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QUARTERLY REPORT – PUBLIC PAGE

Validation and Documentation of Tensile Strain Limit Design Models for Pipelines

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

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Technical Status

Eight full-scale small diameter pipe tension tests were completed in the last quarter and four medium-scale curved wide plate tension tests on material from similar pipes were carried out during this quarter. The primary purpose of the pipe tests was to explore the effects of internal pressure on the tensile strain capacity of pipe with circumferential flaws in the pipe body and weld region. The curved wide plate tests are intended to show the degree to which specimen configuration and constraint conditions (i.e. differences between tension loaded pipes and plates) affect strain capacity.

The project status was presented to the PRCI members at the February 2008 PRCI Pipeline Technology Exchange Meeting held in Atlanta. A follow-on more in-depth project review was held on February 20, 2008 in Houston, TX.

Results and Conclusions

The pipe tests performed to date clearly demonstrated the detrimental effect of internal pressure on the tensile strain capacity. The curved wide plate tests performed this quarter show that the strain capacity obtained from this test configuration is similar to that obtained for unpressurized pipes.

As discussed in the previous quarterly report, the results of small-scale material tests have led to a change in the expected test matrix.

Task 1 – Initial Analyses

There was no activity in this quarter.

Task 2 – Pipe Acquisition

Task No. 2.1 – Acquire Materials
Task 2.1 is complete.

Task No. 2.2 – Fabricate Test Specimens
The re-fabrication of 12¾ diameter high Y/T pipe specimens and curved wide plate weld cans is on going to address the weld under strength issue identified during the previous quarter. It is expected that re-fabrication will be complete by the end of this quarter.

Additional 12¾-inch diameter Nippon girth weld samples were fabricated in late December and early January to provide further data on the effect of welding parameters on all weld metal tensile properties. The results of the girth weld trials were compiled and shared with the Project Team together with recommendations on production fabrication of new girth weld samples. The Project Team agreed that the normal overmatch (10%) production girth welds should be re-fabricated using the welding procedure originally developed to produce the high overmatch condition. This welding procedure results in yield strength overmatch of approximately 12% and tensile strength overmatch > 20%. It was also agreed to drop the original high overmatch (20%)

tests. A revised welding specification was developed for production fabrication highlighting the priority girth welds for the full scale testing.

A set of three priority girth welds were fabricated and shipped for full scale testing.

Task 3 – Material Tests

Task 3.1 – Materials Characterization

In December, the weld procedures and test sample locations were summarized as input in identifying the source of less than expected weld strengths on some of the samples. It was reported that the fusion line test results differed notably from the weld centerline results, and two types of weld behavior were observed for the low overmatch type welds made on the Nippon (high Y/T) pipe. Type One has YS~77 ksi and UTS~89 ksi with ~200HV at midwall. Type Two has YS~86 ksi and UTS~96 ksi with ~220HV at midwall.

The Type One and Two weld geometries were different as well. The hot, fill, and cap passes were wider on the Type One welds by about 2 mm. Interestingly, the recent tests of “no cooling” and “interpass cooling” cases had weld widths that fit Type Two results.

In January, it was noted that there were validity issues regarding the tests because the specimens were designed not to be in the normal range of a/W. In addition, it was reported that only a couple of specimens pass the ASTM E1290 validity test for crack-front straightness. It was noted that if the British Standard validity tests are used, more of the specimens would pass this test.

The testing performed to the end of Quarter 6 had indicated that the desired overmatch had not been obtained on the 10% overmatch welds for the high Y/T pipe. At the stage of the last quarterly report, it appeared that modifications of welding practice that did not change the electrode or the shielding gas would be sufficient to achieve the desired overmatch. It was decided to go forward with the full-pipe testing of 4 welds of the insufficiently overmatched welds. Authorization was given to continue to do some small-scale testing of the insufficiently overmatched weld metal to match with these full pipe tests.

A spreadsheet of the weld procedures used and the testing results and procedures for weld metal testing was provided to the team. This spreadsheet was used to develop the weld testing program to see whether minor procedure modifications would have the desired results.

