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

Date of Report May 31, 2011

Contract Number: DTPH56-08-T-000011

Prepared For: United States Department of Transportation
Pipeline and Hazardous Materials Safety Administration
Office of Pipeline Safety

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

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For Period Ending: May 31, 2011

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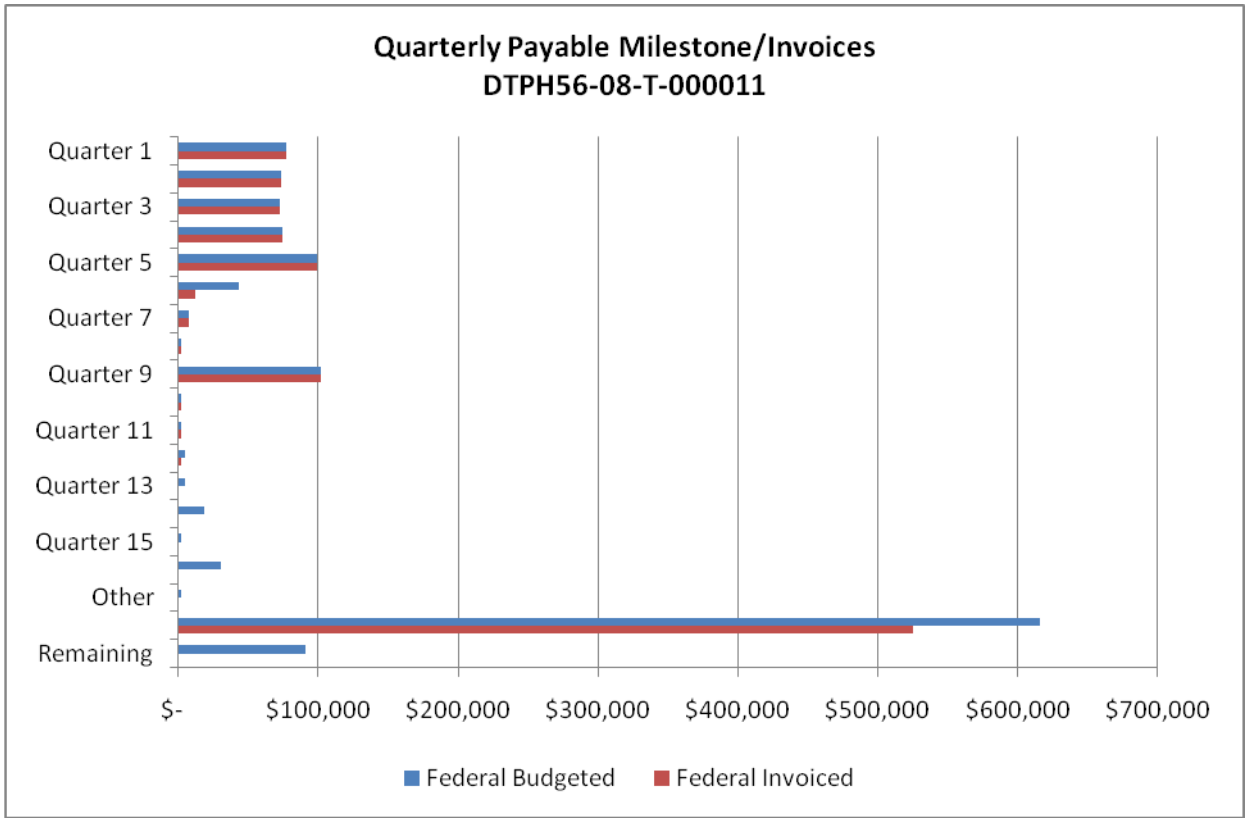
Funds and Work Completed During this Quarterly Period



Technical Status

Technical activities undertaken through the Twelfth 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.

The technical group for this program has maintained close communication with other related research projects being conducted by PRCI and DOT to ensure coordination across all projects that address mechanical damage inspection and assessment and maximize resources to deliver a comprehensive solution for the pipeline industry to manage mechanical damage. The team has forwarded any issues of concern to PRCI and DOT for their consideration.

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

- Pipe 3 is 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: 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).

BMT Fleet Technology (BMT) performed preliminary characterization on vintage Pipe 4a (24 in. diameter and 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. Charpy values are not yet available, but underway. Once all characterization results are available for all three pipes, the project team will decide on the pipe they will use to represent vintage pipe materials in the dent+gouge tests. Results are given in Table 1 below.

Table 1: Characteristics of Vintage Pipes 4a, 4b, and 4c - basic 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

A decision will be made soon by the Project Team, in consultation with the project AOTR from DOT PHMSA and Technical Leader from PRCI, on selecting one pipe among these three options for the experimental study of dent+gouge defects in 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
BMT has developed the next matrix of plain dent testing and submitted itto the project team for comment and approval. Testing will commence once the team approves the final test matrix.

