APPENDICES TO FLOW PUBLIC COMMENTS ON THE JOINT APPLICATION OF ENBRIDGE ENERGY TO OCCUPY GREAT LAKES BOTTOMLANDS FOR ANCHORING SUPPORTS TO TRANSPORT CRUDE OIL IN LINE 5 PIPELINES IN THE STRAITS OF MACKINAC AND LAKE MICHIGAN [2RD-DFDK-Y35G]

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APPENDIX E

Enbridge was violating Line 5 easement for years, documents show

Updated on June 2, 2017 at 2:20 AM
Posted on June 2, 2017 at 2:15 AM

BY GARRET ELLISON

State and federal documents indicate that for years the Enbridge Line 5 pipeline under the Straits of Mackinac was out of compliance with easement rules that govern how far the twin pipes can span the lake bottom unsupported.

Although Enbridge's 1953 easement with the state of Michigan specifies the pipeline must have anchor supports across any gaps in the lakebed span greater than 75 feet, a 2003 survey identified 16 unsupported spans greater than 140 feet, with the longest being 224 feet on the east pipe and 286 feet on the west pipe.

The 286-foot unsupported span was nearly four times the allowable length.

The unsupported spans were identified in an October 2016 engineering report prepared by Kiefner & Associates for Enbridge as part of its negotiated settlement with the federal government over the 2010 Kalamazoo River oil spill.

Line 5 inspection reports submitted to a state pipeline board also document nearly 250 instances between 2005 and the most recent inspection in 2016 where unsupported spans on the twin lines have exceeded the 75-foot mark.

Enbridge says it has anchored all previously unsupported spans, but critics say the damage may already be done and that allowing such unsupported span lengths to go unattended for years may have irrevocably compromised the structural integrity of the pipeline, which carries light crude oil and natural gas liquids.

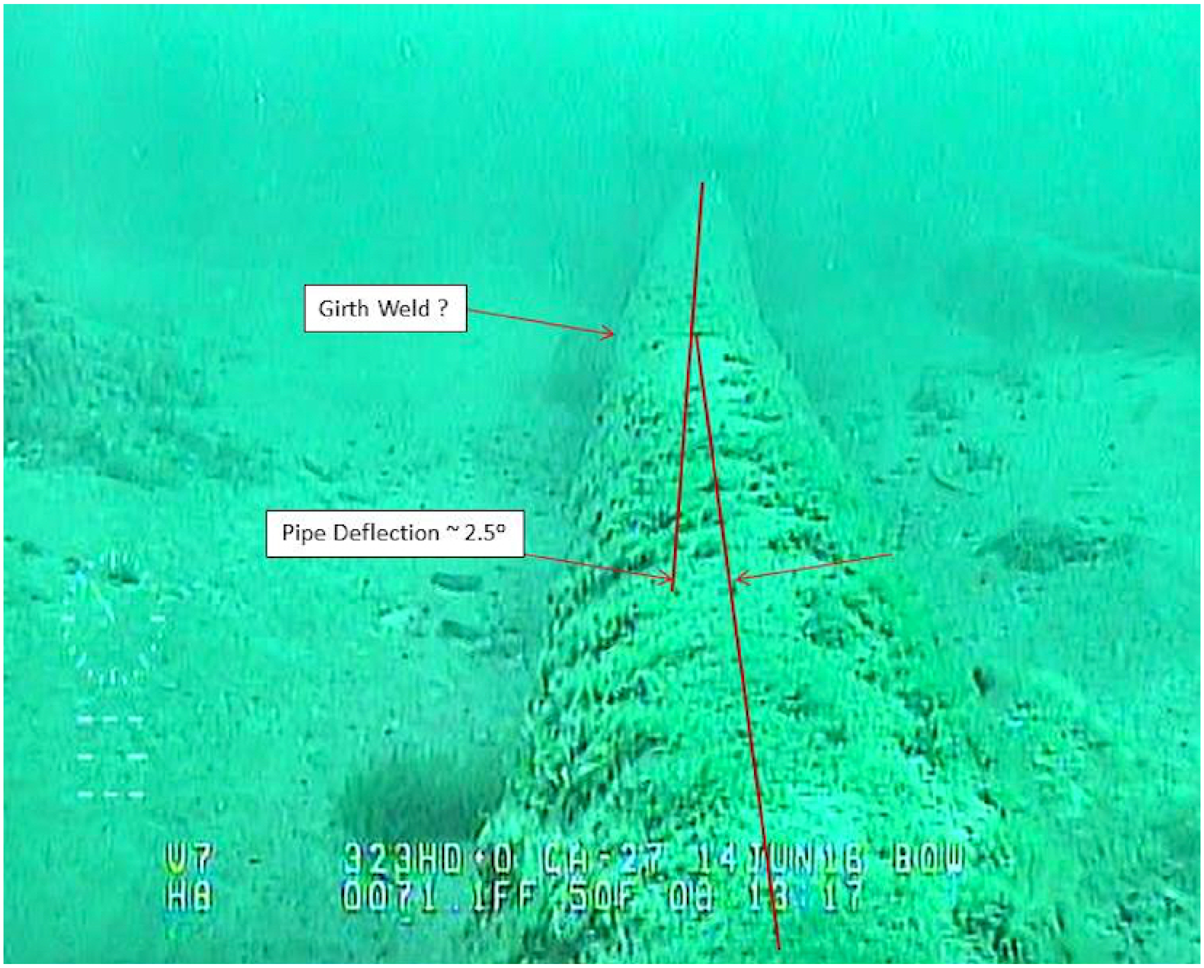
"Clearly, there was a huge period of time when Enbridge just ignored this thing," said Ed Timm, a retired Dow Chemical engineer with a PhD in fluid mechanics who authored an independent technical report on the pipeline integrity this year that was released by the National Wildlife Federation.

Timm believes the pipeline metal is worn out in historically unsupported points after being buffeted for 63 years of stronger currents in the Straits of Mackinac than Enbridge or federal regulators have previously accounted for.

In a report the state gave to independent contractors assessing the risk posed by the pipeline, Timm argued that currents near the straits bottom are higher velocity and more complex than the pipeline's original designers at Bechtel Corp. realized, and the combination of stress over time at key locations has fatigued the metal in ways that can't easily be seen or measured underwater.

Timm has spent three years studying Line 5 and claims that "based on all publicly available data" the company ignored unsupported spans of at least 150 feet until 16 years ago, meaning currents may have been hammering unanchored pipe sections of where the lakebed was washed out since it was installed in 1953.

Evidence of historic neglect in Timm's report includes a 2001 Enbridge application to the Michigan Department of Environmental Quality and U.S. Army Corps of Engineers asking for permission to place grout bags under unsupported spans of "too great a distance" in which an Enbridge engineer writes that "in order to maintain pipeline integrity and safety, these maintenance repairs can wait no longer."



