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

Date of Report August 31, 2011

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

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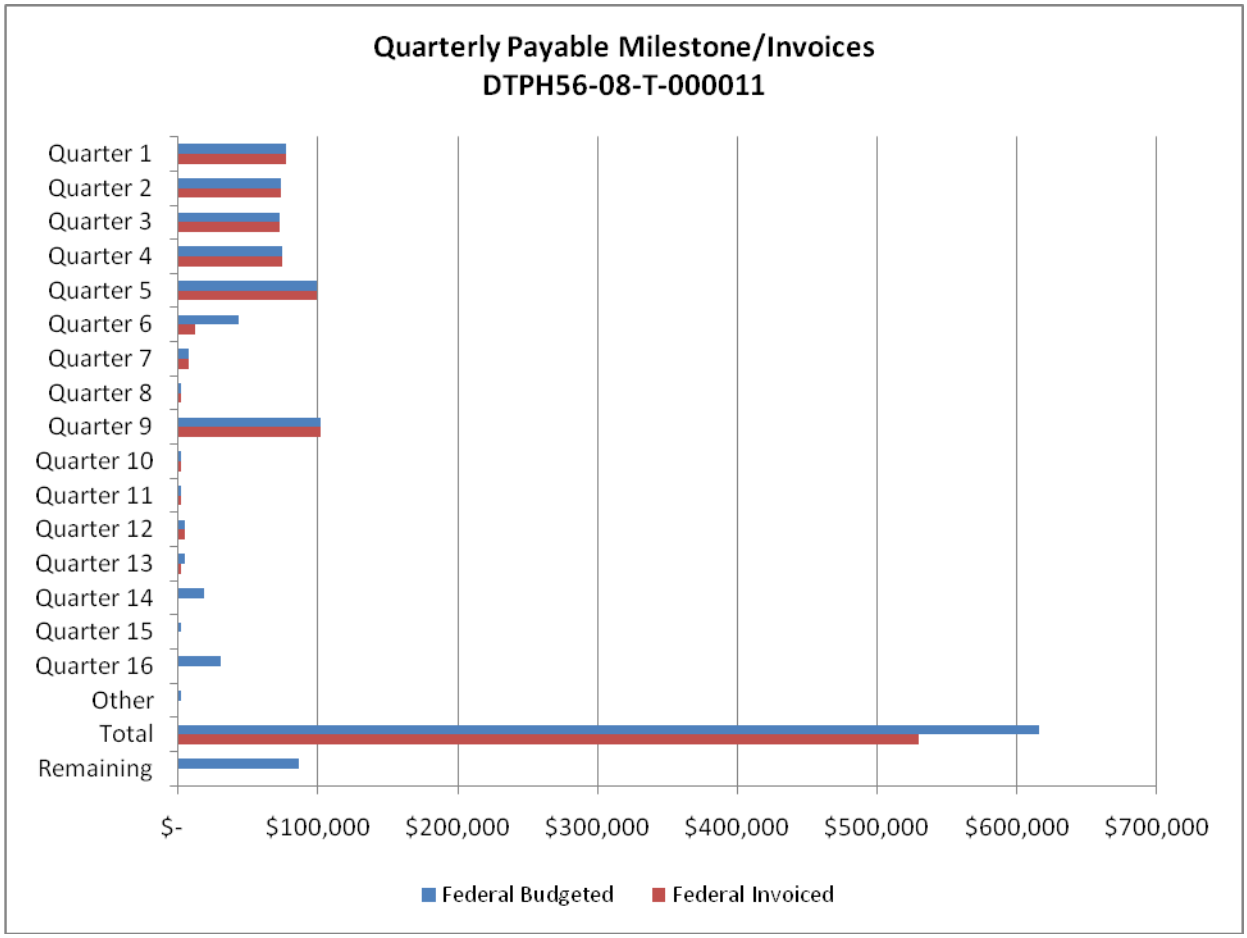
Funds and Work Completed During this Quarterly Period



Technical Status

Technical activities undertaken through the Thirteenth Quarter 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 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

- 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

- A separate **vintage material for creating and testing dent+gouge defects, designated Pipe 4** (there are currently several candidate vintage pipe materials being considered for selection, named 4a, 4b, and 4c, all 24 in. in diameter).