The team presented the results of the full scale tests including the recently completed full-scale tests for eight plain dent test samples on vintage Pipe 3 at the Joint Technical Meeting (Australian Pipline Industry Association (APIA), European Pipeline Research Group (EPRG), and PRCI) held in San Francisco, California, May 16-19.

BMT has received the first eight Pipe 3 plain dent specimens following the completion of the full-scale tests. All of the specimens have been inspected using MPI (Magnetic Particle Inspection). The initial inspection results revealed the presence of cracks in locations around the dents, see **Error! Reference source not found.**. These crack indications will be inspected further using destrutive testing methods to better understand the factors that influence and control their formation and occurrence in the pipe steel, and other inspection methods may be applied to the test samples. The results of the complete testing results will be included in the next quarertly report, after all inspection and destructive testing are completed. BMT has also prepared a recommended test matrix for the next set of full-scale tests using the vintage pipe (Pipe 3) and will provide additonal inspection for indications of cracks during these tests.

In order to accurately characterize the indenters used to create the dents in the test specimens, BMT has created molds and casts of the indenters which were then digitized, as shown in 1 and **Error! Reference source not found.**2below. The results will be provided digitally along with all of the experimental results at the end of the project.

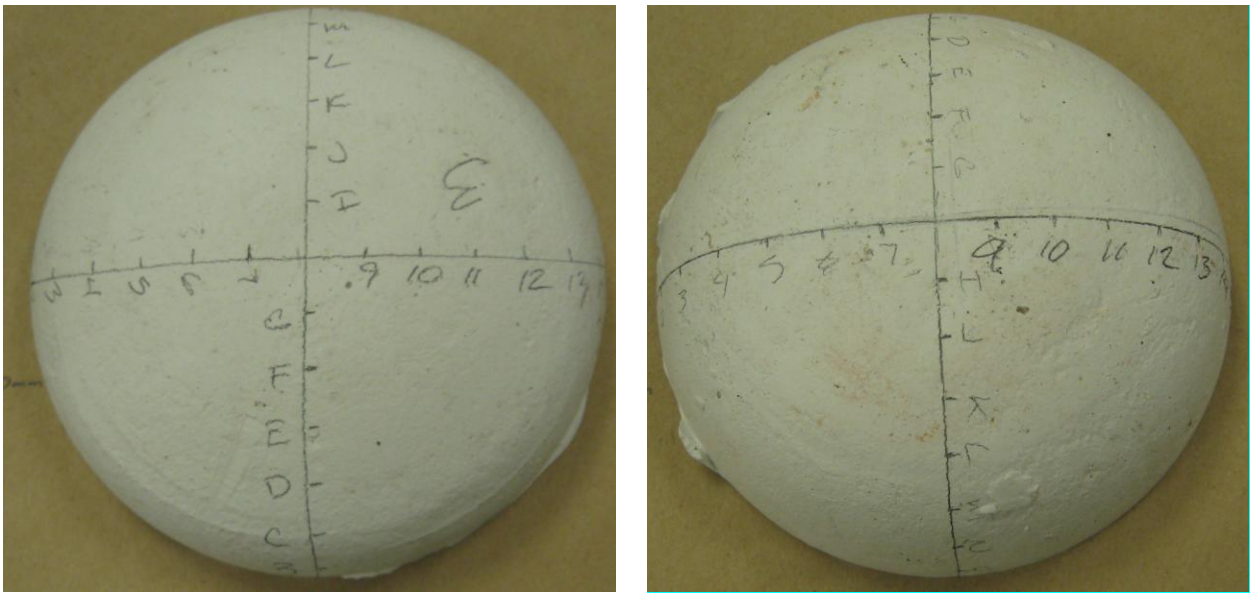


Figure 1: Photos of Indenter Casts (4 in. Nominal Indenters)

