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Review and Analysis of the Metal Loss, Deformation, and Ultrasonic Crack In-Line Inspection Result from Hattiesburg to Demopolis

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Review and Analysis of the Metal Loss, Deformation, and Ultrasonic Crack In-Line Inspection Results from Hattiesburg to Demopolis

Dennis C. Johnston and John F. Kiefner, PE

INTRODUCTION

On November 1, 2007 the 12-inch OD Dixie propane pipeline experienced a rupture approximately 2,900 feet downstream of the Carmichael Pump Station in Clark County, Mississippi. The root cause of the pipeline failure is currently under investigation. As a result of this incident, the Pipeline and Hazardous Materials Safety Administration (PHMSA) issued a Corrective Action Order (CAO), directing the operator to take various specific measures to establish the safety of the pipeline.

Item 4 of the CAO under the heading Required Corrective Action states: "Commission a third party consultant to examine the Tuboscope Linalog Plus Survey Report, the GE PII Ultra Scan (CD Crack Pig) results and the Magpie MFL and EGP results and tabulate the results. The consultant(s) should provide a copy of any draft or final analysis to the Director, Southern Region at the same time or before it provides this information to the Respondents. Provide an analysis of the results reported by the vendor."

Kiefner and Associates, Inc. was selected to provide this analysis. This report presents the results of the evaluation of the 1998 Tuboscope standard resolution magnetic flux leakage (MFL) metal loss in-line inspection (ILI) results, the 2005 GE PII Ultra Scan Crack Detection (USCD) ILI results, the 2006 Magpie deformation ILI results, and the 2006 Magpie high resolution MFL metal loss ILI results. The results of these inspections were tabulated into a consolidated spreadsheet for the Hattiesburg to Demopolis segment. An analysis of the results reported by the vendors is provided.

Excavation and pipe evaluation reports from the metal loss, the deformation, and the crack detection tools were reviewed. The results of a cut-out program based on the crack detection tool results, the hydrostatic burst testing of the cut-out pipes, and the

metallurgical investigation report of the cut-out pipe hydrostatic burst test failures were reviewed.

SUMMARY AND CONCLUSIONS

The Tuboscope and Magpie MFL in-line inspections were performed to assess for the threat of corrosion-caused metal loss on the pipeline. The Magpie deformation tool inspection was performed to assess for the threat of mechanical damage and deformations. The GE PII USCD tool inspection was performed primarily to assess for the threat of longitudinally oriented low-frequency ERW seam defect issues and to verify that stress corrosion cracking (which had not historically been an integrity threat on the Dixie Pipeline system) was not present.

The Tuboscope metal loss tool predicted a total of 34 metal loss anomalies (20-percent or greater) on the 121-mile pipeline segment for a corrosion rate of 0.28 anomalies per mile after 37 years of service.

The GE PII USCD tool predicted the pipeline segment to contain 570 crack-like or notch-like features in the base metal, 13,274 crack-like or notch-like features adjoining the longitudinal seams, 494 crack-like or notch-like features in the longitudinal seams, and 19 crack-like or notch-like features in "not-decidable" locations due to the inability to determine the longitudinal seam location for some of the pipe joints. Engineering critical assessments were performed by GE PII based on the initial tool data. The operator's excavation and field evaluation program assessed 180 cracks, 168 lack-of-fusion anomalies, 3 linear laminations, and 140 volumetric laminations on 41 joints of pipe. A re-analysis of the crack detection tool data and additional engineering critical assessments were performed that took into account the results of the excavation and field evaluation program.

Twenty-one pipe joints were removed from the pipeline that contained USCD features. These 21 pipe joints were hydrostatically burst tested and a metallurgical evaluation of the fracture surfaces was performed. The pipes burst at pressures of 1.0 to 1.6 times the pipe specified minimum yield strength (SMYS). The burst test failures all occurred at hook cracks. Hook cracks are a form of manufacturing defect that is unique to

autogenous seams such as ERW seams. Hook cracks have served as origins for fatigue crack growth in service in some liquid product pipelines. No evidence of fatigue was found on any of the 21 burst test pipe fracture surfaces.

The Magpie MFL metal loss and deformation tools detected 10 deformations and 6 metal loss anomalies with calculated anomaly operating pressures less than the site specific maximum operating pressures. All of these anomalies predicted by Magpie were evaluated to determine their severity using standard corrosion defect assessment methods. One of the deformation anomalies was associated with a stopple fitting, and the remaining 15 anomalies were excavated and evaluated.

The ILI tool data were reviewed for the pipe joint that failed on November 1, 2007. The only indications were a 4.6-inch long, notch-like feature and a geometrical "not-decidable" feature adjacent to the downstream girth weld in the longitudinal seam detected by the GE PII USCD tool.

