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

For Period Ending: May 31, 2010

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Prepared For: United States Department of Transportation
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List of Activities and Deliverables

Task No.	Task	Scheduled Completion Date	Completed Date	Milestone
2	Purchase & Characterize Pipe Material	8/31/2010	Ongoing*	
3	Literature Review	11/30/2009	Completed	MS
4	Testing of Dents on Welds and Corrosion Features	2/28/2012	Ongoing	MS
5	Testing of Dents with Gouges	2/28/2012	Ongoing	MS
6	Demonstration of Mechanical Damage Model Performance	11/30/2011	Ongoing	MS
7	Industry Workshop	5/31/2012	Not Yet Started	
8	Project Management and Reporting	5/31/2012	Ongoing	MS

* Vintage Pipe 3

Technical Status

Technical activities undertaken through the sixth quarter focused on the following tasks:

- Task 2—Purchase & Characterize Pipe Material
- 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.

The technical group for this program has maintained close communication to ensure program coordination. Issues of concern in the program have been forwarded to PRCI and DOT for their consideration.

Task 2: Purchase & Characterize Pipe Material

There are three different pipe steels in this program:

- Pipe 1 and 2 are modern IPSCO pipes manufactured between 2005 and 2006

- Pipe 3 is intended to be of older steel, either a set of former operating / in-service vintage pipes from one of PRCI's member companies or a manufactured pipe that replicates vintage pipe properties.

GDF SUEZ has received three samples of Pipe 1 and two samples of Pipe 2 all with a length of 11.8 m. Pipe 1 is API X52 grade and has a 24 in diameter and 7.9 mm wall thickness. Pipe 2 is API X70 grade. It also has a 24 in diameter but has a wall thickness of 9.0 mm. IPSCO manufactured the pipe using the electric resistance welding (ERW) process.

In the previous quarterly reports, GDF SUEZ presented material characterization results for Pipes 1 and 2:

- Tensile properties in longitudinal and transverse directions
- Charpy V impact values in different directions at room temperature
- Toughness J Curve
- Pre-strain effects on toughness
- Size of slip bands (Additional originally unplanned work)
- Cyclic hardening behavior.

Materials characterization for Pipe 1 and Pipe 2 is now fully complete.

As discussed in the previous progress reports, PRCI has identified sources of the lower toughness vintage pipe for the dent (including plain dents, dents on welds, and dents with corrosion metal loss) and dent and gouge defects. These pipes were removed from the field and stored at Stress Engineering Services (SES) near Houston, TX. The team performed a preliminary visual inspection during a project team meeting in May. SES has catalogued the vintage pipe, with respect to lengths of the segments available and the locations of known anomalies such as existing girth welds, sleeves and metal loss. The researchers will confirm the suitability of the vintage pipes for the project based upon the on initial material characterization tests.

BMT has developed a material property characterization plan for the "SoCal" vintage pipe. The characterization plan includes fully characterizing material from five pipe segments, where the researchers will carry out tensile testing, chemistry, Charpy, microstructure and hardness measurements on all five segments. In addition to the detailed material characterization, the scientists will perform fatigue testing on coupons extracted from the "SoCal" pipe to evaluate the effect of surface notches found on the outer diameter of the pipe, shown in the Figure 1 below created during the pipe manufacturing process. The objective is to ensure the surface features do not significantly affect the fatigue testing results.

Figure 1: Surface Notches on OD of SoCal 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 testing of the six dents interacting with simulated corrosion features, is summarized in the table below, has started with the first two specimens. BMT has completed the fabrication of the simulated corrosion features in the remaining four specimens.

Table 1: Final Test Matrix – Dents Interacting with Simulated Corrosion Features

Test #	Specimen ID	Pipe Material	Nominal Indenter Diameter	Indenter Travel	Dent Depth	Dent Restraint	Interacting With	Indentation Pressure	Second Pressure Cycle	Cyclic Pressure Range	Indenter Location
			(in)	(%)	(%)				(%SMYS)	(%SMYS)	
35	26	A	4	10	10	R	Metal Loss	30	80%	10%-80%	C.L
36	30	A	4	10	10	R	Metal Loss	0	80%	10%-80%	C.L
37	37	A	4	15	~3-5	U	Metal Loss	30	80%	10%-80%	C.L
38	38	A	4	15	~3-5	U	Metal Loss	0	80%	10%-80%	C.L
39	39	B	4	5	5	R	Metal Loss	0	80%	10%-80%	1" Offset
40	40	B	4	15	~3-5	U	Metal Loss	0	80%	10%-80%	1" Offset

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., "dents with gouges", 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 and 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.