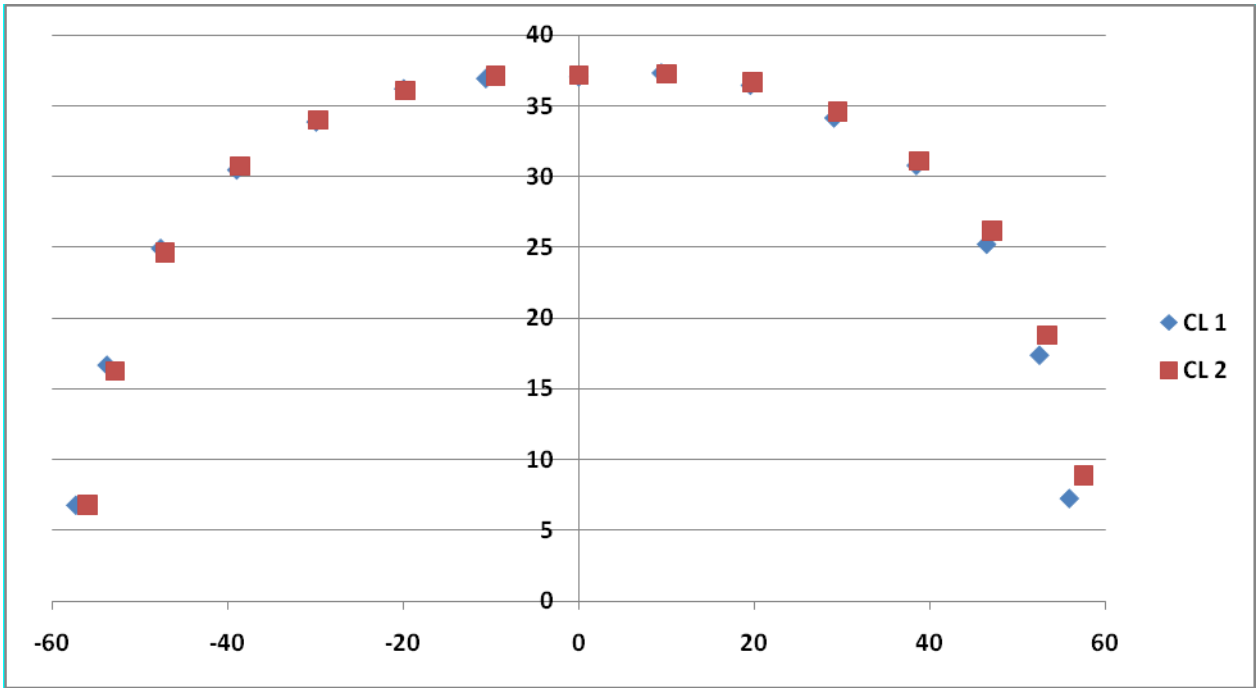


Figure 2: Digitized Centerline Contours of 4 in. Nominal Indenter (Indenter 4)

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:

- <u>**X.**Y.Z.</u>—**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.

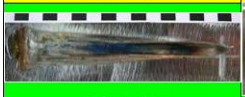
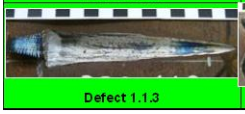
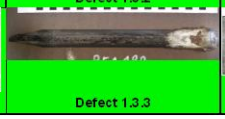
- X.Y.**Z.**—**Z** is the **number of defect in the defined type of defect**. There are three similar defects per type of defect. The number 1 is for a detailed geometrical, mechanical and metallurgical in-depth defect characterization after its creation. Number 2 is a similar defect for the burst test 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.

This report presents the metallurgical investigation of defect 1.1.1.b;

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

- White: Defects not yet created (vintage pipe)
- Yellow: Defects already created but not yet characterized/investigated or submitted to either burst or fatigue tests
- Green: Defects created and all tests completed

Table 2: Status of Dent+Gouge defects

MD 4-1					DOT	
Pipe 1 (current steel X52)			**Pipe 2** (current steel X70)		**Pipe 4** (older	
Type 1	Type 2	Type 3	Type 1 or 2	Type 2 or 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 4.1.1*	*Defect 4.2.1*
 Defect 1.1.2	Defect 1.2.2	Defect 1.3.2	Defect 2.1.2.	Defect 2.2.2	*Defect 4.1.2*	*Defect 4.2.2*
 Defect 1.1.3	Defect 1.2.3	 Defect 1.3.3	Defect 2.1.3	Defect 2.2.3	*Defect 4.1.3*	*Defect 4.2.3*

Task 5: Metallurgical investigation of defect 1.1.1.b

GDF SUEZ cut this defect (created by dynamic aggression) into twelve samples in order to investigate the microstructure, presence of cracks, and to estimate local strains (Figure 3 and Figure 4).