BMT Fleet Technology (BMT) performed preliminary characterization on vintage Pipe 4a (0.25 in. nominal thickness), see Table 1 below, to complement the dent+gouge test program. The results reflect relatively good characteristics for a vintage pipe, especially its Charpy toughness. Stress Engineering Services (SES) characterized another vintage Pipe 4b, with the hope of a lower Charpy V toughness and a thicker wall. A third vintage pipe 4c (Year 1967) from GDF SUEZ was also recently proposed for the study. Basic material characterization results are given in Table 1 below, to be used for choosing the vintage pipe material in the dent+gouge tests.

Table 1: Characteristics of Vintage Pipes 4a, 4b, and 4c - basic material characterization data for selection for dent+gouge tests

	Diameter thickness	Chemical analysis	Tensile properties	Charpy
Pipe A based in U.S.	24″ 0.25″	%C = 0.21-0.25 %S=0.026, %P=0.02 – 0.044	**Transverse (flattened)** YS=400MPa-413MPa UTS =538MPa-542MPa **Longitudinal** YS=370MPa-375MPa UTS =528MPa-568MPa	45 J/cm^2-60 J/cm^2 @ 20°C
Pipe B based in U.S.	24″ 0.29″	%C = 0.11 %S=0.013,%P=0.012 %V=0.06	**Transverse (flattened)** YS=404MPa-482MPa UTS =552MPa-579MPa **Longitudinal** YS=460MPa-485MPa UTS =555MPa-580MPa	37 J/cm^2-48 J/cm^2 @ 20°C
Pipe C based in France	24″ 0.27″min X63 grade (1967)	%C = 0.23 %S=0.020, %P=0.016 %Nb=0.020	Transverse YS=469MPa, UTS =610MPa	68 J /cm^2 @ 0°C

Based on a review of the materials property data and the program objectives, the Project Team has recommended that Pipe 4-c be used as the vintage pipe material for the full-scale testing for dent+gouge features. A notice on selection of the Pipe 4-c material was provided to the PHMSA AOTR in July 2011. The AOTR requested limited additional information on the steel properties, which is being gathered and will be provided in early September. However, the additional information will not have a substantial impact on the selection of Pipe 4-c for the full-scale testing program and the Project Team is preceding with preparations for full-scale testing of the vintage pipe.

Task 3: Literature Review

The literature review regarding cyclic fatigue dent assessment techniques is complete. A report summarizing the findings and demonstrating the performance of the identified assessment techniques will be available following the completion of the testing.

Task 4: Testing of Dents on Welds and Corrosion Features

The project team has approved the test matrix for the second batch of eight Pipe 3 plain dent specimens, shown in the table below. The matrix includes the use of three different spherical indenter size (2, 8 and 12 in.), four levels of indentation depth and three levels of internal pressure during dent formation. The test matrix for the second set of dent samples was provided to PHMSA's AOTR for review in July 2011, with no comments or suggested changes offered by PHMSA.

BMT developed a detailed cutting plan for creating the specimens from the available Pipe 3 segments. They have created the specimens and begun testing.

BMT has completed the detailed ultrasonic inspection of the cracks discovered in the first eight Pipe 3 plain dent specimens.

Table 2: Batch 2 of Pipe 3 Plain Dent Experimental Specimens

Specimen #	Pipe Segment from which to take the specimens	Specimen ID to be recorded on each pipe	Pipe Material	Nominal Indenter Diameter	Indenter Travel	Dent Restraint	Interacting With	Indentation Pressure	Initial Pressure Cycle	Cyclic Pressure Range	Weld Seam/Indenter Location
				(in)	(%)				(%SMYS)	(%SMYS)	
43	EEE-4	EEE-4-43	C	2	7.5	R	Plain	0%	100%	10%-80%	NA
44	EEE-8	EEE-8-44	C	8	7.5	R	Plain	0%	100%	10%-80%	NA
45	EEE-8	EEE-8-45	C	8	7.5	R	Plain	40%	100%	10%-80%	NA
47	EEE-8	EEE-8-47	C	8	7.5	R	Plain	80%	100%	10%-80%	NA
49	EEE-4	EEE-4-49	C	2	10	R	Plain	0%	100%	10%-80%	NA
50	EEE-7	EEE-7-50	C	2	15	U	Plain	40%	100%	10%-80%	NA
51	EEE-7	EEE-7-51	C	2	15	U	Plain	80%	100%	10%-80%	NA
53	EEE-9	EEE-9-53	C	12	20	U	Plain	40%	80%	10%-80%	NA
55	EEE-9	EEE-9-55	C	12	20	U	Plain	80%	80%	10%-80%	NA