Screenshot of the west leg of Enbridge Line 5 under the Straits of Mackinac that appears to show an area of bent pipe. Image from a June 2016 inspection.

Upon reviewing the June 2016 inspection video, Timm says there appears to be a section of the west pipe that is noticeably bent laterally.

Timm thinks the pipeline is "one peak current event" away from failure.

"This thing needs to be shut down and completely strip-searched with full access to Enbridge document databases so we know what's going on with this pipe," he said.

Jennifer McKay, policy specialist for Tip of the Mitt Watershed Council and member of the state's Pipeline Safety Advisory Board, said she "highly questions" the overall pipeline integrity given the unsupported spans disclosure and Enbridge's recent admission that the pipeline outer anti-corrosion coating has failed in several places.

"The lifespan of a pipeline is determined not only by how it's constructed, but by how it is operated and maintained," she said. "If it has not been properly maintained according to the design and safety specifications that were set for it, that calls into question if, in fact, that line is safe to operate currently and if there are any issues with structural integrity."

The pipeline board is holding its next meeting on June 12 at the Petoskey Middle School Auditorium. Discussion of past unsupported spans is not on the agenda, but DEQ spokesperson Melody Kindraka said "we are aware of this report and have shared it with the independent contractors who are preparing the risk and alternatives reports commissioned by the state."

Enbridge spokesperson Ryan Duffy said that inspection data "shows that the longer span lengths did not affect the integrity of the twin pipelines" in an email.

Enbridge has long argued that unsupported spans of 140-feet are safe. In the Kiefner & Associates report, the 140-foot mark is called the "criterion for taking corrective action" and characterizes the state's 75-foot requirement as "conservative."

Spans longer than 195 feet "would continue to be safe owing to several contributing factors, although it is difficult to precisely quantify the exact margins of safety offered by these factors in some cases," report author Michael Rosenfeld wrote.

Last fall, Enbridge installed four helical screw anchor supports on unsupported spans greater than 75 feet following an inspection. The company asked to install 18 more as a "proactive" measure but the state declined to allow the additional anchors, saying it wanted to wait for the conclusions in the two independent studies.

The board is awaiting the results of two state-ordered studies assessing the risk posed by the line, and alternatives to its crossing the straits bottom, which are being prepared by contractors and are expected to be released this month.

McKay said the state plans a public meeting on the draft reports on July 6.

Duffy said Enbridge is nonetheless planning to add those extra anchors.

> "It is important to point out that currently all spans along Line 5 in the Straits are in full compliance with our easement agreement with the State. We continuously monitor and inspect this section of pipe to ensure its safe and reliable operations. Engineering analysis along with inspections have proven the pipeline is safe to continue operations. This summer we are planning to add 22 more steel anchor supports proactively on Line 5 to further ensure it is secure. More than a decade ago, Enbridge hired Kiefner and Associates to conduct an engineering analysis of the spans that cross the Straits of Mackinac. Surveys conducted in 2001 and 2003 identified some sections of the pipe longer than 140 feet. All spans longer than 140 feet were corrected by Enbridge using steel anchor supports."

Sen. Gary Peters, a Michigan Democrat, introduced legislation last week with Sen. Debbie Stabenow that would tighten up pipeline safety laws by raising the insurance liability cap on Line 5 and giving the U.S. Secretary of Transportation authority to shut down a pipeline not in compliance with operating requirements.

Peters said he's "obviously very concerned" by the Kiefner & Associates report.

"Clearly, there was violations of the easement during that time," he said.

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August 11, 2016

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Dear Attorney General Schuette, and Directors Grether and Creagh:

I am writing to acknowledge receipt of your letter dated August 3, 2016 regarding the Line 5 pipelines across the Straits of Mackinac, specifically the pipeline supports, and Enbridge's compliance with the terms and conditions of the April 23, 1953 "Straits of Mackinac Pipe Line Easement" ("Easement") granted by the State of Michigan to the Lakehead Pipe Line Company, Inc., Enbridge Energy, Limited Partnership's ("Enbridge") predecessor-in-interest.

Enbridge clearly understands the requirements and conditions of the Easement agreement and takes monitoring and management of our obligations under the Easement conditions very seriously. Enbridge has and continues to take all appropriate actions to maintain compliance with the Easement. To that end, and as Enbridge informed the state in July, our biennial inspection program continues to work to assure that the pipelines are being maintained in accordance with our commitments.

In June 2016, as part of Enbridge's ongoing inspection process of Line 5 in the Straits, we conducted underwater inspections of the twin pipelines using a remote operated vehicle and an autonomous underwater vehicle. The intent of the inspections is to provide a visual, external inspection of the pipelines to identify potential areas that need additional examination or remediation.

The inspections identified four points along the crossing requiring additional support anchors in order to meet the 75 foot span reinforcement threshold defined within the Easement. The four spans meeting the threshold for anchor reinforcement were found to be slightly more than the 75-foot requirement, specifically one at 76 feet, two at 77 feet, and one at 78 feet. The current condition of those four spans was created by the normally occurring water currents at the lake bottom which shift the soils around the pipe. Importantly for safety confidence, independent engineering calculations have confirmed that spans up to 140 feet are well within safety acceptability. The remediation threshold defined within the Easement provides a safety factor of nearly double the span capability.

The inspection contractor, Ballard Marine, provided the remediation recommendation to Enbridge on July 14, 2016. Since that date, Enbridge has commenced and is diligently pursuing the work to restore the spans to below 75 feet in length. Enbridge contacted the State on July 22, 2016 regarding the results of the inspection and our plans to restore the spans to less than 75 feet. In addition to the required remediation at the four points, Enbridge will also install another 18 anchors which are not required at this time. However, we view this action as proactively addressing our long-term maintenance approach and work crews mobilized for the required work enable us to complete this additional work efficiently.

Enbridge currently is working with the Michigan DEQ to obtain the necessary permits for the identified remediation work. Once the necessary permits are approved by the state, we anticipate installation of the additional support anchors to begin either by the end of August or early September. The installation is planned to be completed well in advance to the 90-day period noticed by the state in your letter. We will notify the state in writing when the installation of the additional support anchors is complete and all easement conditions are met.

With regard to the requests stated in your letter, Enbridge agrees that we are responsible for promptly correcting any conditions and also for taking effective and reasonable measures for preventing conditions of non-compliance. In November 2014, we indicated to the state that we did not anticipate any spans being greater than 75 feet, per the easement, over the next two years. That was based on the information gathered over decades of monitoring the pipelines crossing the Straits. It is important to note that the slight exceedance beyond 75 feet at the four locations represents only a minor change in erosion pattern and is well within the safety factor that is applied within the predictive maintenance program. In other words, the changes to the lake bottom are not unusual and the remediation process continues to assure a conservative approach.

