FINAL REPORT

TGP MLV 205-4 + 11.28 Failure – Root-Cause Analysis

November 16, 2011 Failure

Tennessee Gas Pipeline Company LLC

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TGP MLV 205-4 + 11.28 Failure

Root-Cause Analysis

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Executive Summary

Tennessee Gas Pipeline Company, LLC (TGP) has retained Dynamic Risk Assessment Systems, Inc. (Dynamic Risk) to facilitate and execute a root-cause analysis (RCA) for a TGP pipeline failure that occurred on November 16, 2011. This failure occurred on TPG's 200 system, Line 4 at a milepost 205-4 + 11.28. Post-failure examination of the site identified visual evidence of landslide movement in proximity to the crater produced by the rupture and visual evidence that the failure initiated at a girth weld. The girth weld had been previously hydrostatically tested to 154% of MAOP and was considered stable until acted upon by the landslide.

A root-cause analysis (RCA) process was developed and relied upon during the course of this analysis. An RCA team was established and was comprised of staff from Dynamic Risk and TGP. Resources beyond the core RCA team were relied upon as necessary throughout the investigation.

The problem statement for this analysis was: "Pipeline failed in service at a girth weld." Data and information were compiled and reviewed. Based upon that review, the RCA team determined the primary information sources for the RCA included incident investigation reports produced for this failure (205-4+11.28), incident investigation report from 2 TGP failures that occurred in Ohio in 2011 (209-1 and 214-4), control room operational data and information, and procedures used by TGP.

A preliminary threat assessment was undertaken. In doing so, the RCA team relied upon the threat categories presented in ASME B31.8S. From this assessment, probable contributing factors included weather related/outside force (landslide, earth movement) based upon observations from the failure site and welding related (girth weld) since the failure initiated in a girth weld. Credible evidence existed to conclude that the remaining potential threats were unlikely contributing factors. Nonetheless, all of the threats were continually re-assessed throughout the RCA process.

In addition to the threat assessment, the RCA team completed an assessment of the pipeline design, construction and maintenance activities. This assessment considered materials, design and construction practices, timeline of the pipeline operations related to this failure, prior maintenance activities, and the TGP integrity management program.

This analysis process identified two aspects of the problem – a "condition" and an "event." The condition identifies the susceptibility (e.g. girth weld quality, cracking, etc.) whereas the event is an influence on the condition (e.g., settlement, earth movement, landslides, etc). In most cases, an event is required to affect a condition. An event, however, does not necessarily require a condition.

The RCA team identified five (5) elements to consider in its investigation that potentially contributed to the problem as defined (e.g. "Pipeline failed in service at a girth weld."). Three of the elements are classified as conditions (less than adequate design and/or materials, construction/workmanship issues, limited verification) and two of the elements were classified as events (operational limits exceeded, integrity management gaps).

The RCA team determined the root cause of this failure was displacement produced by a landslide and an inadequate understanding by TGP of the influence of the geotechnical threats on the pipeline in this location. The conclusion that these events were the root cause of the failure is based upon information obtained post-failure and information that was available prior to this failure, but was not adequately understood by TGP.

The contributing factors for this failure are best described by the conditions relative to the girth weld procedures and practices at the time of construction. These conditions resulted in the formation of a hydrogen-assisted cold crack at the toe of the root pass in the heat affected zone of the weld that was produced at the time of construction. The crack in the girth weld, as well as the girth weld itself, acted as a stress concentrator and the displacement (strain) of the pipeline occurred through the on-going progression of the landslide. Even in the absence of a crack in the girth weld, the landslide likely could have resulted in a pipeline failure at a later time if the landslide remained undetected and unmitigated.

A number of recommendations for corrective action have been identified and should be considered and prioritized by TGP. The recommendations are summarized as follows:

- Geotechnical threat identification. Continue the development of a comprehensive geotechnical threat assessment and modify company procedures where necessary.
- Continued validation from 205-4 + 11.28 Failure. Capitalize on the findings from this analysis to further validate ILI IMU bending straining results. Establish procedures for the assessment of loads and strains acting on pipelines including acceptance limits.
- Geotechnical Monitoring and Mitigation. Establish procedures for the assessment, monitoring and mitigation of pipeline segments affected by landslides.
- Continued Girth Weld Condition Assessment. Continue the development and implementation of methods to assess girth weld condition through in-line inspection and direct examination. This will be important when prioritizing the investigation of sites where landslides have been identified and for assessing girth welds exposed during strain relief excavations.
- Gas Control. While not identified as a contributing factor to this failure, a gap identified during the emergency response was the availability of line specific pressure readings from mainline valves.

1. Introduction

Tennessee Gas Pipeline Company, LLC (TGP) has retained Dynamic Risk Assessment Systems, Inc. (Dynamic Risk) to facilitate and execute a root-cause analysis (RCA) for a TGP pipeline failure that occurred on November 16, 2011 at approximately 08:45 am EST in Homer Township (Morgan County), Ohio. This failure occurred on TPG's 200 system, Line 4 at a milepost 205-4 + 11.28 which is 11.28 miles (595+50) downstream of Main Line Valve (MLV) 205-4 on Line 4. The nearest upstream compressor is at Station 204 (Albany) that is located 22.4 miles upstream from the failure site. A schematic for this portion of system is provided in Figure 1[1].

2. Background

The section of pipe which failed is comprised of 36-inch diameter by 0.344-inch wall thickness, API 5L X60 line pipe and contains a double submerged arc welded (DSAW) longitudinal seam. The pipeline was constructed in 1963 and has an MAOP of 790 psig (69% SMYS) that was established through a hydrostatic test performed in 1971[2]. An in-line inspection (ILI) was performed on this line section in June, 2011 using caliper, magnetic flux leakage (MFL), and inertial mapping unit (IMU) technologies[3].

The estimated pressure at the time and location of the failure was 761 psig (66% SMYS)[4]. The failure initiated at a girth weld and the natural gas ignited as a result of the rupture. There were no significant injuries resulting from the ignition of gas, but three homes, two of which had been occupied at the time of the failure, were destroyed.

TGP followed standard protocol in response to the failure including emergency response[5,6,7]. Once the area was secured, the affected site was examined, the failed pipe section was examined, and excavation commenced to remove the pipe section. The failed pipe section was removed and provided to Det Norske Veritas (U.S.A.), Inc. (DNV) for metallurgical investigation. Intact girth welds located just upstream and downstream of the failure were removed and retained by El Paso for non-destructive and metallurgical investigation.

Battelle Memorial Institute (Battelle) was retained to perform initial geotechnical data collection and soil investigation at the failure site. Golder Associates, Inc. (Golder) was subsequently retained to utilize the results obtained by Battelle, provide additional geotechnical expertise related to landslides, provide support for site remediation, and to support the RCA.