By January 2008, it had become apparent that the limited modifications to the welding procedure designed for 10% overmatch were not providing welds that could achieve that level of overmatch reliably between 0.5% and 2% strain. It was decided to discontinue welding efforts on that weld procedure category and use the welding procedure that was designed for 25% overmatch for most of the remaining large scale test matrix. Expected overmatch levels for this procedure were between 10% and 25%.

Testing on the weld materials available continued; the two welds in the low Y/T pipe, and four welds in the high Y/T pipe with the overmatch below 10%. Testing included toughness testing.

Only room temperature tests were done, since the shifting of large-scale testing meant that none of the welds would match those to be tested at lower temperature. All of the welds heat-affected zone (HAZ) and base metal tests exhibited maximum load behavior during the toughness test. This indication of good toughness performance had been expected.

Microtensile testing that confirmed the relative overmatch expected when comparing the all-weld metal and the base metal tests with larger cross-sections was also performed.

Task 3.2 – Prepare Report

It was stated in the previous quarterly report that work in Quarter 7 would complete the characterization activities and continue the development of a report documenting the results of material characterization activities in Task 3.1. Progress on this documentation ceased on January 24, 2008.

Task 4 – Small Diameter Pipe Tests

Task 4.1 – Design Tests

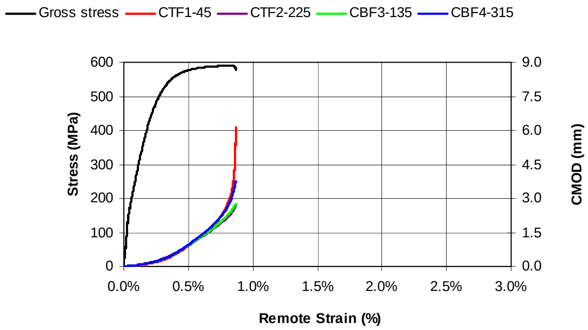
The test design was completed and the specimen geometry and instrumentation layout for both plain-pipe and welded-pipe tests was finalized in Quarter 6.

Task 4.2 – Conduct Tests

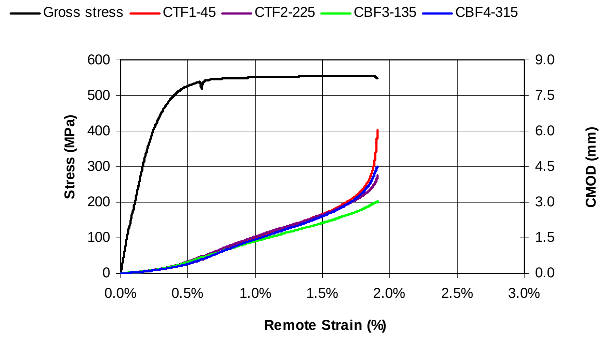
Eight pipe tests were performed in Quarter 6. These tests explored the strain capacity of pressurized and un-pressurized pipes with flaws in the pipe body, the weld metal and the HAZ. Additional tests will be performed starting in Quarter 8 once specimen re-fabrication, required to address weld strength issues has been completed. A summary of test results to date are provided in Table 1 and Figure 1.

Table 1. Results Summary for Small Diameter Pipe Tests Performed to End of Q7

Test No.	Effective Grade	Y/T Ratio	Flaw Size (mm) and Location	Internal Pressure	Strain Limit (%)
1.1	X70	High	3 x 50 - body	High (80% SMYS)	0.90
1.2	X70	High	3 x 50 - body	Low (1% SMYS)	2.02
1.3	X56	Low	3 x 50 - body	High (80% SMYS)	1.56
1.4	X56	Low	3 x 50 - body	Low (1% SMYS)	2.84
1.5	X70	High	3 x 35 - weld	High (80% SMYS)	1.66
1.6	X70	High	3 x 35 - weld	Low (1% SMYS)	4.78
1.7	X70	High	3 x 35 - HAZ	High (80% SMYS)	4.94
1.8	X70	High	3 x 35 - HAZ	Low (1% SMYS)	8.64



Test 1.1 – High Internal Pressure



Test 1.2 – Low Internal Pressure

Figure 1. Axial Stress-Strain Response and Crack Mouth Opening Displacement for Representative Small Diameter Pipe Specimens Tested to Date

Task 4.3 – Prepare Report

No activity this quarter.