Enbridge will provide, in a separate letter, and by August 17, 2016, the inspection results of the most recent underwater inspection of the Straits pipelines. This will include, "a detailed description of the methods used to conduct the inspections, as well as findings regarding pipeline support locations, span lengths observed, and changes to the conditions reported in 2014 that have led to the current situation where four spans now exceed 75 feet." A final report from Ballard Marine will be available upon the completion of the anchor installation work, and will be made available in October.

With respect to your request for further information on the predictive maintenance model that Enbridge uses, in brief, the approach is built upon an assessment that examines the erosion trend observed over the many years of operation. For further detail on the approach, we believe that such information would be best reviewed by the state's consultant Dynamic Risk, as part of the State of Michigan review of the risks associated with pipelines crossing the Straits of Mackinac. We are prepared to provide the information you have requested; however, while some of the material you requested will be available shortly, it will not be available within the 14-day timeline you requested. Enbridge commits to providing all the requested information to Dynamic Risk, as part of their engagement, so that a thorough and comprehensive review of our investigation and mitigation process is part of their review and final report to the State.

Enbridge continues to believe that our ability to predict growth of spans is reliable, but we are enhancing our efforts to preclude spans growing to beyond 75 feet. This includes the installation of screw anchors in 2016 on several spans that currently are at approximately 60 feet in length but are not anticipated to reach 75 feet even within two years. Enbridge is also investigating performing side scan sonar of the Straits every year to ensure our approach continues to be appropriate, and that we meet or exceed the letter and spirit of the Easement Agreement.

Enbridge is committed to continuing to work with the State of Michigan on the safe, effective, and reliable operation of the Line 5 pipelines crossing the Straits of Mackinac, vital to meeting the state's energy needs and keeping the Great Lakes protected. Should you have any questions or need further information, please contact me at (952) 607-3430

Sincerely,

ENBRIDGE ENERGY, LIMITED PARTNERSHIP
By Enbridge Pipelines (Lakehead) L.L.C.
Its General Partner

Bradley F. Shamla
Vice President, U.S. Operations

8/19 - Copy to Carol Peter

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August 17, 2016

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Dear Attorney General Schuette, Director Grether and Director Creagh:

I am writing to provide the additional information requested in your letter dated August 3, 2016 regarding the Line 5 pipelines across the Straits of Mackinac, specifically the pipeline supports, and Enbridge's compliance with the terms and conditions of the April 23, 1953 "Straits of Mackinac Pipe Line Easement" ("Easement") granted by the State of Michigan to the Lakehead Pipe Line Company, Inc., Enbridge Energy, Limited Partnership's ("Enbridge") predecessor-in-interest.

As committed to in our initial response letter dated August 11, 2016, attached is additional detailed information relating to the 2016 inspections. Appendix A is a detailed description of the methods used to conduct the inspection. Appendix B is the findings regarding pipeline support locations, span lengths observed, and changes to the conditions reported in 2014 that have led to the current situation where the four spans now exceed 75 feet. Appendix C is the preliminary report received July 14th from the inspection contractor, Ballard Marine.

Enbridge is committed to continuing to work with the State of Michigan on the safe, effective, and reliable operation of the Line 5 pipelines crossing the Straits of Mackinac and the protection of the Great Lakes. Should you have any questions or need further information, please contact me at (952) 607-3430.

Sincerely,

ENBRIDGE ENERGY, LIMITED PARTNERSHIP
By Enbridge Pipelines (Lakehead) L.L.C.
Its General Partner

Bradley F. Shamla
Vice President, U.S. Operations

Attachments

__Attachment A: Detailed description of the methods used to conduct the inspection__:

Before Autonomous Underwater Vehicle (AUV) and Remotely Operated Vehicle (ROV) calibration and inspections operations took place, a Real Time Kinematic Global Positioning System (GPS) base station was setup on shore to provide high accuracy position updates for use by all on-water equipment used during the inspection process, to ensure that the highest level of positioning accuracy possible could be obtained. After setup, the accuracy of the base station was confirmed (through comparison with another known GPS point) to be within 0.03' both horizontally and vertically, verifying proper setup and data input.

Once the base station was established, on-water AUV calibration, or Patch Testing, was performed. The AUV was sent out to collect data at different locations, water depths and bottom types (including sand vs. clay and flat vs. sloped bottoms). After several hours of data collection, all the data was processed to allow for the insertion of correct offsets into the equipment's software. That process ensures that the raw data collected during the actual inspection operations will be of the highest accuracy level possible for the equipment being used.

Following calibration activities, AUV inspection operations began. The AUV was equipped with GPS, underwater positioning equipment, a water sensor (capable of collecting water temperature, pressure, salinity, conductivity, and speed of sound) and fully operational multi-beam, side scan, and forward-looking sonar systems. The AUV has built-in survey software capable of being pre-programmed with the current known pipeline locations and depths for mission planning. Following launch, the AUV traversed over top of the exposed pipelines plus a minimum of 100' north and south of the last exposed portion of each pipeline, at a height of approximately 20' to 25' above the pipelines and lake bottom. The AUV survey crew followed the AUV, in a boat, from one side of the crossing to the other, remaining in constant communication with the vehicle and relaying real time position updates received for the GPS base station to ensure the highest level accuracy. At the end of each day, all data was reviewed for accuracy and completeness. The 2016 inspection consisted of 14 passes made along the two pipelines (7 passes per line), with 12 (6 per line) of the 14 passes performed at a low altitude (20' to 25') for the collection of multi-beam and side scan data collection and 2 (1 per line) of the 14 passes at high altitude (65' to 100') for additional multi-beam and water column data collection.

Following the AUV survey operations, the ROV was placed into service. The ROV system, equipped with underwater positioning sensors, lights, and cameras was calibrated by traversing the ROV to a known pipeline anchor location and verifying the ROV's position against the known position of the anchor. The ROV was then driven to a second anchor location for position verification.

Once position information of the ROV system was verified to be accurate, the ROV, operated from the top-side survey vessel, began traversing along the pipeline. In areas where the pipelines were buried, the ROV traveled along the coordinates as displayed in the real time data positioning software for the pipeline's route. The intent of the ROV inspection was to visually observe the pipelines for items or areas of concern that may be visually apparent; to inspect the overall outside condition of the pipeline; to inspect all support anchors installed on the pipeline to ensure their integrity; and to make general visual observations of the pipelines and their surroundings. Any spans which were determined to be close to or in excess of 75' were inspected in greater detail with both crude oil and NGL batches in the pipeline, to ensure consistent results with varying specific gravity of the fluid being shipped, to verify maximum span length. During the ROV inspection process, video and positioning information was recorded at all times. Noteworthy items in close proximity to the pipe or abnormal pipeline conditions were subjected to a more detailed examination.

