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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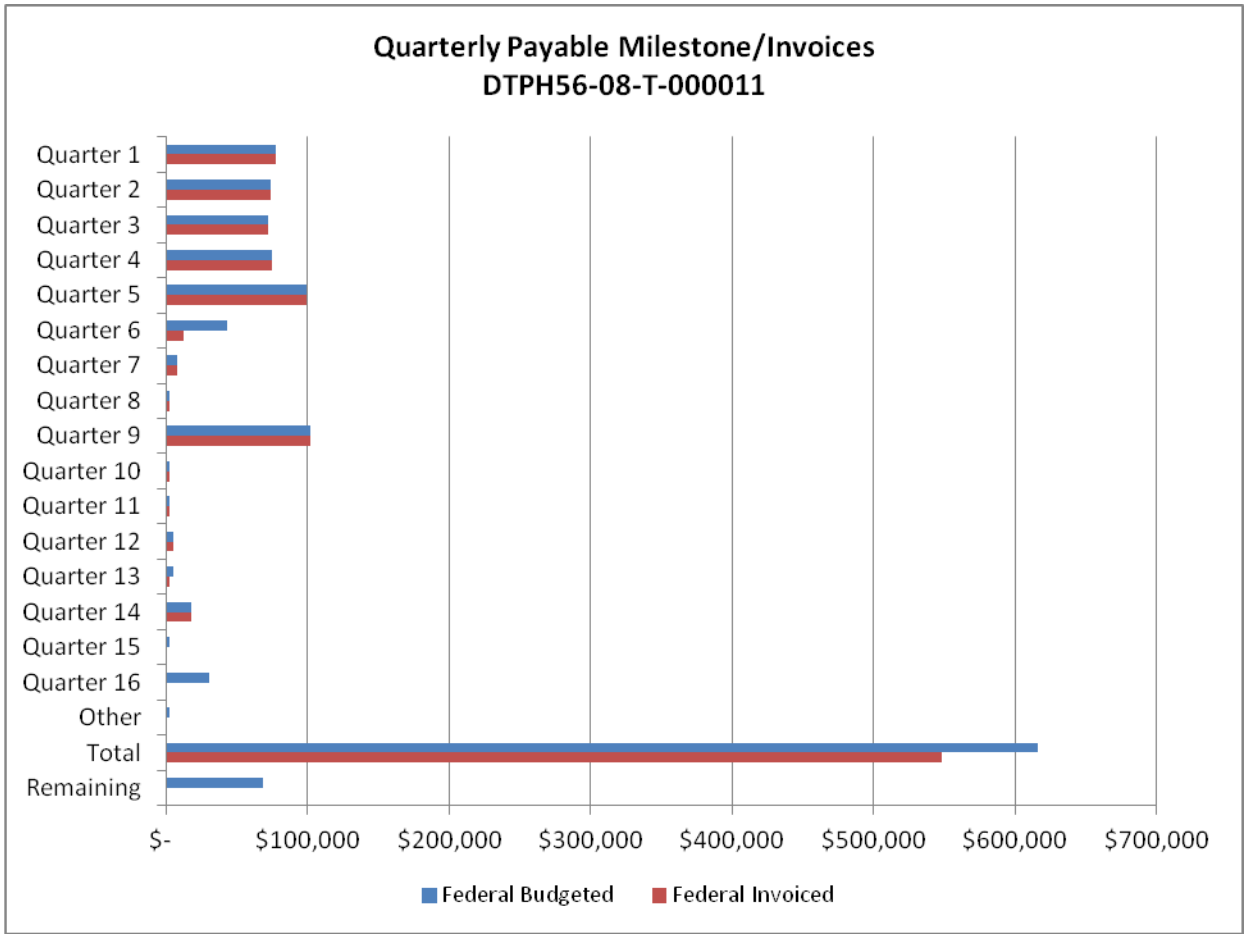
Funds and Work Completed During this Quarterly Period



Technical Status

Technical activities undertaken through 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 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

- 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, (there were three candidate vintage pipe materials being considered for selection, previously named 4a, 4b, and 4c, all 24 in. in diameter). Finally a fourth proposal of vintage pipe was also investigated and validated by PHMSA due to its very low toughness. This pipe is 26 in. diameter, 0.312 in. thickness and X52 grade. Chemical composition and mechanical properties from Control Quality Sheets are reported in the following tables :

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

C	S	P	Si	Cr	Mn	Ni	Cu	Other
0.19	0.024	0.017	0.06	0.03	0.91	0.03	0.08	<0.01

Table 2: Tensile and Charpy properties

Yield Strength Lb/in²	Tensile Strength Lb/in²	Elongation%	Charpy at 32°F Specimen size 10mm*6.7mm Ft.lbs
53.5	74.0	33	9

From theses tables, we can see the vintage pipe has characteristics such as high carbon and sulfur content and very low Charpy toughness equal to 9 ft-lbs. This pipe will complement the previous study on high toughness modern pipes and will allow the team to perform and validate the modeling on a large range of pipe properties.

