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

Date of Report August 31, 2012

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

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For Period Ending: August 31, 2012

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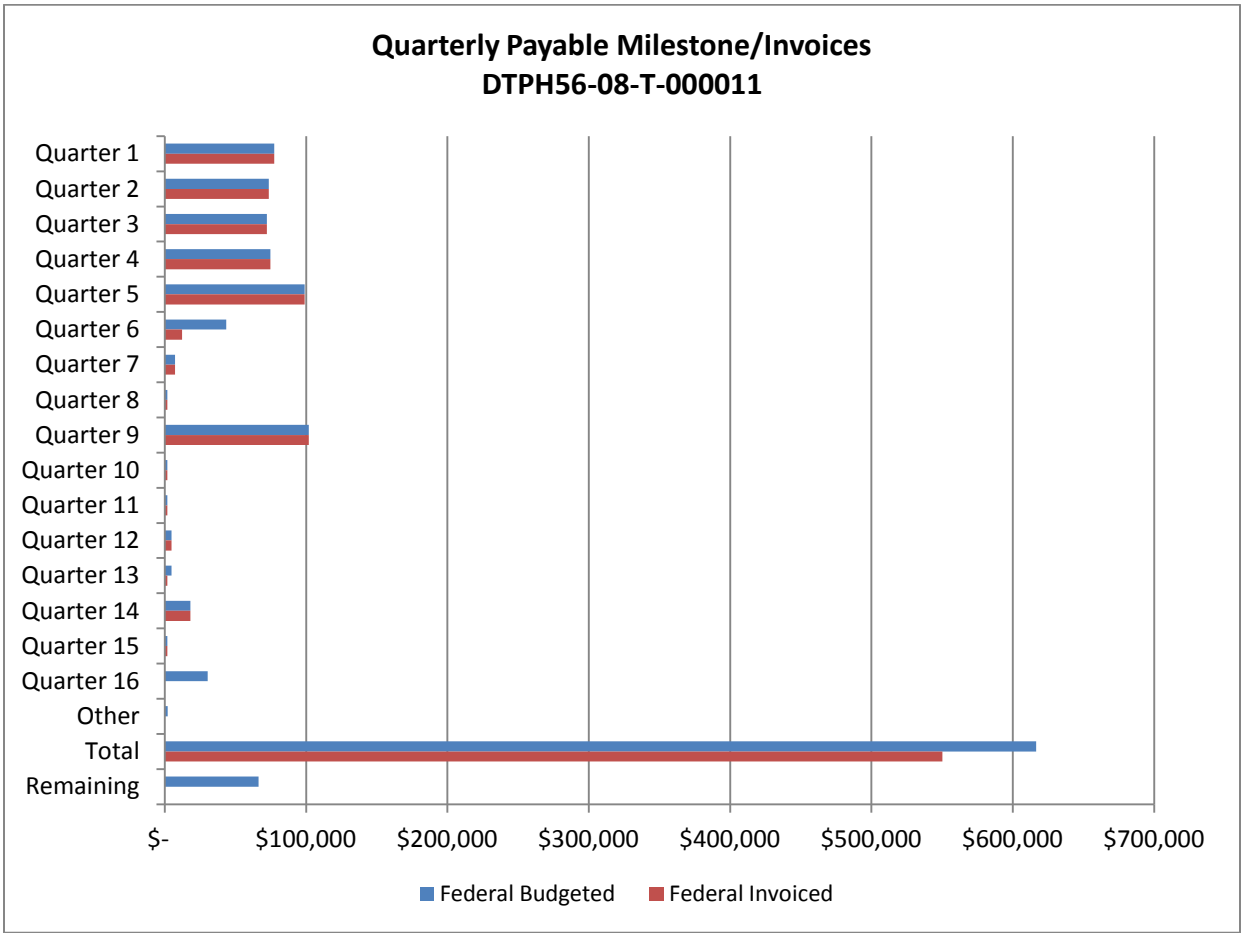
Funds and Work Completed During this Quarterly Period



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 additional characterization results in this current quarter are presented here:

Three longitudinal tensile tests were performed on cylindrical specimens under quasi- static loading at room temperature. Results are given in Table 1 below.