Task 5 – Analysis of Small Diameter Pipe Tests

The objectives of this task were to (1) understand the test results, (2) provide recommendations on any needed changes for the future tests, and (3) provide insight into the revisions of the tensile strain design procedures. In this quarter, the full-scale pipe data from the first 4 plain pipes and 4 high Y/T pipes welded pipes were analyzed. The analysis used the measured material properties of the actual tested welds. The magnitude of the internal pressures was adjusted to have the same values as the internal pressure applied during the full scale tests.

Figure 2 and Figure 3 show the nominal longitudinal stress versus remote strain relations of low *Y*/*T* plain pipes and high *Y*/*T* welded pipes. The agreement between the experimental test data and the numerical simulation results is very good. Figure 4 and Figure 5 show the CMOD versus remote strain relations of low *Y*/*T* plain pipes and high *Y*/*T* welded pipes. The CMOD measured from the experimental tests tend to be higher. At high values of CMOD, the experimentally measured CMOD would increase at a faster rate than the CMOD of the finite element models. This is expected as the current finite element models have no built-in flaw growth mechanisms.

The analysis of the full-scale test data identified possible directions for further model development. Further model development will proceed to add additional features, including material anisotropy, variation of material properties, and flaw growth mechanisms. The effectiveness of these new features will be examined in the next quarters.

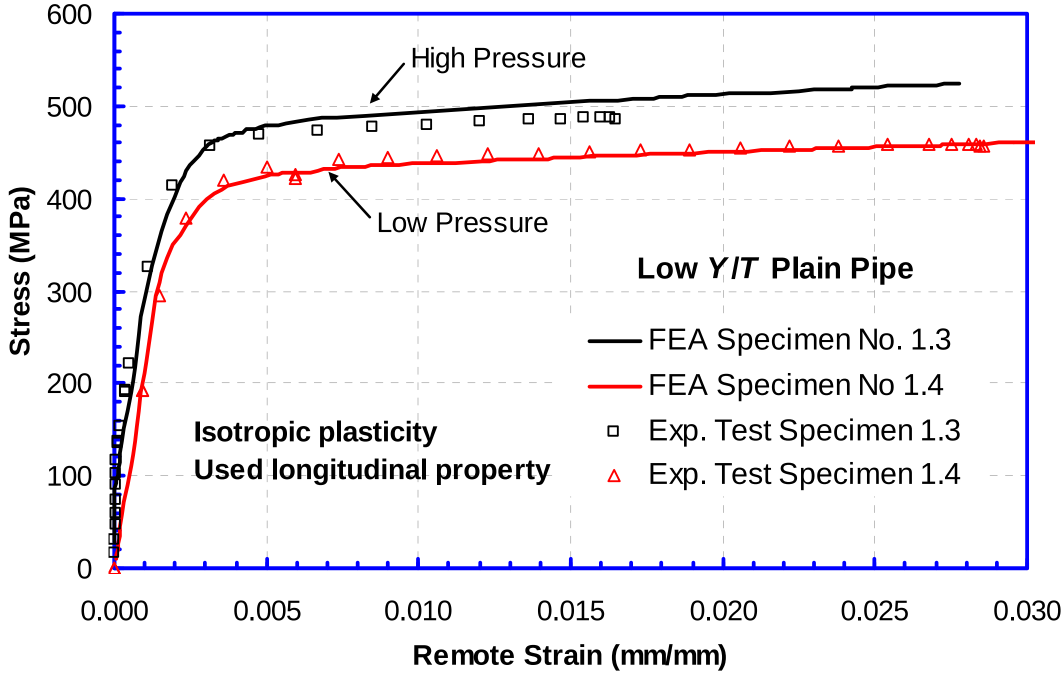


Figure 2. **Nominal longitudinal stress vs. remote strain relations of low *Y*/*T* plain pipes. Comparison between the experimental tests and numerical simulation.**