To discriminate with vintage Pipe 3 used in Task 4 by BMT, this pipe is called “3DG”, standing for “dent + gouge”.

The team, using an economical shipping method, will send the 3DG pipes from US (Houston) to France (Paris) before the end of the year and will start their research immediately upon arrival.

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 continues to test the second batch of eight Pipe 3 plain dent specimens. The matrix below shows 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. They have completed five tests out of eight and the results are shown in the Table 3 below.

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

Specimen #	Nominal Indenter diameter	Indenter Travel	Dent restraint	Interacting with	Indentation Pressure	Initial Pressure Cycle	cyclic Pressure Range	Final Dent Dpeth	Cycles to Failure
	(in)	(%)			(%SMYS)	(%SMYS)	(%SMYS)	(%OD)	
43	2	7.5	R	Plain	0%	100%	10%-80%	4.91%	30604
44	8	7.5	R	Plain	0%	100%	10%-80%	4.10%	54036
49	2	10	R	Plain	0%	100%	10%-80%	6.31%	30604
50	2	15	U	Plain	40%	100%	10%-80%	4.26%	16600
51	2	15	U	Plain	80%	100%	10%-80%	4.78%	12131

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 4: 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 [98% done, residual stress needed, expected 100% completed October 2011]	Defect 1.3.1	Defect 2.1.1 [98% done, residual stress needed, expected 100% completed October 2011]	Defect 2.2.1 [98% done, residual stress needed, expected 100% 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 is waiting for the completion of the residual stress analysis by neutron diffraction of defects 1.2.1.b, 2.1.1 and 2.2.1 by Chalk River Laboratories. Due to delays of the neutron diffraction analysis, GDF SUEZ recently received defect 1.2.1.b in France and expects to receive the other at the beginning of next year.

Task 6: Demonstration of Mechanical Damage Model Performance

GDF SUEZ performed numerical simulations of dent+gouge defect creations by highly dynamic aggression and slower dynamic creation. Defects 1.1.2 and 1.3.2 were chosen respectively as highly dynamic and slower dynamic aggression cases. The researchers performed Finite Element Analysis using Abaqus Standard® 6.9 EF2 code and implicit solving method. Due to symmetry, only one half of the vessel is modeled as shown Figure 1, where boundary conditions are indicated.