3. Approach

A root-cause analysis was undertaken by TGP with the assistance of Dynamic Risk and other experts as detailed below. Prior to commencing the RCA, a process was proposed, approved by US Department of Transportation (DOT), Pipeline and Hazardous Materials Administration (PHMSA), and adopted[8]. In addition, on November 17, 2011, a day following the incident, PHMSA issued a Corrective Action Order[9] that identified the required elements of the root cause analysis.

The objectives of the RCA were accomplished through the successful completion of the following activities as described in detail in this report:

- Form the RCA Analysis Team
- Define the Problem and Boundaries
- Gather the Data and Information
- Analyze and Understand the Problem
- Execute Activities to Support Investigation
- Identify the Root Cause
- Produce Recommendations
- Assist TGP in Developing Monitoring Process

Each is addressed in the following sections.

4. Form the RCA Analysis Team

The RCA Team Members are:

- Bennie Barnes, Director - Pipeline Risk Management, TGP
- Patrick Vieth, President, Dynamic Risk
- Nathan Len, P. Eng., Manager – Engineering, Dynamic Risk
- Don West, L.E.G., L.G., Engineering Geologist, Golder Associates Inc.
- Mark R. O'Neill, NDE Superintendant, TGP
- Ken Johnson, Area Manager- Catlettsburg, TGP
- Samuel Vasquez, Principal Engineer – Metallurgist, TGP

The RCA Team was assembled and was responsible for organizing and facilitating most of the work streams undertaken post-failure. As a result, this group was fully engaged in the activities, communications, and investigations related to this failure. This group provided a balance across technical disciplines, operations, and field activities. In addition, other company personnel and contractors were relied upon as necessary.

5. Define the Problem and Boundaries

5.1. Problem Statement

Pipeline failed in service at a girth weld.

5.2. RCA Boundary

The boundary for the purpose of this RCA is approximately 1000-feet along the Line 4 right of way based upon a post-failure assessment[10,11,12]. While the focus of this RCA is the failure that occurred at MLV 205-4 + 11.28, it is anticipated that the lessons learned from this assessment will be applied across the system in a prioritized manner.

6. Gather the Data and Information

The RCA team visited the site and spent significant time compiling and reviewing available information, providing input and direction into obtaining additional information, and establishing the best approach for performing the RCA. This included a brainstorming session to identify information necessary to perform the RCA (see Appendix 1). The primary data sources specifically relied upon are as follows:

- Prior Incident Investigation Report[13] of 214-4+11.49* and 209-1+0.44 †
    - DNV Metallurgical Report TGP MLV 214-4+11.49 (Appendix 5)‡
    - El Paso Radiography of six (6) Girth Welds adjacent to 214-4+11.49 (Appendix 3)‡ and DNV Metallurgical investigation of one of the welds where a crack was identified (Appendix 4)‡
    - DNV Metallurgical Report TGP MLV 209-1+0.44 (Appendix 8)‡
    - Battelle Geological Hazard Assessment for 214-4 and 209-1 (Appendix 9)‡.
- Incident Investigation Reports for 205-4 + 11.28
    - Battelle[11] and Golder Field Reports[10]
    - DNV Metallurgical Investigation[14]
    - In-Line Inspection Results[3]
- Operations related to the 205-4 + 11.28 Failure
    - 205-4 Gas Control Incident Summary[7]
    - Gas Control Notes[5,6]
- El Paso Procedures
    - El Paso Pipeline Group, Operations & Maintenance Manual , 12/13/2011[15]
    - El Paso Pipeline Group, Integrity Management Program for High Consequence Areas, 06/28/2011[16]
    - El Paso Pipeline Group, Pipeline Operating Procedures, 06/09/2011[17]

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* Also referenced as 214-4 606+77

† Also referenced as 209-1 22+58

‡ These referenced Appendices are related to and included in Reference 13.

7. Analyze and Understand the Problem

In order to understand the background and contributing factors related to the MLV 205-4+11.28 failure, the RCA team performed a threat assessment using the threat categories recognized in ASME B31.8S[18]. The purpose of this preliminary threat assessment was to focus on potentially relevant factors that may have contributed to this failure to ensure all potential threats were continually assessed throughout the process.

In addition, a preliminary assessment of the pipeline design, construction and maintenance information was compiled, reviewed and assessed.

A summary of these assessments is provided below.

7.1. Threat Assessment

As a first pass at understanding and dissecting this failure, a preliminary threat assessment was performed using the available information. This assessment was performed as it related to this failure and the threats were classified as 'unlikely' and 'probable' contributing factors. This classification helped the RCA team to focus efforts for data gathering and analysis.

A summary of the categories for the threat assessment is provided in Table 1. Based upon the available information, the categorization of the threats is as follows:

- Unlikely[*] contributing factors included External Corrosion, Internal Corrosion, Environmental Cracking, Pipe Manufacturing related, equipment, 3rd Party damage, incorrect operations.
- Probable[†] contributing factors included weather related/outside force (landslide, earth movement) based upon observations from the failure site[‡] and welding related (girth weld) since the failure initiated in a girth weld.

This was a preliminary classification and all threats were continually assessed throughout the RCA process as evidence was collected and evaluated.

The unlikely contributing factors were classified based primarily on the DNV Metallurgical report for this failure[14] and the gas control incident summary[7]. The DNV report concluded there is no evidence of damage to the ID or OD pipe surface and further supported by the fact that no features were identified during the ILI survey performed in June, 2011 within this failed sections (e.g., internal or external metal loss,

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* Defining a factor as an "unlikely" contributing factor is meant to convey that no credible evidence was identified to support it as a causal factor.

† Defining a factor as a "probable contributing factor is meant to convey credible evidence was identified to support a causal factor.

‡ Based upon geomorphic evidence, the failure site is located within a complex landslide, spans approximately 1,000 feet along the pipeline length, and usually appears to have displaced 5 to 6 feet downslope from an as-built position.

deformations, girth weld indications, etc.). The gas control incident summary did not identify any evidence that incorrect operations contributed to this failure.

Weather related/outside force (landslide, earth movement) and welding related conditions (girth weld) were classified as probable contributing factors as a result of clear evidence obtained from the failure site.

An aerial photograph of the failure site is provided in Figure 2. The direction of flow in this photograph is from right to left and shows a section of pipe extending from the crater produced by the failure. A photograph of the soil located at an elevation higher than the crater produced by the failure is provided in Figure 3 and shows the fissures that developed near the crater. These fissures were not evident immediately after the failure but developed several days after the failure. The potential for soil movement is evident from this photograph taken a few days after the failure.

The DNV metallurgical report[14] concluded that rupture initiated at a pre-existing crack in the field girth weld. A photograph of the girth weld fracture surface is provided in Figure 4. The morphology of the crack is typical of hydrogen-assisted cold cracking and initiated at the toe of the root pass on the pipe ID.