In the previous quarterly reports, the following results were presented:

- Creation conditions and results for 15 defects (13 + 2 repeated ones): 1.1.1, 1.1.1b, 1.1.2, 1.1.3, 1.2.1, 1.2.1b, 1.2.2, 1.3.1,1.3.2, 1.2.3, 2.1.1, 2.1.2, 2.1.3 , 2.2.1 and 2.2.2
- Burst test conditions and results for 2 defects in Pipe 1, 1.1.2, 1.2.2 and one in Pipe 2: 2.1.2
- Fatigue test conditions and results for 2 defects in Pipe 1: 1.1.3, 1.2.3 and one in Pipe 2 : 2.1.3
- Metallurgical Failure Investigation for 3 defects: 1.1.2, 1.1.3, 1.2.2 and 2.1.3

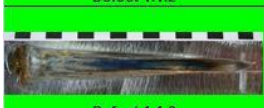
This report presents:

- Creation of defect 2.2.3
- Burst tests of defects 1.3.2 and 2.2.2.

Table 2 below summarizes the progress of the task on "Dent and Gouge" defects for the MD4-1 part of the program. The background color in the table represents:

- White: Defects not yet created
- Yellow: Defects already created but not yet characterized/investigated or submitted to either Burst or Fatigue tests
- Green: Defects created and tests completed

Table 2: Status of "Dent and Gouge" defects for the MD4-1part of the program

MD 4-1				
Pipe 1 (current steel X52)			Pipe 2 (current steel X70)	
Type 1	Type 2	Type 3	Type 1 or 2	Type 2 or 3
Defect 1.1.1b	Defect 1.2.1b	Defect 1.3.1	Defect 2.1.1	Defect 2.2.1
Defect 1.1.2	Defect 1.2.2	Defect 1.3.2	Defect 2.1.2.	Defect 2.2.2
 Defect 1.1.3	Defect 1.2.3.	Defect 1.3.3	Defect 2.1.3	Defect 2.2.3

Business Status

The project remains well coordinated with the pipeline industry through the PRCI partnership on the project.

Funds Expended

The financial condition of the project is shown in Table 3 below. Please note that a contract modification was submitted to DOT which will affect the budget.

Table 3: Status of the budget for the Project

		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	% Task Work Completed
1	Project Kick Off Meeting and Subcontracting	$9,335	$0	$9,335	$831	$0	$831	100%
2	Purchase & Characterize Pipe Material	$134,674	$0	$19,567	$146,108	$0	$8,166	100%
3	Literature Review	$11,549	$0	$11,549	$8,669	$0	$3,684	100%
4	Testing of Dents on Welds & Corrosion Features	$188,507	$0	$188,507	$599,632	$77,802	$463,999	65%
5	Testing of Dents with Gouges	$150,020	$0	$150,020	$254,404	$0	$0	80%
6	Demonstration of Mechanical Damage Model Performance	$22,008	$0	$0	$10,930	$0	$0	30%
7	Industry Workshop	$12,030	$0	$0	$4,325	$0	$0	0%
8	Project Management and Reporting	$88,366	$1,834	$55,242	$43,959	$0	$0	On-going
	GRAND TOTAL	**$616,490**	**$1,834**	**$434,220**	**$1,068,858**	**$77,802**	**$476,680**	

Schedule

The project is generally on schedule, but as discussed in prior reports, Task 5 is impacted by the decision to add neutron diffraction testing of selected dent+gouge samples to the program. The facility initially selected to perform the neutron diffraction testing, the Canadian Neutron Beam Centre (CNBC) at Chalk River, ON, experienced a shutdown for an extended period and this has delayed the proposed additional testing. To help address the delay, the Program Team has coordinated with National Institute of Standards and Technology (NIST) Center for Neutron Research at Gaithersburg, MD to perform the testing. In April, NIST received defects 1.1.1b and 1.3.1 and begun the neutron diffraction analysis. The reader should note that the analysis of the defect samples using neutron diffraction was not included in the original scope of work and was added to the program to capitalize on the availability of the neutron diffraction testing equipment and laboratories at no cost to the project. The data generated will be very beneficial to improving the understanding the behavior of dent+gouge defects and providing further input for improving the mechanical damage modeling projects.

Also, the team has executed a modified contract with DOT in order to support the procurement and testing of manufactured vintage pipe which was delayed. The modification will extend the project for 24 months through May 2012

Payable Milestones

Task status for this period is shown in Table 4.