Figure 3: Defect 1.1.1.b before cutting, with samples reference # and observation direction

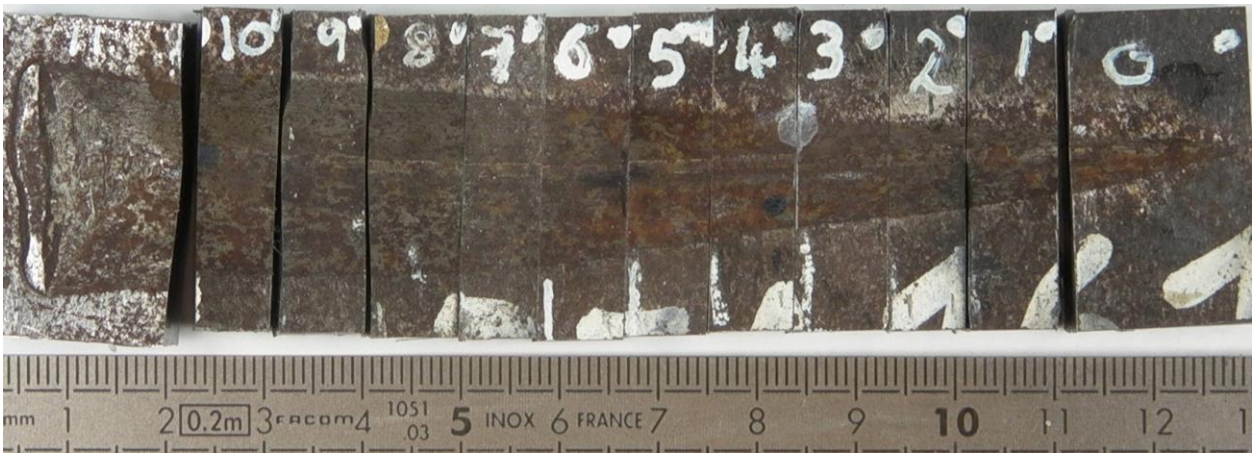


Figure 4: Defect 1.1.1.b after cutting into 12 samples.

Microstructure:

As mentioned in prior progress reports on other defects created by dynamic aggression, a hard layer of about 50–100µm depth is observed at the gouge surface (Figure 5). This layer is composed of tooth material which has been transferred to the pipe surface during the impact. Below this layer, a second layer corresponds to pipe steel which has been heated and transformed.

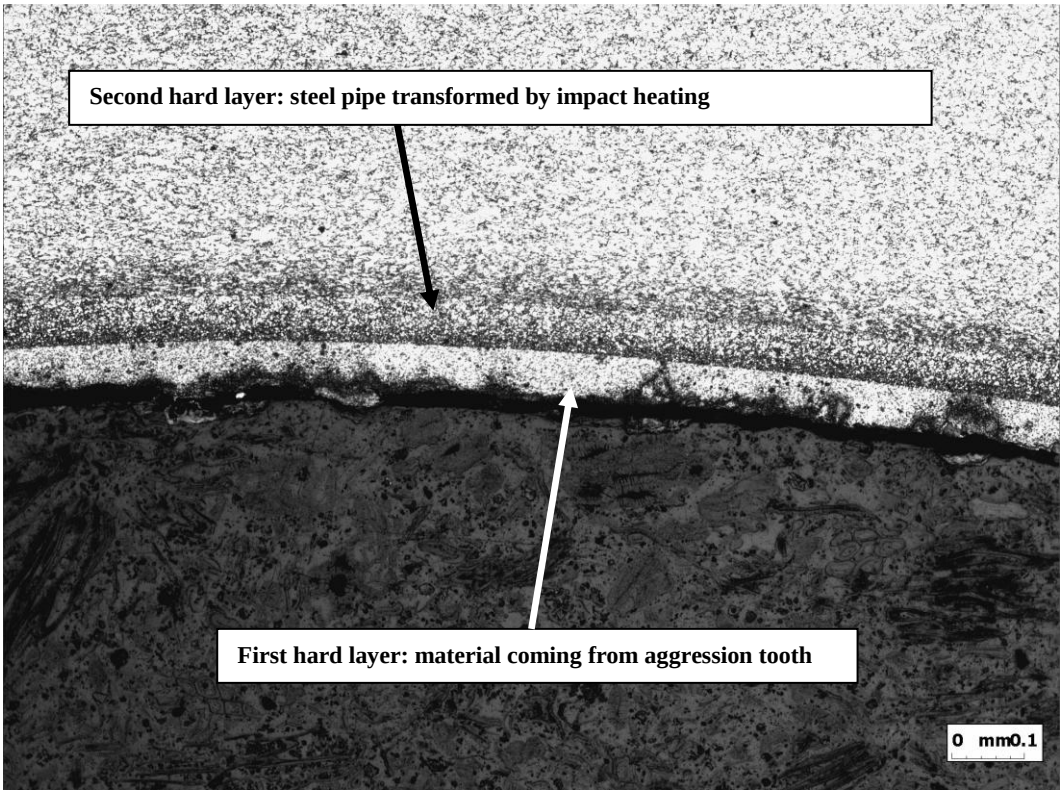


Figure 5: Defect 1.1.1.b - sample 10: presence of hard layers at the gouge surface.

