

Protocol

Aliso Canyon RCA Phase 4 Protocol for Metallurgical Investigation of the SS-25 Failure

Prepared For:

RCA SS-25: CPUC, DOGGR, SoCalGas



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Provide a protocol for laboratory metallurgical and fractographic investigation of the SS-25 failure.

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1 Introduction

Blade is in the process of conducting a Root Cause Analysis (RCA) of the October 2015 gas leak in the Southern California Gas Co. Aliso Canyon gas storage field located near Porter Ranch, California. Blade has provisional authority as granted by the CPUC to conduct a Root Cause Analysis (RCA) on well SS-25. The person in charge (PIC) of the RCA is the Blade Team Lead, Ravi Krishnamurthy. Should clarification be required or disagreements arise, the CPUC, DOGGR and Blade shall meet and attempt to agree on steps going forward. If the entities are unable to agree on any activities described for the metallurgical investigation, Blade will document such differences and the designated regulatory agency will act as the arbiter, and make the final decision.

Blade reserves the right to deviate from these procedures as unique situations arise. Furthermore, the Blade team shall document any significant deviation from these procedures that may affect the ability to collect data and evidence for RCA purposes, and will notify the CPUC and DOGGR. Blade shall obtain appropriate approvals from CPUC and DOGGR in advance of subsequent activity, however, should agreement not be reached, Blade will document such differences and the designated regulatory agency will act as the arbiter, and make the final decision.

The objective of this document is to provide a protocol for the SS-25 failure investigation with respect to laboratory testing post extraction. This procedure specifically addresses the metallurgical and fractographic aspects of the SS-25 failure investigation and Root Cause Analysis (RCA).

The 7" casing was inspected with an EV downhole video camera on August 30th, 2017. The inspection identified a fully parted casing at an approximate depth of 887' WLM (wireline measurement). Figure 1 shows a snapshot taken from the downhole camera video showing the upper portion of the parted 7" casing. The joint associated with the parted casing was identified as joint 22.

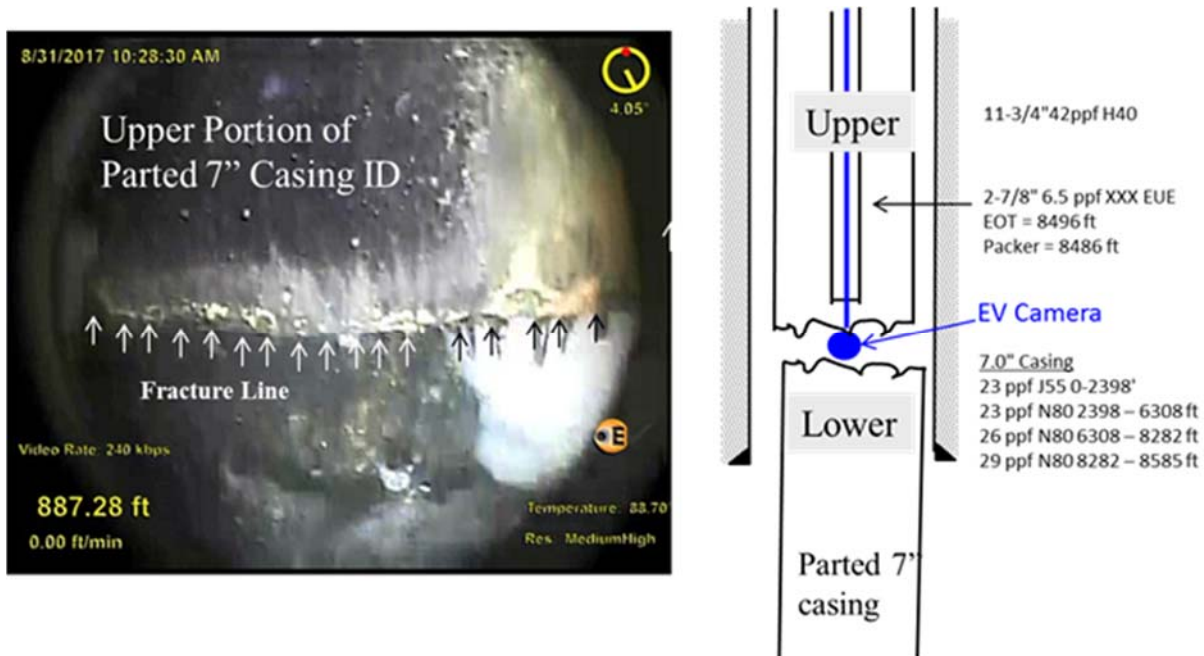


Figure 1: An EV video camera image showing the parted casing located at 887.28 ft WLM

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A total of 24 casing joints were extracted from the well. Both the top and bottom fracture surfaces of the parted casing (joint 22) were recovered. Visual examination of the parted casing showed, in addition to the circumferential fracture, a 19" long axial split on the lower parted casing (upward facing fracture surface) which had merged with the circumferential fracture. Figure 2 is a sketch of the 24 joints recovered from the well and the location of the parted casing (joint 22). Figure 2 includes the post extraction corrected depths used by Blade. These depths are based on consolidation and verification from downhole tools and physical measurements. The official depth for the parted casing is shown in the schematic as 892'. Figure 3 shows the photographs of the parted casing and the axial split (cracking).

The casing, casing connections, tubing and wellhead equipment was transported from Aliso Canyon, California to a storage location in Houston, Texas.

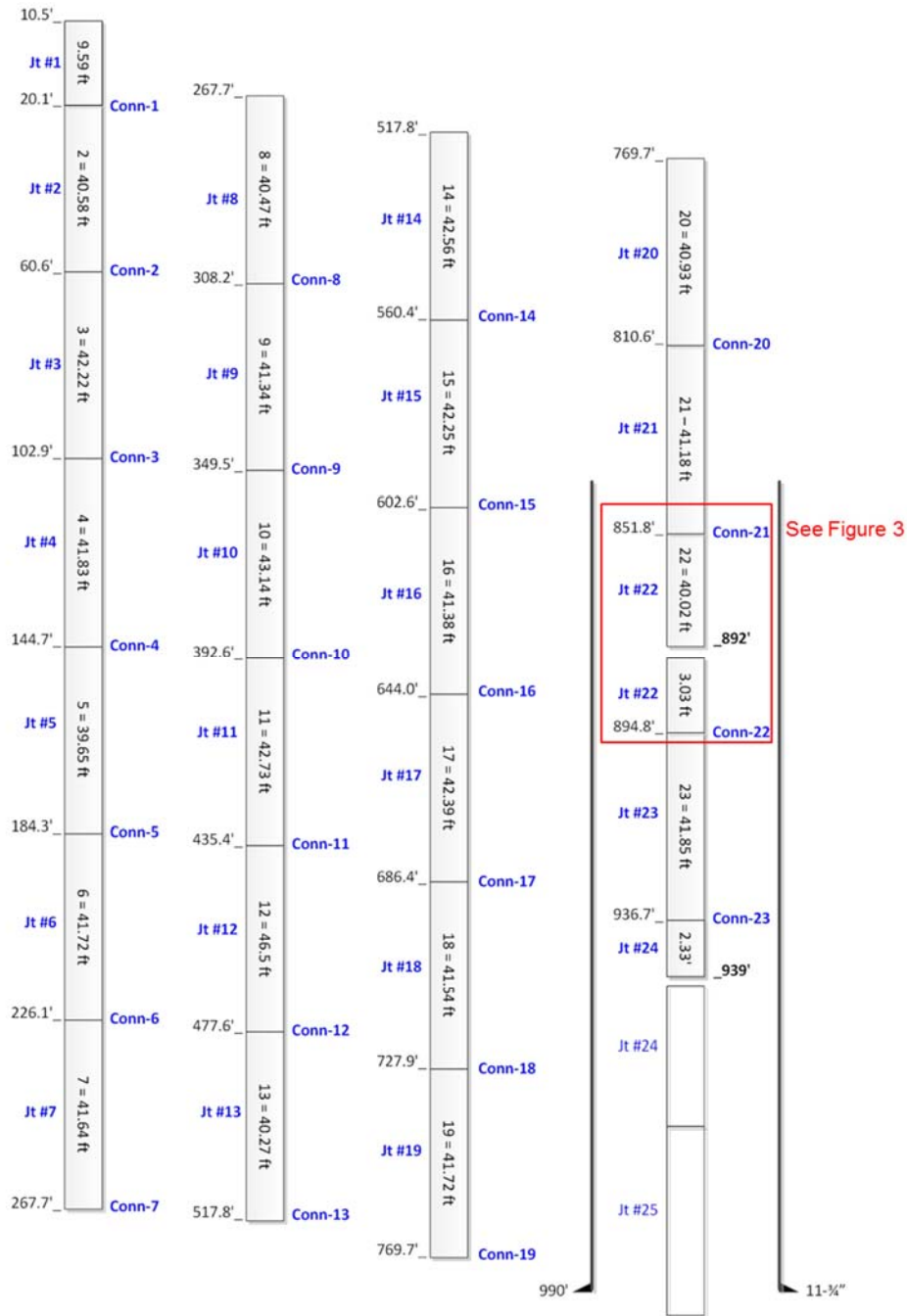


Figure 2: A schematic of the 24 joints of 7” casing in the well showing the parted Joint 22 with an axial split

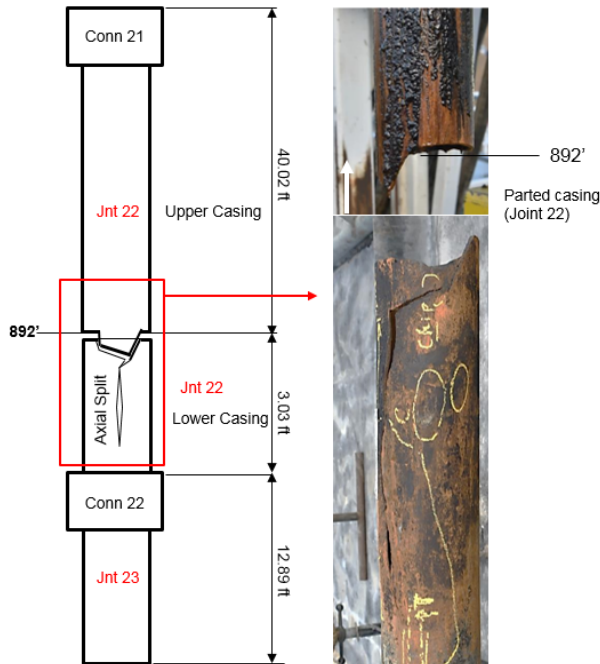


Figure 3: Sketch and field photo showing the upper and lower fish of the parted 7” casing (Joint 22)

On-site examination of the failure indicated that the circumferential parted-failure of Joint 22 was brittle with little plastic deformation such as necking or shear (Figure 3). The axial split (cracking) exhibited some degree of bulging (i.e., plastic deformation), Figure 4a. Severe external corrosion (i.e., OD corrosion) was observed in the failure areas; indicating the axial split that is associated with wall thinning due to corrosion, Figure 4b.

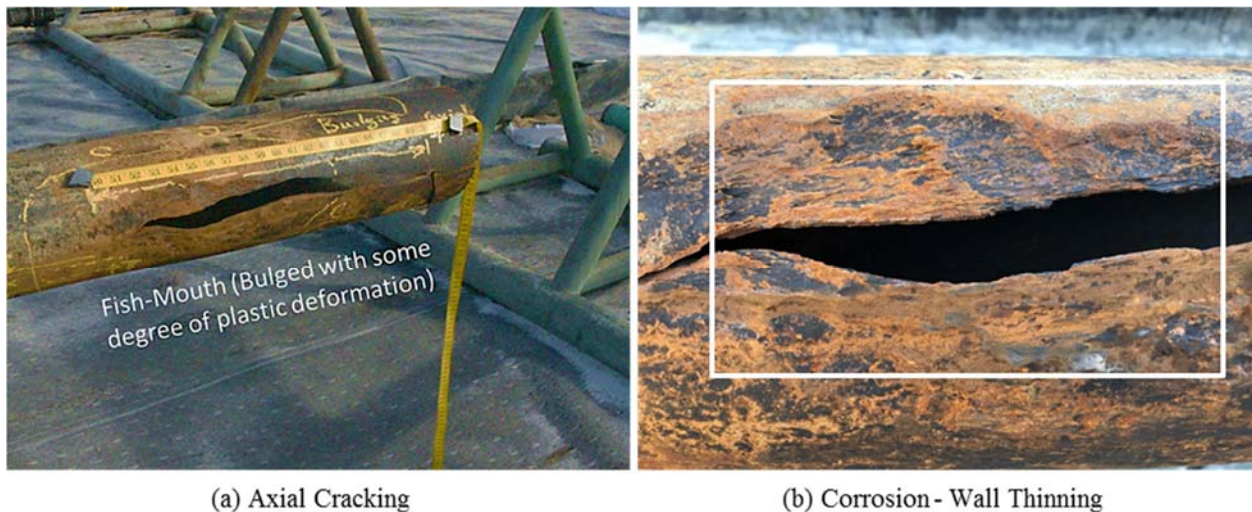


Figure 4: Images of the axial split showing the (a) fish-mouth appearance with some degree of bulging and (b) failure associated with corrosion/wall thinning

The severity of corrosion appears to increase with increasing depth, with the most severe corrosion seen at failed joint 22. Figure 5 shows examples of the observed corrosion trend. The

images show that Joint 2 (at the depth of 20.1'-60.6') and Joint 14 (at the depth of 517.8'-560.4') contain increasing amounts of shallow corrosion while Joint 20 (at the depth of 769.7'-810.6') contains severe corrosion.