Table 4: Status of Tasks for Project

Task No.	Task	Status	Scheduled Completion Date	Payable Milestone (Item No)
1	Project Kick Off Meeting and Subcontracting	100% Complete	8/31/2008	
2	Purchase & Characterize Pipe Material	100% Complete	8/31/2010	
3	Literature Review – effect of pre-strain and dent-gouge defect from field feed-back	100% Complete	11/30/2009	
4	Testing of Dents on Welds and Corrosion Features	65% Complete	2/28/2012	25, 28, 31
5	Testing of Dents with Gouges	80% Complete	2/28/2012	
6	Demonstration of Mech. Damage Model Performance	30% Complete	11/30/2011	
7	Industry Workshop	0% Complete	5/31/2012	
8	Project Management and Reporting	On-Going	5/31/2012	

Results and Conclusions

A summary of the results are:

- Task 3—The literature review regarding cyclic fatigue dent assessment techniques is complete.

- Task 4—The testing of dents interacting with girth welds is complete.

- Task 5
  - The team created a dent and gouge defect labeled 2.2.3. It has a maximum dent depth of 5.2% and a maximum gouge depth of 21% (As a comparison, dent depth were 5% and 4.6% s for respectively defects 2.2.2 and 2.2.1)

  - GDF SUEZ performed burst tests on defects 1.3.2 and 2.2.2. In addition to strain gauges and a clip gauge, they built a specific profiling tool was built. The researchers used a video camera to follow the evolution of the longitudinal dent profile during the pressure increase until burst. The results showed the dent re-rounding and subsequent bulging.

Task 4: Testing of Dents on Welds and Corrosion Features

The team has not generated any new results for the dents interacting with simulated corrosion features. The testing is currently ongoing and an update to the results will be provided in the next quarterly report.

BMT has developed a cutting plan for the vintage pipe based on the catalogue of segments provided by SES. It has identified sufficient material for all of the specimens in the extended matrix developed previously. The plan also includes locations where the researchers can remove material for the detailed material characterization program previously described.

Task 5: Testing dents with gouges: Creation of defect 2.2.3 and burst tests of defects 1.3.2 and 2.2.2.

The team created with a slower aggression procedure defect 2.2.3, similar to defects 2.2.1 and 2.2.2. The defect was created under an internal pressure of 20 bar in order to ensure the process would produce a deep dent. The force versus displacement curves are plotted below in Figure 2 and Figure 3.