Crack Analysis:

The researchers observed eleven of the twelve cut samples by optical microscope to identify cracks just after the aggression test with the following load history:

- Impact aggression on the pressurized pipe,
- Re-rounding after tooth removal, and
- Pressure decrease to atmosphere pressure before destructive defect examination.

The team counted 109 anomalies or micro-cracks at the gouge surface. They did not observe any macro-cracks or larger cracks outside of the gouge surface. Among the micro-cracks identified at the gouge surface, the deepest was less than 200 µm as shown in Figure 6.

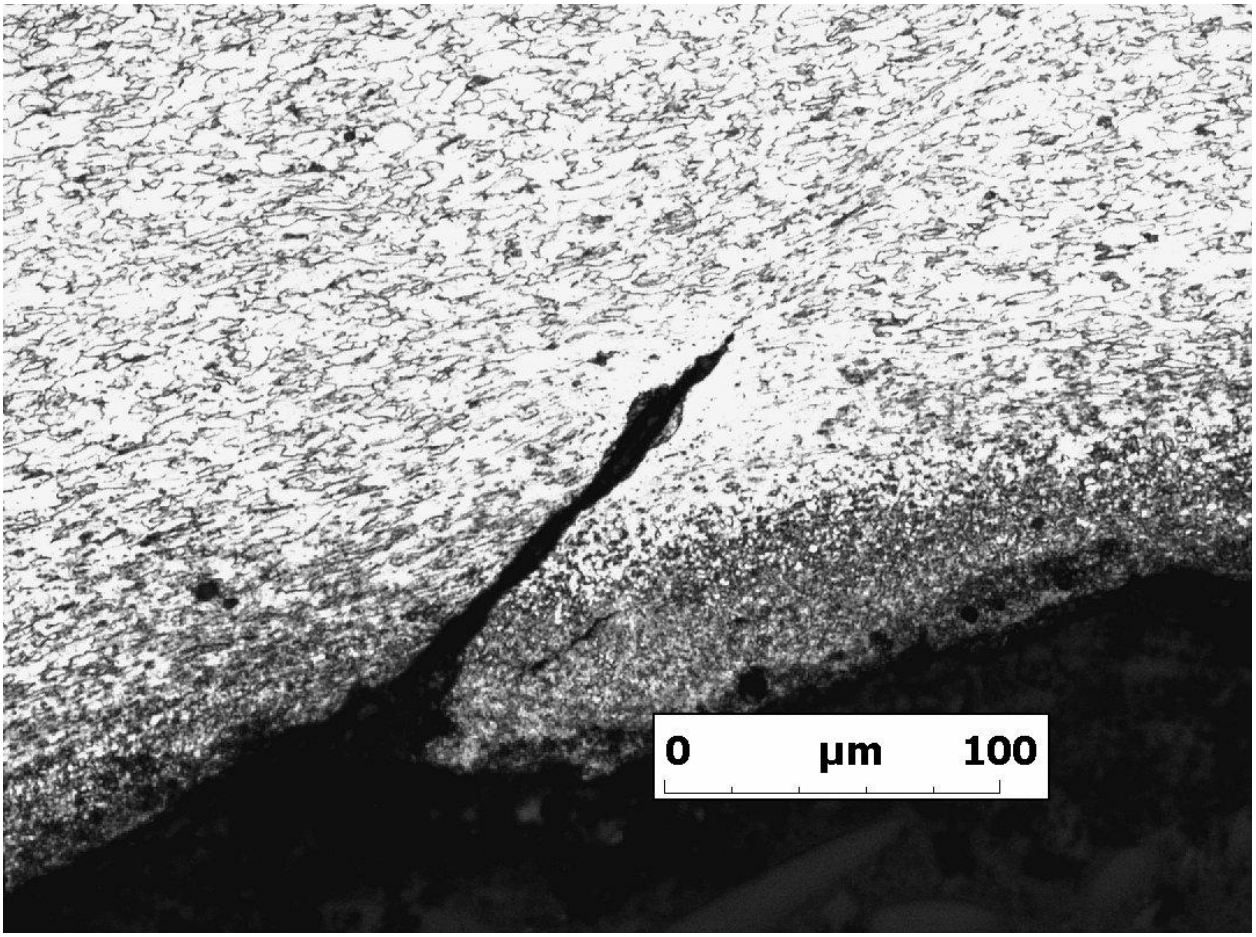


Figure 6: Defect 1.1.1.b – Micro-crack from gouge surface – sample 2.

On a population of 109 anomalies, only a minority (< 5%) have a crack depth exceeding 50 µm and none exceeds 200 µm as shown in Figure 7.