For the 2016 ROV inspection, the east and west legs of the pipeline were surveyed from south to north, with the east leg being inspected first.

<u>Appendix B: Findings regarding pipeline support locations, span lengths observed, and changes to the conditions reported in 2014 that have led to the current situation where the four spans now exceed 75 feet:</u>

Evaluation of each instance where pipeline spans were in excess of the 75' Easement-specified limit found that the span length change was attributed to a combination of lake-bottom sand movement and improvements in the inspection accuracy.

<u>Span W-5:</u> Between 2014 and 2016, comparison of inspection results indicated that this span grew from a length of 71' to 78'. The north end of the span was secured by a hill on the lake bottom, while the southern exposure that previously displayed shadowing beneath the pipe was found to increase.

<u>Span W-53A:</u> Between 2014 and 2016, comparison of inspection results indicated that this span grew from a length of 69' to 77'. The north end of the span was secured by an anchor, which prevented any future growth at this location. A reduction of support was observed at the south end of the span where shadowing beneath the pipe had previously been observed.

<u>Span W-69:</u> Between 2014 and 2016, comparison of inspection results indicated that this span grew from 64' to 77'. Shadowing previously observed on both ends of the span were confirmed in this inspection to represent a slight reduction in support, and hence, growth of the span.

<u>Span E-39:</u> Between 2014 and 2016, comparison of inspection results indicated that this span grew from 63' to 77'. The south end of the span was deemed to be well supported by the lake bed topography, while the northern exposure that previously displayed shadowing beneath the pipe was found to increase.

Enbridge Pipelines

Final Report No. 16-154

Assessment of Span Exposures on the 20-inch Petroleum Pipelines Crossing the Straits of Mackinac

Michael Rosenfeld, P.E.
October 12, 2016

Kiefner

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Final Report No. 16-154

Final Report

on

ASSESSMENT OF SPAN EXPOSURES ON THE 20-INCH PETROLEUM PIPELINES CROSSING THE STRAITS OF MACKINAC

to

ENBRIDGE PIPELINES

October 12, 2016

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DISCLAIMER

This document presents findings and/or recommendations based on engineering services performed by employees of Kiefner and Associates, Inc. The work addressed herein has been performed according to the authors' knowledge, information, and belief in accordance with commonly accepted procedures consistent with applicable standards of practice, and is not a guaranty or warranty, either expressed or implied.

The analysis and conclusions provided in this report are for the sole use and benefit of the Client. No information or representations contained herein are for the use or benefit of any party other than the party contracting with Kiefner. The scope of use of the information presented herein is limited to the facts as presented and examined, as outlined within the body of this document. No additional representations are made as to matters not specifically addressed within this report. Any additional facts or circumstances in existence but not described or considered within this report may change the analysis, outcomes and representations made in this report.

This report issued as a Final Report in 2016 describes work performed by Kiefner in 2003 and 2004 and reported in Draft form in January 2005. Data, regulations, and other input discussed herein were the most recent available at the time the work was performed. Data, regulations, and other input developed or revised subsequent to the 2005 Draft report are not accounted for and could change the analysis, outcomes, and representations made in this report.

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Assessment of Span Exposures on the 20-inch Petroleum Pipelines Crossing the Straits of Mackinac

M. J. Rosenfeld, PE

INTRODUCTION

Enbridge Pipelines operates two 20-inch OD pipelines that cross the Straits of Mackinac 1.5 miles west of the Mackinaw Bridge. The pipelines, which were constructed in 1953, are part of a system that transports petroleum products from Superior, Wisconsin to Sarnia, Ontario.

Enbridge has periodically conducted subaquatic inspections to monitor the condition of the pipelines. The most recent inspection prior to the preparation of this report was during the summer of 2001. The inspection revealed a number of areas where scouring effects from water currents caused sections of the pipelines to span freely above the bottom. Several sections were determined to have lengths in excess of the 75 ft limit specified in the original easement granted by the State of Michigan in 1953.

Enbridge took prompt action to correct several of the longer spans, and is continuing to develop technical criteria and identify effective means to remediate other spans. At the request of Enbridge, in 2003 and 2004 Kiefner & Associates, Inc. (Kiefner) undertook a study of the following matters:

- the applicable regulations, industry standards, and original construction documents pertaining to the Straits crossings;
- the extent to which spans in excess of the 75-ft limit could be permitted while assuring continued safe operation of the pipelines and compliance to applicable regulations and standards;
- the effect of operating conditions on the spans;
- available options for supporting spans; and
- susceptibility to vibration induced by vortex-shedding.

CONCLUSIONS

Codes, Standard, and Regulations

From a review of applicable pipeline regulations and industry standards, it is clear that the Straits crossings fall within the scope of US Federal pipeline safety regulations. The crossings share all the physical attributes of offshore pipelines in terms of their method of construction as well as the loading and operating environment. For this reason, an offshore pipeline technical standard is the most appropriate place to seek technical guidance on matters such as allowable working stress levels. The offshore section of ASME B31.4 was recommended by convention. Chapter IX therein recommends maximum longitudinal stresses of 80% of specified minimum yield strength (SMYS), and maximum biaxial combined stresses of 90% of SMYS. An alternative criterion for noncyclical displacement-controlled loadings is also permitted. While a strain-based criterion remains a technically feasible option, it has not been recommended because insufficient data concerning material and weld strain capacity is available to develop a criterion having a known degree of conservatism.

Engineering Analysis of Spans

Engineering studies carried out by the original design team for Bechtel (1951) were reviewed in detail. An independent analysis was carried out in conjunction with this study as well. The two studies used similar parameters for static and live loadings on the pipeline. The original design observed an allowable stress criterion of 60% of SMYS, and then adopted an allowable span length for construction of 75 ft corresponding to a stress level of about half this limit. The current study determined that a longitudinal tensile stress limit of 80% of SMYS, used for offshore pipelines, was appropriate and safe. Spans of between 155 ft and 195 ft in length (depending on operating temperature conditions) could meet this limit. Based on these results, it appears that spans longer than 75 ft as specified in the original right of way easement granted by the State of Michigan could be safely permitted.