Figure 5: Severity of 7" casing external corrosion as a function of joint depth

Another type of indication found during the field investigation was oblique, shallow crack-like features. The angle of the crack-like features was slightly deviated from the longitudinal axis of the casing. The features were identified by visual examination and confirmed by field magnetic particle (MPI) and ultrasonic inspection. Figure 6 shows an example of this type of indication on the casing OD surface from joint 19 both before and after white paint MPI. In addition, areas of mechanical damages such as gouges, tong marks, slip marks, and possibly erosion/corrosion marks were also observed. Figure 7 provides examples of these types of mechanical damage.

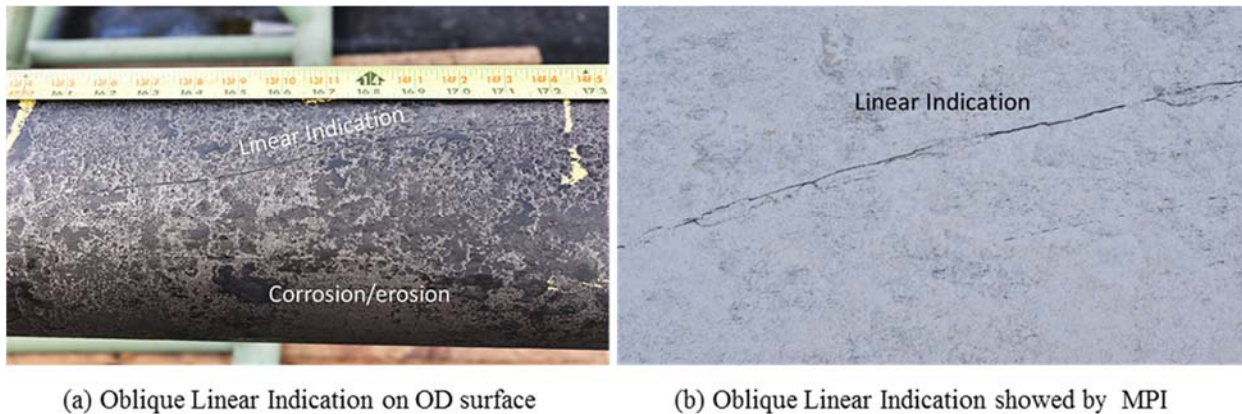


Figure 6: Images of joint 19 showing an oblique crack-like feature (a) before and (b) after MPI

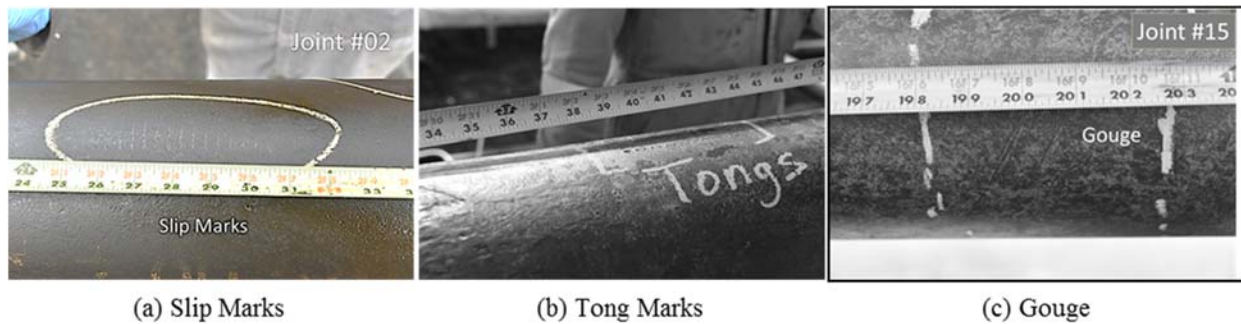


Figure 7: Type of mechanical damages seen on the 7” casing (a) Slip Marks, (b) Tong Marks and (c) Gouge

This protocol is primarily based on observations made during the field investigation. Additional facts and observations shall be made throughout the investigation. These findings shall dictate the direction of the investigation and may require modifications from the current version of this protocol. Any modifications from the protocol shall be documented and the appropriate entities notified. Based on the above field examination, this protocol will cover:

1. 3D mapping of corrosion and other features on the OD surface of the 24 extracted casing joints.
2. Reconstruction of the fracture from the upper and lower parts (C023A1 and C022B) of the failed 7” casing (joint 22). The intention of the exercise is to ensure that there is no missing fracture fragments.
3. Metallurgical and fractographic evaluation of the longitudinal split at the lower parted casing (Joint 22, C022A1) to establish the failure origin(s) and propagation and associated mechanisms.
4. Metallurgical and fractographic evaluation of the circumferential fracture on the upper and lower parted casing to establish failure origins and propagation of the parted fracture.
5. Assessment of the connectivity of the longitudinal split to the circumferential fracture of the lower parted casing.
6. Metallographic and fractographic analysis of the oblique crack-like features and mechanical damage.
7. Assessment of the surface corrosion scale/products. Corrosion scale/products remaining on the pipe surface in the corrosion areas will be analyzed at designated laboratories with appropriate methodologies to establish the corrosion mechanism(s). These laboratories will perform the work under the direction of Blade. Blade is responsible for interpretation of the factual evidence provided by the laboratories.
8. Metallurgical evaluation of erosion/corrosion features on 7” casing body and connections to establish erosion/corrosion events associated with the failure.
9. Mechanicals, chemistry and microstructural analysis of the 7” casing to establish a material database for the failed joint (Joint 22) and unfailed joints based on the testing data.

A summary of the above investigations and associated laboratories covered by this protocol is given in Table 1.

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Table 1: Planned investigation and associated laboratories

| Item | Investigation to be Performed | Techniques used for the investigation | Identified Fact Laboratories | Location | Data Interpretation |
|------|--|---|------------------------------|-------------------------------|-----------------------|
| 1 | 3D mapping Corrosion in 24 joints | 360 degree Laser Scan of Areas of Interest | Blade Energy | Warehouse in Houston | Blade Energy Partners |
| 2 | Mapping and Reconstruction of Joint 22 failure | Paper Tracing and/or LaserScan | Blade Energy | Warehouse in Houston | Blade Energy Partners |
| 3 | Evaluation of the longitudinal split at the lower bottom fish (Joint 22, CO022) | OM, Stero, SEM, EDS | Element | Element Laboratory in Houston | Blade Energy Partners |
| 4 | Evaluation of the circumferential fracture at the top/lower bottom fish (Joint 22, CO022) | OM, Stereo, SEM, EDS | Element | Element Laboratory in Houston | Blade Energy Partners |
| 5 | Evaluation of the connectivity of the longitudinal split to the circumferential fracture of the bottom fish. | OM, Stereo, SEM, EDS | Element | Element Laboratory in Houston | Blade Energy Partners |
| 6 | Metallographic and Fractography Analysis the oblique longitudinal surface cracking indications. | OM, Stero, SEM, EDS | Element | Element Laboratory in Houston | Blade Energy Partners |
| 7 | Assessment of the surface with corrosion scale/products | XRD (or others such as XPS, AES or SIMS) | To be determined | To be determined | Blade Energy Partners |
| 8 | Evaluation of erosion/corrosion features on 7" casing body and connections | OM, Stero, SEM, EDS, Profiler | Element | Element Laboratory in Houston | Blade Energy Partners |
| 9 | Mechanicals / Chemistry / Microstructure Structure Analysis of the 7" casing | Tensile, Charpy, Hardness, J-R, Emission Spectroscopy | Element | Element Laboratory in Houston | Blade Energy Partners |

Much of the work will be conducted at the Element Laboratory in Houston (Element). Element personnel will be conducting the data/evidence collection under the direction of Blade. Blade will be directing the data/evidence collection exercise. Blade will be doing all of the interpretation. Some of the work will be conducted by Blade personnel, such as laser scanning of the pipe and reconstruction. This work will be done at the Blade Warehouse or at Blade. Blade will be responsible and accountable for all the work conducted at Element and at any other laboratories. The location of the work may change depending on the scope as additional information or insight is obtained as the investigation progresses.

Because multiple fact-laboratories are to be involved in the investigation, transfer and associated transportation of the evidence from the Blade Warehouse to the respective laboratories will be the first step in the investigation. The protocol for evidence transfer and transport is included in this document. The protocol also includes minimum requirements for the receipt, handling, storage and retention of evidence.

This protocol focuses primarily on the investigation of the failed 7" casing. In addition to the 7" casing, tubing and wellhead components were also collected from the well. This evidence is briefly discussed in this protocol. The work associated with the tubing and wellhead components will depend on the results of the 7" casing investigation but will be similar in intent, practice and philosophy.

2 Documentation during local transportation

The casing, tubing and wellhead has been transported to the warehouse following other protocols with appropriate corrosion protection in place. This section discusses primarily movement of the casing, tubing and wellhead samples as necessary for laboratory examination within Houston.

Documentation is required any time evidence is transported to another location, for example, from the Blade Warehouse to another facility such as Element or other fact-laboratories. The documentation is intended to ensure that the condition of the evidence upon arrival is the same as when it departed.

Following receipt of samples, from Aliso Canyon, at the warehouse all security seals such as Blade zip-ties and crate tape were inspected for tampering and photo documented. No damage was documented during the initial documentation. All containers were intact and security seals were in place. Some of the tamper proof crate tape showed signs of damage caused by wind during transportation. These were noted and documented. Additional documentation will be required when bolsters are disassembled, sealed containers are opened and when evidence is transported to other facilities. The minimum requirements for each are described in the following sub-sections.

Figure 8 shows a diagram of how evidence may move during the investigation. The diagram serves as an example of when documentation of evidence should occur prior to departure and upon arrival. The blue dots shown in Figure 8 indicate documentation required prior to evidence departure. The red dots indicate required as-received documentation. Complete documentation of the as-received condition of the evidence (full disassembly of bolster and/or sealed containers) must occur prior to commencing any work or shipment to another location.

For example, the bolsters have been received at the Blade Warehouse. Bolsters were inspected for damage but were not disassembled for inspection of every joint. The disassembly process and inspection must occur prior to any work at the warehouse or shipment of the bolster to another facility. The items in green indicate completed steps. Items in black indicate steps that may occur during the investigation.

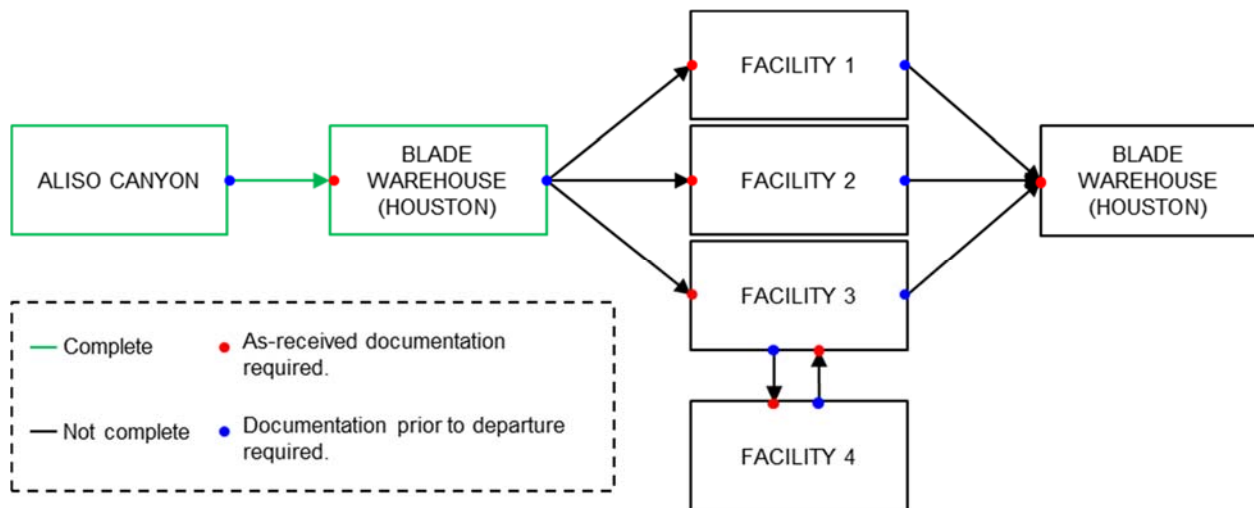


Figure 8: Example diagram of evidence transportation

2.1 As-received Documentation for Bolsters

Bolstered items will be inspected for handling and/or transportation damage at any time. Documentation of handling and/or transportation damage must be completed prior to commencing any work or additional transportation. For inspection, each joint will be removed from the bolster and inspected for any damage caused by handling or transportation. Any damage identified during the inspection will be noted and photo documented. The steps below serve as a guideline for documenting evidence stored in a bolster.

1. Photograph all bolsters upon arrival (prior to unloading). Include photos of the bolsters on the truck, unloading process and new location after unloading.
2. Unload bolster from the truck.
3. Photograph the bolster prior to disassembling.
4. Document and photograph any damaged identified during the inspection.
5. Inspect each joint after removal from the bolster.
6. Document and photograph any damage caused by handling or transportation identified during the inspection.