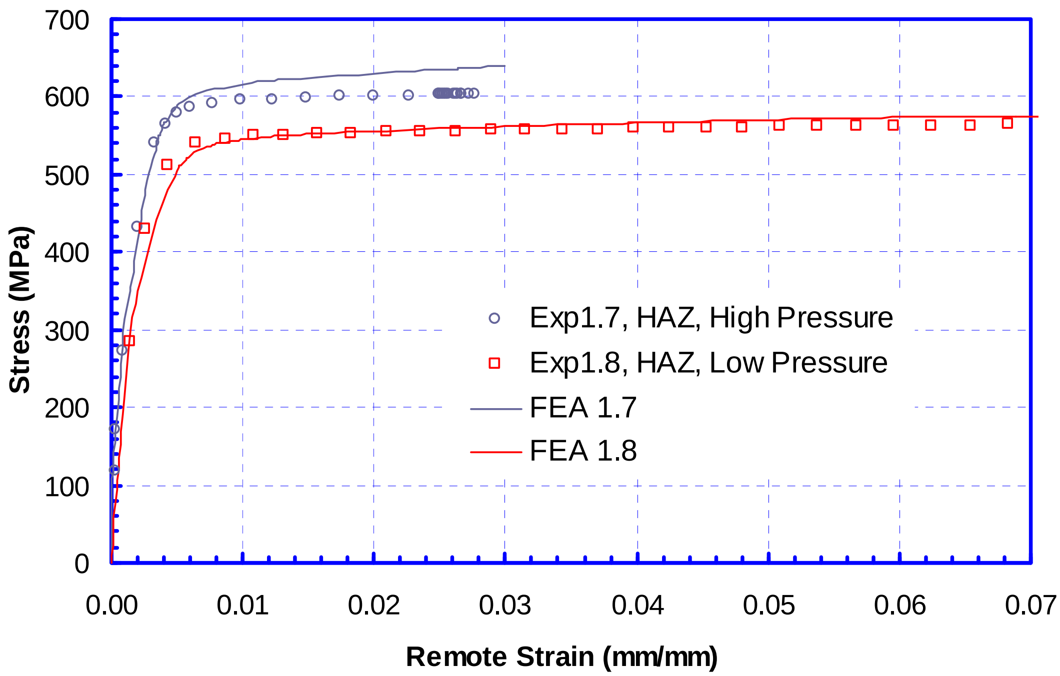


Figure 3. **Nominal longitudinal stress vs. remote strain relations of high *Y*/*T* welded pipes. Comparison between the experimental tests and numerical simulation.**