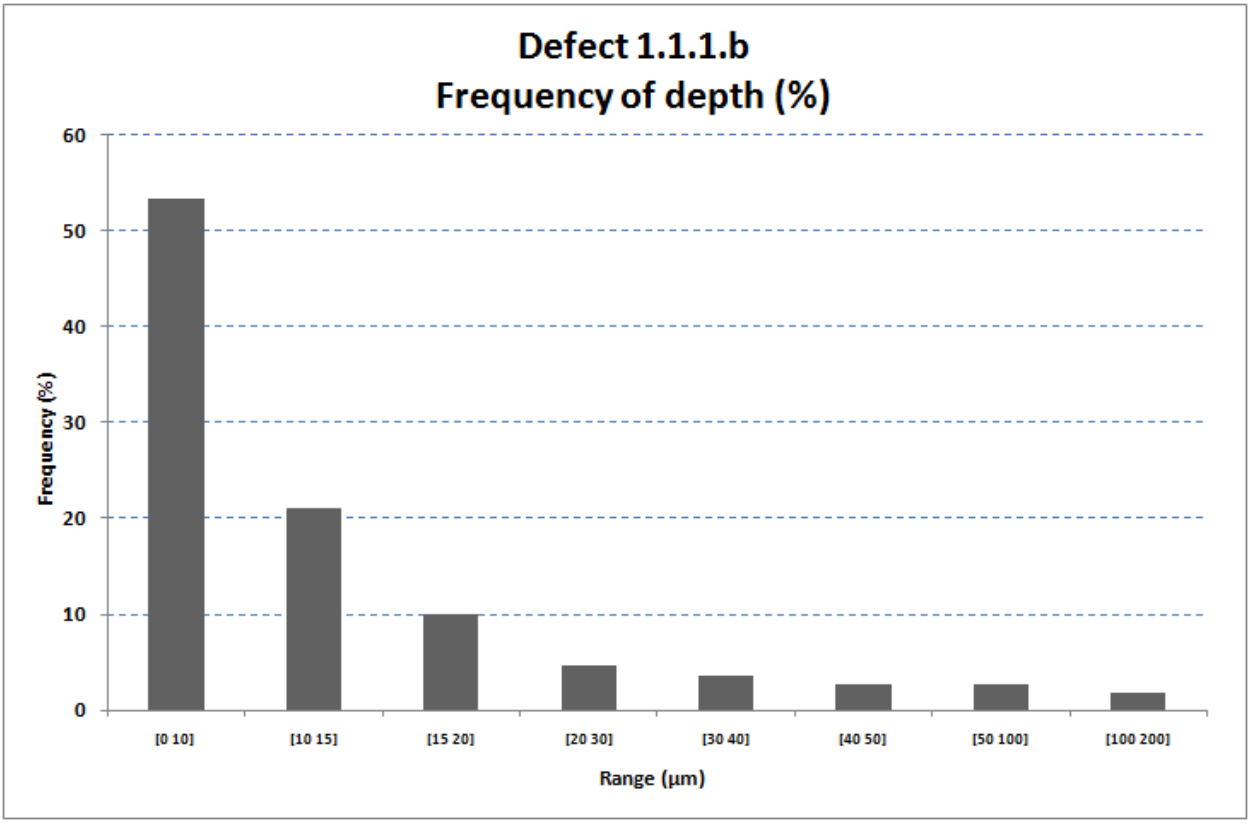


Figure 7: Distribution of crack depths or anomaly depths measured on a population of 109 anomalies

This analysis shows that the creation by dynamic aggression of type 1 defects in Pipe 1, which are classified as moderate gouges in shallow dents, leads **to initial micro-cracks at the gouge surface with a depth of less than 200 µm.**

Estimation of strain:

GDF SUEZ performed several micro-hardness progressions through the thickness from the dent surface to the internal wall surface on several cuts at five positions represented by the following color code in Figure 8 (in progressive order, from the top of the picture in Figure 8:

- Black line: Micro-hardness Progression 1;
- Green line: Micro-hardness Progression 2;
- Red line: Micro-hardness Progression 3;
- Blue line: Micro-hardness Progression 4;
- White line: Micro-hardness Progression 5.