2.2 As-received Documentation for Sealed Containers

Sealed containers will be inspected for handling and/or transportation damage at any time. Documentation of handling and/or transportation damage must be completed prior to any work or additional transportation of evidence. In order to perform the inspection, security seals will be broken prior to opening the container. All security seals will be photographed prior to breaking. The container will then be opened/disassembled. Photo documentation will occur at each stage of the disassembly process. The steps below serve as a guideline for documenting evidence stored in a sealed container.

1. Photograph all sealed containers upon arrival (prior to unloading). Include photos of the containers on the truck, unloading process and new location after unloading.
2. Photograph sealed container.
3. Photograph all security seals used to secure the container.
4. Break seals and open container. Seals should be saved if applicable (zip-ties can be saved whereas crate tape cannot).
5. Photograph each step of the disassembly process (for example, joints were sealed in a Mylar bag. Photographs should be taken of the Mylar bag prior to opening).
6. Photograph all evidence prior to removal.
7. Remove all evidence.
8. Photograph evidence after removal.
9. Inspect the evidence and document and photograph any handling or transportation damage.

2.3 Documentation before Transportation

Any evidence shipped to a different location will require documentation before departure and upon arrival. Before departure, each bolster and/or sealed container must be unbolstered or disassembled for a detailed before transportation inspection. The purpose of this step is to complete the documentation at the current location prior to moving evidence to a new location. Any damage identified during an investigation must be isolated to a single transport. In other words, the source of the transportation damage should be traceable. Photo documentation prior to shipment will include the following:

1. Photograph all evidence in its shipping container (bolster, wooden crate, etc.)
2. Include photos of securement methods. Care should be taken when transporting evidence to ensure no damage occurs to the evidence.
3. Photograph loading procedure for the evidence including equipment used for handling and loading (forklift, crane, straps, etc.).
4. Photograph all evidence after securement to the transportation vehicle. Include photos of equipment used to secure evidence to vehicle (wood, ratchet straps, etc.).
5. Photograph all security seals used to secure the evidence.
6. Photograph any relevant information for the shipment (license plate, DOT number, etc.).

Upon arrival at the destination the evidence will undergo as-received documentation by the recipient and/or Blade. Blade shall be present upon receipt of the evidence when applicable. The as-received guidelines stated above will be followed by the recipient. The previously described procedures are minimum guidelines for as-received documentation. Recipients of evidence may have facility protocols in place for as-received documentation. These protocols shall govern as long as they meet the minimum requirements stated above.

3 Protective Storage: Receipt, Handling, and Retention of Evidence

The investigation will require shipping, handling and storage of evidence. The type and size of the evidence will vary throughout the investigation. Evidence may include items as large as wellhead components and joints, or may be as small as fracture surface metallographic cross sections and scale. All items shipped to Houston for investigation constitute as evidence and great care shall be taken in the shipping, handling and storage of all evidence outside of the Blade Warehouse.

The following procedures are the requirements for receipt, handling, storage and retention of evidence. Many of the test facilities/laboratories have their own procedures. Each facility shall provide their procedures to Blade in advance for review and approval. Before releasing the evidence to a facility, Blade will confirm that it follows the procedures that are equivalent to or exceed those discussed in this section.

3.1 Evidence Receipt

Evidence transported to a test facility/laboratory will undergo a transfer of custody. The receiving facility will sign the COC forms and accept custody of the evidence. As-received documentation by the receiving facility shall be conducted as described in Section 2. All evidence transported to a facility shall have identification numbers. These identification numbers will be maintained at the receiving facility. These identification numbers will be marked in packaging or other documentation that will travel with the samples. After the transfer of custody and as-received documentation, all evidence shall be protectively stored in a secure location.

Many of the test facilities/laboratories have their own inventory system/identification numbers, and prefer to keep their system unchanged. Continuity of specimen identification is crucial for the integrity of the evidence. It is preferred that the name/identification of any evidence transported to a facility be maintained. In the event that a new name/identification number must be issued, a cross reference to previous name/identification numbers shall be constructed and approved by Blade. The original Aliso Canyon identifiers shall be traceable as the samples go through the metallurgical examination.

Naming conventions will be changed to provide clarity for the evidence being identified or due to facility requirements. In any event, it must be possible to trace evidence at any stage of the investigation back to its parent material in the well or location in Aliso Canyon. All naming changes to ensure traceability will be logged by Blade.

3.2 Evidence Handling

Handling of evidence shall be conducted in a way that minimizes the risk of damage or contamination. Evidence will be inspected, tested and examined by various parties involved in the metallurgical analysis to assist with the determination of the root cause. If handling damage occurs, it must immediately be documented. Blade personnel will always be present with evidence is handled. This guideline is to prevent confusion during interpretation of test results and inspections. The following guidelines shall be followed to minimize the risk of handling damage or contamination.

Tools and equipment used for handling tubulars, wellhead components, and other large evidence should be blunt and soft. Equipment or material in contact with evidence should not be able to damage the contact area or leave visible marks, for example:

- A forklift shall have padded forks.

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- A crane shall use nylon slings.
- Evidence should be placed on wood or some other non-marking material to prevent surface damage during storage or examination.
- Wood used to contact evidence should be free of nails or other metal fragments.
- If metal or hard materials must be used to manipulate or hold evidence, a soft material shall be placed between the evidence and the contacting material.
- When using ratchet straps, a soft barrier shall be used to prevent the ratchet from contacting the evidence.

Handling of small evidence shall follow the guidelines stated above. Additional care must be taken to prevent damage to critical evidence containing features such as fracture surfaces and corrosion.

3.3 Evidence Storage

Evidence will be stored at various facilities throughout the investigation. Storage requirements depend on the evidence size and type. Protective storage of evidence shall meet the following minimum requirements and shall be approved by Blade.

1. **Secure:** Evidence associated with this project should be stored in a location that prevents access from unauthorized personnel.
2. **Traceable:** Movement of any evidence in and out of the storage location should be well documented. Unauthorized access should be traceable (seals, alarms, etc.).
3. **Environmentally harmless:** The as-received state of the evidence should not change due to the condition of the storage environment.

3.3.1 Protective Storage at Element Houston

Storage of metallurgical and fractographic analysis samples at Element, depending on the sample size, require the following:

1. For long, flawed or ruptured tubular samples and wellhead components, the storage requirements include:
 - Isolated storage area(s) assigned for this project only.
 - Storage area(s) should not be accessible to the public or unauthorized personnel.
 - Storage area(s) should provide cover such as a roof or equivalent.
 - Wellhead components should be stored on a wood/plastic pallet, stands or equivalent.
 - Wellhead components can be stored on a shelf, depending on the size and weight of the components.
 - Access to stored tubulars should be traceable (paper and electronic log book) by authorized personnel.
 - A worksheet for evidence handling, sampling and retention is required for tracking various details.

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2. For smaller samples such as fracture fragments of the failed tubular and samples created during the investigation, in addition to the above, the following requirements shall be followed for protective storage:
 - A specific storage container such as a desiccator, vacuum storage container, sealed plastic bag containing desiccant, vacuum sealed plastic bag or equivalent should be used.
 - The storage container shall have the same ID(s) as that of the sample(s) stored inside.
 - The space or room for storing the storage container should not be accessible to the public or unauthorized personnel.
 - The room for storing the storage container should be environment-controlled according to the required environment conditions in such a manner to prevent contamination, deterioration, loss or damage.
 - Access of the storage container should be traceable (log book).
 - A worksheet for evidence handling, sampling and retention is required for tracking various details.

All evidence shall be logged in a log book maintained by the facility. The log book shall contain all key information and be consistent with the Chain of Custody (COC) process. The log book shall be in both paper and electronic form. The log book shall only be accessed by authorized personnel. The electronic log book must be password-protected to prevent unauthorized use. There will be a process owner for the log book.

The log book shall be updated during the course of the investigation. The log book will provide a clear record as to the movement of evidence in and out of the secure location. The log book should include, but is not limited to, the following information:

- Facility Name
- Storage location description and ID
- Evidence ID (Facility ID and associated Blade ID if different)
- Reason for Action (logged in or out)
- Date and time
- Facility representative removing or returning evidence
- Blade witness
- Additional comments or notes

3.4 Retention of Evidence

All evidence shall be retained at the facility throughout the duration of the investigation. At no time will any evidence be disposed of without proper approvals. Sectioning and cutting of evidence may occur during the investigation. Non-critical pieces of evidence created during sectioning and other similar activities are not considered scrap and shall not be disposed of. Care shall be taken to record and document the location of any non-critical pieces of evidence relative to the parent material. All pieces of evidence associated with a larger parent piece of evidence shall be kept together and properly identified.

4 Establish the Mating Fracture Surface of Parted 7” Casing

During a fracture failure, there is always a possibility that some additional fragments of the casing are lost in the hole. For example, when the casing parted there is a possible scenario where there was another parted piece, and being small may be lost in the wellbore. Therefore, prior to initiation of the failure analyses, it must be established as to whether or not all the fracture fragments have been recovered from the well. Reconstruction of the mating fracture surfaces is a necessary first task.

Two reconstruction methods will be attempted here, including tracing and 3D image reconstruction of the fracture profile to piece the fracture back together. Once the mating fracture surfaces are reconstructed, if there are any missing fragments they will be identified.

Two techniques will be utilized to perform the reconstruction. The first is to simply use paper and pencil to trace the fracture surface profile. The traces are then cut and pieced together, then wrapped around a 7” OD cardboard tube to examine how the segments match. Figure 9 shows reconstruction of a pipeline failure performed by Blade using the paper method. The second technique uses 3D laser scanning technology to create a model of the fracture profile. Measurements taken from a reference line can then be used to create a 2D trace of the fracture profile. The first method is the primary means of reconstructing the mating fracture surfaces. The second method, using the laser scan, will be attempted; either one may be used for the final report.



Figure 9: Reconstruction of pipeline failure using paper method

Figure 10 is a diagram showing sections made in the field for C022 and C023. The target segments for mating fracture surface reconstruction will be C022B and C023A1 which correspond to the downward facing and upward facing fracture surfaces, respectively. Segment C022B contained the downward facing circumferential fracture surface only. Segment C023A1 contained the upward facing circumferential fracture surface as well as a longitudinal split. Additional features were noted on the OD surface of the pipe as well. These features may also be transferred to the paper trace and 3D model.

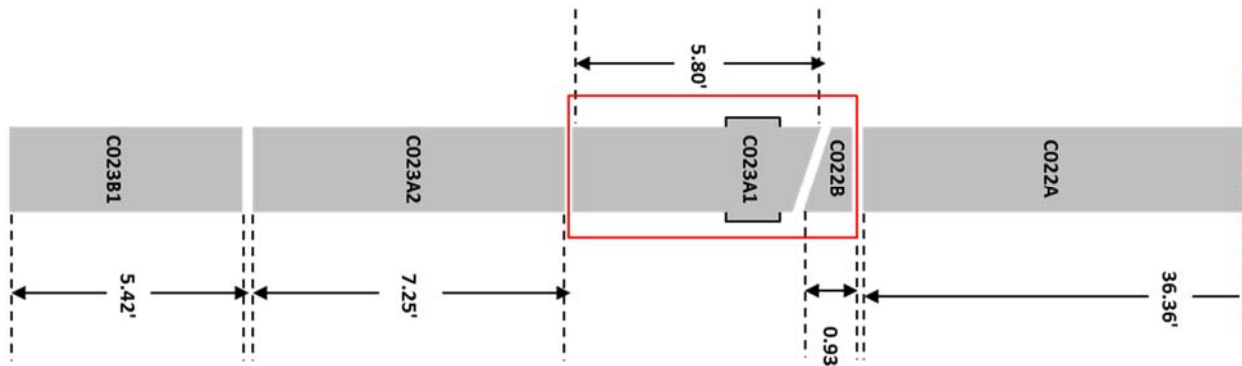


Figure 10: Section diagram for failure location

4.1 Paper Reconstruction

Paper reconstruction shall be done for C022B and C023A1. The trace will cover the entire longitudinal and circumferential fracture surfaces as well as other features identified during the reconstruction. The procedure for paper reconstruction is described below.

1. Collect the necessary equipment to perform paper reconstruction. Required equipment includes:
 - a. Scissors and precision utility knife
 - b. Non-marking tape
 - c. Pencil
 - d. Butcher paper or equivalent
 - e. Clear plastic wrap or equivalent
2. Cut the paper into a rectangle large enough to cover the fracture surface. The length of the rectangle should be long enough to cover the fracture surface and some length of non-damaged pipe. The width of the rectangle should be slightly longer than the OD circumference. Figure 11 is a diagram showing the dimensional layout for the initial paper rectangles for both C022B and C023A1.
 - a. Multiple rectangles may be used for any dimension (length or width) that is too long to be covered by a single sheet.
 - b. Multiple rectangles will be taped together to maintain continuity of the reconstruction.