Table 1: Results on tensile longitudinal properties for Pipe 3DG

Test number	YS (MPa ksi)	UTS (MPa ksi)	YS/UTS	Elongation at rupture (%)	Section area reduction at rupture (%)
1	373 54	595 87	0.63	52	60
2	373 54	591 86	0.63	42	63
3	380 55	589 86	0.65	39	61
Average	375 54.5	592 86	0.63	41	61

The average values of tensile mechanical properties in the transverse direction presented in the previous report are presented 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 (%)
Average	490 71	606 88	0.81	26	58

Comparison of mechanical properties in both directions reveals that the steel showed significant anisotropic mechanical behavior.

Three Charpy impact tests with Transverse—Short Transverse (TS) orientation and three others with Transverse—Longitudinal (TL) orientation were also performed at room temperature (see Figure 1).

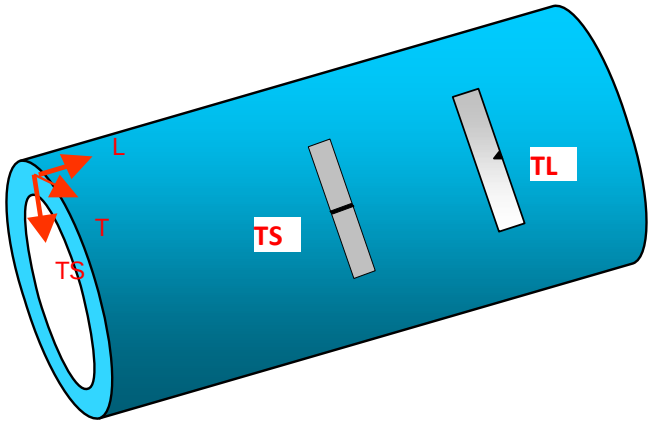


Figure 1: TS and TL orientations of Charpy specimen

Tables 3 and 4 show the results for TS and TL orientation tests.

Table 3: Charpy impact results in TS direction

Test Location	Test Temperature		Impact Energy					Broken
			Spec N°	J		J/cm^2		
	°C	°F		Meas.	Avg.	Meas.	Avg.	
Base Metal	21	70	1	18.33	19.02	45	47	No
			2	16.95		42		No
			3	21.78		53		No

Table 4: Charpy impact results in TL direction

Test Location	Test Temperature		Impact Energy					Broken
			Spec N°	J		J/cm^2		
	°C	°F		Meas.	Avg.	Meas.	Avg.	
Base Metal	20	70	1	21.71	18.55	53	46	Yes
			2	18.67		46		Yes
			3	15.27		38		Yes

At room temperature, the Charpy toughness is relatively low in both directions. In the TL orientation, all specimens were broken in two pieces after the impact. It is an indicator of low toughness where rupture mode could be partially brittle. This point has to be checked next by fractographic examination of the rupture on broken Charpy specimens.

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 finalized selection of the parameters for the final series of four full-scale test specimens. Table 5 below shows the last batch of test samples 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 and had the objective of determining the affect on the fatigue life due to the dent interacting with the weld. Based upon this goal, the researchers chose the location of the dents with respect to the girth welds because it was the place where the fatigue crack would likely initiate. .

Table 5: 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 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, instead of the axial shoulder or dent center as reported in the previous quarterly report. The dents in both the cases were unrestrained and created using the 12 in. indenter while the pipe was pressurized. The researchers sectioned the dent region in both the specimens at different locations for metallographic evaluations as shown in Figure 2 and Figure 3. In both the cases the team found corrosion pits (~0.15 mm and 0.2 mm) at the ID surfaces at the transverse shoulders of the dents as shown inFigure 4 and Figure 5. The presence of the deep pits on the ID surface at the transverse shoulders promoted fatigue crack initiation at their locations.