7.2. Pipeline Design, Construction and Maintenance Assessment

In order to identify relevant contributing factors, an assessment of the pipeline design, construction, operations and maintenance factors has been completed as part of the RCA. The areas of focus included:

- Materials - MTR's, material specifications
- Design & Construction - Procedures, practices, regulatory/code requirements, hydrostatic test
- Operations - Gas Control (temp, pressure, etc.), timeline
- Maintenance - Upgrades, re-routes, CP, Regulatory-Required activities
- Integrity Management - In-line inspection, hydrostatic test, surveys

7.2.1 Materials

No line pipe material deficiencies were identified[14]. The carbon equivalent (CE) for the line pipe on either side of the failed girth weld was 0.48 and 0.43. In cases where the CE exceeds 0.43, the potential for hydrogen cracking exists under certain conditions (e.g., cooling rate, etc.). Mechanical properties for the line pipe material met minimum requirements. Mechanical properties for the girth weld produced an axial tensile strength of 80.3 ksi and can be compared to 83.4 ksi for the axial tensile strength of the line pipe.

7.2.2 Design and Construction

Based upon non-destructive examinations (NDE) and metallurgical work performed in response to this failure and the 209-1 and 214-4 failures, there have been recurring questions about the potential for hydrogen assisted cracking, welding procedures and welding electrodes used at the time of construction (1963), and field NDE[13].

The pipeline was constructed in 1963 and subjected to a hydrostatic test in 1971[2]. The hydrostatic test pressure at the location of the failure was 1,114 psig (97% SMYS) based upon an elevation of 890 feet at the failure site.

There is no evidence that geotechnical threats were considered during the design or construction of the pipeline routing.

7.2.3 Operations

No evidence of pipeline operational issues were identified that may have contributed to the failure. The control room operations for the affected line segment are summarized in the control room timeline[7]. This includes a summary of the pressures experienced over a 90-day period prior to the failure. There is a common header at Station 204 (Albany) that feeds Line 4 in addition to Lines 1, 2, and 3. As a result of the common header, the control room first learned of the failure and its location after a landowner reported the failure to TGP.

Automatic shutdown valves (ASV) were located upstream and downstream of the failure site. While there is evidence that these valves worked effectively (except one of the full opening gate valves did not shut completely automatically), the control room relied upon anecdotal evidence to confirm that the ASV valves had closed.

The supervisory control and data acquisition (SCADA) system monitors pressure from a pressure transmitter that is within Station 204 where the pressure transmitter is sensing pressure from the four lines that are common in the station pipe. There are no pressure transmitters monitoring individual lines.

7.2.4 Maintenance

No historical maintenance activities have been identified in proximity to the failure location. Post-incident interviews with landowners identified that the landowner was aware of landslide activity which had affected the dwelling in closest proximity to the failure because the landowner reported work was required on the dwellings' foundation "about 10 years ago."

7.2.5 Integrity Management for TGP

As part of this review for the integrity management program, the Tennessee Gas Manual's reviewed were: Operations and Maintenance (O&M) Manual[15], Integrity Management Program (IMP) for High Consequence Areas[16], and Pipeline Operating Procedure (POP)[17]. This review focused on the 'probable' threat classifications from above.

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A summary is provided below.

7.2.5.1 *Operations and Maintenance Manual (O&M)*

The O&M procedures utilized by TGP contain procedures for the detection of certain earth movements that include washouts, pipe exposures, etc. The procedure to assess these conditions is mentioned in O&M Section 501 (Surveillance) where it states that:

> "Continuing surveillance shall be conducted on all pipeline facilities and surrounding areas, extending from the center of the respective pipeline to the limits of the calculated potential impact circle (for PIC calculations see Pipeline Risk Management) or 660 feet, whichever is greater. Surveillance is awareness of:
>
> a. Surface deterioration;
>
> b. Conditions on and adjacent to pipeline right-of-way;..."

The O&M procedures utilized by TGP do not, however, contain specific and clear guidance related to the identification of areas of geotechnical interest or landslide occurrences. There is no evidence from the surveillance activities undertaken by TGP personnel that landslide conditions were identified at the failure site.

7.2.5.2 *Pipeline Operating Procedures Manual (POP)*

7.2.5.2.1. Section 301: Pipeline/Right-of-Way Inspection (Patrol)

POP 301 contains requirements for right-of-way inspections (patrols) to allow for prompt detection of pipeline conditions. With respect to identification of weather related conditions potentially affecting the right of way, the procedures dictate that special notice be given to the following items:

- Erosion of pipeline right-of-way
- Broken and damaged terraces (diversions)
- Condition of river and creek banks
- Sink holes

There is no evidence that any of the indications listed in POP 301 had occurred or had been observed at the failure site prior to this incident. In addition, the POP procedures do not provide specific or clear guidance on the identification of areas of geotechnical interest and/or landslides.

7.2.5.2.2. Section 306: Inline Inspection and Data Analysis (POP 306)

In the case of the 205-4+11.28 failure, the subject girth weld did not have a flaw detected or reported by the ILI vendor. Furthermore, a post-failure review of the ILI data confirmed that no anomaly was present in the ILI data.

Since POP 306 provides guidance on the assessment and investigation of girth weld anomalies, it is not relevant to this failure location since no anomaly was identified. This girth weld assessment process was developed in response to prior the 214-4 and 209-1 failures[13] where girth weld defects were identified. This procedure requires the assessment of girth welds that meet a threshold made up of the unique combination of percent of circumferential length of the girth weld indication and the percentage of pipe hoop stress. This analysis is referred to as the "K-factor" analysis.

7.2.5.3 *Integrity Management Program (IMP)*

While not applicable to areas outside of High Consequence Areas (HCA), the Integrity Management Program used by TGP details the methodologies used to conduct threat identification and risk analysis. Even though MLV 205-4 + 11.28 was not within an HCA[*] and therefore not subject to the IMP requirements, the IMP was reviewed by the RCA Team with regard to the relevant threats and appropriate assessment methods covered by Table 4-1 in the IMP.

In the IMP, unstable construction-related threats are assessed through a hydrostatic test. Also, a hydrostatic test would be required if the HCA has a stable construction threat and: (a) the pipeline has been operated over the 5 year high preceding HCA identification, (b) if the MAOP has increased, or (c) if pressure cycling is present. None of these factors would have triggered a hydrostatic test for the MLV 205-4 + 11.28 segment.

IMP Appendix A-5 contains the Construction Threat Checklist and contains one reference to land movement. However, land movement within IMP Table A-5 pertains only to coupled and bell and spigot pipe and therefore does not apply to this failure.

The IMP does not identify assessment methods for weather and outside forces threats (including landslides, earth movement, etc.). These threats are managed through the implementation of preventive and mitigative (P&M) measures.

IMP Appendix A-9 contains the Weather and Outside Forces Threat Checklist. Table A-9 contains the screening question: "Are there subsidence areas within this HCA?" While there is guidance on subsidence, washouts, etc, there is no clear guidance on how to identify landslides or mitigate risks arising from landslides.