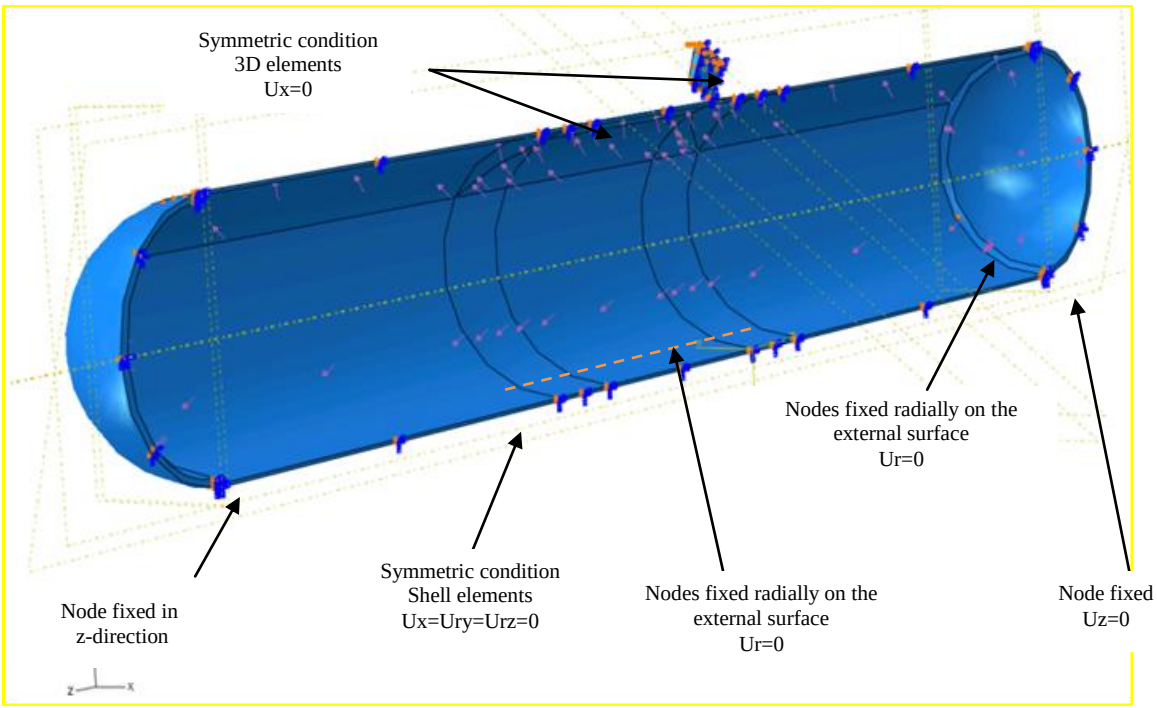


Figure 1: Numerical model (half vessel) with boundary conditions.

For the same reason of geometry, one half of the tooth is simulated (see Figure 2).

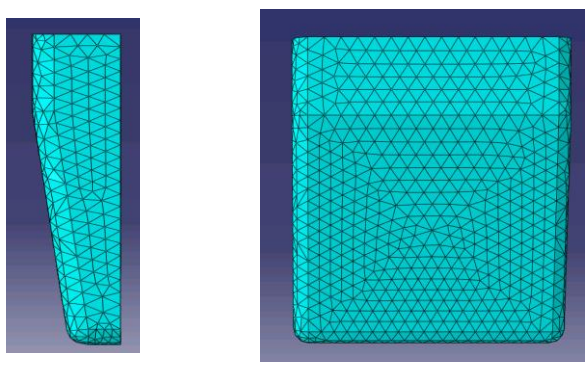


Figure 2: Numerical model of half tooth

The pipe wall model is meshed with six eight-node linear brick elements. The applied load history has three steps:

- Step 1: Pressure is increased in the pipe up to defect creation pressure
- Step 2: Longitudinal and vertical displacements are imposed to the tooth
- Step 3: Internal pressure is decreased to zero bar (relative)

Figure 3 shows a satisfactory comparison of simulated and experimental forces respectively for defects 1.1.2 and 1.3.2.

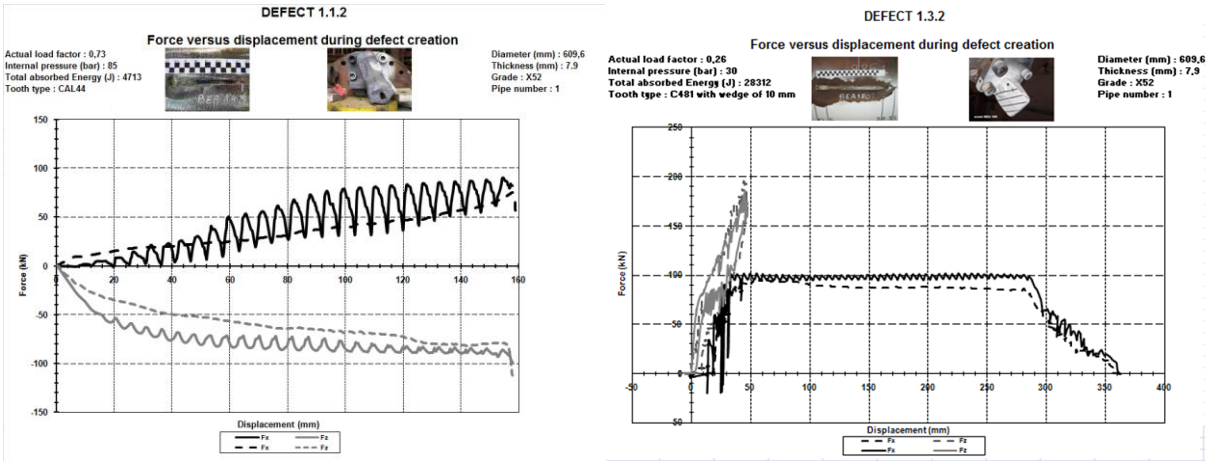


Figure 3: Comparison of simulated and experimental (dashed line) forces for creation of defects 1.1.2 (left) and 1.3.2 (right)

In the same way, Figure 4 compares simulated and experimental longitudinal profiles after defect creation and after removing the internal pressure for both defects.