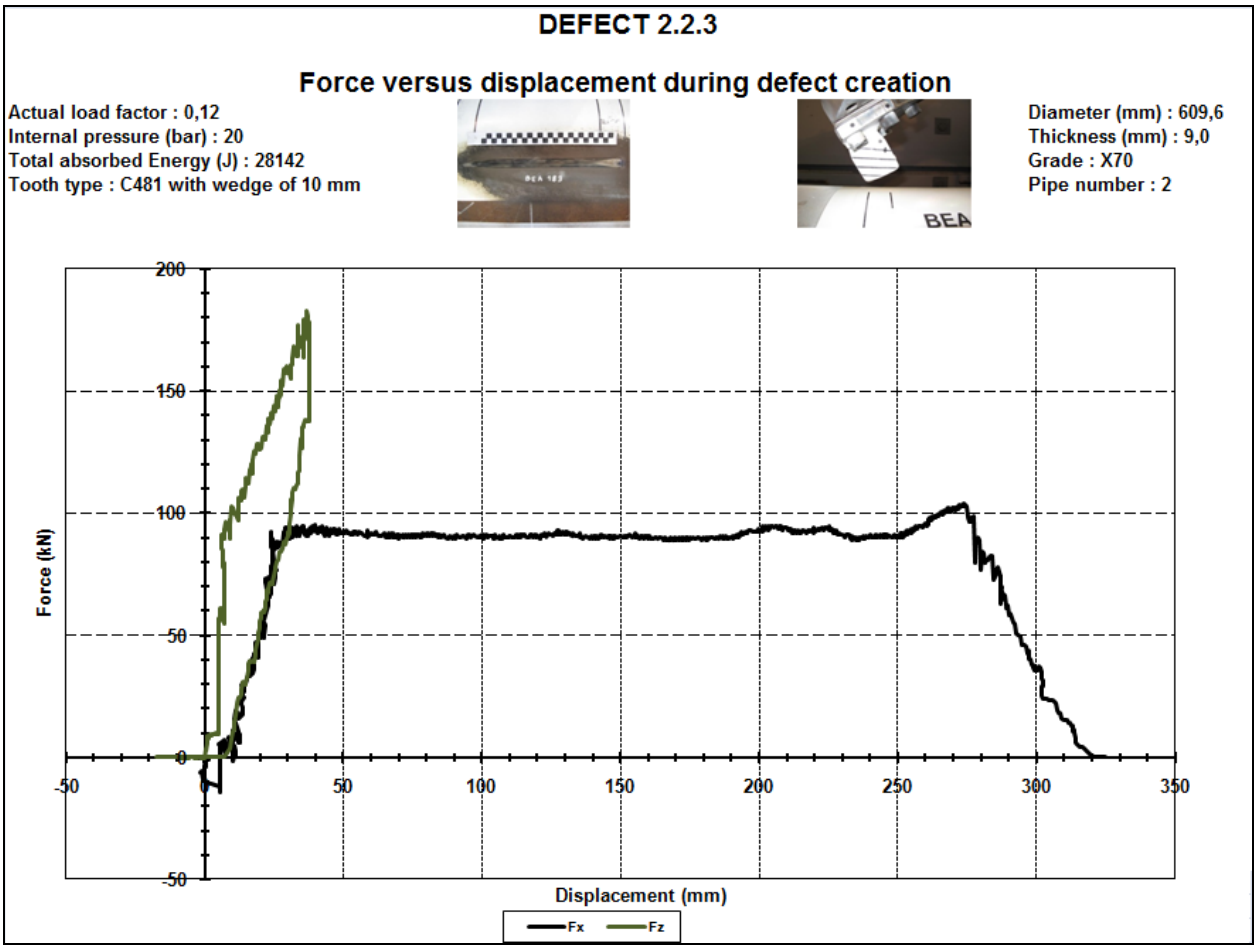


Figure 2: Force-displacement curve for creation of defect 2.2.3

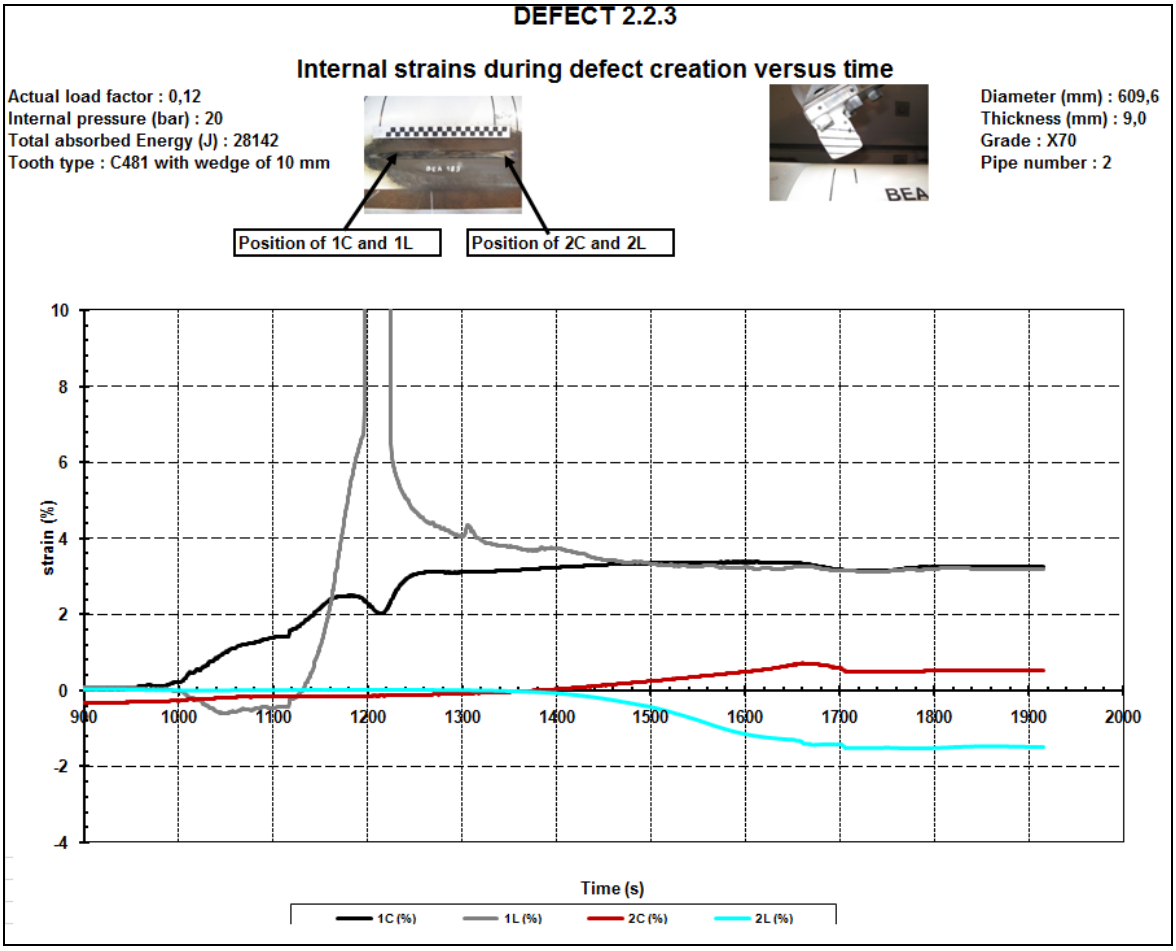


Figure 3: Evolution of internal strains during the creation of defect 2.2.3

Figure 4 shows defect 2.2.3

Figure 4: View of defect 2.2.3

For the burst tests, defects 1.3.2 and 2.2.2 were equipped each with the specific profiling tool to record the evolution of the dent longitudinal profile