IMP Appendix K provides risk program criteria for threat interaction. In this table, it is shown that the earth movement threat does have a multiplier on the overall risk score when a girth weld threat is present. Therefore, threat interaction is considered in the IMP and appropriately includes a multiplier. Prior to the failure, earth movement was not considered a threat at MLV 205-4 + 11.28.

[*] The failure site was in a rural Class 1 area.

8. Activities to Support Investigation

As part of this assessment, the RCA team requested information, performed analysis, and conducted investigations on many fronts. Presented herein is a summary of the major activities undertaken and relied upon as part of the RCA.

8.1. Load Calculations Across Girth Weld

As part of the metallurgical investigation performed[14], DNV estimated the axial load across the girth weld that would be required to produce a failure[19]. This estimated load was based upon actual material properties obtained from an adjacent, intact girth weld and considered both fracture toughness and flow stress dependent failure. The estimated load across the girth weld was 70.5 ksi and corresponds to 88% of the measured ultimate tensile strength of the weld (80.3 ksi). This failure was predicted to be flow strength dependent (as opposed to fracture toughness dependent). The primary purpose of this load calculation was to confirm the findings of the metallurgical investigation, which it did.

8.2. Interaction between Pipelines and Landslides

While DNV estimated the failure load across the girth weld, the RCA team needed to develop further understanding in order to better understand how the loading applies at the failure site. Golder Associates produced a summary[20] on the interaction between landslides and pipelines. While both load and bending load are important parameters, understanding the role of displacement (strain) is also critical. For this failure, the RCA determined the important factors to be considered include relative displacement between soil masses and the soil type within the landslide mass.

The soil masses produce greater relative displacement resulting in greater bending, and thus greater strain. The soil type within this landslide mass is comprised of clay soils. Clay soils are relatively rigid during landslide movement and cause more strain in the pipeline than if the soil consists predominantly of loose sand.

8.3. Inertial Mapping Unit Data Analysis

An in-line inspection (ILI) was performed in June, 2011 using caliper, magnetic flux leakage (MFL), and inertial mapping unit (IMU) technologies. The original intent of the IMU was to obtain GPS centerline data for the pipeline. Post failure, TGP subjected the IMU data to a bending strain analysis.[3] and identified 9 locations between MLV 204-4 and 209-4 where the bending strains exceed 0.2%.

The location of highest bending strain was reported to be 0.28% and covered a length of 159 feet. The failed girth weld was located within this 159-foot long section. Detailed analysis of this location is underway[21] and a schematic of the IMU data at the failure location is provided in Figure 5. Additional work is currently underway with regard to reviewing the IMU bending strain data and integrating these IMU bending strain data with field measurements.

9. Identify the Root Cause

Several techniques for performing the RCA were considered and tested for best assessing this root cause. This included a detailed review of the prior investigation[13] that relied upon the Conger & Elsea methods, fault trees, and MORT. As a result of brainstorming sessions, a flowchart method was adopted to best convey the thought process for this failure and also include learning's from the prior investigation. This was completed in several stages.

As presented above, the problem statement is "Pipeline failed in service at a girth weld". In order to commence the process, the first question was raised. Why could this girth weld have failed? From this question, five possible elements were identified and summarized as follows:

- Less than Adequate Design and/or Materials: What was available to start with?
- Construction / Workmanship Issues: How was it done?
- Limited Verification: How was it checked?
- Operational Limits Exceeded: How was it operated?
- Integrity Management Gaps::How was it continually re-assessed?

From these 5 elements, the RCA team was able to evaluate these elements as they relate to "Conditions and Events" where:

- "Condition" identifies the susceptibility and is typically identified through an understanding of the material, construction, welding, NDT, etc. For example, the condition for the 209-1 and 214-4 failures would have been girth weld properties/quality including hydrogen assisted cracking. The condition in-and-of itself is unlikely to produce a failure.
- "Event" is used to identify influencing factors that can affect the condition. For example, the event could include operational changes (pressures, temperatures, fluctuations, etc.) and/or geotechnical influences (landslides, settlement, etc.).

In most cases, an <u>event</u> is required to affect a <u>condition</u> whereas an <u>event</u> does not necessarily require a <u>condition</u> for a failure to occur.

These five elements were then expanded and flow charted. A breakdown for the next level of assessment is also presented in Table 2 where the question was "What influenced why this girth weld failed". The right-hand column of Table 2 presents a classification for the 5 elements. The first 3 elements are classified as Conditions and the last 2 elements are classified as Events. In order to ensure that all factors were identified as assessed, a flowchart was developed, and is presented in Figure 6. This flowchart was developed through brainstorming, review of available information that was available prior to and post-failure, and a detailed review of the prior investigation for 209-1 and 214-4[13] (see Appendix 2).

Based upon this flowchart, the root cause and contributing factors were identified and are described below.

9.1. Root Cause for MLV 205-4 + 11.28 Failure

The root cause was determined to be displacement produced by a landslide and inadequate understanding by TGP of the influence of geotechnical threats on the pipeline in the location of the failure. While the flow chart certainly supports this conclusion, there are several key factors that further validate this conclusion. These factors are:

- Post-failure geotechnical assessment of failure site identified geomorphic expressions of the landslides within the complex and indicate that they are geologically old (on the order of a few hundred to a few thousand years old) and that they are currently active resulting in the observed downslope displacement of the pipeline[10].
- Landslide had been occurring 10 years prior to this failure as reported post-incident by the landowner.
- Landslide that occurred during excavation of the failure site post-incident.

Review of the investigation from the prior incidents at MLV 214-9 and MVL 209-1 indicates that the investigation focused on girth weld condition with limited investigation of geotechnical threats as root or contributing factors. Battelle evaluated geological hazards which may have contributed to the failures and several indicators of soil creep and mass wasting were identified at the MLV 209-1 locations (soil samples were silty clay loam, which is susceptible to soil instability).

9.2. Contributing Factors

Contributing factors to this failure are summarized below as related to the five (5) elements presented above. These contributing factors focused on the Condition aspect and are primarily the factors that affect the potential for a crack to exist in a girth weld. While the crack in the girth weld acted as a stress concentrator in addition to the girth weld itself, the displacement (strain) of the pipeline was created by the on-going progression of the landslide. Even in the absence of a crack in the girth weld, the landslide likely could have resulted in a pipeline failure at a later time if the landslide remained undetected and unmitigated.

9.2.1 <u>Conditions</u>

- Design and/or Materials
    - Codes and standards at the time of construction did not limit carbon equivalents enough for line pipe materials.
    - During pipeline right-of-way routing, did not consider the monitoring and mitigation methods required if traversing a geotechnically active area.

- Construction / Workmanship Issues
  - Welding workmanship at the time of construction would not meet current standards of practice.
- Limited Inspection and Verification
  - Procedures for x-ray inspection of girth welds at the time of construction were limited to 10% of the welds.
  - In-line inspection technologies do not currently reliably detect and characterize potential girth weld defects.