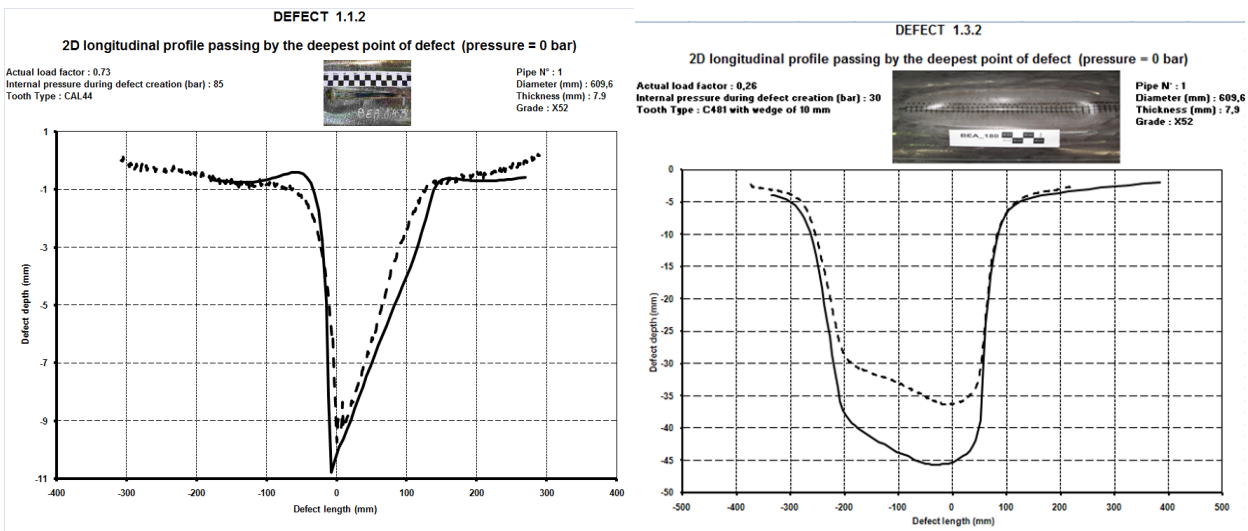


Figure 4: Comparison of simulated and experimental (dashed line) longitudinal profiles for defects 1.1.2 (left) and 1.3.2 (right)

The comparison shows that the modeling results in a deeper dent for the severe dent of defect 1.3.2. The researcher believe that one possible cause is that the simulation underestimates the spring-back upon re-rounding after removing the tooth, even if the model accounts for material cyclic behavior. They propose that other causes include pipe movement on the "V" support, the size of mesh, or the complex shape of the tooth in the impact zone. Nevertheless, the comparison shows reasonable agreement. Furthermore, the model estimation of the residual wall thickness values are accurate for both defects.

The model can also determine all of the local mechanical parameters, and local components of stress and strain. Figure 5 shows the high local value of equivalent plastic strain for defect 1.1.2

on the upper and lower layer of the defect at position 1 which is the instant when the longitudinal displacement of the tooth is 80 mm and at position 2 which is the end of the defect creation when the tooth is removed.

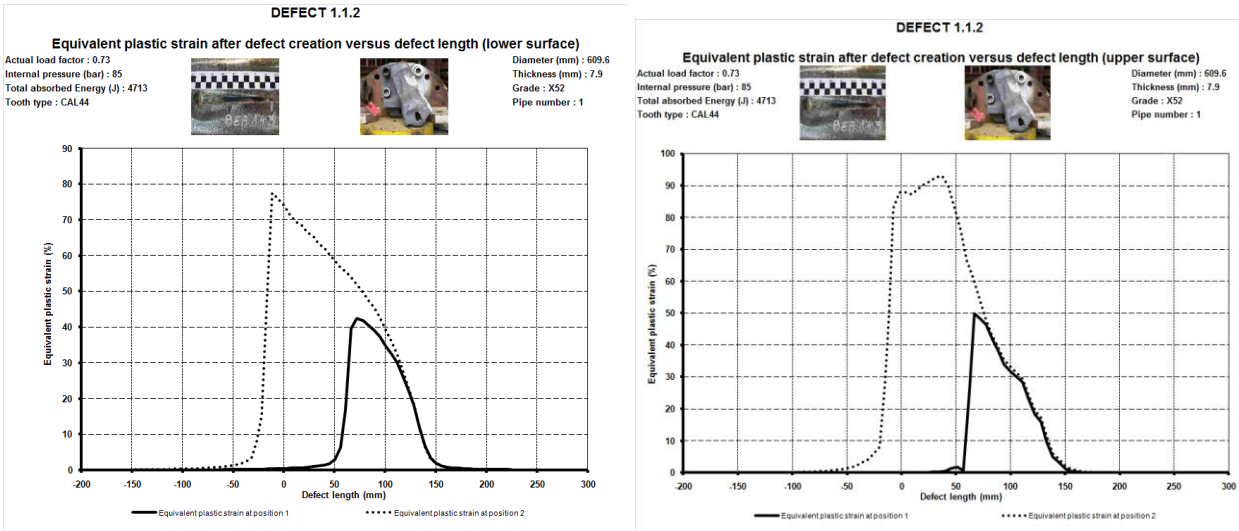


Figure 5: Defect 1.1.2: Equivalent plastic deformation versus defect length 1.1.2 at lower (left) and upper (right) surfaces for positions 1 (solid line) and 2 (dashed line).