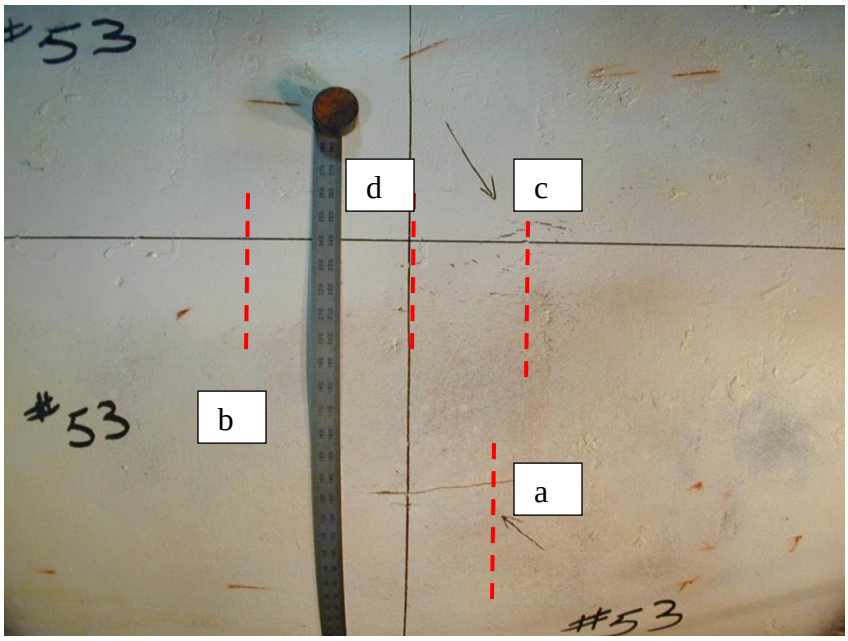


Figure 2: Dent Cut out from Pipe 53. Transverse Section Locations marked by red lines.

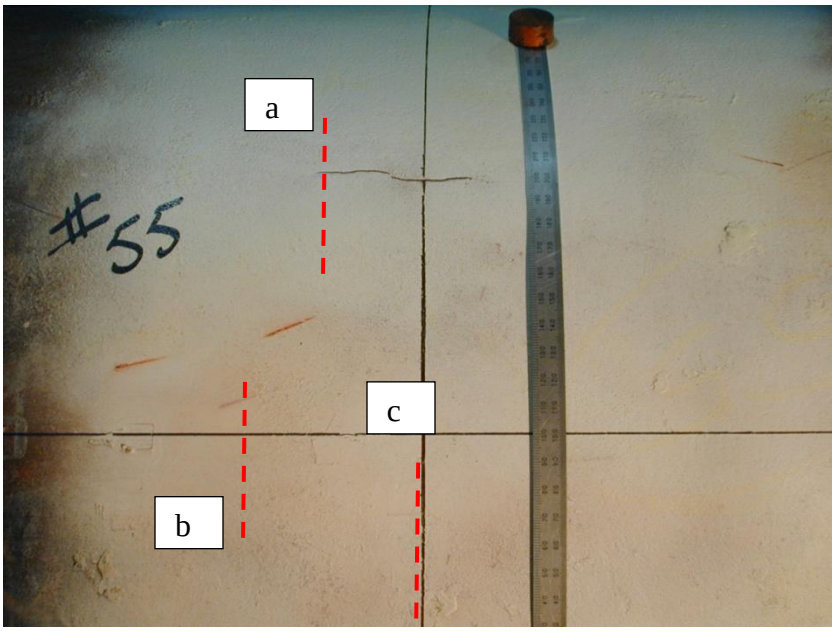


Figure 3: Dent Cut out from Pipe 55. Transverse Section Locations marked by red lines.