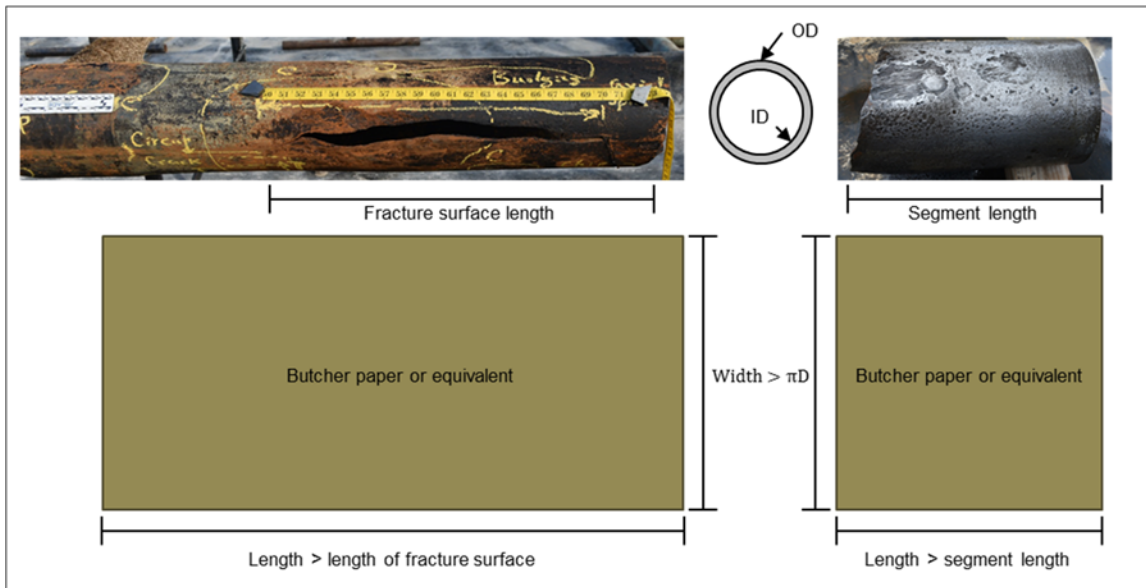


Figure 11: Butcher paper dimension layout

3. Wrap the paper around the OD surface of the segment. Ensure that the paper extends beyond the fracture surface and that the paper overlaps around the circumference of the pipe.

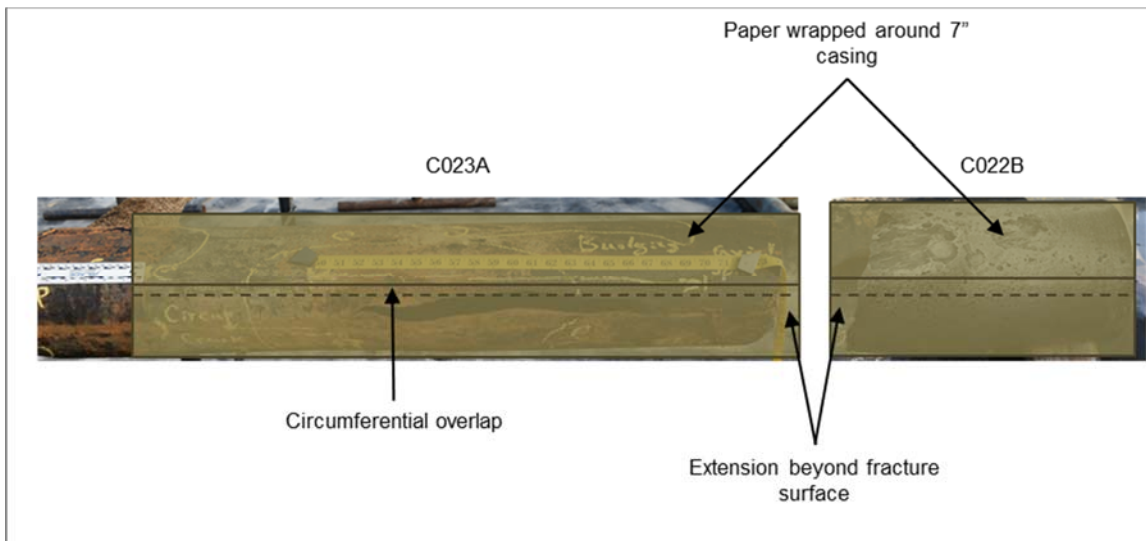


Figure 12: Segments wrapped with paper prior to tracing

4. Using a pencil or other soft non-permanent mark, trace the entire fracture surface profile onto the paper.
5. Unwrap the paper from the pipe and lay it on a flat surface. Cut out the trace of the fracture surface. Cut down the rectangle so that the width is equal to the circumference of the pipe.
6. Repeat steps 3-5 for the next segment.

7. Stitch together the two fracture surface traces and tape them together (Figure 13). Check for any missing fracture surface fragments. These are identified by traces that do not match or leave a hole. Photograph the stitched segments with emphasis on the stitch locations and any missing fracture surface fragments.

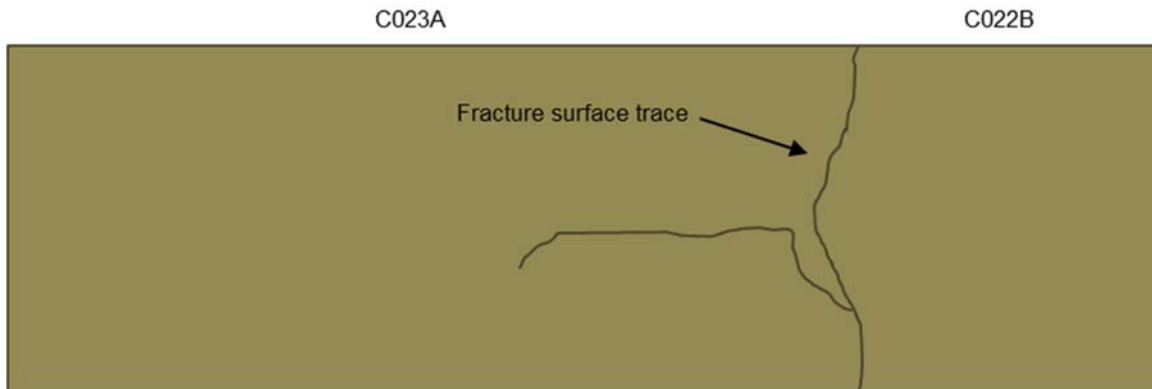


Figure 13: Stitched paper traces

8. Place plastic wrap over the paper traces and transfer the traces to the plastic using permanent marker. This will create a single 2D trace for both segments stitched together (Figure 14).

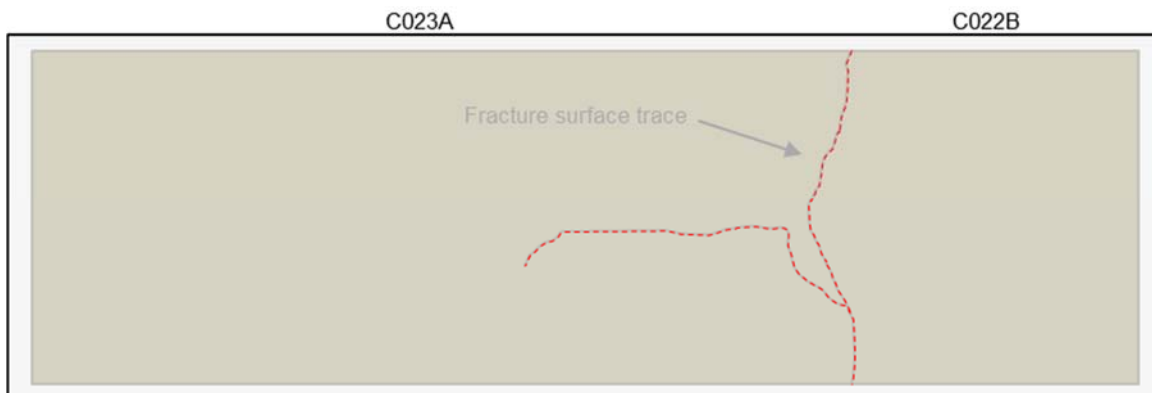


Figure 14: Plastic wrap over paper with traces transferred to plastic

9. Wrap each segment with the newly created plastic trace and transfer any features from the OD surface (corrosion, mechanical damage, etc.). Any notes regarding the fracture surface may be transferred as well (missing fragment locations, chevron marks, arrest locations, etc.).
10. Wrap the plastic around a 7" cardboard tube to complete the reconstruction (Figure 15).



Figure 15: Plastic wrap over 7" cardboard tube or equivalent

4.2 3D-LaserScan Reconstruction

The second method, 3D-LaserScan reconstruction shall be done for C022B and C023A1. The model will cover the entire longitudinal and circumferential fracture surfaces as well as other features identified during the reconstruction. The procedure for 3D-LaserScan reconstruction is described below. The high level procedures for scanning are as follows:

1. 3D LaserScanner Hardware and software installation and setup.
2. Surface preparation.
3. Optimize the scanner calibration.
4. Set the scanner configuration.
5. Build the positioning targets.
6. Reference point selection.
7. Set scan parameters.
8. Scan.

4.2.1 Hardware installation

The hardware components of the 3D laser scanner are listed below. Figure 16 shows an image of the scanner hardware for reference.

1. Laser scanner
2. Firewire cable for connecting the laser scanner to the computer
3. Power cord
4. Computer expansion card for connecting the scanner
5. Scanner stand
6. Positioning targets
7. Reference arrow



Figure 16: Laser scan hardware

Metallurgical Protocol

The procedure for connecting the hardware is shown below.

1. Turn on the laptop and wait for the computer to boot-up.
2. Install the expansion card into one of the expansion slots of the computer.
3. Connect the computer end of the firewire cable (Figure 17) to the expansion card.
4. Plug in the power cable to an outlet.
5. Connect the power to the firewire cable (Figure 17).
6. Plug the scanner end of the firewire cable into the scanner. The power indicator should light up (Figure 17). If not, try disconnecting the cable and power supply and reconnect. Check the wall outlet to ensure power is supplied to the outlet.

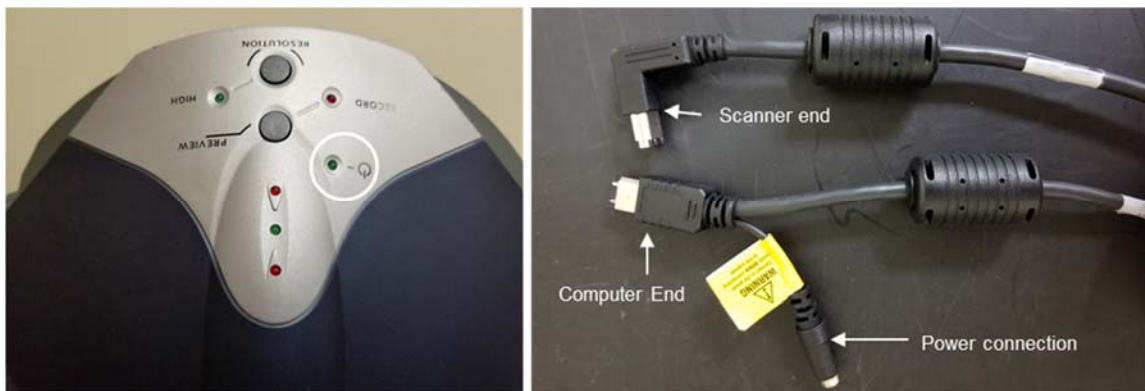


Figure 17: Power indicator (left) and firewire cable diagram (right)

7. Launch Pipecheck. The software will take you to the Pipecheck home screen (Figure 18). Note: If Pipecheck indicates that the scanner is disconnected (Figure 19), disconnect the scanner, close Pipecheck and repeat steps 2-7. If the second attempt fails, refer to the user manual for details on how to troubleshoot.

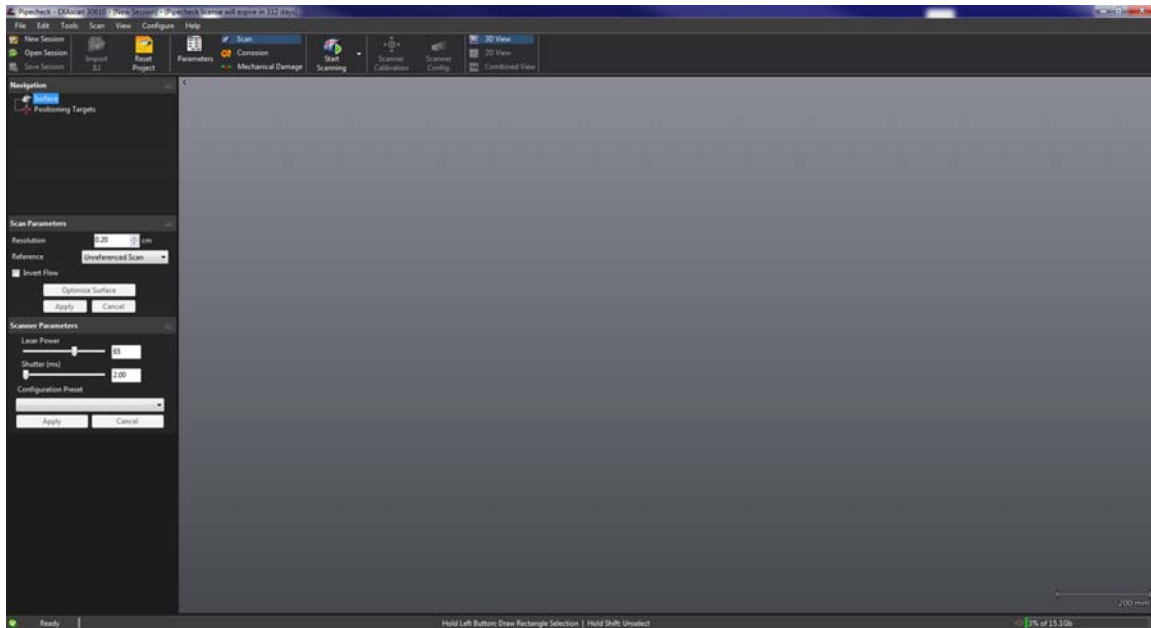


Figure 18: Pipecheck software

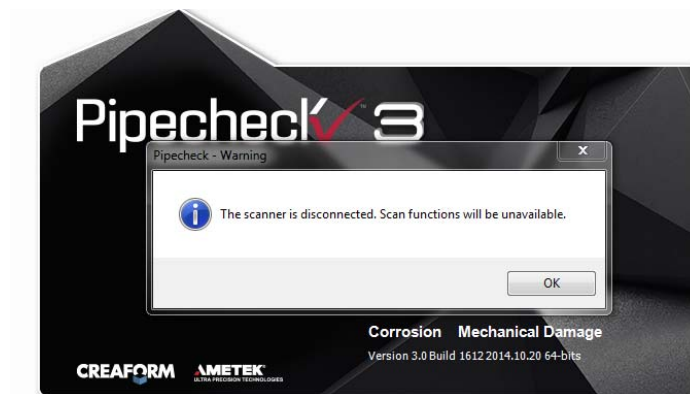


Figure 19: Pipecheck scanner disconnected prompt

4.2.2 Surface Preparation

As is the case with many evaluation equipment (such as Non-Destructive Evaluation (NDE)), surface preparation is not only required but is essential for obtaining reliable results. The same is true for laser scanning technology. There are two aspects to consider when preparing the pipe surface. The first is that the laser lines make a physical measurement of the location of the pipe surface. Dirt and corrosion residue that is stuck to the pipe may obscure features that lie below. The laser lines will read the dirt profile rather than the feature. The second consideration is that the scanner works like a camera. Images of the laser lines are read to determine surface location. Artifacts can be generated by the software if the pipe surface is too shiny. To prevent this, the surface may be covered with powder or a white paint (only used if absolutely necessary).