9.2.2 Events

- Operational Limits Exceeded
  - No operational limits were exceeded and, therefore, were not a contributing factor.
- Integrity Management Gaps
  - Limited understanding of the influence of geotechnical threats on the pipeline and lack of clarity of guidance within the Operating and Maintenance Procedures Manual (O&M), Section 501, "Surveillance" and Pipeline Operating Procedures Manual (POP), Section 301, "Pipeline/Right-Of-Way Inspection (Patrol)" regarding surveillance observations (e.g., identification of areas of geotechnical interest, landslides).

10. Recommendations

Based upon the information currently available, the Investigation Team makes the following recommendations:

10.1. Geotechnical Threat Identification

A. Continue to identify areas of geotechnical interest, establish appropriate responses, and take appropriate actions to mitigate risks. Information that can be relied upon includes:

1. Field identification of areas of geotechnical interest
2. Site-specific topographic and geologic data and maps
3. Aerial imagery
4. Aerial reconnaissance of the pipeline ROW by qualified geotechnical experts.
5. Bending strain analysis of available IMU data

B. In support of identifying areas of geotechnical interest, the Company should:

1. Further develop understanding of IMU Bending strain data.
2. Obtain IMU data and bending strain analysis for all pipelines where ILI can be performed and where a geotechnical hazard exists.

C. Develop of a comprehensive Geotechnical Threat Assessment program for inclusion in the appropriate Company procedures (O&M, POP, IMP). This should incorporate the lessons learned from the geotechnical investigation program that was initiated following the failure.

D. Develop training programs for staff (e.g., engineers, field personnel, ROW surveillance, etc.) on how to identify, report and analyze geotechnical hazards.

10.2. Continued Validation Based upon 205-4 + 11.28 Failure

A. Additional correlation between IMU bending strain data and post-failure GPS survey data will provide further insight and understanding of the IMU data.

B. Procedures should be developed for the assessment of strains on pipeline segments subjected to landslide movement. This procedure should also provide criteria for acceptance limits that can be applied to field measurements and to IMU data. Consideration for discontinuities (girth welds, crack in girth welds, appurtenances, crossings, etc.) should be included in the procedure. This procedure can then be validated against this failure.

10.3. Geotechnical Monitoring and Mitigation

A. Procedures should be developed to identify appropriate actions for the assessment, monitoring and mitigation for identified earth movement areas. An example of these actions is provided in Table 3.

B. Strain relief excavation procedures and analysis should be developed that consider:

1. Site-specific geotechnical assessment to define boundaries of landslide
2. Pressure reductions during excavations
3. Monitoring and or instrumentation of the pipe before and during the excavation
4. Establish appropriate repair methods with consideration given to possible stiffening of the pipeline in areas of potential subsidence
5. Select backfill procedures
6. Long term monitoring program, where necessary.

10.4. Gas Control

While not a contributing factor to this failure, the RCA team identified an opportunity to learn from a gap related to confirmation of closure of automatic shutdown valves (ASV). In order to improve the response time for negative rate of change pressure indications, pressure transmitters should be installed on all four lines at Station 204 on both the upstream and downstream side of the mainline valves.

10.5. Continued Girth Weld Condition Assessment

As part of an overall program to address and understand the interactive impacts between potential geotechnical threats and girth welds, girth weld "condition" assessment methods should be further developed to support the assessment and prioritization of potential geotechnical hazards. Programs are already in progress and should consider:

A. Assessment of pipeline vintages, line pipe materials, girth weld consumables and procedures, and operational experience.

B. Continued assessment and analysis of girth welds removed from service in proximity to this failure (205-4+11.28) and prior failures (209-1 and 214-4)

C. In-line inspection tool development and program development to reliably identify actionable girth weld defects

D. Non-destructive examination (NDE) procedures for the field inspection of girth welds

E. Engineering critical assessment (ECA) methods for the fitness for service assessment of girth welds even if the girth welds don't meet current API 1104 standards.

The girth weld assessment program is a key part in prioritizing investigation of sites where landslides have been identified and in assessing girth welds exposed during strain-relief excavations in landslide areas.

10.6. Previous Failures[13] (209-1 and 214-4)

Based on the findings of the root cause and contributing factors of this failure, TGP should consider re-examining the 209-1 and 214-4 failures with a focus on whether geotechnical hazards played a role in those failures. Specifically, the RCA team recommends TGP re-visit the potential contribution of landslides and or earth movement in proximity to the failure locations.

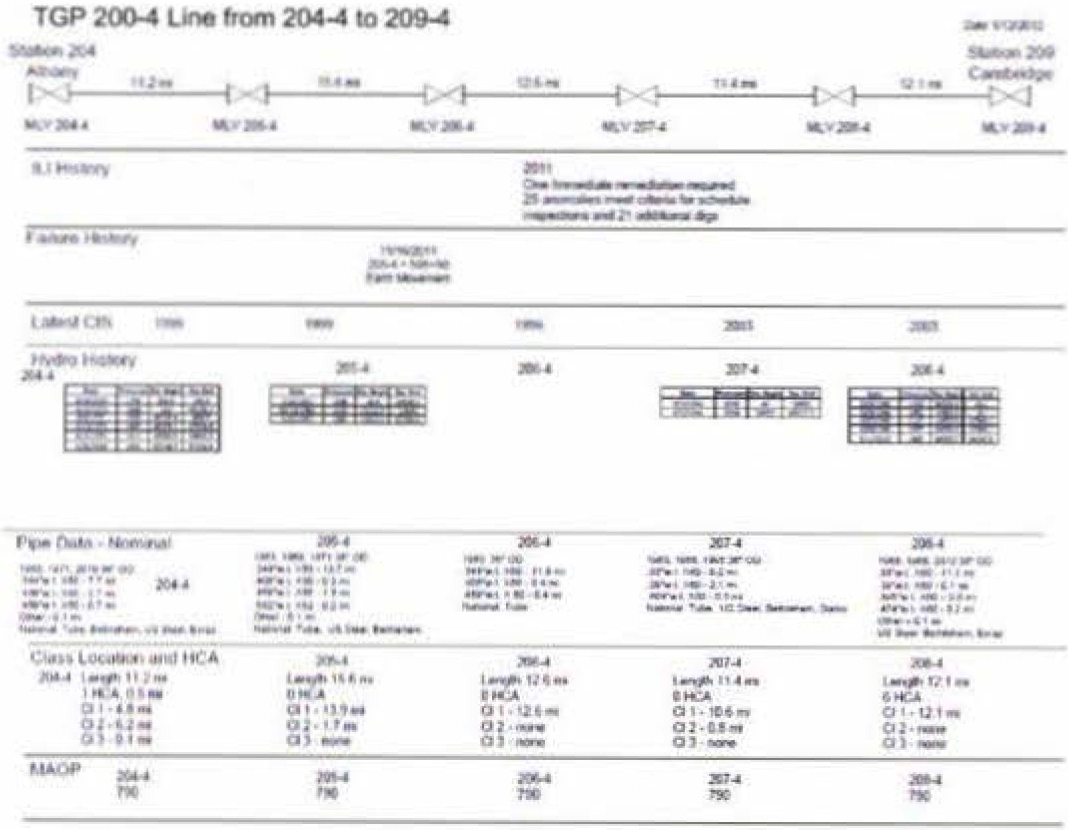
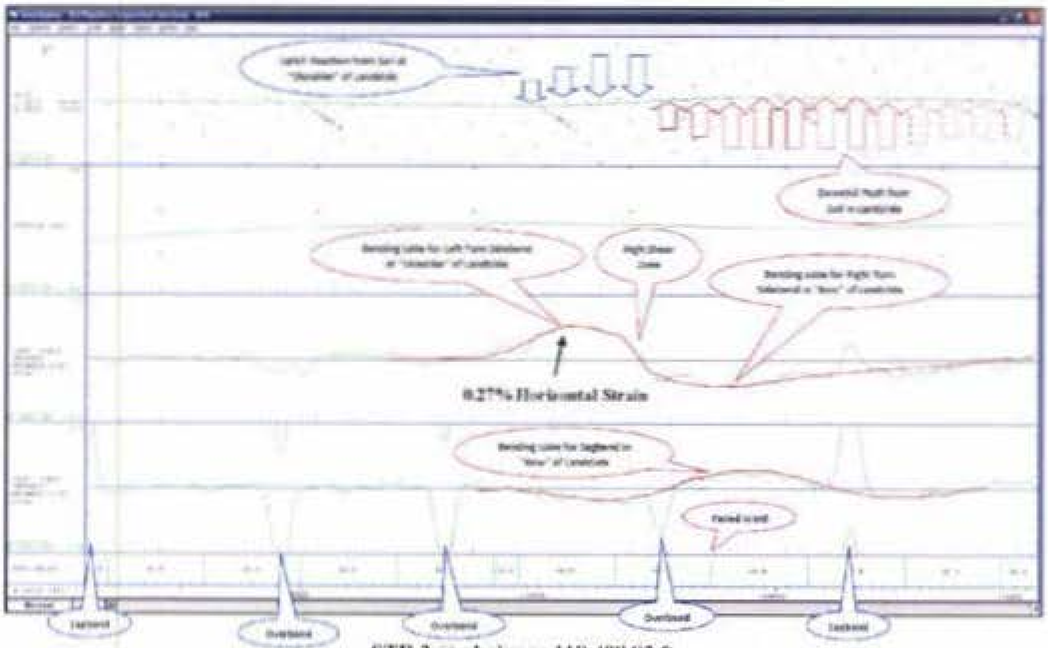