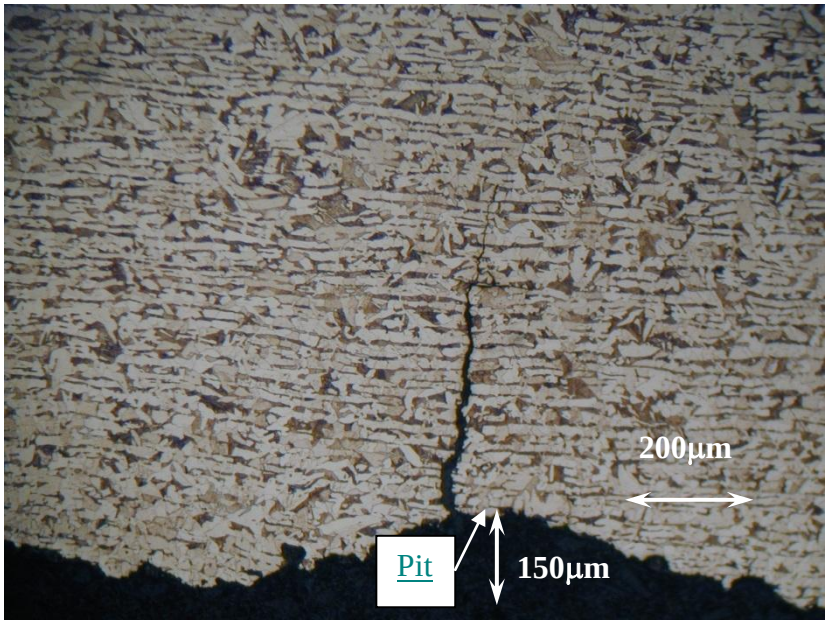


Figure 4: Micrographs from Section (a) on ID side (bottom) for Pipe 53

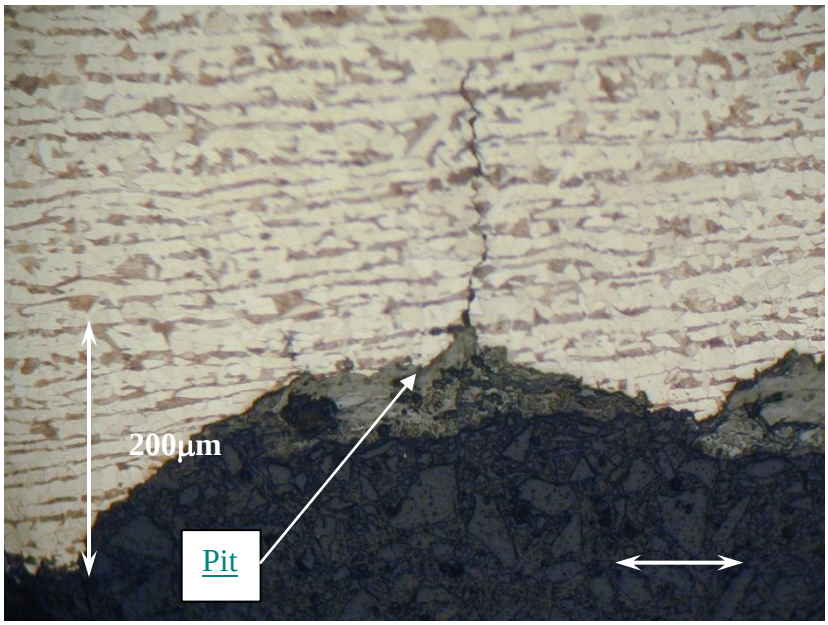


Figure 5: Micrographs from Section (a) on ID side (bottom) for Pipe 55

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 5:

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

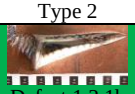
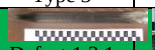
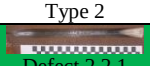
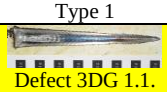
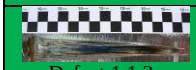
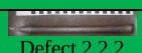
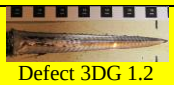
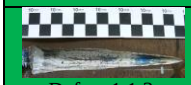
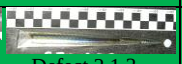
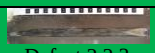
maximum of three different kinds of defects per pipe material, and therefore, the value of Y can range from 1 to 3; two extreme aggression conditions are considered in this study: highly dynamic and slower aggression. The former corresponds to defect Types 1 and 2 for Pipe 1 (two different excavator 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 5: Status of Dent+Gouge defects in Modern Pipes 1 and 2 and vintage pipe 3DG

PRCI 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 1.1.1b	 Defect 1.2.1b	 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 1.1.2	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

During this quarter, GDF SUEZ performed the following actions :

- Determination of residual stresses by x-ray on Defect 3DG.1.1;
- Creation of the third defect 3DG.1.3 with determination of impact energy, geometrical characterization and Magnetic Particles Inspection of the defect;
- Fatigue test of defect 3DG.1.3

The fatigue test led to a rupture that propagated at a very low number of cycles (around 1700 cycles). Figure 6 shows the extension of rupture propagation.

Figure 6: Rupture propagation of defect 3DG.1.3 after 1700 cycles of fatigue loading

On the rupture surface, "chevron" shapes are observed, which are typically the sign of fast brittle rupture propagation (Figure 7).

Figure 7: "Chevron" shapes on rupture surface.

In Figure 8, the brisk opening of clip gauge near 1700 number of cycles indicates the start of instability of fatigue crack to rupture propagation.