during pressure increase as shown in Figures 5 and 6. The burst pressures of defects 1.3.2 and 2.2.2 are respectively 130.9 bar and 193.5 bar, which are close to those of undamaged pipes.

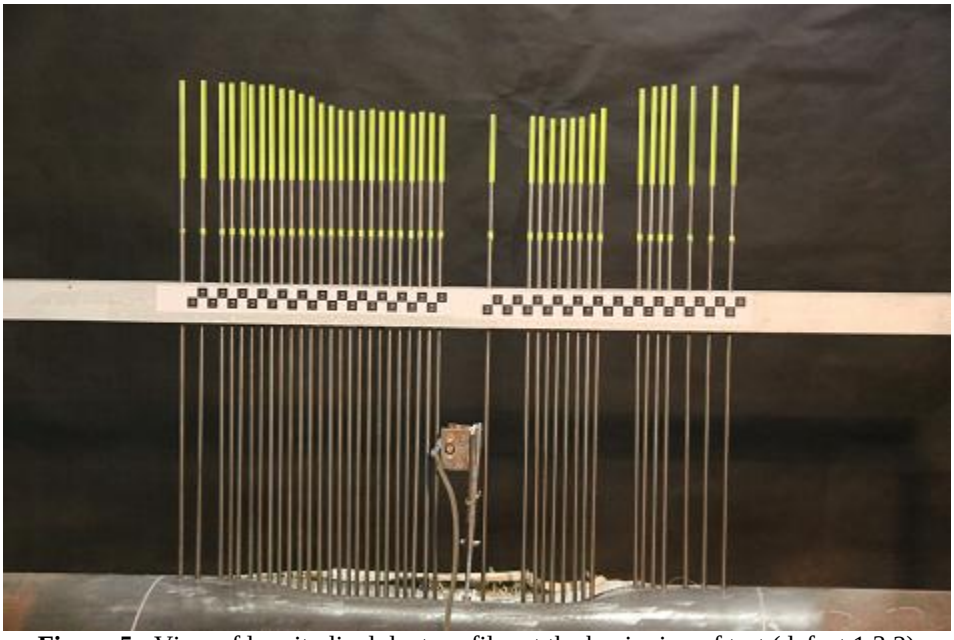


Figure 5: View of longitudinal dent profiler at the beginning of test (defect 1.3.2)

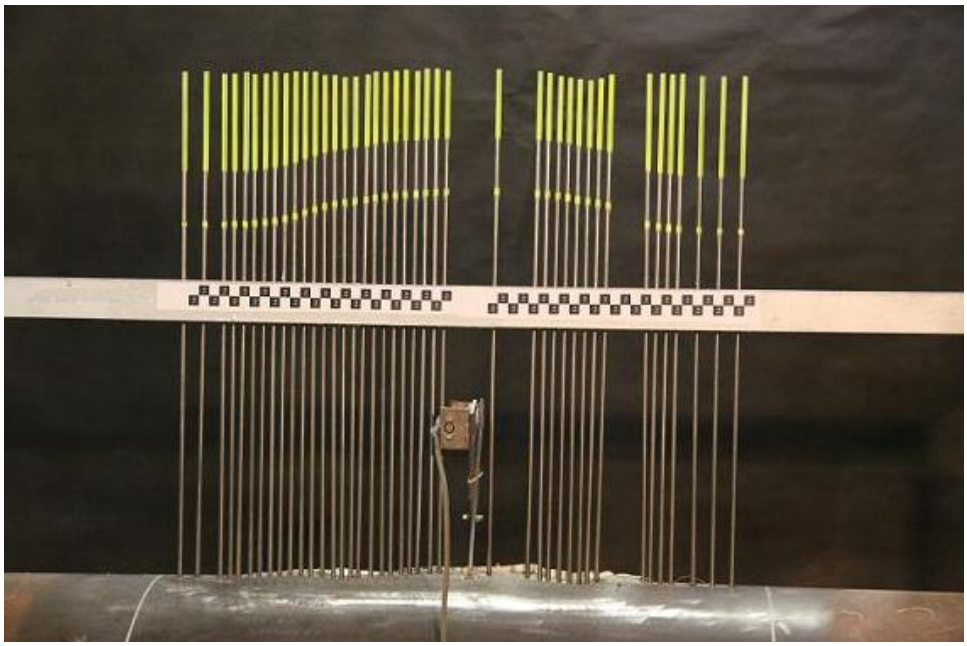


Figure 6: View of longitudinal dent profiler close to burst pressure (defect 1.3.2)