Figure 1. Schematic of Line Section

Figure 2. Aerial Photograph of Failure Site

Figure 3. Photograph of Hillside Post-Failure and located above Pipeline Failure

Figure 4. Photograph of the fracture surface from Failed Girth Weld Section (U/S) from approximately 0 to 1 foot clockwise (looking D/S) of TDC.



STR 2 @ chainage 118,408.82 ft

Figure 5. Preliminary Detailed Analysis of IMU Bending Strains in Proximity to MLV 205-4+11.28

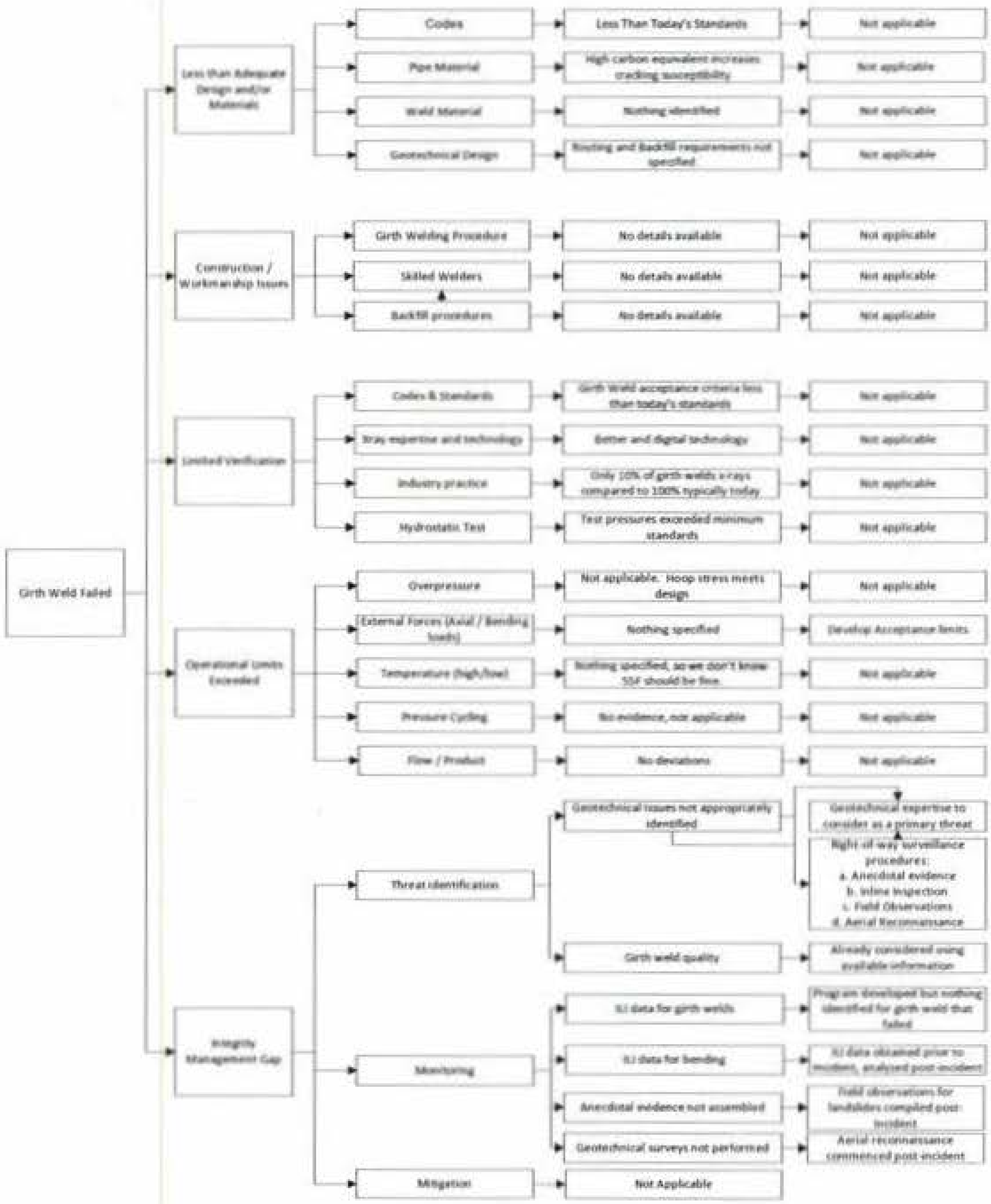


Figure 6. Flow Chart for RCA

Table 1. Preliminary Threat Assessment

Threat	Classification	Data Source	Notes
External Corrosion	Unlikely	DNV Report[14] ILI Survey	
Internal Corrosion	Unlikely	DNV Report[14] ILI Survey	
Environmental Cracking	Unlikely	DNV Report[14]	MPI performed
Manufacturing-Related (Defective Pipe Seam, Defective Pipe)	Unlikely	DNV Report14	
Welding/Fabrication Related (Defective pipe girth weld, defective fabrication weld, wrinkle, bend, buckle)	Probable	DNV Report[14] ILI IMU Report[3]	Failure at a Girth weld; no evidence of wrinkle, bend, buckle.
Equipment (gasket, control/relief, seal/pump, Misc)	Unlikely	Operations Notes[5,6,7]	
3rd Party/Mechanical Damage (Instantaneous/immediate, Delayed/Previous, Vandalism)	Unlikely	DNV Report[14]	
Incorrect Operations	Unlikely	Operations Notes[5,6,7]	
Weather-Related/Outside Force (Cold Weather, Lightening, Heavy rains/floods, Earth Movement	Probable	Site observations, Battelle report[11], Golder report[10]	

Table 2. RCA Framework

1. Less than Adequate Design and/or Materials a. Codes b. Pipe Material c. Weld Material d. Geotechnical Design	Condition
2. Construction / Workmanship Issues a. Girth Welding Procedure b. Skilled Welders c. Backfill procedures	
3. Limited Verification a. Codes & Standards b. Xray expertise and technology c. Industry practice d. Hydrostatic Test	
4. Operational Limits Exceeded a. Overpressure (Hoop stress) b. External Forces (Axial / Bending loads) including landslides c. Temperature (High/Low) d. Pressure Cycling e. Flow / Product	Event
5. Integrity Management Gap a. Threat identification b. Monitoring c. Mitigation	

Table 3. Geotechnical Matrix of Actions

Assessment Desktop	Assessment Field	Monitoring	Mitigation*
Stereoscopic Aerial Photographs	Geomorphic and Geologic Mapping	Inclinometers	Strain Relief Excavation with Select Backfill
Satellite Imagery	Exploratory Drilling	Extensometers	Surface Drainage Improvements
USGS Maps (topographic)	Soil/Rock Samples and Lab Testing	Piezometers	Reroute (avoidance)
Geologic Maps	Geophysics	Geodetic	HDD (under hazard)
Existing Hazard Mapping	Site-specific Topography	Visual (aerial and ground)	Mechanical Landslide Stabilization: • Buttress • Pile installation • Grading
Photogrammetric Imagery	Aerial Reconnaissance	Strain Gauges	Lower Groundwater: • Horizontal drains • Interceptor trenches
LiDAR DEM Data		In-line Inspection	Above-Ground Installation
Slope Stability Analyses		H-R Phased Array (external)	
Pipeline O&M Records		InSAR	
Geologic/Landslide Model			

* The mitigation measures may include performance monitoring to demonstrate stability, or provide premonitory data to assist in planning for additional mitigation