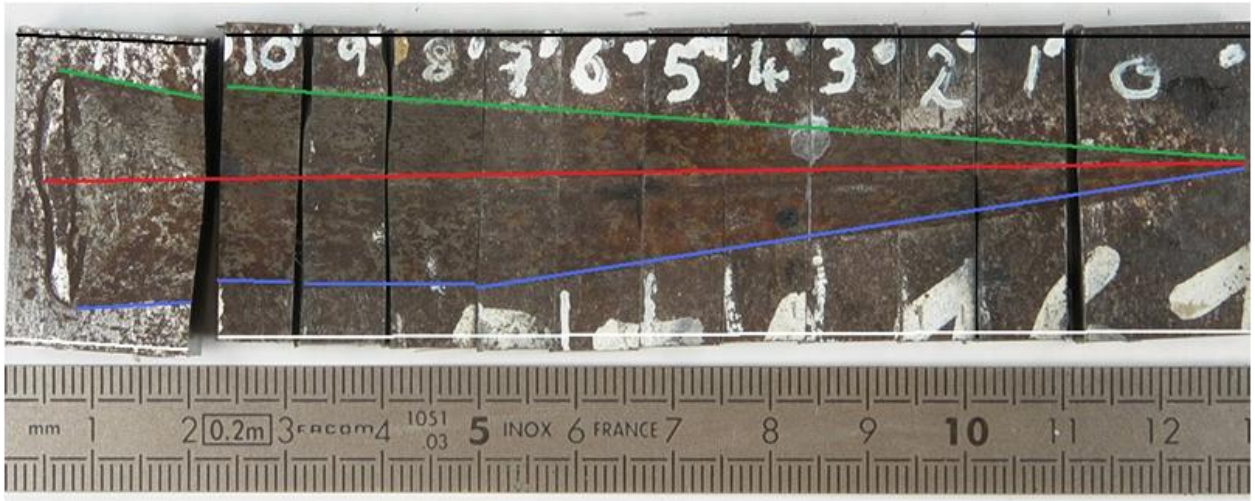


Figure 8: Defect 1.1.1.b – Micro-hardness progression position.

Micro-hardness values were converted to strains by the empirical formulation:

$$\boxed{\varepsilon_{\%} = 0.3377 \times HV_{0.5} - 56.786}$$

As an example, Figure 9 shows the local strains deduced from the micro-hardness profiles for the five micro-hardness progressions on Sample 5 (Figure 8). The researchers estimate local strains of up to 30% under the dent, in the pipe steel, below the first hard layer at the gouge surface.

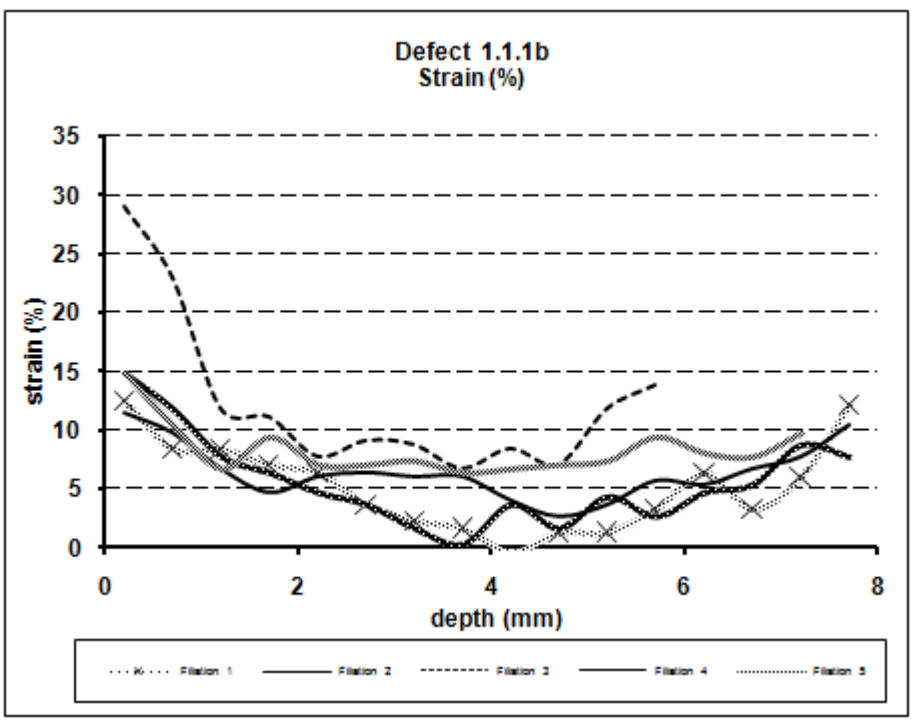


Figure 9: Defect 1.1.1.b - Local estimated strain profiles along the thickness under the dent – sample 5.

Technical Results and Conclusions

A summary of the results are:

- Task 2—Material characterization are complete for Pipe 1 and Pipe 2;
- Task 3—The literature review of cyclic fatigue dent assessment techniques is complete;
- Task 4—Full-scale testing of the first set of dent samples (eight samples total) in the vintage pipe material (Pipe 3) was completed and initial inspection of the samples was conducted. In addition, molds and casts of the indenters were made to measure differences bewteen the indenter shapes and evaluate their impact on full-scale testing
- Task 5—Metallurgical investigation of defect 1.1.1.b shows the presence of micro-cracks at the gouge surface with depths less than 200 µm.