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 next table:

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
- Green: Defects created and all tests completed

Table 3: Status of dent+gouge defects

MD-4-1					DOT	
Pipe 1 (modern steel X52)			Pipe 2 (modern steel X70)		Pipe 4 (vintage)	
Type 1	Type 2	Type 3	Type 1	Type 2	Type 1 or 2	Type 2 or 3
Defect 1.1.1.b	Defect 1.2.1.b [38X done, residual stress needed, repeated 38X completed October 2011]	Defect 1.3.1	Defect 2.1.1 [38X done, residual stress needed, repeated 38X completed October 2011]	Defect 2.2.1 [38X done, residual stress needed, repeated 38X completed October 2011]	Defect 4.1.1 or Defect 4.2.1	Defect 4.2.1 or Defect 4.3.1
Defect 1.1.2	Defect 1.2.2	Defect 1.3.2	Defect 2.1.2	Defect 2.2.2	Defect 4.1.2 or Defect 4.2.2	Defect 4.2.2 or Defect 4.3.2
Defect 1.1.3	Defect 1.2.3	Defect 1.3.3	Defect 2.1.3	Defect 2.2.3	Defect 4.1.3 or Defect 4.2.3	Defect 4.2.3 or Defect 4.3.3

GDF SUEZ has completed the metallurgical investigation of defect 1.3.1 which is the first defect created by slower dynamic aggression.

GDF SUEZ is waiting for the completion of the residual stress analysis of defects 1.2.1.b, 2.1.1 and 2.2.1 by Chalk River Laboratories. They expect to receive them by the end of September and will then begin their destructive metallurgical investigation.

During this quarter, GDF SUEZ also investigated defect 1.1.1.b which was created using a greater degree of dynamic aggression which exhibited hard layers at gouge surface and the presence of micro-cracks at a depth below 200 µm. These results confirmed that dynamic aggression from excavator tooth can create severe damage.

Task 5: Metallurgical Investigation of Defect 1.3.1

GDF SUEZ investigated defect 1.3.1 which was created by slower dynamic aggression, with a worn, rounded tooth and at a lower pressure. The resulting defect 1.3.1 is a deep dent with an intermediate gouge.

The defect investigation reported in the twelfth quarterly report (May 2011) on defect 1.1.1.b created by dynamic aggression with a sharp new tooth at high pressure resulted in very hard layers at the gouge surface that presented micro-cracks less than 200 µm deep. An important check is to compare these observations with those on defect 1.3.1, that was created in different conditions.

To perform this investigation, defect 1.3.1 was cut in seven pieces after creation (Figure 1).