A span of 140 ft was established by Enbridge as a criterion for taking corrective action. Engineering analyses performed with this study confirmed that Enbridge's criterion safely allows for span growth beyond the original 75-ft specification over time and is conservative for all operating conditions. Spans longer than the 155 to 195 ft limit would continue to be safe owing to several contributing factors, although it is difficult to precisely quantify the exact margins of safety offered by these factors in some cases. Factors that contribute to additional margins of safety include the fact that the allowable longitudinal stress level provides by definition a minimum factor of safety of 1.25 against failure; the pipe and weld materials tend to have greater actual strength than the minimum specified quantities; pipe may potentially have heavier wall thickness than specified; very long spans tend to eventually "touch down" on the

Straits bottom (thereby becoming supported for any continued growth of the span); and the line sometimes transports product (NGL) having a lower density than what was assumed in the analysis (crude oil). The conclusion that longer spans can remain safe is logically supported by recognition that longer spans have historically occurred with no apparent distress to the pipeline, although Enbridge prudently took steps to correct spans in those instances.

Effects of Operating Conditions

Some relief of span sag during the installation of supports would be beneficial because it would immediately transfer some load to the supports. Relief may be accomplished by lifting the line prior to support installation, or by installing supports that provide a jacking or lifting function after installation. Without some means of preloading, the supports do not become effective for reducing sag-induced stresses until the spans extend in length through a continued bottom scour process. However, they will help mitigate vortex-induced vibration without preload.

There is no benefit to reducing the operating pressure during the support installation process from the standpoint of stresses due to internal pressure, because those stress components are too small to make a significant difference. Shutting in flow could reduce span sag due to the line cooling down, but this runs the risk of increasing stress levels in the spans until the supports are installed and flow is restored. Therefore, shutting in the line while the supports are being installed is not preferred. Switching over to natural gas liquids (NGL) will yield only a relatively small change in the sag if the transporting temperature of the NGL is as warm as the crude oil. If the NGL runs cooler than the crude oil, the combination of lower pipe temperature and reduced span weight could reduce span sag so as to make the supports at least partially effective at the present span lengths when crude oil is being transported. The most optimal situation, solely from the standpoint of immediate effectiveness of the supports, is to take the line out of service, including clearing the pipe of product contents. This study did not evaluate the impact of this strategy on operation.

Support Options

Several proven techniques for supporting spans in submerged pipelines were reviewed. Recommendations are as follows for mitigating the spans on the Straits crossings: grout bags for low-clearance spans; screw anchors with mechanical clamps for high-clearance spans; and rock-dumping for permanent system-wide mitigation. An analysis of local stresses in the pipe wall associated with mechanical support clamps determined that the stresses are not excessive.

Vortex-Induced Vibration

A simplified analysis for vibration induced by vortex-shedding was conducted. At water velocities of 2.3 ft/sec or less, which encompasses almost all periods of operation, the flow regime is subcritical (either laminar or transitional) with a periodic wake. The pipe spans are therefore subjected to alternating lift and drag forces having a frequency between 0.04 and 0.77 Hz. Critical span lengths were determined based on the span structural frequency being sufficiently close to the vortex-shedding frequency for vortex "lock-on" to occur. Critical span lengths vary inversely with the water velocity. The critical span lengths for the water velocities where the flow regime produces a periodic wake, up to 2.3 ft/sec, are 140 ft or longer, so vortex-induced vibration (VIV) considerations appear not to be limiting. At the water current velocities expected, drag-induced forces on the span are very low compared to the buoyant weight of the pipe.

RECOMMENDATIONS

Based on considerations for static stresses and susceptibility to vibration induced by vortex shedding, a maximum free span of 140 ft is recommended. Longer spans do not appear to jeopardize the safety of the pipeline, but the stresses would be in excess of conservative levels derived from design code limits.

The rate at which individual spans increase in length or adjacent spans coalesce to form longer spans over time remains unknown. In order to avoid frequent span remediation efforts due to span growth or coalescence processes, spans that occur in series with other spans nearby should be targeted for support even if they are shorter than 140 ft. Annual or biennial bathymetric (bottom) inspections should be undertaken in order to determine span growth rates and identify locations that are susceptible to rapid span formation.

BACKGROUND

Description of the Pipelines

The Straits of Mackinac Crossing is comprised of two individual 20-inch outside diameter (OD), 0.812-inch wall thickness (WT) pipelines. The crossing was constructed in 1953 using Grade A seamless line pipe having an SMYS of 30 ksi and specified minimum tensile strength of 48 ksi, in accordance with the contemporaneous edition of API 5L[1]. The actual yield strength of pipe joints based on mill tests varied from 30 ksi to 44 ksi, with an average of 37 ksi.[2] The construction specifications called for using the lowest strength joints at the deepest elevations in order to take advantage of their perceived greater ductility.

The pipelines were constructed on shore, and the constructed string of pipe floated out and was lowered into place. The pipelines were hydrostatically tested in place at a pressure of 1,200 psig, corresponding to a hoop stress of 49% of SMYS (without correcting for external pressure), for a period of 10 hours.[2]

Pipe joints were welded using the shielded-metal arc welding (SMAW, or stick welding) with E6010 coated electrodes. The construction of the line occurred at about the same time as the first publication of API 1104. Procedure and welder qualification standards and production workmanship standards applied to the construction were generally similar to those of modern editions of API 1104. Pipe chemistry was limited to 0.24 C, 0.90 Mn, 0.045 Ph, and 0.06 S, by weight percent.[2]

The maximum operating pressure (MOP) of each line is 600 psig, corresponding to a hoop stress of 7,389 psi, or 24.6% of SMYS, without correcting for the external pressure associated with the pipeline's submerged depth. The normal operation is at pressures up to 280 psig, with a correspondingly reduced hoop stress level.

The products transported by the lines are crude oil and natural gas liquids (NGL) having specific gravities of 0.868 and 0.547, respectively. The pipes are coated with asphalt primer, fiberglass matting, and asbestos felt in a net thickness of 1.25 inch and having a specific gravity of 1.28. The buoyant (submerged) weight of the lines is 140.3 lb/ft when transporting crude oil, or 103.4 lb/ft when transporting NGL.

The Straits crossing is approximately 5 miles in length, extending from Point La Barbe on the north side to McGulpin Point on the south side of the Straits. The pipelines are located in the pipeline corridor indicated in Figure 1. The direction of flow is from north to south. The two lines are approximately 1,300 ft apart and situated approximately 1.3 miles west of the Mackinaw Bridge. The maximum depth of the crossing is approximately 250 ft. Limited current velocity data indicates currents are 2 knots (1.7 ft/hr). Enbridge is in the process of obtaining additional current velocity data.

The product temperature in the line varies seasonally between 39 F (4 C) and 61 F (16 C). The water temperature varies seasonally and with depth due to stratification and turnover phenomena. Deepwater temperatures vary from 39 F (4 C) to 43 F (8 C), while shallow water temperatures vary over a wider range. The differential between pipeline operating temperature and ambient deepwater temperature are the least in the winter and the greatest in the summer. The temperature difference is expected to vary between 0 F and +20 F, with the pipeline operating warmer than the water.