4.2.3 Scanner Configuration and Calibration

The scanner must be calibrated and configured prior to scanning. Calibration requires the use of a calibration plate that uses a known pattern to calibrate the sensor. Calibration should occur at

least once per day or if a significant change in scanning environment occurs (such as a change in temperature). A recalibration should occur in the event the scanner is bumped or dropped. If the scanner experiences a significant bump or drop, tests should be conducted to evaluate the accuracy of the scanner. In the event that the accuracy is in question due to damage, the scanner should be sent to the manufacturer for repair and/or calibration. In most cases, calibration at the beginning of the day should be sufficient.

Configuration of the scanner requires adjustment of the laser power and shutter speed for optimization of the scan quality for the scanning environment (scan surface and lighting). Each surface has different reflection properties. It is important to adjust the scanner's parameters to obtain optimal detection of the laser lines.

4.2.3.1 Calibration

To calibrate the scanner go to **Scan | Scanner | Calibration**.

1. Place the calibration reference plate on a flat surface. Verify that no reflective objects lay near the calibration plate.
2. Click Acquire.
3. Place the scanner at approximately 4" above the calibration plate and press the trigger. The current position of the scanner relative to the calibration plate will appear in gray in 3 of the 4 views.
4. Keeping the trigger pressed, align the gray shape with the green shape. The views show arrows to indicate in which direction the scanner must be displaced to match the green position.
5. Remaining at the same position, slightly change the scanner orientation in order to align the red laser cross with the white cross drawn on the calibration plate.
6. Slightly raise the scanner to match the second position.
7. Repeat 4 and 5 until you complete the 14th calibration position (10 vertical positions and 4 orientations).
8. Click on Optimize.

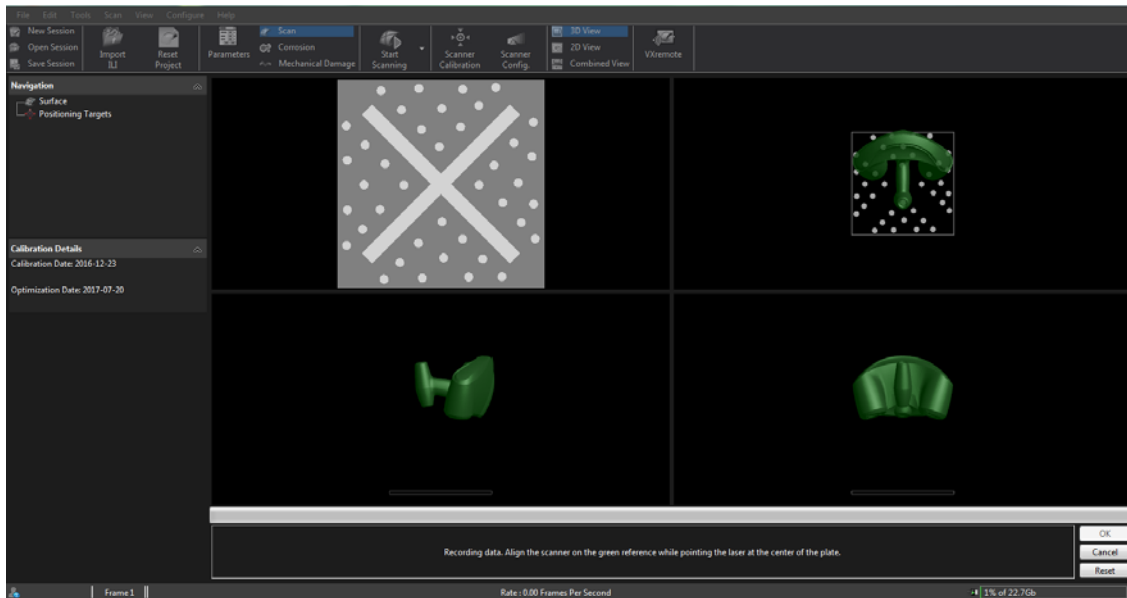


Figure 20: Calibration screen

4.2.3.2 Configuration

To configure the scanner go to **Scan | Scanner | Configuration**. The screen shown in Figure 21 will appear. The goal of the configuration is to optimize the laser power and shutter speed to avoid over and under exposure. The laser lines cannot be read properly if the image is over or under exposed. To run the automatic adjustment of the configuration, perform the following steps:

1. Click on Auto Adjust.
2. Hold the scanner at 12" from the pipe and press the trigger.
3. Keeping the trigger pressed, orient the scanner so that laser lines only contact the pipe surface.
4. Hold the trigger until the Laser Power and the Shutter values remain stable at their new position.
5. Manual adjustments can be made by moving the sliders.
6. Click Apply.

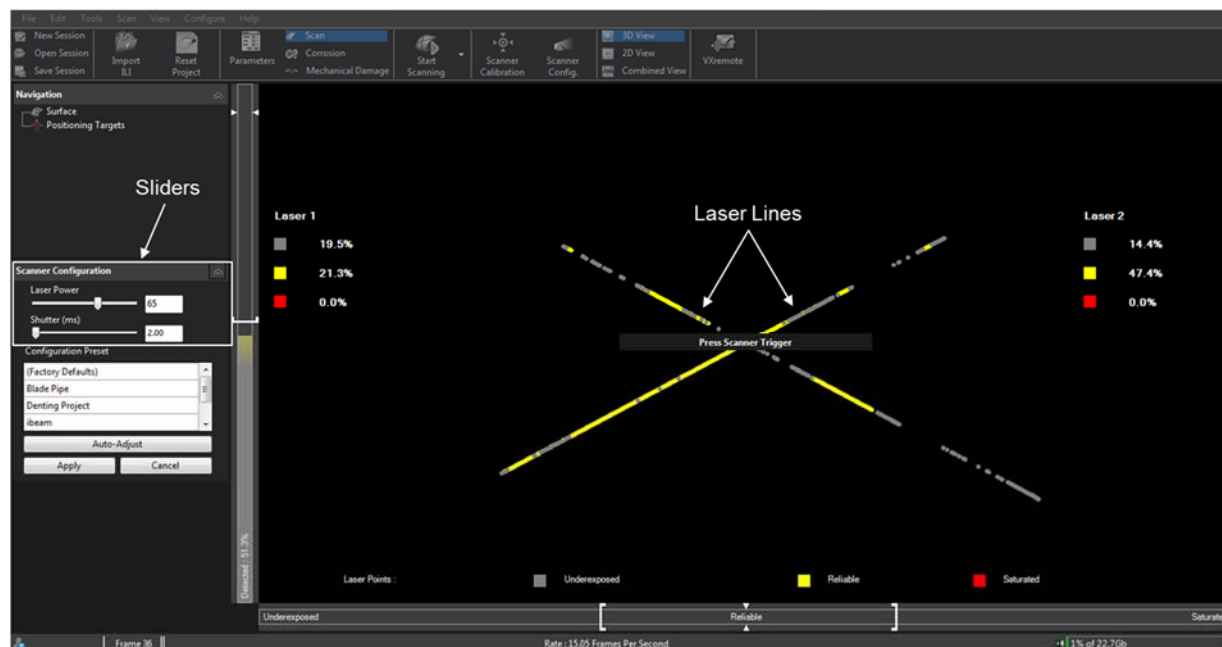


Figure 21: Configuration screen

4.2.4 Apply Positioning Targets

Before scanning the pipe, you need to put targets on its surface, randomly, to cover the entire surface you want to scan. These targets are used by the software to calculate the position of the scanner relatively to the pipe surface. There are a few guidelines to follow when placing targets.

- Targets create a spot of no data. This means the laser scanner will not take depth measurements anywhere a target is placed. Avoid placing targets on feature spots to avoid missing useful data. If this cannot be avoided, place the targets on shallower areas of the feature.
- Make sure the targets are not damaged or dirty. Damaged targets affect the quality of the scan.
- Try to place targets further than 1/8" from edges.
- Avoid aligning targets in a line.
- Avoid relying on only 4 detected targets at a time when scanning.
- Targets can be added during a scan if necessary. Targets shall not be moved or removed during a scan. This will affect the quality of the scan and could even corrupt the file.

4.2.5 Reference Point Selection

Reference point selection is critical for reconstruction. A clear reference must be identified in order to stitch the models together. The origin of the scan is selected based on the placement of the reference arrow. Figure 22 shows the location of the scan origin relative to the reference arrow. The white circle shown in Figure 22 represents the coordinate (0,0). The coordinates are described by axial and circumferential location along the pipe as is shown in Figure 23.

Reconstruction requires that both scans (C022B and C023A1) be stitched together using 3D modeling software. This process can be simplified if a common circumferential reference is identified on both segments. This could simplify the model stitching to simply sliding the fracture surfaces together (depending on the conversion algorithms of the modeling software). For pipelines, the circumferential reference is typically a seam weld. Some other marker must be identified for the 7" casing as this is seamless pipe.



Figure 22: Reference arrow showing scan origin and flow direction

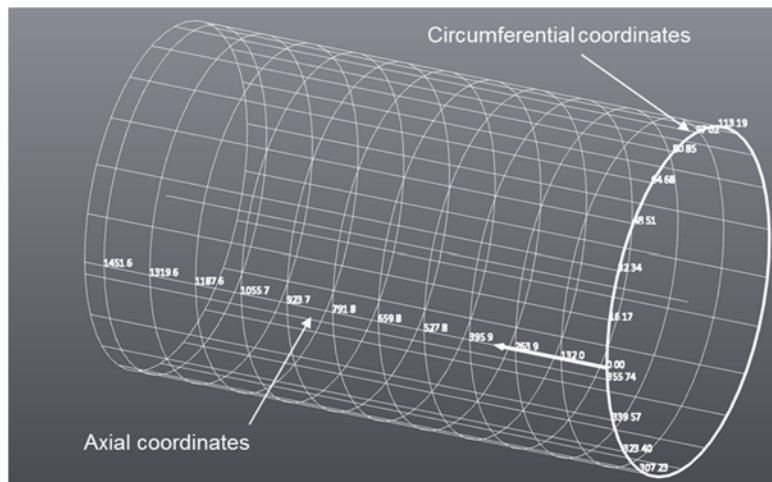


Figure 23: Pipecheck grid system showing circumferential and axial coordinates

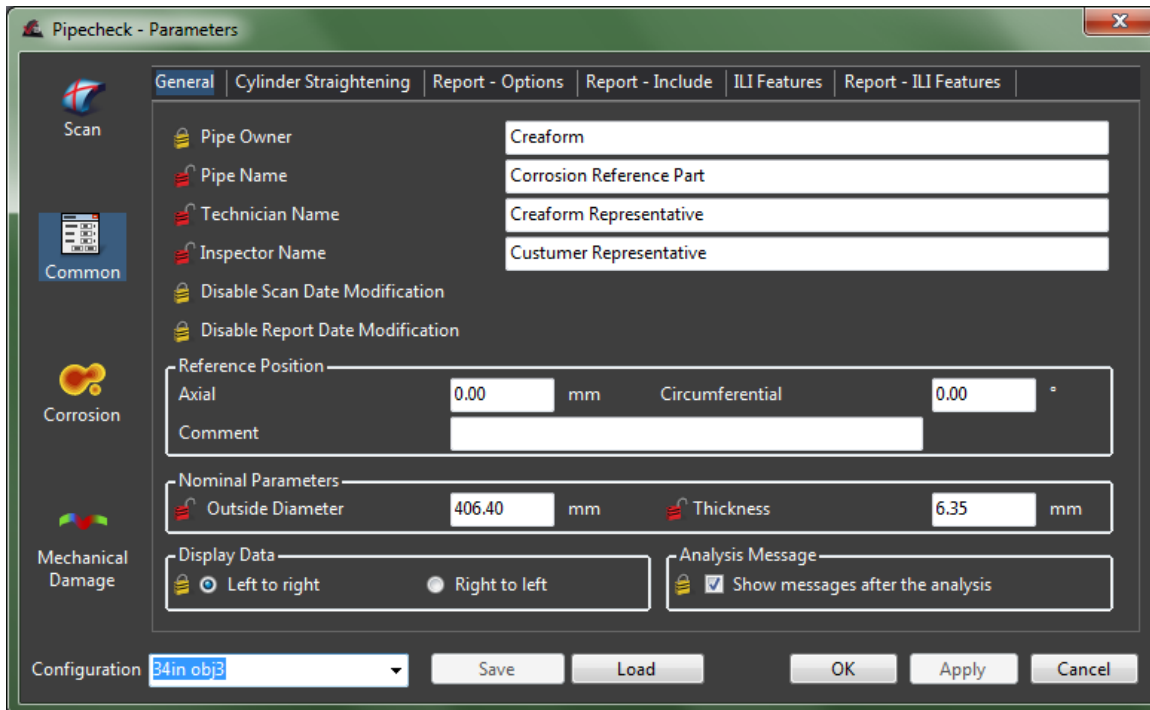
4.2.6 Scanning Parameters

Scanning parameters must be set prior to scanning. Scanning parameters include the scan resolution, reference and flow inversion. The resolution defines the size of the triangles of the meshed surface. A coarse resolution reduces the time and size of a session. A finer resolution, although more time and size intensive, allows for modeling of small features with higher precision. The recommended resolution to start with is 0.05 to 0.06 in. The lowest available value (highest resolution) is 0.008 in.