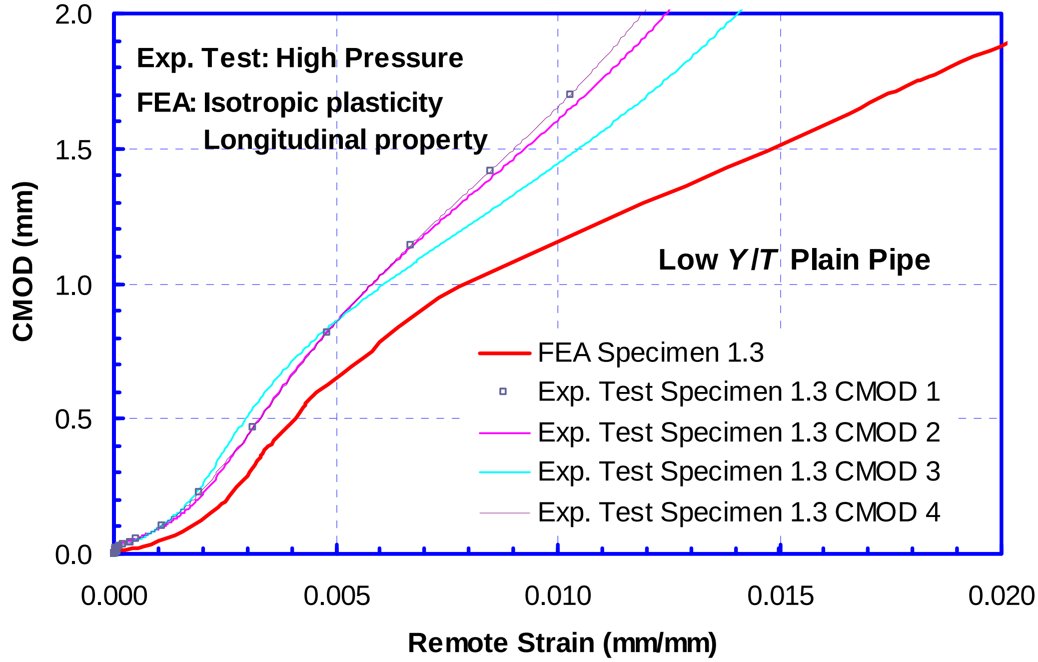


Figure 4. Crack mouth opening displacement (CMOD) vs. remote strain relations of low *Y/T* plain pipes. Comparison between the experimental tests and numerical simulation

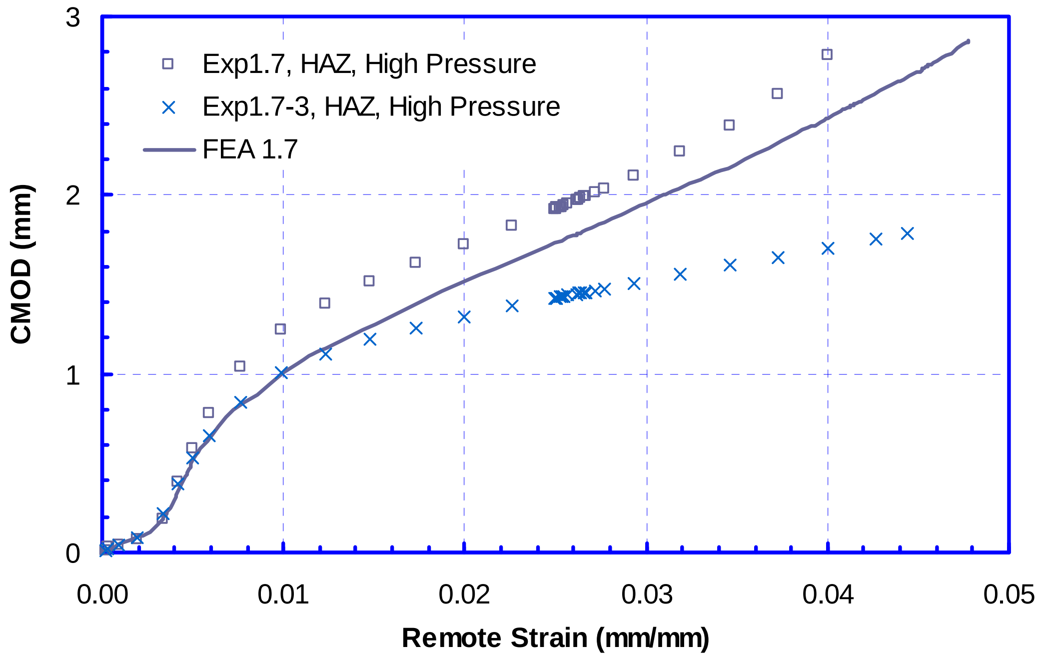


Figure 5. Crack mouth opening displacement (CMOD) vs. remote strain relations of high *Y/T* welded pipes. Comparison between the experimental tests and numerical simulation

The work in this task is ongoing. The results will be reported later.

Task 6- Large Diameter Pipe Tests

Task 6.1 – Design Tests

The test design has been completed and the specimen geometry has been finalized.

Task 6.2 – Conduct Tests

No activity this quarter. Testing is currently scheduled to commence in Quarter 10.