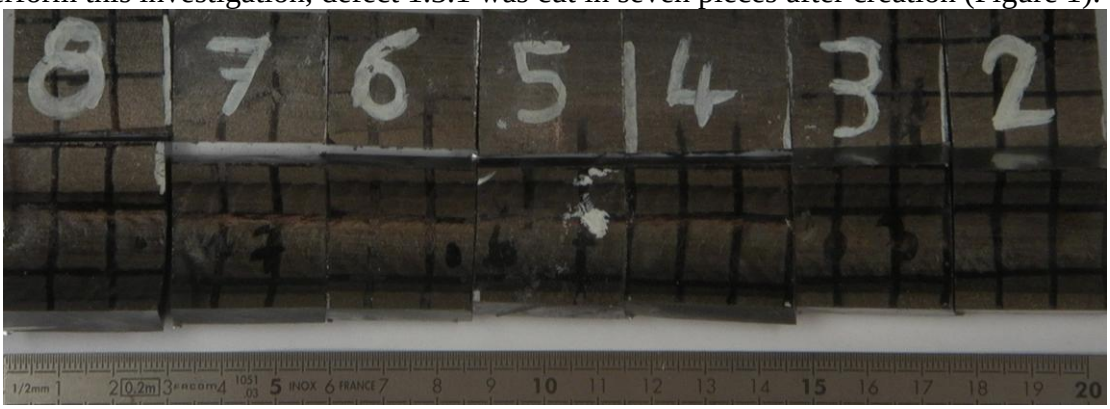


Figure 1: Defect 1.3.1 cut in seven samples

On these samples, the researchers examined the microstructure by optical microscope with emphasis on the area near the gouge surface. They did not observe any hard layer and did not identify any micro-cracks by fully scanning each of the seven samples (Figure 2).

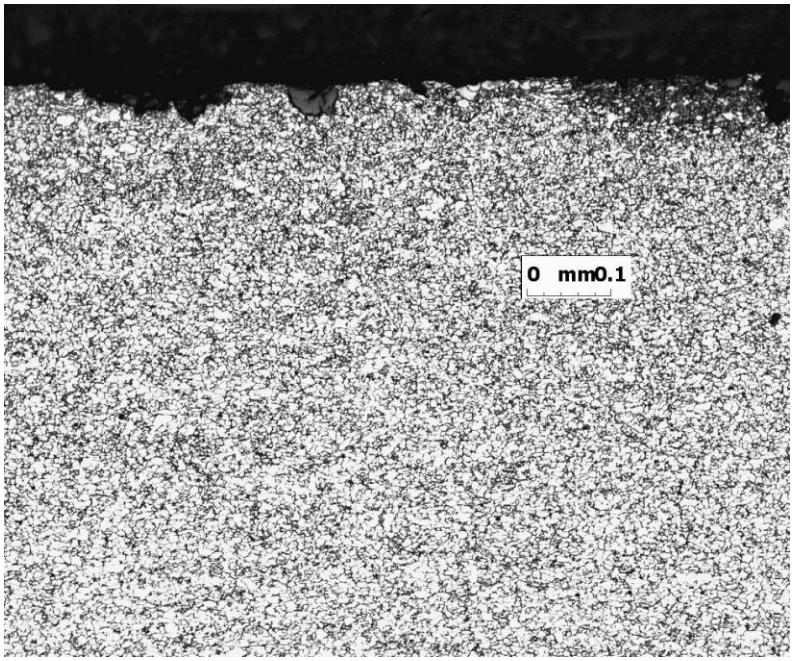


Figure 2: Microstructure of Defect 1.3.1 near the gouge and dent surface (sample 6 from Figure 1)).

Figure 2 shows that the ferritic grains are not very deformed. The researchers also confirmed the results of this optical examination through the micro-hardness measurement which showed that the local strain did not exceed 25%.

This newly-developed data shows that the condition of mechanical aggression by the impact of the tooth lead to different types of dent+gouge defects in terms of geometry and material damage. The defects created by dynamic conditions with a sharp tooth at high pressure result in shallow dents and moderate gouges with the presence of hard layers and micro-cracks near the gouge. Whereas defects created by slower dynamic aggression with a worn rounded tooth and lower pressure lead to severe dents and moderate gouges without hard layer microstructure and without micro-crack. These differences should have an impact on fatigue and burst behaviour.

Technical Results and Conclusions

A summary of the results are:

- Task 2—The Project Team has selected vintage pipe materials for full-scale testing of dent+gouge features and has communicated the selection to PHMSA;

- Task 4—The team has approved the second batch of Pipe 3 plain dent specimens has and testing has commenced. The team estimates that they will complete the testing during the next quarter.

- Task 5—The researchers performed metallurgical investigation on a defect created by slower dynamic aggression with a worn tooth at lower pressure and did not observe any hard layer microstructures nor the presence of micro-cracks near the gouge surface. This is a significant difference with respect to defects created by dynamic aggression with a sharp tooth at high pressure, resulting in hardened layers and micro-cracks at the gouge surface.