The scan reference allows the selection of a reference arrow, imported targets, or an unreferenced scan. The supplied reference arrow will typically be used to tie the 3D mesh to a reference grid. The grid is defined by the placement and orientation of the reference arrow. If multiple scans of the same item are required, imported targets may be selected to use the reference system that was in place for previous scans. This will allow users to merge scans if necessary.

4.2.7 Scanning

There are other parameters that should be set. These parameters can be found by pressing the parameters button located at the top ribbon of the software. Parameters may be changed at any point during the sessions. The parameters are used for scanning and analysis purposes. The general parameters menu will show as is shown in Figure 24. General parameters include settings such as outside pipe name, technician name, inspector name, pipe diameter, pipe thickness, reference position and other settings. The main parameters that will be used for reconstruction are outside diameter and thickness. These settings determine the reference cylinder used to determine circumferential coordinates and depth.



Pipecheck - Parameters

General | Cylinder Straightening | Report - Options | Report - Include | ILI Features | Report - ILI Features

Scan

Common

Corrosion

Mechanical Damage

Configuration: 34in obj3

Save Load OK Apply Cancel

Figure 24: General parameters

Once all the parameters are set, the scan button may be pressed to start the scanning procedure. The scanner should be approximately 12" from the pipe surface during scanning. There are several indicators that show whether the scanner is either too close or too far away from the pipe surface. The indicators are located on the scanner and software scan screen as is shown in Figure 25.

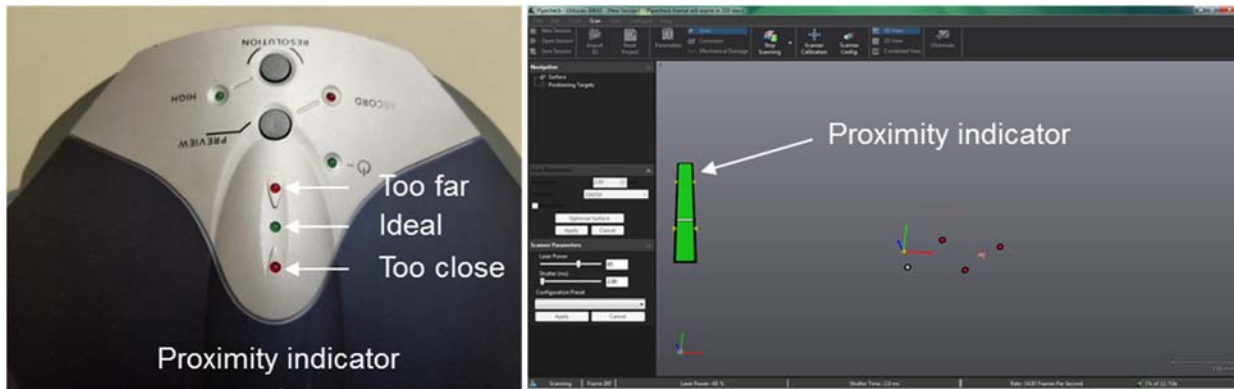


Figure 25: Proximity indicator on the scanner (left) and software (right)

The scanning process requires slow and smooth sweeps of the scanner over the pipe surface. The laser lines (X) should be visible on the pipe surface depending on lighting conditions. As the person makes slow sweeping motions of the scanner, the software will generate a real time image of the scanned surface. Continue scanning until the entire surface of the specimen has been modeled by the software. The scanning process may be paused and any time. The model can be rotated, zoomed and panned to examine the quality of the model during a pause. The process can then be resumed to repair or complete the scan. The scanning process should be stopped at regular intervals so the model can be saved. Performing this task often ensure that too much time is not lost in the event of a systems crash.

4.2.8 Reconstruction

3D modeling software shall be used to manipulate the completed scans. Pipecheck can export scanned models in several different formats which can be read by a majority of the modeling software. Both models will be imported into the same model so that the fracture surfaces may be joined. Measurements will be taken in the model software so that the 3D fracture surface can be converted into a 2D map. The conversion may be completed outside of the 3D software using excel or equivalent software.

5 OD Surface Corrosion Mapping

Surface corrosion was noted on the outside diameter (OD) surface of the 7" casing during field inspections. The OD corrosion was documented and a possible trend in corrosion severity was noted (See Section 1 Introduction). An effort will be made to confirm and quantify the trend noted in the field. The effort will also be made to identify the clock position of corrosion features around the casing. Identification of the clock position distribution of corrosion is essential to understand the corrosion events that occurred randomly or preferentially around the circumference of the casing. Careful mapping of the OD surface corrosion will be conducted in an attempt to quantify the OD corrosion.

A portable 3D laser scanning device will be used to map the OD surface. The technology uses auto position stereo vision and positioning targets to create real time rendering of objects. The OD surface of the 7" casing will be scanned and analyzed using the Creaform Pipecheck Software. The software is able analyze the 3D data generated by the laser scanner and translate it to depth measurements that correspond to specific longitudinal and circumferential coordinates. Further analysis can provide quantitative data that will help determine the severity of the OD corrosion and highlight any possible trends related to depth within the well.

The same steps discussed in Section 4.2 shall be used to setup and operate the 3D laser scanner. The high level steps are repeated below for convenience.

1. Hardware and software installation and setup.
2. Surface preparation.
3. Optimize the scanner calibration.
4. Set the scanner configuration.
5. Build the positioning targets.
6. Reference point selection.
7. Set scan parameters.
8. Scan.

Post processing of the data will be required to generate the required output. After the operational steps discussed above have been executed for a particular joint, the built in corrosion analysis tool will be used to analyze and interpret the data.

5.1 Data Analysis

General parameters such as pipe OD and thickness were discussed in Section 4.2.7. In addition to the general parameters, corrosion parameters must be set to run a corrosion analysis. The corrosion parameters are shown in Figure 26. The corrosion sites will be identified visually, and also using some of the preliminary laser scan data.

Many values are available after running the corrosion analysis, such as maximum depth, river bottom profile, feature length and width, clock position, and other data. The software has 3D and 2D viewing capabilities that allow a user to view the depth profile at any location along the pipe. The clock position distribution of corrosion features can be also extracted to determine if corrosion occurred randomly or preferentially around the casing circumference. This clock position (orientation) information will be used to assist in understanding corrosion events associated with the failure. The software is very useful for quickly examining features and generating reports.

Metallurgical Protocol

To see an overall trend of corrosion vs depth (or severity of the corrosion feature in terms of predicted failure pressure), the data for each joint must be exported so addition analysis can be completed. Exported data will be in the form of a 2D array. Columns and rows are associated with circumferential and longitudinal coordinates. Values in the 2D array represent depths at that particular coordinate. 2D maps can be generated and combined using this data. Attempts will be made to combine data from multiple joints to generate a comprehensive 2D map of the corrosion features with respect to depth or predicted failure pressure. Limitations in computer power may prevent this task as the program works with large amounts of data.

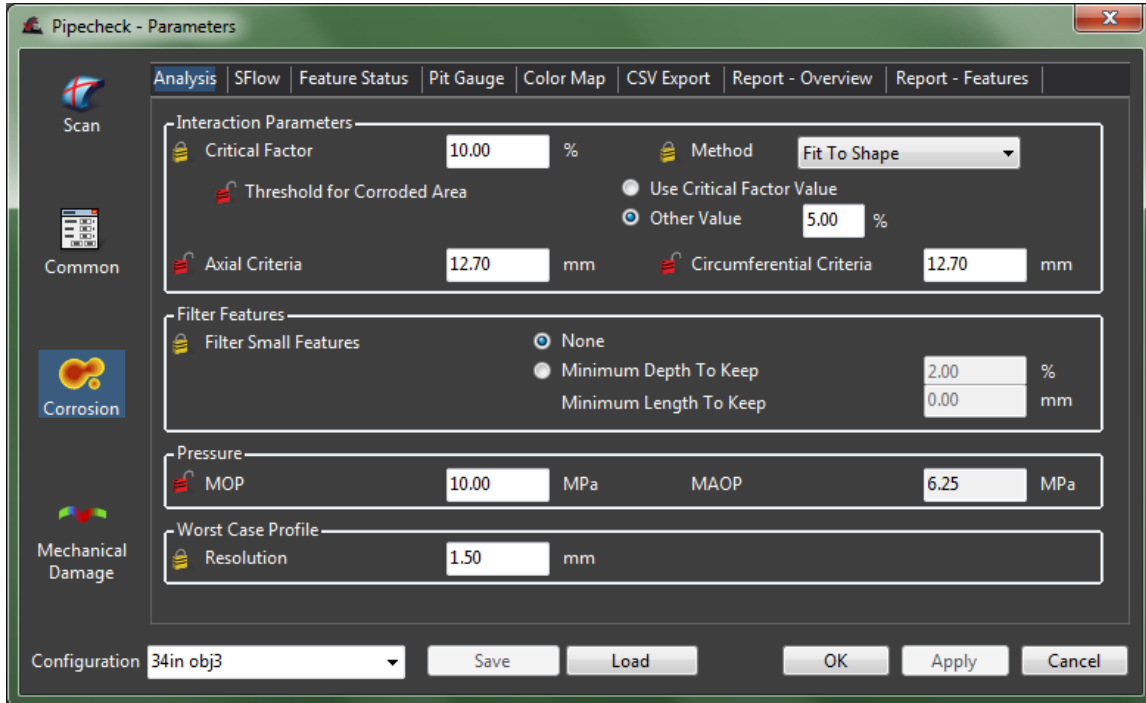


Figure 26: Corrosion parameters

6 Metallurgical Investigation

This section discusses the objectives and procedures of the metallurgical investigation. The metallurgical investigation is one of the main tasks to be completed for Phase 4 of the RCA. Element at Element Houston is selected as a factual lab to conduct metallurgical work under the direction and supervision of Blade. There may be situations that other laboratories will be utilized for work either for expediency or availability of appropriate equipment. These laboratories will also be required to have procedures must be equivalent or exceed those discussed in this document, and will be reviewed and approved by Blade prior to any work. Additionally, the need for an additional laboratory will be identified and documented via the Management of Change (MOC) process, and Blade will notify CPUC and DOGGR at least two weeks in advance. Blade will direct and supervise and will be responsible for any work sent to other labs/facilities.

6.1 *Type of Features and Investigation Goals*

Various features were identified during the field inspection of the 7" casing. A list summarizing the features is shown below.

1. Lower and upper parted 7" casing
2. Corrosion and/or Erosion features
3. Oblique crack-like features
4. Mechanical damage

Each feature will be investigated. However, the primary focus of the metallurgical investigation will be the lower and upper 7" parted casing). The lower parted casing contains an axial split and circumferential part. The upper parted casing contains the mating circumferential part. These fractures will be investigated to determine the cause of both events. The other features to be investigated include the corrosion, corrosion/erosion features, oblique crack-like features, and mechanical damage. It is unclear which of these features really exist, and that requires verification and validation.

Details describing the goals for each feature are discussed in the following sub-section.

Due to the dynamic nature of metallurgical investigations, the following investigation goals serve as a general guideline for the investigation based on the information available at the time of writing this document. These goals may change as more data is collected because the data used to develop these investigation goals was collected in the field by Blade personnel and is considered as preliminary.

6.1.1 *Lower and Upper Parted Casing*

The lower and upper parted casing will constitute the majority of the metallurgical work. The fracture surfaces will require macro photography, stereo microscopy, metallographic sectioning, and Scanning Electron Microscope (SEM) work. Minimum procedures and guidelines for performing these tasks are discussed in later sub-sections. The primary goals for the failed 7" casing is as follows:

- Identify the origin location for the failure.
- Identify fracture zones along the fracture surface to determine the sequence of events that led up to and followed the initial failure.

Metallurgical Protocol

- Characterize the nature of fracture for each of the fracture zones both macroscopically and microscopically.
- Determine how the axial split and circumferential part connected, one single event of fracture or two events occurred at different time.