The lines were buried in a trench at shore approaches out to water depths of 85 ft. (The right of way easement granted by the State of Michigan specified burial to a water depth of only 50 ft.[3]) Where water depths exceeded 85 ft, the lines were laid on the Straits bottom without cover. Due to natural variations in bottom elevation, the pipelines were installed with some free spans of up to 75 ft in length. The minimum radius of curvature was specified to be 1,350 ft, corresponding to an elastic bending strain equal to 0.062% and an elastic bending stress equal to 18.3 ksi or 61% of SMYS. The bottom profiles of the East and West lines are shown in Figure 2.

Recent Assessments

Enbridge has conducted several subaquatic surveys of the condition of the pipelines. Surveys were conducted in 2001 and 2003 by Onyx Superior Special Services, Inc. consisting of side-scan and multi-beam sonar, followed by video examination by remotely operated vehicle (ROV).[4] The sonar imaging revealed the locations and free lengths of exposed spans on the Straits bottom. The 2003 survey identified 7 spans longer than 140 ft in the east leg, with the longest being 224 ft, and 9 spans longer than 140 ft in the west leg, with the longest being 286 ft (due to a failed grout bag support). Both lines exhibited about the same number of spans and distribution with respect to span length. All spans longer than 140 ft were corrected by Enbridge using screw anchor supports.

CODES, STANDARDS, AND REGULATIONS

Federal Pipeline Safety Regulations

Federal regulations set forth in 49 CFR Part 195[5] ("Part 195") provide safety standards for pipelines used to transport hazardous liquids. Enbridge's pipelines crossing the Straits fall within the scope of Part 195. A number of clauses in Part 195 apply to the Straits pipelines, while some others might be incorrectly interpreted as being applicable. These will be reviewed in the following section.

<u>Are the Straits crossings "offshore" pipelines?</u>

The first question is whether or not the Straits crossings are "offshore pipelines" under the regulations. Subpart A – General, 195.2 Definitions states:

> "*Offshore* means beyond the line of ordinary low water along that portion of the coast of the United States that is in direct contact with the open seas and beyond the line marking the seaward limit of inland waters."

This clause perhaps did not contemplate a crossing of the Great Lakes, even though such a crossing would possess all the physical attributes of an offshore pipeline in terms of its construction and its loading environment. If one interprets "open seas" to mean "open waters", the foregoing definition would readily apply to the Straits crossings. Note that although Part 195 defines "offshore", nowhere does it require observance of a particular design code for offshore pipelines, nor does it establish minimum requirements with respect to safety that differ substantially from those for onshore pipelines, except for those of a practical matter (e.g., pipeline marking or underwater surveys).

What design requirements apply?

The Straits crossings were constructed prior to development of Part 195. Under Subpart C – Design Requirements, Paragraph 195.100 states:

> "This subpart prescribes minimum requirements for new pipeline systems…and for relocating, replacing, or otherwise changing existing systems".
>
> Under Subpart D – Construction, Paragraph 195 states:
>
> "This subpart prescribes minimum requirements for constructing new pipeline systems… and for relocating, replacing, or otherwise changing existing systems".

Consistent with the approach adopted by most technical codes, this clause refrains from imposing new design or construction requirements on an existing facility that remains essentially unaltered, such as the Straits crossings.

> Under Subpart E – Pressure Testing, Paragraph 195.302 states:
>
> "(b) Except for pipelines converted under 195.5, the following pipelines may be operated without pressure testing under this subpart: (1) Any hazardous liquid pipeline whose maximum operating pressure is established under 195.406(a)(5) that is – (i) An interstate pipeline constructed before January 8, 1971;"
>
> Paragraph 195.406 then states:
>
> "(a) Except for surge pressures and other variations from normal operations, no operator may operate a pipeline at a pressure that exceeds any of the following: … (5) For pipelines under 195.302(b)(1)… that have not been pressure tested under subpart E of this part, 80 percent of the test pressure …to which the pipeline was subjected for 4 or more continuous hours…"

The Straits crossings meet the requirements of 195.302 and 195.406.

The safety requirements under Part 195 applicable to the existing Straits crossings are found primarily under Subpart F, Operations & Maintenance. Hence, the application to an existing facility of standards of a design nature that might be applied to new facilities today remains discretionary on the part of the operator where doing so makes sense.

What allowable stress limits apply?

The only maximum allowable stress levels prescribed by Part 195 are those pertaining to the hoop stress due to internal pressure. There are no maximum allowable levels specified for longitudinal stresses caused by deadweight, thermal expansion, or external loadings acting on the pipeline. Paragraph 195.110 External Pressure states:

"Anticipated external loads (e.g.), earthquakes, vibration, thermal expansion, and contraction must be provided for in designing a pipeline system. In providing for expansion and flexibility, Section 419 of ASME B31.4 must be followed."

A review of the original design documents, to be discussed subsequently, indicates that the expected external loads, such as deadweight and water currents, were considered in detail during the design process.

The provision cited above to follow Section 419[6] deserves discussion because it is sometimes incorrectly applied to pipelines in situations for which it was not intended. Section 419 applies specifically to piping systems where flexibility for absorbing thermal expansion is provided by means of bends, expansion loops, or offsets. The Straits crossing was not constructed in this fashion. It is essentially an axially restrained pipeline with some number of exposed, freely spanning sections. The present-day version of ASME B31.4 recognizes that there is a fundamental difference between piping systems constructed so as to be flexible and those that are not, and specifies differing allowable stress levels accordingly. It also recognizes that exposed spans may be present in otherwise restrained systems and that they should be treated similarly to the balance of the buried pipeline, with the addition of bending stresses due to spanning. These concepts are expressed in paragraph 419.6.4(a):

"There are fundamental differences in loading conditions for the buried, or similarly restrained, portions of the piping and the aboveground portions not subject to substantial axial restraint. Therefore, different limits on allowable longitudinal expansion stresses are necessary."

In any case, the requirement in 195.110 that Section 419 be followed does not apply to the crossings.

<u>What operational provisions apply?</u>

The provisions of operation and maintenance apply to any existing facility, in general. Subpart F – Operation and Maintenance, Paragraph 195.401(b) states:

"Whenever an operator discovers any adverse condition that could affect the safe operation of its pipeline system, it shall correct it within a reasonable time."

This could apply to a situation where, in Enbridge's judgment, the exposed span lengths become excessive. However, Part 195 gives no specific guidance on determining what is "safe". Subpart B – Reporting Accidents and Safety-Related Conditions, Paragraph 195.55 states:

"…each operator shall report … the existence of any of the following safety-related conditions involving pipelines in service:…(2) unintended movement or abnormal loading of a pipeline by environmental causes, such as an earthquake, landslide, or flood, that impairs its serviceability."