Technical Issues, Problems or Challenges
None

Plans for Future Activity

Task 2: Purchase & Characterize Pipe Material

The team will begin creating dent+gouge features in the selected vintage pipe and start full-scale testing and material property testing.

Task 4: Testing of Dents on Welds and Corrosion Features

BMT will finish the testing of the second batch of Pipe 3 plain dents specimens in the coming quarter. They will deliver a report documenting the results w to the project team and will present the results in the next quarterly report.

Task 5: Testing of Dents with Gouges

GDF SUEZ will continue the destructive characterization of defects just after creation, conditioned by the progress of neutron diffraction analysis, and will launch full material characterization and dent+gouge tests of vintage pipe.

Business Status

The team has proposed a 12-month, additional cost modification to DOT PHMSA. The additional testing being proposed under this modification includes expanding the full-scale testing matrices for mechanical damage defects to evaluate a broader range of pipeline operating conditions and increasing the number of variables and parameters monitored during the tests performed. Funds Expended

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	80%
3	Literature Review	$11,549	$0	$11,549	$8,669	$0	$8,669	100%
4	Testing of Dents on Welds & Corrosion Features	$188,507	$1,834	$157,363	$599,632	$0	$679,246	80%
5	Testing of Dents with Gouges	$150,020	$0	$150,020	$254,404	$15,619	$222,093	70%
6	Demonstration of Mechanical Damage Model Performance	$22,008	$0	$2,952	$10,930	$0	$5,530	75%
7	Industry Workshop	$12,030	$0	$0	$4,325	$0	$0	80%
8	Project Management and Reporting	$88,366	$0	$64,412	$43,959	$0	$21,692	On-going
	GRAND TOTAL	**$616,490**	**$1,834**	**$530,305**	**$1,068,858**	**$15,619**	**$1,084,169**	

Schedule

The project is generally on schedule, but as discussed in prior reports, Task 5 was impacted by the decision to add neutron diffraction testing of selected dent+gouge samples to the program. The analysis for some samples was recently completed in August and the researchers expect that

these samples will return to GDF Suez by the end of September 2011. The schedule for analysis of the additional samples is being reviewed and will need to be considered in the scheduling of work for this project. The researchers will immediately begin the destructive analysis and expect to complete it by the end of 2011. The researchers believe the data generated will be very beneficial for improving the understanding of the dent+gouge defects behavior and for providing further input to improve current mechanical damage remaining strength assessment models.

The schedule has also been affected by the identification and procurement of an appropriate vintage pipe material for the dent+gouge defect creation and full-scale testing. A recommendation for vintage pipe material was made by the Project Team and submitted to PHMSA in July 2011 for concurrence. There is no objection to use of the materials and the team is planning to initiate the full-scale testing program for the vintage pipe in September 2011.

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	80%	Pipe 1, 2 and 3 complete. Pipe 4 pending
3	Literature Review	11/30/2009	11/30/2009	100%	
4	Testing of Dents on Welds and Corrosion Features	2/28/2012	Ongoing	80%	Work continues on full-scale testing of vintage pipe
5	Testing of Dents with Gouges	2/28/2012	Ongoing	65%	Work continues on full-scale testing of dent+gouge on vintage pipe and detailed characterization for modern steel defect samples
6	Demonstration of Mechanical Damage Model Performance	11/30/2011	Ongoing	80%	
7	Industry Workshop	5/31/2012	Ongoing	80%	
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	16
3	Literature Review	$11,549	$0	$11,549	$8,669	$0	$8,669	
4	Testing of Dents on Welds & Corrosion Features	$188,507	$1,834	$157,363	$599,632	$0	$679,246	35
5	Testing of Dents with Gouges	$150,020	$0	$150,020	$254,404	$15,619	$222,093	46
6	Demonstration of Mechanical Damage Model Performance	$22,008	$0	$2,952	$10,930	$0	$5,530	
7	Industry Workshop	$12,030	$0	$0	$4,325	$0	$0	
8	Project Management and Reporting	$88,366	$0	$64,412	$43,959	$0	$21,692	44
	GRAND TOTAL	**$616,490**	**$1,834**	**$530,305**	**$1,068,858**	**$15,619**	**$1,084,169**	