Figure 27 shows an image of the upper and lower fish of the 7" parted casing. The images illustrate the axial split and circumferential part. The origin of the failure will be determined by investigating the fractures surfaces of the axial split and circumferential part. This will be accomplished using visual examination, macro photography and stereo microscopy. Fracture surface features identified during the investigation will assist in determining the origin of the fracture. Once identified, the origin will be clearly marked and sized (for example, length, depth and width for corrosion). The remaining areas of the fracture surface will also be further examined and sized for zones of fracture. This will also be accomplished using macro photography and stereo microscopy. Each unique zone will be clearly marked for future investigation.

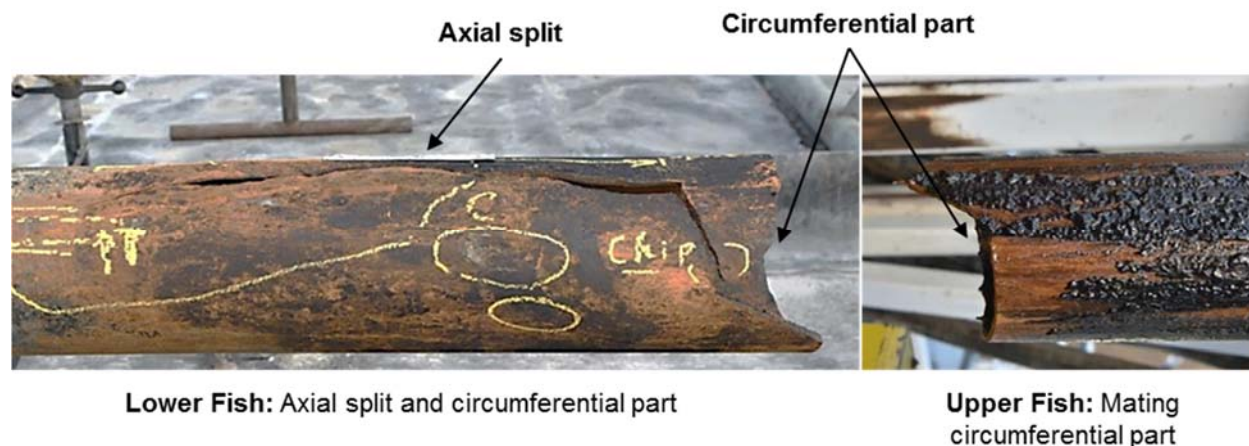


Figure 27: Lower and upper fish (parted 7" casing Jnt 22)

Quantitative measurements shall be taken during the initial visual examination of the fracture surface. This may include wall thickness measurements, fracture zone size (for example, length/depth/width for corrosion and length/depth for crack, etc.), circumferential measurement to features and other such measurements as is deemed necessary. Measurements may be taken from a macro point of view, such as pipe ovality, wall thickness and other similar measurements. Measurements will be made using appropriate devices. Small scale measurements may be taken with the stereo microscope or other devices designed for small scale measurements. It should be noted that the OD surface shall be documented using the 3D laser scanner. The details of which are covered in Section 4. This data will be preserved allowing some measurements to be taken later on in the investigation (even after the sample has been cut).

Once the fracture surfaces have been fully documented with the camera and stereo microscope and all quantitative data has been collected, cut locations will be determined for metallographic sections and scanning electron microscope (SEM) samples. Cut locations will be determined by Blade and will be based on observations made of the fracture surfaces.

Metallographic sections will typically be documented in the as-polished and etched conditions. Exceptions may arise based on the particular section. SEM samples will be examined under the direction and supervision of Blade. Samples will be documented in the non-cleaned and cleaned conditions. Cleaning will be performed in stages with documentation occurring at each stage.

Cleaning procedures will be discussed between Blade and Element prior to proceeding with any cleaning.

Determination of the cause of the parted 7" as well as the sequence of failure events shall be determined on the basis of the factual data collected during the metallurgical investigation.

6.1.2 Corrosion Features

Corrosion features were identified during the field examination of the 7" casing. The severity of the corrosion appeared to increase with depth. The observation is qualitative in nature. Attempts will be made to quantify the observations using 3D laser scanning techniques as is described in Section 5. Figure 28 shows an example of a more severe corrosion feature. The main goals of the corrosion investigation are as follows:

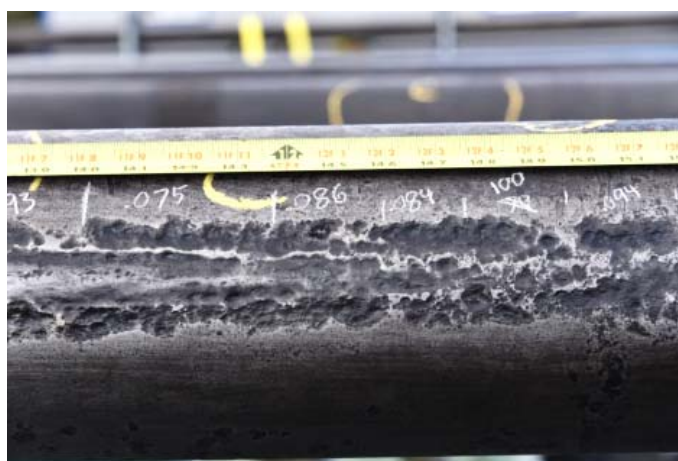


Figure 28: Example of erosion/corrosion feature (Jnt 20)

- Fully characterize corrosion features (size, depth, frequency, severity)
- Determine the relationship of the corrosion features to the failure of the 7" casing
- Classify the features in detail (corrosion, erosion, corrosion/erosion, etc.)

Much of the investigation will be conducted in the same manner on the lower and upper parted casing samples. Macro and stereo microscopy will be used to assist with documentation and characterization of the features. Much of the characterization will be accomplished using 3D laser technology as described in Section 5. The 3D models of the features will provide a record of the feature location and dimensions for future analysis (even after the feature is cut for metallurgical work).

Once documentation is complete using the camera and stereo microscope, features will be selected for further investigation. Sampling of the features should include variations of the observed features to ensure a good representation. Variation may include differences in general appearance, maximum depth, overall severity and other such variables. Cut locations will be selected for each selected feature for metallurgical sections and SEM specimens.

Measurements will be taken using a stereo or metallurgical microscope to verify maximum depths and other dimensions to the 3D laser scans. Metallurgical cross sections are typically documented in the polished and etched conditions. Exceptions may arise based on the particular section.

SEM samples will be selected based on features identified during the initial visual examination. Energy Dispersive Spectroscopy (EDS), X-Ray Diffraction (XRD) or similar techniques may be used for elemental and/or compositional analysis of the fracture surface. Data obtained using these techniques may provide evidence as to the source of the corrosion. Other, more advanced techniques may be used. This will be determined based on the direction of the metallurgical investigation at that time.

Determination of the source of the corrosion features as well as the relationship to the split, if any and parted 7” casing shall be determined on the basis of the factual data collected during the metallurgical investigation.

6.1.3 Oblique Crack Like Features

Oblique crack-like features were identified during the field visual examination of the 7” casing. The features were visible after cleaning, but were more apparent after black and white magnetic particle inspection (MPI). The features were oblique to the axial orientation of the casing. The crack-like features appeared straight and tight. The main goals of the oblique crack-like feature investigation are as follows:

- Fully characterize the crack-like features and determine dimensions (length, depth, angle inclined from casing longitudinal axis, etc.)
- Determine the source of the features (manufacturing, well environment, etc.)
- Determine whether the features are dormant or active and whether the features act as a significant threat to the integrity of the casing.
- Determine the relationship of the oblique crack-like features, if any, to the failure of the 7” casing



Figure 29: Example of oblique crack-like feature

The metallurgical work for the oblique crack-like features will initially be focused on a few selected features. The relationship to the failure will be determined based on the selected features. If it is determined that the oblique crack-like features are not associated with the parted 7” casing then the investigation will be complete and no further work will be conducted on these features. If a connection between these features and the failure is suspected or confirmed, more features may be selected for further investigation.

The investigation will follow similar steps as discussed in Sections 6.1.1 and 6.1.2. Majority of the work will be done using stereo, metallurgical and scanning electron microscopes. Characterization of the feature prior to opening is limited to length (MPI), depth (UT or other) and

inclination mostly. Most of the work will be conducted once the feature is sectioned and opened. Metallographic sectioning and opening of the crack-like features shall be conducted under the direction and supervision of Blade. Crack opening may be conducted using liquid nitrogen. Cuts may be made to increase the likelihood of opening a shallow crack by removing excess material from the ligament of the fracture plane. SEM samples will be selected after the features are open and the fracture surface is completely documented. Fractographic examination will be used to identify features that will help determine the source of the crack-like features.

The nature and cause of the oblique crack-like features as well as the relationship to the parted 7" casing shall be determined on the basis of the factual data collected during the metallurgical investigation. Determination may also include whether the features were dormant or active and whether they were preexisting or occurred in the well.

Following full length NDE examination of the extracted casing joints additional metallurgical work may be required.

6.1.4 Mechanical Damage

Mechanical damage was observed during the field examination of the 7" casing. Typical features were identified such as slip marks, tool marks, tong marks and other mechanical damage associated with operations. Some of the mechanical damage features will be assessed. The main goals for mechanical damage are as follows:

- Classify observed damage
- Determine the severity of the damage.
- Determine the most likely source of the damage.
- Determine the relationship of the mechanical damage to the parted 7" casing.

Similar steps will be taken as described in Section 6.1.3. A few of the features will be selected for investigation. These features will be completely investigated and documented. Further investigation may be required based on the findings of the initial investigation. Stereo, metallography and scanning electron microscopes may be used to characterize the features. EDS, XRD or similar techniques may be used for elemental and/or compositional analysis of the feature surface. Use of these technologies is on a case by case basis of the feature under investigation.

The relationship of the mechanical damage to the parted 7" casing shall be determined on the basis of the factual data collected during the metallurgical investigation.

6.1.5 Tubing and Wellhead Components

In addition to the 7" casing, tubing and wellhead components were also extracted from the well. The initial field investigation did not identify any evidence directly linking the tubing or wellhead components to the 7" casing failure. Further work will be completed to clarify the findings from the initial field investigation. Investigation of the tubing and wellhead components will follow the minimum guidelines discussed in the following sub-sections. Details of the investigation goals will be identified after partial completion of the investigation goals described for the 7" casing above.

6.2 Macro-Fractographic Examination

Macro-fractographic examination of fracture surfaces, corrosion and other features is the first step when performing the metallurgical work. The purpose of the macro-fractographic examination is

to capture the big picture of the feature under examination. This initial work is typically carried out using:

1. Visual Examination
2. Digital photography
3. Stereo microscopy

6.2.1 Visual Examination

Visual examination of the failure area and adjacent areas is the first and essential step to determine, photograph, and/or schematically record: (a) origin of the failure; (b) direction of crack propagation and sequence of failure, (c) failure modes and possible mechanism, (d) presence of contributing imperfections, such as wall thinning due to corrosion, mechanical damage, cracks, or other metallurgical and/or manufacturing defects; (e) presence of corrosion scale/deposits on fracture surfaces; (f) orientation and magnitude of stresses; and (g) sizes and other physical data. Throughout the visual examination phase of the failure study, all information obtained from investigation should be clearly and properly recorded or photographed.

6.2.2 Digital Photography

Digital photography has the advantage of various magnifications and portability. This allows for overall photographs showing fracture surfaces, corrosion, cracks and other features in relation to the parent material while also allowing higher magnification photos of the fracture surface and its features. Digital photography is the primary source of documentation and will be used extensively throughout the investigation. When performing digital photography, these guidelines should be followed:

- Document subjects from every angle to capture all information associated with the subject. This will allow the Blade Investigation Team to create a special map of the subject that will be used to piece back together evidence that is sectioned into smaller pieces. It also acts as a record of the original subject in the event that the subject is altered for testing or analysis.
- Digital photography should occur for every piece of evidence identified by visual examination no matter how large or small. Images may be stitched for larger evidence. Images of small evidence may not provide detail but it shall provide a record of what the specimen looked like.
- Documentation shall occur using an out-to-in method. Wide angle low magnification shots shall occur first to capture the entire subject. Increasing levels of magnification should occur to capture more and more detail when appropriate. The high magnification photographs shall be taken in such a way that the images can be traced back to the original location in the parent material.
- Additional photos should be taken using a scale for reference. This should be done for all photos showing features that may require sizing during interpretation. Photos taken with a scale may be repeated without a scale based on need. These photos are necessary to provide visual clarity and may be used for annotation and communication. Ensure photos are taken perpendicular to scales when sizing is critical.
- Cameras should be white balance and tested so images accurately represent color.

Metallurgical Protocol

- Photography should occur on a clean memory card used for this project only. Photos will be transferred to a secure location and organized by subject/evidence to maintain traceability. It is understood that labs may have protocols for storing photographs. This procedure shall be discussed with Blade.

All features must be fully documented prior to cutting, cleaning and/or performing any action that may alter the appearance, composition and/or current state of the evidence. Each stage of the metallurgical investigation shall be photographically document. This includes but is not limited to:

- Before and after performing cuts to extract or section areas of interest.
- Before and after cleaning any evidence.
- Before, during and after performing any NDE work such as MPI, Ultrasonic Testing (UT) or other non-destructive testing methods.