11. References

[1] El Paso Internal Document, TGP 200-4, MLV 204-4 to 209-4 'Swim Lane" (TGPUS-0000673).

[2] Tennessee Gas Pipeline, "Pipe Test Report", Hydrostatic Test Information, TGP MVL 205-4 to MLV 206-4, May 26, 1971 (TGPUS-0000674 to TGPUS-0000683).

[3] Bending Strain Analysis Report, "Pipeline Bending Strain Analysis Report", IMU Survey Report, Prepared by Baker Hughes Pipeline December 12, 2011 (TGPUS-0000684 to TGPUS-0000715).

[4] Incident Report – Gas Transmission and Gathering Pipeline Systems, DOT PHMSA 7000-1 Report, December 12, 2011 (TGPUS-0000716 to TGPUS-0000728).

[5] "Dispatcher Notes", Gas Control Timeline for MLV 205-4 + 11.28 Failure (TGPUS-0000729 to TGPUS-0000733).

[6] Notes from "Houston Crisis Room", prepared by Tim Canton (TGPUS-0000734 to TGPUS-0000791).

[7] "Gas Control Incident Summary", Notes and analysis produced by Gas Control (TGPUS-0000792 to TGPUS-0000811).

[8] "Root Cause Analysis Process", Prepared by Dynamic Risk Assessment Systems, DR-RCA-v1.1, November 22, 2011 (TGPUS-0000295 to TGPUS-0000305).

[9] Corrective Action Order (CAO) issued by PHMSA to TGP, CPF No. 3-2011-1018H, November 17, 2011 (TGPUS-0000812 to TGPUS-0000821).

[10] "Results of December 4, 2011 Site Reconnaissance", prepared by Golder Associates, January 9, 2012 (TGPUS-0000665 to TGPUS-0000672).

[11] "Geologic Hazards Screening Survey 205-4 + 11.2785", Final Report prepared by Battelle, November 19, 2011 (TGPUS-0000539 to TGPUS-0000664).

[12] "US Geological Survey - Landslide Incidence and Susceptibility Schematic", November 21, 2011 (TGPUS-0000822).

[13] "Incident Investigation Report - Rupture and Fire of TGP Line 214-4 606+77 (2/10/2011, Columbiana County) and Leak of TGP Line 209-1 22+58 (3/1/2011, Guernsey County, Ohio)", Prepared by Investigation Team at the direction of Jesus Soto, VP Operations Services, June 29, 2011 (TGPUS-0001551 through TGPUS-0001981).

[14] "TGP MLV 205-4 + 11.28 Failure – Metallurgical Analysis of Girth Weld Rupture (11/16/11)", Final Report prepared by Det Norske Veritas USA, Inc. (DNV), December 13, 2011 (TGPUS-0000413 to TGPUS-0000492).

[15] "Operations & Maintenance Manual", El Paso Pipeline Group, December 13, 2011 (TGPUS-0000838 to TGPUS-0001024).

[16] "Integrity Management Program for High Consequence Areas", El Paso Pipeline Group, June 28, 2011 (TGPUS-0001025 to TGPUS-0001318).

[17] "Pipeline Operating Procedures Manual", El Paso Pipeline Group, June 9, 2011 (TGPUS-0001319 to TGPUS-0001444).

[18] "ASME B31.8S – Managing System Integrity for Gas Pipelines – 2004", American Society of Mechanical Engineers (ASME), January 14, 2005.

[19] "TGP MLV 205-4 + 11.28 Failure – Material Testing of Intact GW and Load Calculation of Failed GW", Final Report produced by DNV, January 16, 2012 (TGPUS-0001499 through TGPUS-0001550).

[20] "Summary Discussion on Pipeline and Landslide Interaction", Draft reported prepared by Golder Associates, Golder Project No. 113-93712, January 9, 2012 (TGPUS-0001491 to TGPUS-0001492).