Task 6.3 – Prepare Report

No activity this quarter.

Task 7 – Curved Wide Plate Tests

Task 7.1 – Design Tests

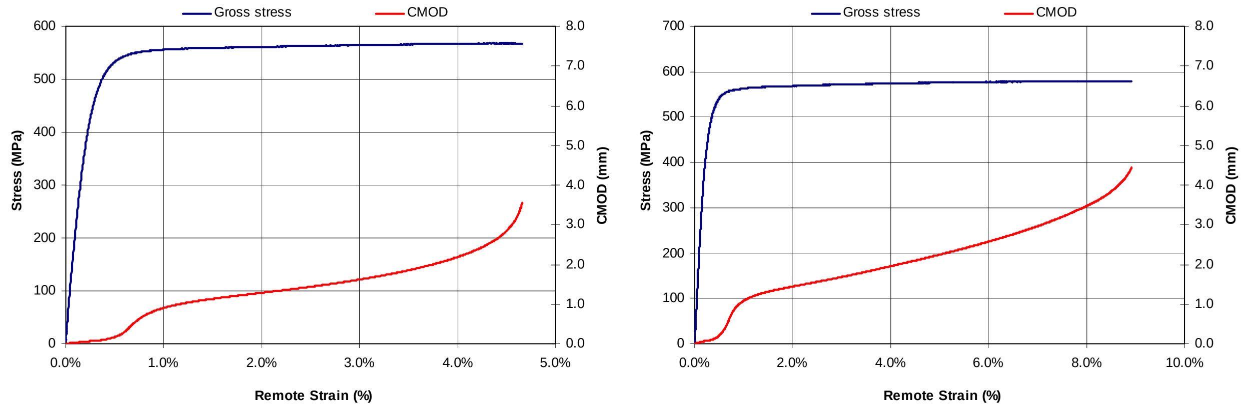
The test design was completed and the specimen geometry and instrumentation layout for the small diameter curved wide plate tests was finalized in Quarter 6.

Task 7.2 – Conduct Tests

Four tests were performed in Quarter 7 on small diameter curved wide plate panel specimens with circumferential flaws located in the weld metal and HAZ. Additional tests on panels cut from small diameter pipe will be performed starting in Quarter 8 once specimen re-fabrication, required to address weld strength issues, has been completed. Curved wide plate tests on panels cut from the large diameter pipe material are scheduled for Quarter 9. A summary of curved wide plate (CWP) test results to date are provided in Table 2 and Figure 6.

Table 2. Results Summary for Small Diameter CWP Tests Performed to End of Q7

Test No.	Effective Grade	Y/T Ratio	Flaw Size (mm) and Location	Internal Pressure	Strain Limit (%)
3.1a	X70	High	3 x 35 - weld	N/A	7.08
3.1b	X70	High	3 x 35 - weld	N/A	4.66
3.2a	X70	High	3 x 35 - HAZ	N/A	12.6
3.2b	X70	High	3 x 35 - HAZ	N/A	8.93



Test 3.1b – Weld Metal Flaw **Test 3.2b – Heat Affected Zone Flaw**

Figure 6. Axial Stress-Strain Response and Crack Mouth Opening Displacement for Representative Small Diameter CWP Specimens Tested to Date

Task 7.3 – Prepare Report
No activity this quarter.

Task 8 – Model Modification

No activity this quarter; scheduled for Quarter 8 initiation.

Task 9 – Guidance Document

No activity this quarter; scheduled for Quarter 8 initiation.

Task 10 – Review Meetings

The third industry project team review meeting was held February 20, 2008 in Houston.

Task 11 – Reporting

Task No. 11.1
The quarterly progress report for PHMSA was developed and submitted and will be distributed to the Project Team.

A quarterly progress report will be prepared for the Project Team in Quarter 8.

Plans for Future Activity

Plans to continue the post analysis of the full-scale small-diameter pipe test data are in place. The analysis will incorporate additional features identified from the analysis conducted to date.