This clause goes a step farther than 195.401(b). It would require Enbridge to report conditions involving spans where, in Enbridge's judgment, the stresses exceed reasonably safe levels, or if significant dislocation of the pipelines were evident.

INDUSTRY STANDARDS

ASME B31.4 is an industry consensus safety standard. It is an engineering and technical standard that provides design criteria based on simplified engineering concepts. Chapter I Scope and Definitions, Paragraph 400(b) states:

> "Requirements for all abnormal or unusual conditions are not specifically provided for."
>
> Paragraph 400(e) states:
>
> "It is intended that a designer capable of applying more complete and rigorous analysis to special or unusual problems shall have latitude in … the evaluation of complex or combined stresses. In such cases, the designer is responsible for demonstrating the validity of his approach."

These provisions clearly communicate the latitude for Enbridge to apply methods and criteria that may not be spelled out in detail in the Code, or that are alternative to those in the Code, along with the need to meet the intent of the Code insofar as safety is concerned and to exercise sound engineering judgment.

> Paragraph 400(f) states:
>
> "This Code shall not be retroactive or construed as applying to piping systems installed before date of issuance … insofar as design, materials, construction, assembly, inspection, and testing are concerned. It is intended, however, that the … Code shall be applicable … to the relocation, replacement, and uprating or otherwise changing existing piping systems; and to the operation, maintenance, and corrosion control of new or existing piping systems."

Like the Federal regulations, this means that current requirements of a design matter are not retroactive on existing pipelines systems, though current operations and maintenance requirements apply to all pipelines regardless of installed date.

<u>Are the Straits crossings "offshore" pipelines?</u>

Paragraph 400.1.1 states: "Requirements for offshore pipelines are found in Chapter IX." This indicates that certain requirements apply separately to pipelines constructed offshore. ASME B31.4 comprises a main code body applicable to pipelines in general but usually taken to apply to those located on shore, along with an "offshore chapter" (Chapter IX, Offshore Liquid Pipeline Systems) containing exceptions or additional requirements as befitting the unique

aspects of pipelines located offshore. A definition for "offshore" is found in ASME B31.4, Paragraph A400.2, that is similar to the one found in Part 195. Based on the characteristics of the pipeline, where it is located, and the environment it operates in, it is logical to consider the Straits crossings to be "offshore" pipelines rather than "onshore" pipelines that happen to cross a lake.

Other standards exist for offshore pipelines internationally which could be applicable from a technical standpoint. Although there is no regulatory requirement to use ASME B31.4, it would be a logical code choice since B31.4 embodies technical concepts and practices observed by the US pipeline industry and the Straits crossings are located in US waters.

What design requirements apply?

The "onshore" portion of the Code contains provisions to consider hazards from the effects of ambient loadings, such as waves or currents acting on a pipeline crossing a waterway, which could be applied in a general sense to an offshore pipeline as well. However, the offshore chapter addresses the specific concerns for offshore pipelines more directly. Paragraph A401 Design Conditions lists design conditions to be considered for offshore pipelines, including installation (buoyancy, external pressure, laying); environmental loads (waves, currents, ice); and operational loads. These are, for all practical purposes, the same technical considerations applicable to the Straits crossings. Conversely, many of these items are of no concern to a pipeline buried onshore. The offshore chapter more clearly articulates the maximum longitudinal stress levels, and it is no less conservative than the "onshore" part of the Code unless the option to use plastic design concepts is chosen. It would therefore make a better choice from a technical standpoint for addressing the concerns with the Straits crossings than the "onshore" part of the Code.

What allowable stress limits apply?

> Paragraph A402.3.5(a)(2) Longitudinal Stress states:
>
> "For offshore pipeline systems, the longitudinal stress shall not exceed values found from $S_L < F_2S_Y$."

The term S_L is the absolute value of the longitudinal stress calculated as the sum of axial and longitudinal bending (either tensile or compressive values, whichever gives the higher stress). From Table A402.3.5(a), F_2=0.80, so $S_L \leq$ 80% SMYS. A402.3.5(a)(3) Combined Stress states:

> "For offshore pipeline systems, the combined stress shall not exceed the value given by … $< F_3S_Y$."

The combined stress is the effective biaxial tensile stress, computed in accordance with either the Maximum Shear (Tresca) Theory or the Distortion Energy (von Mises) Theory. The calculation must consider both tensile and compressive axial and bending components. From Table A402.3.5(a), F_2=0.90, so $S_e \leq$ 90% SMYS.

A third criterion is worth noting, though for conservatism it is not suggested that it be applied in this situation. Paragraph A402.3.5(a)(4) Strain states:

> "When the pipeline experiences a predictable noncyclic displacement of its support (e.g. fault movement along the pipeline route or differential subsidence along the line) or pipe sag before support contact, the longitudinal and combined stress limits may be replaced with an allowable strain limit, so long as the consequences of yielding do not impair the serviceability of the installed pipeline. Where plastic strains are anticipated, … the ability of the weld to undergo such strains without detrimental effect should be considered."

This clearly gives the latitude to exceed the stress limits in A402.3.5(a) and work toward a strain limit instead. A common strain limit used in new construction is 2%. New revisions to the ASME gas pipeline code (B31.8) will allow that for onshore pipelines, and it has been a feature in foreign pipeline codes for many years. One application for this in the Straits crossings is curvature-induced stress imposed by installation settlement of the pipeline onto the Straits bottom, as inferred from in-line inspection. Another would be for exposed spans where the pipe is sagging onto the bottom. A key consideration in developing a strain limit is the quality and properties of the girth welds.

What were the original design requirements?

On a historical note, the 1953 piping code[7] prescribed minimum requirements for various types of piping systems. Section 3 – Oil Piping prescribed requirements for materials selection, pressure design (e.g. allowable hoop stress and minimum wall thickness), hydrostatic testing, and pressure-temperature ratings for valves and flanges. Hoop stress due to internal pressure was limited in API 5L Grade A seamless to a value of 25,500 psi, or 85% of SMYS, computed considering the minimum wall tolerance for the specified pipe product. The hydrostatic test requirement was the greater of 1.25 times the maximum operating pressure or 1.1 times the maximum surge pressure, except that neither the hoop stress from the test pressure nor the biaxial stress were permitted to exceed 90% of SMYS, computed considering the full wall thickness less the manufacturing tolerance. Section 3 imposed no specific allowable longitudinal stress limits on buried or restrained piping systems.