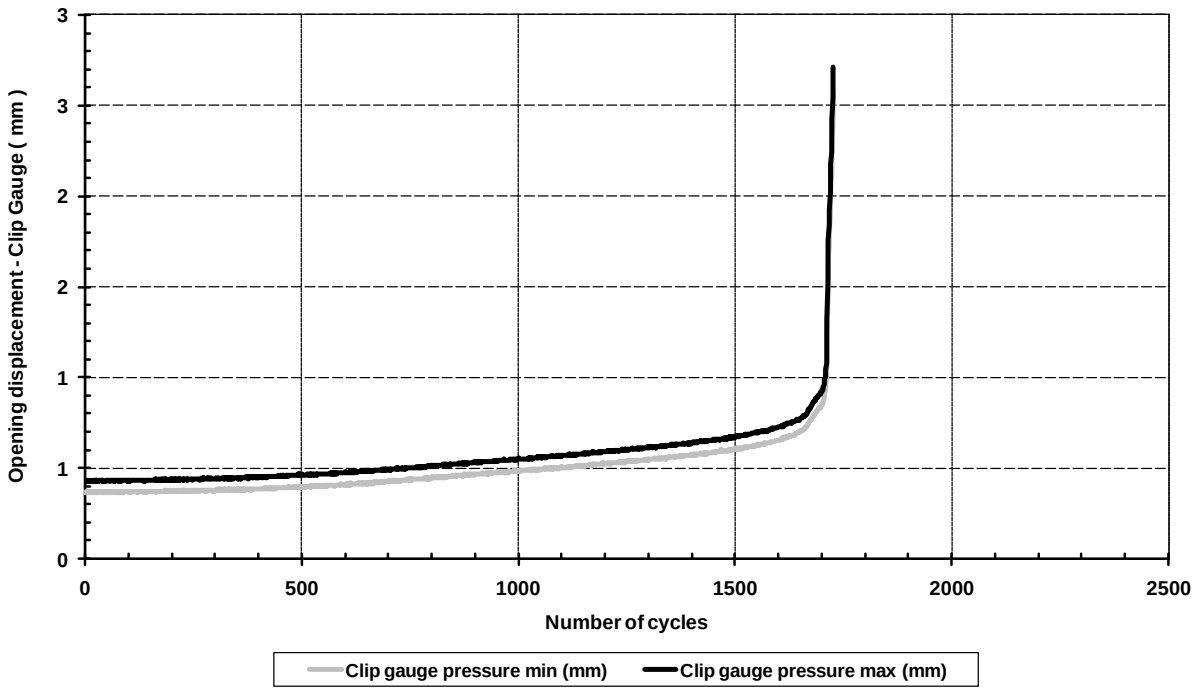


Figure 8: Evolution of opening displacement (clip gauge) versus number of cycles

Technical Results and Conclusions

Task 2: Purchase & Characterize Pipe Material

Vintage pipe 3DG showed significant anisotropy mechanical properties with higher strength and lower ductility in transverse direction than the longitudinal direction. The Charpy toughness values were relatively low at ambient temperature.

Task 4: Testing of Dents on Welds and Corrosion Features

BMT Fleet carried out a detailed investigation of samples 53 and 55. In both the cases they found corrosion pits on the ID surface at the transverse shoulders of the dents which resulted in fatigue crack initiation at the pits. BMT will start the full scale testing of the remaining four specimens and report the results in the next quarter.

Task 5: Testing of Dents with Gouges

GDF SUEZ determined through x-ray analysis that the residual stresses on 3DG.1.1 defect are compressive on the external and internal surfaces. The external surfaces had higher stresses.

The 3DG.1.3 defect tested under fatigue loading quickly failed at a low number of cycles (about 1700 cycles), in a brittle fracture mode with some propagation. Examination of the rupture surface showed “chevron” marks which are indications of fast brittle rupture propagation.

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 has submitted 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 of the dent fatigue test.

Plans for Future Activity

Task 2: Purchase & Characterize Pipe Material

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

Task 4: Testing of Dents on Welds and Corrosion Features

BMT Fleet will start the testing of the remaining four specimens and report the results in the next quarter.

Task 5: Testing of Dents with Gouges

GDF SUEZ will proceed with burst test of defect 3DG.1.2. Defect 3DG.1.1 will be sent for neutron diffraction evaluation to NIST to measure residual stresses at the defect surface as well as locations along the thickness under the defect.

GDF SUEZ will start the creation and tests of three type 2 defects (slower dynamic aggression) in 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	85%
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	96%
5	Testing of Dents with Gouges	$150,020	$0	$150,020	$254,404	$0	$237,711	80%
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	85%	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	96%	
5	Testing of Dents with Gouges	2/28/2012	Ongoing	80%	Delay due 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**	