0	$831	
2	Purchase & Characterize Pipe Material	$134,674	$0	$134,674	$146,108	$0	$146,108	
3	Literature Review	$11,549	$0	$11,549	$8,669	$0	$8,669	
4	Testing of Dents on Welds & Corrosion Features	$188,507	$0	$157,363	$599,632	$16,692	$753,725	
5	Testing of Dents with Gouges	$150,020	$10,000	$160,020	$254,404	$50,000	$304,403	
6	Demonstration of Mechanical Damage Model Performance	$22,008	$0	$19,126	$10,930	$0	$5,530	
7	Industry Workshop	$12,030	$0	$0	$4,325	$0	$0	
8	Project Management and Reporting	$88,366	$1,834	$68,080	$43,959	$0	$21,692	
	GRAND TOTAL	**$616,490**	**$1,834**	**$550,147**	**$1,068,858**	**$16,692**	**$1,190,958**	