The modeled equivalent local plastic deformation reaches about 80% at the lower layer and 90% at the upper layer after the removing the tooth (position 2).

Technical Results and Conclusions

Task 2: Purchase & Characterize Pipe Material

Vintage pipe materials with very toughness for full-scale testing of dent+gouge features, called pipe 3DG, was validated by PHMSA and the team is working to transfer theses pipes from the US to France;

Task 4: Testing of Dents on Welds and Corrosion Features

The team at BMT has completed five tests out of the eight have been completed and estimates that they will complete the remaining tests during the next quarter.

Task 5: Testing of Dents with Gouges

Due to delays from neutron diffraction analysis (malfunctioning beam devices) in Canada at Chalk River laboratories, GDF SUEZ was not able to perform destructive characterization of defects 1.2.1.b, 2.1.1 and 2.2.1 during the last months. Defect 1.2.1.b will arrive at the GDF SUEZ lab at the end of November and defects 2.1.1 and 2.2.1 are expected at the beginning of next year.

Task 6: Demonstration of Mechanical Damage Model Performance

GDF Suez simulated defect creations by highly dynamic and slower dynamic aggression using finite element analysis. Simulated results compared well with experimental results from defects 1.1.2 and 1.3.2 in terms of forces during defect creation, defect profiles and residual thickness.

The model also determines the local mechanical parameters during the defect creation process.

Task 8: Project Management and Reporting

The team completed the required monthly status updates and quarterly reports and also met via teleconference when necessary.

Technical Issues, Problems or Challenges

None

Plans for Future Activity

Task 2: Purchase & Characterize Pipe Material

GDF SUEZ will start the material characterization of vintage pipe 3DG upon delivery.

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 to the project team and will present the results in the next quarterly report.

Task 5: Testing of Dents with Gouges

GDF SUEZ will proceed with destructive characterization of defect 1.2.1.b and will continue in the same way for defects 2.1.1 and 2.2.1 conditioned by the progress of neutron diffraction analysis.

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.

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	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	$0	$157,363	$599,632	$77,800	$753,725	85%
5	Testing of Dents with Gouges	$150,020	$0	$150,020	$254,404	$15,618	$237,711	70%
6	Demonstration of Mechanical Damage Model Performance	$22,008	$16,174	$19,126	$10,930	$0	$5,530	90%
7	Industry Workshop	$12,030	$0	$0	$4,325	$0	$0	80%
8	Project Management and Reporting	$88,366	$1,834	$66,246	$43,959	$0	$21,692	On-going
	GRAND TOTAL	**$616,490**	**$18,008**	**$548,313**	**$1,068,858**	**$93,418**	**$1,174,266**	

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. Defect 1.2.1.b reached at GDF SUEZ at the end of November and the team plans destructive metallurgical investigation in January 2012. GDF SUEZ expects to receive the other defects 2.1.1 and 2.2.1 at the beginning of next year and will immediately begin the investigation. Furthermore, the transfer of selected and validated pipe 3DG from US to France underway. At this time the pipe is expected to reach in December and the team will begin its to be ready to start material characterization upon arrival.

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. This task was exteneded 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	85%	
5	Testing of Dents with Gouges	2/28/2012	Ongoing	70%	
6	Demonstration of Mechanical Damage Model Performance	11/30/2011	Ongoing	90%	
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	
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	$77,800	$753,725	45, 49, 53
5	Testing of Dents with Gouges	$150,020	$0	$150,020	$254,404	$15,618	$237,711	50
6	Demonstration of Mechanical Damage Model Performance	$22,008	$16,174	$19,126	$10,930	$0	$5,530	51
7	Industry Workshop	$12,030	$0	$0	$4,325	$0	$0	
8	Project Management and Reporting	$88,366	$1,834	$66,246	$43,959	$0	$21,692	52
	GRAND TOTAL	**$616,490**	**$18,008**	**$548,313**	**$1,068,858**	**$93,418**	**$1,174,266**	