Figures 7 and 8 present the vertical displacements at several positions along the dent versus pressure of defects 1.3.2 and 2.2.2. The graph shows a quick re-rounding at low pressure (from 35 bar for defect 1.3.2 and from 30-35 bar for defect 2.2.2) above the indentation pressures.

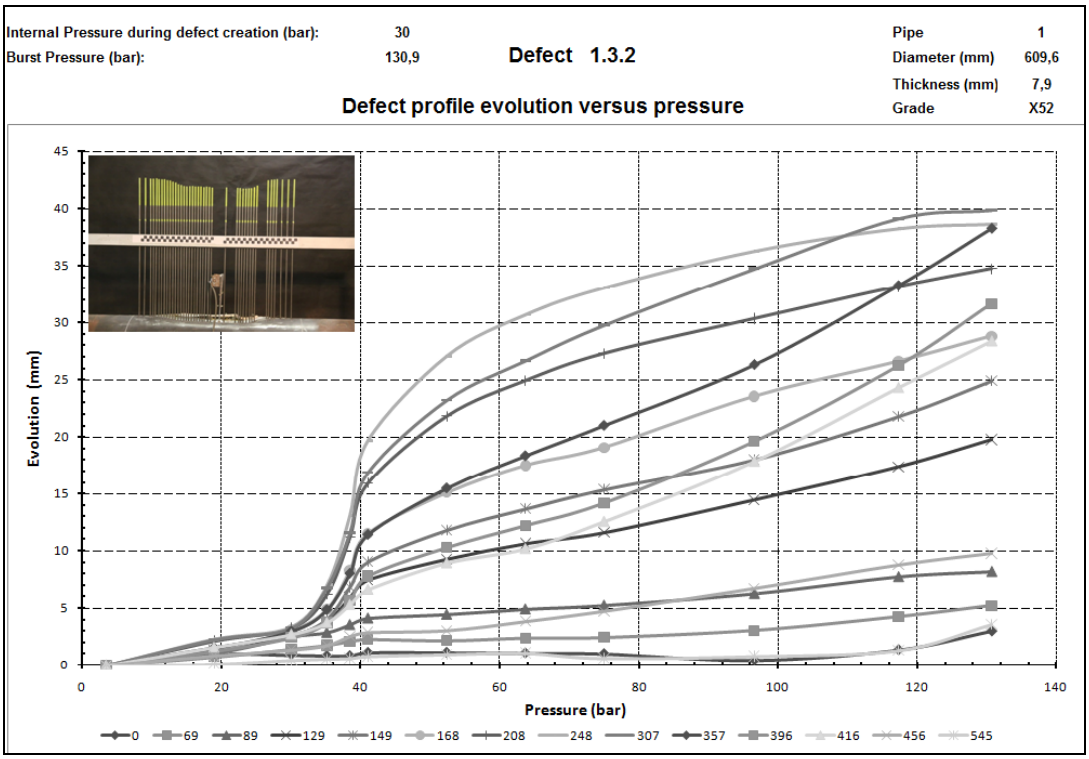


Figure 7: Vertical dent displacement versus pressure (defect 1.3.2)