IN-LINE INSPECTION TOOL RESULTS

1998 Tuboscope MFL Metal Loss Tool

The Tuboscope standard resolution MFL metal loss tool was run on the Hattiesburg to Demopolis segment in May of 1998. The standard resolution tool reported the most significant metal loss anomaly per pipe joint. Five reporting categories were used by Tuboscope for this inspection:

• Grade 1	20 to 30-percent wall loss	20 pipes
• Grade 2	30 to 40-percent wall loss	6 pipes
• Grade 3	40 to 50-percent wall loss	1 pipe
• Grade 4	50 to 60-percent wall loss	1 pipe
• Grade 5	> 60-percent wall loss	0 pipe

A flawlist with predicted anomaly depth, predicted length, and orientation was provided by Tuboscope. The flawlist contained a total of 34 metal loss anomalies on the 28 joints of pipe with predicted metal loss. Nine of the 34 Tuboscope metal loss anomalies have been excavated and evaluated. Six of the anomalies were repaired with pressure

containing sleeves (Type B), 1 anomaly was cut-out, and 2 of the anomalies were recoated.

2005 GE PII Ultra Scan Crack Detection Tool

The GE PII USCD tool was run in June of 2005 for the first 45.6 miles and in August of 2005 for the remaining 75.3 miles of the Hattiesburg to Demopolis segment. The crack detection tool detected anomalies in the longitudinal pipe seam as well as in the body of the pipe.

In order to determine the nature of the indications, an engineering critical assessment of the anomalies detected by the crack tool was performed by GE PII. API 579-2000 was the basis for the engineering critical assessment using a fracture mechanics based failure assessment diagram (FAD). The API 579 approach is a two-parameter failure assessment process that considers failure through both brittle fracture and net-section plastic collapse. The dimensions of each anomaly, the applicable level of hoop stress, the pipe geometry, and the pipe material properties determine how close the anomaly is to failure either by brittle fracture or by net-section collapse. The propensity for failure by brittle fracture is calculated as the ratio of the stress intensity factor associated with the anomaly to the fracture toughness of the material. This ratio is called the "fracture" ratio. The propensity for failure by net-section collapse is calculated as the ratio of a "reference stress" to the yield strength of the material. The latter ratio is called the "load" ratio. The reference stress of the particular anomaly indicates the hoop stress level at which it would fail by net-section collapse. Since the FAD is a plot with fracture ratio on the y-axis versus load ratio on the x-axis, each anomaly is represented by a point on the FAD. Anomalies that plot within the acceptable area are considered to be acceptable, and those anomalies that plot outside the acceptable area are listed for further analysis or evaluation. To account for tool tolerance in the initial engineering critical assessment, the upper limit value of each of the predicted crack depths was increased by 10-percent of the pipe wall thickness, and the predicted crack length was increased by 1-percent.

The initial crack detection tool analysis predicted 1353 indications in or adjacent to the longitudinal pipe seam and 198 indications in the pipe base material. The indications were separated into three categories: seam weld defects, surface breaking indications, and

mill trim tracks. The depth ranges were separated into four categories: deeper than 40-percent of the pipe wall thickness (WT), 25-percent to 40-percent WT, 12.5-percent to 25-percent WT, and shallower than 12.5-percent WT.

The preliminary 2005 engineering critical assessment predicted that 56 indications were considered to be outside the acceptability curve based on the Level II API 579 crack initiation analysis. The 56 indications are represented by 32 seam weld features, 5 surface breaking laminations, 18 mill track related features, and 1 crack-like feature. Fourteen joints of pipe containing 16 indications were recommended as the initial anomalies for excavation and evaluation to determine the actual indication characteristics.

GE PII Inspection Services was utilized on the excavations to perform thorough non-destructive testing (NDT) using magnetic particle, ultrasonic shear wave, and ultrasonic phased array testing. All indications detected on each of the selected pipe joints were measured and documented in order that this information could be used to correlate the field findings to the crack detection tool data. Excavations were initially performed at 41 sites to determine the dimensions and characteristics of 102 USCD features. The 102 features included 46 crack-like features, 7 crack-field features, 25 notch-like features, 22 not decidable features, and 2 dent features. The 2005 excavation program found 180 cracks, 168 lack-of-fusion anomalies, 3 linear laminations, and 140 volumetric laminations. The field excavations were assessed using the FAD Level II assessment with the recommendation that 12 cracks and 10 lack-of-fusion features be repaired. These 22 features were removed from the pipeline as part of the cut-out program and metallurgical investigation. One lamination was recommended for further assessment. The pipe joint containing the lamination (Pipe 329) was excavated, evaluated, and determined not to be an integrity issue.

The excavation program confirmed that indications reported as mill trim tracks, surface breaking laminations, or probable weld defects should be assessed as crack-like features. The notch-like indications may be associated with cracks or lack of fusion (cold weld) anomalies and are sized and assessed as cracks. The excavation program confirmed to a high degree of confidence (98-percent) that the depths of the features reported by the

crack detection tool are greater than the excavation measurements, and the wall thicknesses measured in the field are greater than those reported by the crack detection tool. Based on the excavation program, the tool tolerance on depth was excluded from the August 2006 engineering critical assessment performed by GE PII.