[21] "Preliminary Observations at STR2 and Recommendations for Gathering Additional Data", Draft Memo prepared by SSD, Inc., January 9, 2012 (TGPUS-0001493 to TGPUS-0001498).

Appendix 1. Data Gathering

A significant amount of data and information was obtained and is summarized as follows.

A.1.1. Construction, Operations and Maintenance

- Construction Notes
- Cathodic Protection surveys, legacy pipeline surveillance notes, One Call Notes
- Prior Pipeline Maintenance Activities
  - SCC Dig program, Girth weld investigation program
- Procedures
  - Operations and Maintenance (O&M), Pipeline Operations Procedure (POP), Integrity Management Program (IMP)

A.1.2. Prior Failures

- TGP MLV 214-4+11.49, TGP MLV 209-1+0.44
  - RCA, Metallurgical and NDE Reports from Prior Failures
- Geotechnical Report
  - Battelle report
- Non-destructive examination of girth welds.

A.1.3. Response to the Failure

- Metallurgical
  - Non-destructive examination (NDE) of adjacent intact girth welds
  - DNV Metallurgical report on failed girth weld
  - El Paso metallurgical report on adjacent girth welds
- Geotechnical
  - Battelle Initial Site Visit, Soil analysis
  - Golder Site Visit and Reconnaissance
  - Identification and compilation of areas of geotechnical interest

- Operations
    - Control room Notes, SCADA data, description of operations, shut down, etc.
- Regulatory
    - US DOT PHMSA Corrective Action Order, 7000-1 form
- Maps
    - Swimlanes, Alignment Sheets, GPS centerline coordinates
- Field Notes/Observations
    - Photographs, Interviews,

A.1.4. In-Line Inspection Surveys

- MFL and Caliper results for 204-4 to 209-4
- Analysis of IMU data for 204-4 to 209-4
- Detailed analysis of IMU Data

Appendix 2. Detailed Review of Prior Incident Investigation

As part of the RCA for TGP MLV 205-4 + 11.28, a detailed review of the RCA report for the previous failures (209-1+0.44 and 214-4+11.5)[13] was undertaken. The purpose of this review was to identify if there were any similar root causes or contributing factors.

Both of the previous failures occurred at a girth weld with a pre-existing hydrogen assisted crack. A combination of external stresses acting on the pipeline was identified for each incident, however the source of the external stresses varied. The 214-4+11.5 failure was likely a combination of stressors including thermal contraction factors and stressors that may have been introduced during a valve replacement in a 2004. The 209-1+0.44 leak, while having thermal stressors present, also had stressors introduced due to soil instability.

The following sections examine the MORT analysis, fault tree analysis, and the recommendations included in the previous RCA report for their applicability to the 205-4+11.28 failure.

A.2.1. MORT Analysis

<u>*209-1 and 214-4 Failures*</u>

A Management Oversight and Risk Tree (MORT) analysis was conducted for the previous failures to focus on the following items:

1. Girth Weld Evaluation
2. ILI Evaluation
3. 1963 Welding Inspections
4. 1950 NDE Inspections
5. Replacement of 215-4 Valve

The MORT analysis identified issues identified that were less than adequate.

<u>*Applicability to 205-4+11.28 Failure*</u>

The previous MORT analysis was evaluated on the basis of its applicability to the 205-4+11.28 Failure. Of the five items listed above, the only relevant sections of the previous MORT analysis are:

1. Girth Weld Evaluation
2. ILI Evaluation
3. 1963 Welding Inspections

A review of these applicable sections of the previous MORT analysis concluded that responses from the previous RCA team were still applicable. It was also concluded that a gap existed in the previous analysis, as there was no consideration of procedures or activities related to the adequate identification of geotechnical threats.

A.2.2. Fault Tree Analysis

209-1 and 214-4 Failures

The fault tree analysis for the previous failures concentrated on the design, construction, operations and maintenance aspects of the pipeline. The focus on both of the previous failures was on why there was a crack in the girth weld, why it wasn't detected through inline inspection and what caused it to fail.

Applicability to 205-4+11.28 Failure

The fault tree analysis prepared for the previous failures were reviewed to determine if there were any common contributing factors to the 205-4+11.28 failure.

The 205-4+11.28 failure is located 40.86 miles upstream from the 214-4+11.5 failure. These are located on the same pipeline (TGP 200-4), were constructed about the same time, and are operated in a similar manner. These failure locations are also similar as it relates to the condition; more specifically similarities with all aspects of the girth weld quality are present

A fault tree analysis was conducted for the 205-4+11.28 failure. Results from this analysis indicated that there were deficiencies in all areas of the pipeline lifecycle (design, construction, operations and maintenance) that contributed to the failure once the appropriateness of geotechnical considerations were taken into account. The inclusion of the geotechnical aspect of the failure in the design, construction and operations stages of the pipeline lifecycle is the main differentiating factor between this analysis and the analysis previously conducted for the other failures.

In order to build on the lessons learned from the fault tree analysis, the RCA team flow charted the problem statement by asking simple relevant questions to ultimately answer the question "Why could this girth weld have failed." Results of this flow chart exercise were used in place of the fault tree analysis in order to determine the true root cause and contributing factors. This flowchart is provided in Figure 5.

A.2.3. Recommendations from Previous Incident Investigation

The following recommendations were made in the previous RCA report:

> "Based upon the information currently available, the Investigation Team makes the following recommendations for Management to consider:
>
> 1. Developing a risk-based assessment and fitness for service decision making process to be applied with girth welds installed before 1963.

2. Continue supporting industry research efforts to improve ILI tools that would be able to better detect girth weld anomalies. This may be independent or in conjunction with PRCI or other similar organizations.
3. Review and further develop the K Factor criteria for evaluating ILI girth weld anomaly data.

In addition, as part of our commitment to continuous improvement, we recommend Management consider implementing the following items:

1. Consider whether we have a sufficient long term staffing plan to add the evaluation of the girth weld anomaly data in-house by reducing/re-distributing were review the work load for the individuals involved in this analysis at the current time, or consider outsourcing the development of that analysis.
2. Consider developing a process and creating an "index" that would contain information regarding when certain past editions of company standards and manuals were applied so the user can search by subject matter to determine what procedure applied at a certain time in the past.
3. Consider improving historical construction project records to enhance the ability to research the history of segments. This improvement may occur, in part, by better defining and communicating the process for retrieval to all Operations Services personnel."

The RCA team conducting the investigation into the failure at TGP MLV 204-4 +11.28 reviewed these recommendations made in response to the prior incidents as part of the this investigation. Generally, the recommendations seem to address a contributing factor of a girth weld defect, but do not appear to fully address the geotechnical aspect of the 205-4+11.28 failure

The RCA team concluded that based on the findings of the root cause and contributing factors of this failure, TGP should consider re-examining the 209-1 and 214-4 failures with a focus on whether geotechnical hazards played a role in those failures. Specifically, the RCA team recommends TGP re-visit the potential contribution of landslides and or earth movement in proximity to the failure locations.