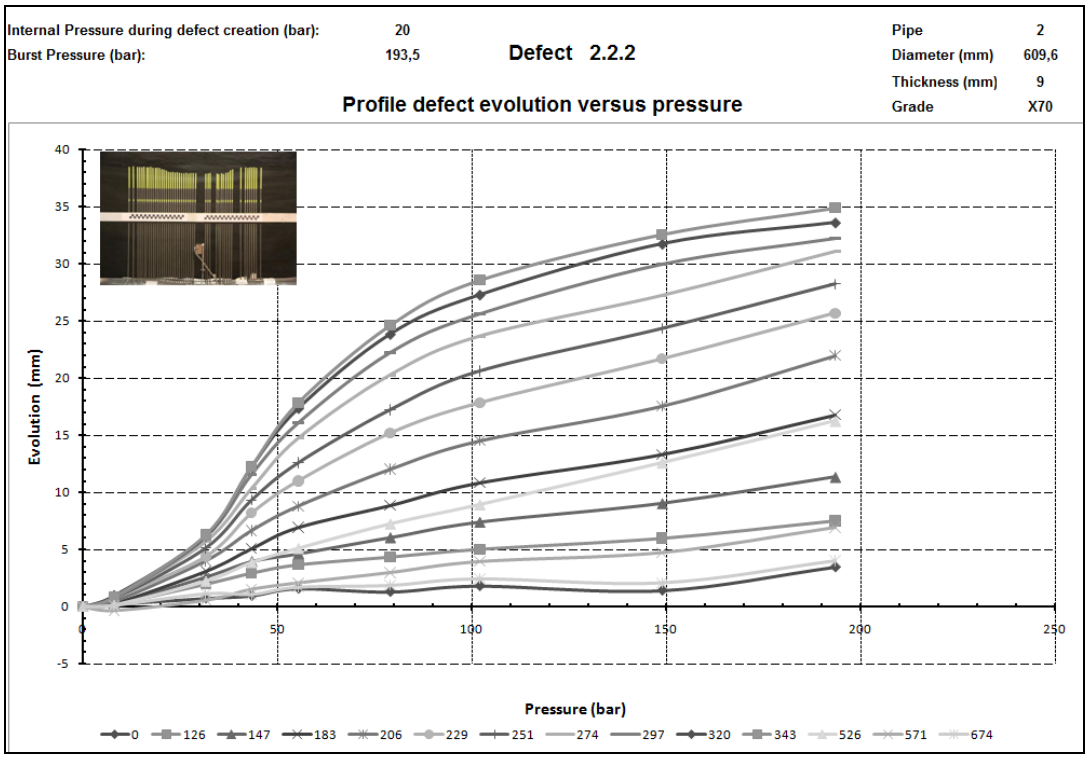


Figure 8: Vertical dent displacement versus pressure (defect 2.2.2)

Task 8: Project Management and Reporting

The team has received approval for a twenty four month extension in order to complete the testing program on the vintage pipe materials, as there was delay in identifying and confirming sources for the vintage pipe.

A project progress meeting was held on May 13-14, 2010, at SES in Houston, TX. The meeting was scheduled to provide a report to PHMSA and the program team on the status of defect testing and development of the mechanical damage database, and to review the proposed modifications to the program that have been identified based on results to date and recent discussions with PHMSA's representatives. The meeting also provided the opportunity for PHMSA, the Principal Investigators, and the members of the program team in attendance to visually inspect the vintage pipe.

Due to the timing of the meeting relative to developing this progress report, meeting minutes have not yet been compiled and completed. Meeting minutes will be included as an attachment in a future progress report (either monthly or quarterly).

Issues, Problems or Challenges

- GDF SUEZ measures the residual stresses in defects called x.x.1 on the same vessel for a given material. This process avoids wasting material by using the same vessel for different x.y.1 defects. However, the consequence is that the residual stress measurements and the metallurgical characterization of these already created defects will be performed at the end of the defect creation process for a given material (Pipe 1, Pipe 2, or Pipe 3). Two defects (1.1.1b and 1.3.1) were sent to NIST for neutron diffraction and so the metallurgical characterization could be done this year for these defects.

- The team is planning on delaying the demonstration of mechanical models until 2010 to include the results from the vintage pipe testing program and, therefore, provide for a more substantial set of data for the analysis.

- The process to mark the cracks and micro-cracks by ink injection in "dent and gouge" defects was not satisfactory. The team is looking for a new or modified process. The challenge with ink marking is that most inks are water-based and the use of hydrostatic pressure for burst and fatigue testing results in wash out of the ink when the defects fail. Solvent-based inks are more difficult to find due to environmental considerations.

- A number of adjustments and modifications have been made to the program to improve the outcomes and generate additional and/or more robust data. These changes have included additional tests (e.g., neutron diffraction), additional instrumentation to expand/improve the data collected during the tests, and related coordination, planning, and management to implement the modifications. The project team is attempting to offset any cost increases associated with these changes by improvements in productivity. However, it may be necessary to request a contract modification to account for the costs directly attributed to these changes. The team is preparing this modification and plans to submit it

during the next quarter.

Plans for Future Activity

Planned activities for the project are presented below.

Task 2: Purchase & Characterize Pipe Material

Testing on vintage pipe material will begin once the materials are delivered to the test facilities (SES in Houston, TX, and GDF SUEZ in Saint Denis, France). Prior to delivering the materials to the testing facilities, preliminary material characterization will be performed to verify that the selected materials are representatives of vintage pipe properties. Preliminary testing will be performed by BMT Fleet Technology and SES, pending approval by the team.