The USCD tool data were re-analyzed in 2006 to incorporate the findings from the 2005 excavation and evaluation program. The re-analysis of the crack data indicated that there were 570 crack-like or notch-like features in the base metal, 13,274 crack-like or notch-like features adjoining the longitudinal seams, 494 crack-line or notch-like features in the longitudinal seams, and 19 crack-like or notch-like features in "not-decidable" locations due to the inability to determine the longitudinal seam location for some of the pipe joints.

The August 2006 GE PII engineering critical assessment determined that 201 crack-like features and 26 notch-like features were considered to be potentially unacceptable based on the Level II FAD at a MOP of 1,440 psig. Fifteen pipe joints that included 7 of the top 8 potentially unacceptable features were part of the cut-out and metallurgical evaluation program that was completed in 2006.

Twenty-one joints of pipe containing crack detection tool features were removed from the Hattiesburg to Demopolis segment for hydrostatic burst testing and metallurgical evaluation. Stork Metallurgical Consultants, Inc. hydrostatically burst tested the pipes, examined and documented the flaws discovered on the resulting fracture surfaces, prepared metallurgical samples for further examination, determined the pipe chemical composition, and provided mechanical pipe properties. Portions of two pipe joints (the portions that did not fail during the burst tests) were subjected to pressure cycles to determine the fatigue growth of the longitudinal seam flaws and to characterize the morphology of fatigue growth on these seam anomalies. The pressure cycle pipe specimen fracture surfaces were examined in a scanning electron microscope to determine if fatigue occurred and if so, the surface patterns produced in the seam. The results of this investigation were:

- The 21 pipe joints burst in the ERW seam weld at failure pressures from 1.0 to 1.6 times the pipe specified minimum yield strength

- The burst test failures originated at hook cracks
- Hook cracks and lack-of-fusion (cold weld) defects were prominent on the fracture surfaces
- The chemical and mechanical properties met API 5LX for 1961 pipe
- Only 1 of the 2 pressure cycle fatigue tests resulted in a failure after 1,768 cycles from 300 psig to 1,440 psig
- The fatigue test failure originated at a hook crack that grew by fatigue crack propagation during the testing

Based on the results of the metallurgical investigation, the absence of fatigue on any of the 21 burst test pipe fracture surfaces, and the history of no in-service failures on the Hattiesburg to Demopolis segment after the 1984 hydrostatic test program, the remaining USCD features were categorized as monitored conditions. The future plan was to reassess the features detected by the USCD tool with additional in-line inspection.

2006 Magpie Deformation Tool

The Magpie deformation tool was run in March of 2006 on the Hattiesburg to Demopolis segment. Ten dents greater than 0.25 inches deep were detected by the deformation survey. Two deformations less than 0.25 inches deep that were subsequently predicted (by the MFL tool data correlation) to contain metal loss were detected during the surveys. The remaining deformations predicted to be less than 0.25 inches deep were correlated to the MFL metal loss tool and determined to not be associated with any metal loss.

The two deformation anomalies predicted to contain metal loss were addressed during the subsequent 2006 remediation program. All of the deformation anomalies predicted to be greater than 0.25 inches in depth were evaluated during the 2006 rehabilitation program. Nine of the deformation anomalies were addressed, and 1 of the deformation anomalies was determined to be associated with a stopple fitting and therefore not considered to be an integrity concern.

2006 Magpie MFL Metal Loss Tool

The Magpie high resolution MFL metal loss tool was run in March 2006 on the Hattiesburg to Demopolis segment. No anomalies with a predicted depth exceeding 80-percent of the wall thickness nor any anomalies with a calculated burst pressure less than the site specific maximum operating pressure of the pipeline were detected by the MFL survey. All 6 of the metal loss anomalies with calculated anomaly operating pressures less than the site-specific maximum operating pressures were evaluated and addressed during the 2006 rehabilitation program. The maximum remaining Magpie unaddressed metal loss anomaly is predicted to be 34-percent of WT. The minimum calculated remaining metal loss anomaly pressure is 2,071 psig.

ILI Tool Data from the November 1, 2007 Failure

The ILI tool data from the pipe joint that failed were reviewed. The failed pipe joint was determined to be GE PII pipe joint 5808 and Magpie pipe joint 58340. The pipe joint is 52.09 feet long. This pipe joint was identified in the log based on the proximity of a permanent magnet marker on the upstream pipe joint. The only ILI indications (2) that were detected on this pipe joint were from the GE PII USCD tool. A notch-like feature predicted to be 4.6 inches long and less than 12.5-percent deep was detected 51.43 feet from the upstream girth weld and 0.66 feet from the downstream girth weld. A geometry "not-decidable" feature predicted to be 2.8 inches long and 2 inches wide was detected 51.86 feet from the upstream girth weld and 0.23 feet from the downstream girth weld. These features are associated with the longitudinal seam. These features were not detected by either the Magpie MFL or deformation tools.