Technical Issues, Problems or Challenges
As discussed above, the team began preliminary material characterization of the vintage pipe for Pipe 3 in September 2010 and went on with other vintage pipes (i.e., Pipe 4a, 4b, and 4c to be used for dent+gouge test samples). The basic characterization of three options of Pipe 4 is done and a choice has to be made to launch the dent+gouge test in vintage pipe.

Plans for Future Activity

Task 2: Purchase & Characterize Pipe Material

BMT Fleet completed preliminary characterization for the three vintage pipes (Pipe 4a, 4b, 4c) which are potential candidates for the DOT program. The project team will review the results and select one of the three vintage pipes to be used for the full material characterization and the dent + gouge tests.

Task 4: Testing of Dents on Welds and Corrosion Features

The next batch of Pipe 3 plain dent testing will commence in the next quarterly period following approval of the test sample matrix recommended by BMT. It is anticipated that the testing will be completed in the coming quarter.

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 at NRC Canadian Neutron Beam Centre (CNBC), and will launch full material characterization and dent+gouge tests of vintage pipe, once the vintage pipe option is decided by the Project Team.

Business Status

The project team has prepared a proposal for increasing the test variables for full scale dent tests and will submit it to DOT and PRCI.

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	$15,107	$134,674	$146,108	$0	$146,108	75%
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	$25,934	$691,028	75%
5	Testing of Dents with Gouges	$150,020	$0	$150,020	$254,404	$15,619	$206,474	65%
6	Demonstration of Mechanical Damage Model Performance	$22,008	$0	$0	$10,930	$0	$0	40%
7	Industry Workshop	$12,030	$0	$0	$4,325	$0	$0	0%
8	Project Management and Reporting	$88,366	$1,834	$62,578	$43,959	$0	$21,692	On-going
	GRAND TOTAL	**$616,490**	**$16,941**	**$525,519**	**$1,068,858**	**$41,553**	**$1,074,802**	

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 team has completed the neutron diffraction testing on two defect samples, 1.1.1b and 1.3.1, and have been returned to GDF SUEZ, which has begun the destructive metallurgical investigation of defect 1.1.1b. They will send three other defects, 1.2.1b, 2.1.1 and 2.2.1 to CNBC next month for neutron diffraction to determine residual stresses in the region of the dent+gouge damage. The researchers expect that these defect samples will return to GDF Suez in the Fall of 2011 for destructive analysis, which will be completed by the end of the year (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. The team is currently considering three options, and will select one of the pipe materials to initiate the dent+gouge vintage pipe testing program. PRCI will continue to work with member companies to identify additional vintage pipe materials that represent the range of pipe grades and quality

for in-service vintage pipelines and may propose additional testing with these materials. Any additonal materials proposed to be included in the full-scale matrix will be reviewed with the DOT AOTR.

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%	Completed
2	Purchase & Characterize Pipe Material	8/31/2010	02/01/2011 for Pipes, 1, 2 and 3	75%	Pipe 1 and 2 complete, work on Vintage Pipe 3 is on-going. Pipe 4 has to be done
3	Literature Review	11/30/2009	11/30/2009	100%	
4	Testing of Dents on Welds and Corrosion Features	2/28/2012	Ongoing	75%	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 aterial characterization for modern steel defect samples
6	Demonstration of Mechanical Damage Model Performance	11/30/2011	Ongoing	40%	
7	Industry Workshop	5/31/2012	Not Yet Started	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	$15,107	$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	$0	$157,363	$599,632	$25,934	$691,028	35
5	Testing of Dents with Gouges	$150,020	$0	$150,020	$254,404	$15,619	$206,474	42
6	Demonstration of Mechanical Damage Model Performance	$22,008	$0	$0	$10,930	$0	$0	

7	Industry Workshop	$12,030	$0	$0	$4,325	$0	$0	
8	Project Management and Reporting	$88,366	$1,834	$62,578	$43,959	$0	$21,692	44
	GRAND TOTAL	**$616,490**	**$16,941**	**$525,519**	**$1,068,858**	**$41,553**	**$1,074,802**	

PUBLIC PAGE

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Public Page for Quarter Ending November 30, 2010

Project WP#339: Structural Significance of Mechanical Damage

Background

The primary objective of the project is to establish a detailed experimental database to support the development and validation of improved burst and fatigue strength models for assessing the interaction of mechanical damage with secondary features (gouges, corrosion, and welds). The data will be used to develop and validate mechanistic models which will produce reliable tools to assess a wide range of mechanical damage forms. This will improve safety, reduce unnecessary maintenance, and support the improvement of pipeline standards and codes of practice.

Progress in the Quarter

A summary of the results are:

- Task 2—Material characterization are complete for Pipe 1 and Pipe 2;
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