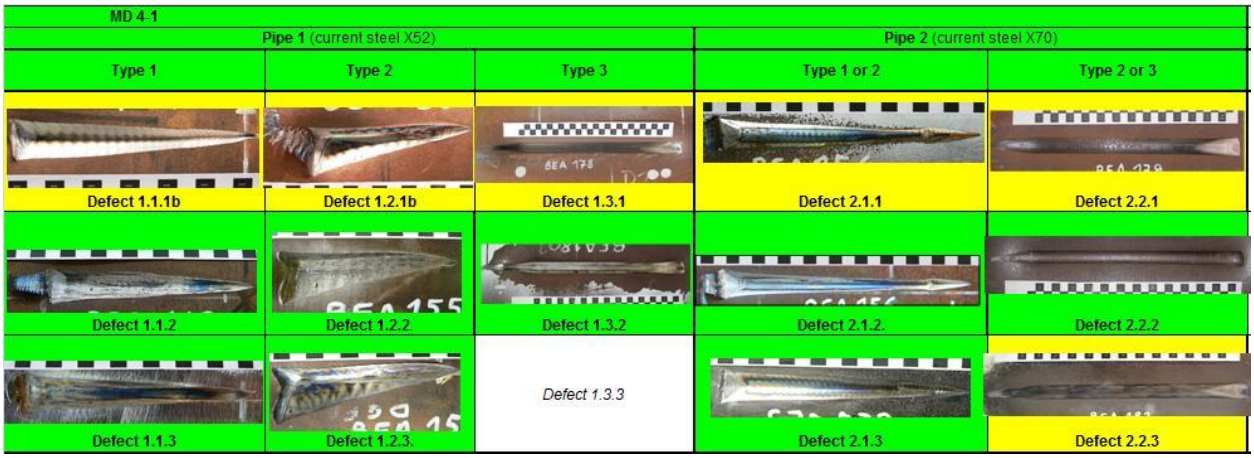
Task 4: Testing of Dents on Welds and Corrosion Features

BMT has begun the testing of the dents on simulated corrosion features and plans to conclude it in the coming quarter.

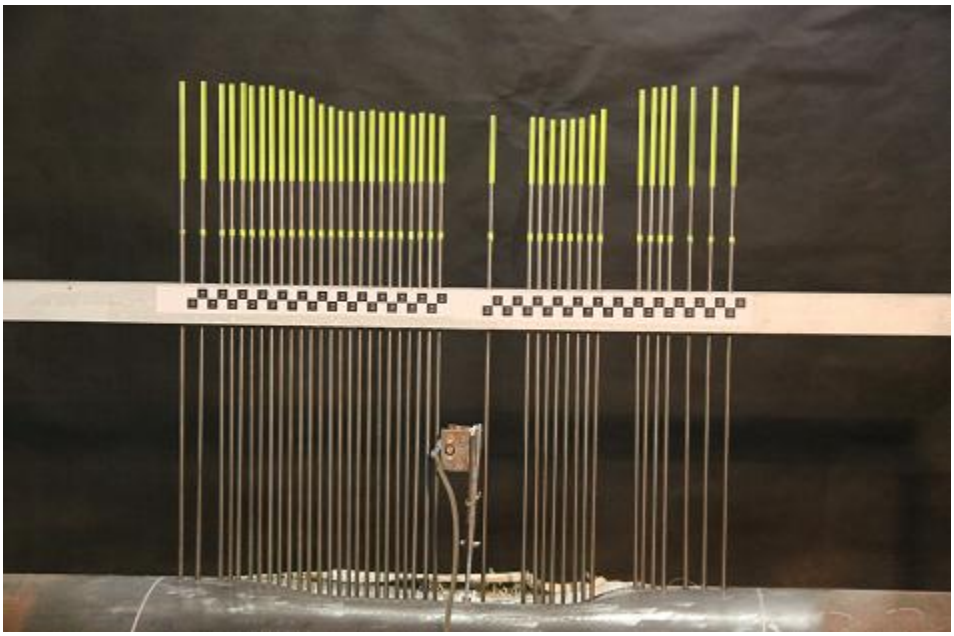
Work will begin on creating the vintage pipe specimens for the extended testing matrix. Additionally, the detailed material characterization program for the vintage pipe material will begin in the coming quarter.

Task 5: Testing of Dents with Gouges

GDF SUEZ will create defect 1.3.3 and perform fatigue tests on defects 1.3.3 and 2.2.3



- GDF SUEZ continued the tests on dents and gouges during this reporting period with the following results:

- GDF SUEZ created Defect 2.2.3 with slower aggression and low internal pressure, (20 bars) to promote deep denting in the range of 5%.

- GDF SUEZ performed burst tests on defects 1.3.2 and 2.2.2 with additional instrumentation in order to video the longitudinal profile of severe dent versus the increase of pressure