An example of this process would be the lower and upper fish. The following sequence is an example of what photo documentation may be required:

1. All findings obtained from Visual examination as described in Section 6.2.1 should be photo documented.
2. Overall photos showing the lower and upper parted casing oriented in a way that the circumferential parts are close but never touching. Features should be identified to approximately align the fractures surfaces circumferentially. Appropriate scales should be used throughout the documentation process.
3. Overall photos showing the axial split and circumferential part in relation to the overall joint, nearby connections and other features that may be present on the OD surface.
4. Higher magnification photos should be taken sequentially at different clock positions showing the entire OD surface. These images may be stitched at a later time to show overall photos with increased detail.
5. High magnification photos of the axial and circumferential fractures surface shall be taken to highlight fracture surface features. These will also be taken sequentially so they may be stitched together.
6. Fracture surface features of interest may be identified. These shall be documented with high magnification photos. Images of the overall pipe should be taken first followed by higher magnifications of the same location ending with the high magnification image of the feature. These photos may be used to identify the location of the feature at a later time.
7. This process shall continue for both the lower and upper parted casing until the entire OD surface, fracture surfaces and features of interest have been well documented.
8. Prior to cutting out the axial split and circumferential part, images should be taken of the proposed cut locations marked on the pipe. This should be standard for all cuts including metallurgical sections.
9. Images of the entire pipe with the extracted fracture surface should also be taken post cutting.
10. The procedure shall continue as metallographic sections and SEM specimens are extracted from the fracture surface. Extracted sections and specimens taken from fracture surface shall be documented in their extracted location post cutting.

6.2.3 Stereo Microscopy

Stereo microscope used at this stage of investigation takes low magnification images (up to 10X) of fracture surface with increased detail. They also allow measurements of small scale features. The stereo microscope may not be used until the evidence has been cut and critical features have been extracted. This is due to size requirements of the stereo microscope. When using the stereo microscope, these minimum guidelines should be followed:

- Large samples may not fit under the microscope. The minimum amount of cuts permissible should be made to allow key features to fit under the stereo microscope.
- Complete documentation of the entire fracture surface or feature using various magnifications. Images should be taken in one direction and in sequence.
- When documenting cross sections (such as fracture surfaces), a single orientation should be maintained throughout the investigation (i.e. OD is always at the top of the image).
- When a features is cleaned or altered. Documentation should be repeated at that same magnification to show changes.

6.3 Micro-Fractographic Examination

This is also a critical phase of the overall metallurgical examination of failure area and adjacent areas. This is applicable for tubing/casing/connection/wellhead/tree/other components. This will provide insight into any and all failure mechanisms. Various equipment will be used including but not limited to metallographic microscope, stereo microscope; and scanning electron microscope (SEM). As discussed previously, an out-to-in approach shall be used to document specimens. The approach is used to focus on specific features and areas of interest identified during the macro investigation. The following is a list of but not limited to areas of interest for the micro-fractographic examination. Additional areas may be identified during the investigation.

1. The stereo microscope shall be used at higher magnifications at this stage of investigation to thoroughly document the fracture surface including feature dimensions before and after cleaning. The stereo microscope will be indispensable for locating key features accurately for further investigation.
2. Key fractographic samples will be extracted as necessary for detailed microscopic examination using a scanning electron microscope. Further examination of the initiation, subcritical and final failure region is essential for mechanism indications. The examination will include documentation of the fracture surface morphology before and after cleaning.
3. Characterization of fracture surface chemistry of surface deposits and corrosion scales will be conducted using SEM/EDS for environmental indications.
4. Specimens will be cleaned using appropriate solutions and techniques (see Section 6.3.3.) to remove rust, scale, etc. as necessary. Cleaning exposes underlying morphology and microscopic features essential for determining failure mechanisms.

6.3.1 Stereomicroscopic Examination

Following macro-fractographic examination of the fracture surfaces, examination should be performed using a stereo microscope at higher magnifications for capturing detail. The following is a list of some of the tasks that should be carried out during the stereo microscope examination.

1. Confirm the findings provided by the macro-fractographic examination

2. Photo-document the detailed characteristics of the fracture surfaces for each of the fracture zones, namely, failure initiation zone (site), failure propagation zone; and final rupture zone.
3. Measure the respective dimensions (length, width, and depth) for each of the fracture zones, namely, failure initiation site, failure propagation zone; and final rupture. Measurement can be performed on the photo prints or directly from the screen using the supporting software. The measured profile along with the measurements by SEM shall be used as support for remaining strength calculations.
4. Identify areas for extracting samples for Scanning Electronic Microscope (SEM) examination and metallurgical sectioning.
5. Provide maps for SEM/EDS examination for each of the areas of concern.

The following is a minimum set of guidelines that should be followed when conducting the micro stereo microscopic examination.

- Overall stereo images of the fracture surface should be compiled showing a complete map of the fracture zones and features of interest. The maps should be marked showing the various areas of interest.
- Key words used to identify areas of interest should be used to correlate high magnification images to the overall map. Naming conventions should be used to identify specimens extracted from the fracture surface or feature (corrosion, cracks, etc.) under examination. The naming convention should easily identify the specimen and be maintained throughout the investigation. Naming schemes should be discussed with Blade prior to specimen examination.
- Images should be taken using various lighting techniques to exaggerate target features. Although the stereo can see depth when using the eyepieces, this depth may not be visible when taking a digital image. Lighting is an excellent tool to convey depth in an image.
- The microscope shall be properly calibrated so accurate measurements can be taken with the supplied software. Scale bars shall be overlaid on images. In some cases, scales may be placed at the same depth as the feature being measured for reference.

6.3.2 SEM and EDS/EDX Characterization

Scanning Electron Microscopic (SEM) examination and Energy Dispersive Spectroscopy (EDS) characterization shall be performed on the selected samples. The following is a list of regions and areas of interest that will be investigated using the SEM/EDS. Additional areas of interest may become apparent as the investigation progresses.

1. At or near the fracture initiation site – characterization of the nature of failure initiation: pre-existing metallurgical/manufacturing/mechanical defects, etc.
2. In the sub-critical fracture propagation area - characterization of the nature of propagation: cleavage, quasi-cleavage, fatigue striations, intergranular, corrosion, corrosion deposition and deposited products, etc.
3. For the final rupture zone - characterization of the fracture mode of rupture: shear lip, cleavage, quasi-cleavage, dimples, microvoid coalescence (MVC), ductile tearing deformation markings, etc.

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4. In case of presence of erosion/corrosion markings that prevent a meaningful microfractographic examination, break-open the selected secondary cracks for SEM/EDS examination.

The following is a partial list of tasks to be completed:

1. Profiling and sizing of the identified critical defect(s). This requires taking a series of photographs (with appropriate overlap). The SEM measurements should be calibrated with those measured by the stereo microscope when applicable.
2. The measured profile and sizes shall be used as support for remaining strength calculations.
3. Perform Energy Dispersive Spectroscopy (EDS) analysis at locations of interest for failure such as the following:
 - a. At or near the fracture origin: steel chemistry, inclusions, oxides and deposits.
 - b. Deposits and corrosion products on the fracture surface in general.
 - c. Other features, such as elemental and inclusions segregations,
 - d. For non-failed flaws, the same as above applies.

The following are minimal guidelines to follow when conducting a SEM investigation:

- Maps created using the stereo microscope shall be used to identify and document areas of interest during the SEM examination.
- Areas of interest should be documented in full prior to moving to another area. Proper documentation should allow an SEM operator to return to an area of interest at a later date.
- A naming convention shall be used to identify areas of interest. This naming convention shall be used throughout the investigation to maintain traceability.
- Documentation should be reviewed at the end of an SEM session to ensure complete documentation.

6.3.3 Fracture Specimen Cleaning

It is noted that the test samples received were preliminarily cleaned with Sentinel 909 or 747 or acetone at the well site. If they have not been cleaned, similar chemicals such as Sentinel 909 or 747 will be used in the laboratory. The fracture surfaces may have been coated with preservation coating like the solvent-cutback petroleum-based compounds (Tectyl 506) for handling. Mineral spirits will be used when appropriate to remove Tectyl 506 or others.

Before any cleaning procedures begin, the fracture surface should be surveyed and the results should be documented with appropriate sketches or photographs. It is important to emphasize that deposits/scales on the fracture surface can contain information that is vital to understanding the cause of fracture. Examples are fractures that originated from Sulfide Stress Cracking/Sulfate Reducing Bacteria, which are often known to have the presence of iron sulfide on the subcritical crack growth zone.

The techniques used for cleaning the fracture surface, in the order of increasing aggressiveness, are:

- Dry air blast or soft organic-fiber brush cleaning

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- Organic-solvent (such as acetone, methanol xylene) cleaning
- Water-based detergent (such as Alconox, Citronox solution) cleaning

Among the above cleaning methods, the mildest, least aggressive cleaning procedure should be tried first, and the results should be monitored with the stereo microscope and/or the SEM. If residues are still left on the fracture surface, more aggressive cleaning procedures should be implemented in order of increasing aggressiveness.

Ultrasonic agitation of the organic solvent and water-base detergent is effective in removing debris and deposits from the fracture surface and should be used.

If after using the above cleaning methods, residues are still left on the fracture surface which prevents obtaining meaningful micro-fractographic results, the following more aggressive cleaning methods may be used:

- Cathodic cleaning
- Chemical-etch cleaning

Procedures shall be reviewed by Blade prior to any cleaning. To ensure proper parameters are used for cleaning without attacking the fracture surface, a pre-cleaning trial test(s) should be considered using a freshly produced fracture surface of the same material.

6.4 Metallographic Examination

The purpose of metallographic examination is to determine (1) the relationship between microstructure and the crack path and/or the nature of corrosion or wear damage and (2) whether metal processing has produced undesirable microstructure that contributed to the failure, such as abnormalities due to material quality, fabrications, and heat treatment.

6.4.1 Metallographic Sectioning

Metallographic samples should be taken not only across the main fracture surface but also along secondary cracks. The following issues specific to the failure should be examined in a great detail and photo documented:

1. Fractographic conclusions or interpretation might require validation through metallographic sectioning:
 - a. Transgranular
 - b. Intergranular
 - c. Micro void or other plastic modes
 - d. Mixed modes of failure
2. Correlation between cracking and corrosion pitting/other defects,
3. Evidence of corrosion/erosion/wear/mechanical damage,
4. Across tong marks/slip markings to assess presences of cracking in this region,
5. Variation of microstructure and properties across wall thickness.

It should be noted that metallographic sectioning will be used for investigating many of the features as listed in Section 6.3.1, namely, parted and split 7" casing, corrosion features, erosion

marks, oblique crack-like features and mechanical damage that was identified in the field examinations.

6.4.2 Microstructure Evaluation

The purpose of microstructure evaluation is to determine the microstructure in general and its influence on the failure.

Areas of concern to be examined are:

- Microstructures of the pipe body metal (normal and representative microstructure).
- At or near the fracture/failure origin,
- At or near indications of cracks/defects identified through visual and/or non-destructive testing,
- At or near anomalies including areas with plastic deformation and mechanical damages,

6.4.3 Micro-hardness Profiling

Perform micro-hardness profiles at appropriate locations to determine if the hardness of the pipe material within the required specifications and if there is the evidence of hard spots associated with the failure. The locations of concerns are the following:

- At or near the fracture origin
- At or near corroded regions to confirm the impact of microstructure
- Base material

7 Mechanicals / Chemistry / Microstructure Structure Analysis

Material properties, chemistry and microstructure analysis must be conducted to determine if any material irregularities may have existed for materials used in the well. Material properties and microstructure shall be analyzed for the following components:

1. 2-7/8" tubing
2. 7" casing
3. Wellhead components

7.1 Mechanical Testing and Chemistry

The mechanical testing described below will be conducted for all tubulars. Approximately three 2-7/8" joints will be selected for mechanical testing. Additional joints may be tested based on the findings of the investigation. Specimens from each 7" casing joint will be mechanically tested. The tests described below are a minimum requirement. Additional tests (i.e., J-R curves) may be necessary based on findings during the investigation. All testing equipment shall be calibrated and certified according to appropriate standards. All calibrations and certifications must be valid prior to any testing.

1. Tensile Test
 - Tensile properties shall be determined with specimens conforming to the requirements of ASTM A370.
 - A set of three specimens (triplicate) will be tested from each selected test joint.
 - Three specimens from multiple orientations will be required for selected joints.
2. Charpy-V Notch (CVN) Impact Test
 - CVN impact tests shall be conducted as specified in ASTM A370 and ASTM E23.
 - Three specimens will be tested from each selected test joint.
 - Triplicates from multiple orientations will be required for selected joints.
 - A full temperature transition curve shall be generated for selected 7" casing joints.
3. Hardness
 - Hardness tests shall be made in accordance with ASTM E18 for Rockwell hardness tests.
 - Through-wall hardness tests shall be made on test rings.
 - Rings will be tested from each selected test joint.
4. Chemistry
 - Chemical composition will be determined by any of the procedures commonly used for determining chemical composition (emission spectroscopy, X-ray emission, etc.).
 - Chemical composition will be tested from each selected test joint.

Results from the tests shall be compared to relevant API specifications or equivalent. Results will be used for analyses during the investigation.

7.2 Microstructural Analysis

In addition to metallographic sectioning and microstructural evaluation of the failed 7" joint and listed features as given in Section 6.4, the microstructure will be examined for selected joints. The microstructure will be compared to relevant standards and to other specimens to determine if any irregularities exist in any of the tubulars. Other microstructural testing may be required such as micro-hardness or grain size determination based on the direction of the investigation. These additional tests and analysis will be determined at a later date.

7.3 Wellhead Components

Mechanical testing and microstructural analysis will occur on some of the wellhead components. The exact testing and examinations will be determined at a later date depending on the findings of the investigation. At that time a detailed protocol for the wellhead components will be created.