Additional requirements were provided in Section 6 – Fabrication Details, Chapter 3 – Expansion and Flexibility. The only longitudinal stress limits provided therein were in the context of flexibility analysis, a concept that does not apply to restrained pipelines such as the Straits crossings. Separate limits for restrained pipelines or offshore pipelines, such as are found in today's Code, had not yet been developed. In any case, the 1953 Code, Paragraph 620 "Flexibility", required that:

> "(g) Where the piping system is subject to the occasional temperature changes and to combinations of constant stress and minor cycle variable stresses associated with the normal operation of a plant, the maximum allowable combined stress due to bending and pressure shall … be limited to 40 percent of the specified tensile strength…"

There is no evidence that the designers of the Straits crossings specifically followed the provisions in Paragraph 620(g).

The 1953 Code specified welding in accordance with ASME Section IX[8], but the project adopted welding requirements very similar to those found in API 1104[9], though no mention of API 1104 was made in the project specifications.

SUMMARY

From a review of applicable pipeline regulations and industry standards, it is clear that the Straits crossings fall within the scope of US Federal pipeline safety regulations. The crossings share all the physical attributes of offshore pipelines in terms of their method of construction as well as the loading and operating environment. For this reason, an offshore pipeline technical standard is the most appropriate place to seek technical guidance on matters such as allowable working stress levels. The offshore section of ASME B31.4 was identified as the most applicable. Chapter IX therein recommends maximum longitudinal stresses of 80% of SMYS, and maximum biaxial combined stresses of 90% of SMYS. An alternative criterion for noncyclical displacement-controlled loadings is also permitted. While a strain-based criterion remains a technically feasible option, it has not been recommended for the sake of conservatism.

ENGINEERING ANALYSIS

Original Design Studies

At the time that the Straits crossings were conceived, designed, and constructed, they were the deepest offshore pipelines ever built, though not the longest. Extensive design calculations were performed by engineers at George S. Colley, Jr. and Associates under the supervision of Dr. Mario G. Salvadori, Dept. of Civil Engineering, Columbia University.[10] The loadings considered in the design included internal pressure due to operation at 600 psig and hydrostatic testing to 1,200 psig, vertical loading from deadweight and buoyancy, thermal expansion corresponding to a temperature differential of +30 F (with the pipeline operating warmer than the water), horizontal loading due to drag from water currents, torsional loading from the pipe rolling on slopes and from water currents, soil friction, and the effects of catenary action. Limit states considered were tensile overload, biaxial combined stresses, lateral instability, collapse of the empty pipe, and local buckling. The calculations were all performed by hand, using closed-form solutions based on traditional structural engineering methods and assumptions.

The original design study recommended a maximum span length of 140 ft and the recommended minimum bend radius of 1,750 ft, based on a maximum allowable tensile stress of 60% of SMYS (18 ksi). For additional conservatism in order to allow for unanticipated conditions or changes in conditions during operation, a maximum construction span of 75 ft was ultimately suggested. Since stresses other than those induced by operation of the pipeline are roughly proportional to the square of the span length (L^2), a span of 75 ft corresponds to a summed tensile stress of less than 30% of SMYS, which is an extremely conservative operating stress level.

Kiefner Spanning Study

At the request of Enbridge, Kiefner reviewed the original studies, and performed an independent analysis. As discussed in the first part of this report, Kiefner concluded that the appropriate criteria for allowable stress limits are those found in ASME B31.4, Chapter IX, Offshore Liquid Pipeline Systems, rather than those for unrestrained onshore pipelines. These limits are 80% of SMYS for longitudinal stresses, and 90% of SMYS for biaxial effective stresses.

The pipelines were first analyzed using closed-form solutions for a beam with simultaneous lateral and axial loading. Because adjacent spans are unlikely to be of uniform length, while individual spans may be bedded in compliant soil media, engineering judgment suggests that neither full fixity or full rotational freedom accurately represents span end conditions. Rather, actual end restraint conditions were thought to more likely be midway between the two extremes. Consequently, the stresses at any point along the beam were calculated as the average of the fixed and pinned solutions, which is an assumption that is consistent with standard structural analysis methods. The same pressure, weight, and current loadings were considered as in the previous studies. The resulting equations are presented in the following discussion. The pipeline behaves as a catenary with resistance to lateral deflection developed through increased axial tension rather than additional bending stress for spans much in excess of 80 ft.

The equations for the tensioned beam-catenary span, as an average of the fixed and pinned cases, are given below.

$$M_P = \frac{w}{k^2}\left[\frac{1}{\cos(kL/2)} - 1\right], \quad M_F = \frac{w}{k^2}\left[\frac{1}{\sin(kL/2)} - 1\right]$$

$$M_{FP} = \frac{w}{2k^2}\left[\frac{\sin(kL/2) + (kL/2)\cos(kL/2)}{\sin(kL/2)\cos(kL/2)} - 2\right]$$

$$\sigma_b = \frac{MD}{2\,I}\ , \quad \sigma_x = \frac{T}{A}$$

where

M_P	= bending moment for pinned-end condition
M_F	= bending moment for fixed-end condition
k	= $(T/EI)^{1/4}$
T	= axial compressive force
E	= elastic modulus
I	= pipe section moment of inertia
A	= pipe section metal area
L	= pipe span length
w	= resultant lateral load per unit length
σ_b	= bending stress
σ_x	= axial stress

Considering a negligible temperature differential between the transported product and the water temperature results in the solution indicated by the dashed lines in Figure 3. The longitudinal tensile stress component and biaxial stresses converge for long spans. The allowable longitudinal tensile stress of 80% of SMYS is achieved at a span length of 155 ft.

The original design study recognized that deflection of the spans would relieve the compressive stress due to thermal expansion where the pipeline operates at temperatures warmer than the water. The product temperature in the line varies seasonally between 39 F (4 C) and 61 F (16 C). The water temperature varies seasonally and with depth due to stratification and turnover phenomena. Deepwater temperatures vary from 39 F (4 C) to 43 F (8 C), while shallow water temperatures vary over a wider range. The differential between pipeline operating temperature and ambient deepwater temperature is the least in the winter and the greatest in the summer. The temperature difference is expected to vary between 0 F and +20 F, with the pipeline operating warmer than the water. Figure 4 shows the expected seasonal temperature variations.

Relief of the thermal stress by normal span sag from weight and current effects occurs gradually with spans of increasing length greater than 80 ft. Full relief occurs in spans longer than 120 ft. As the compressive stress becomes increasingly relieved with increasing span length between 80 and 120 ft, the span increasingly develops catenary behavior. The equations for a catenary span with fixed ends and compressive axial load relieved by sag are presented below.

$$y + \frac{Ay^3}{16\,I} = \frac{w}{4\,EI}\left(\frac{L}{\pi}\right)^4 \quad , \quad T = EA\left(\frac{\pi\,y}{2L}\right)^2$$

$$M = C\frac{wL^2}{12} \quad , \quad C = \frac{1}{1+0.0107\,(kL^2)}$$

$$\sigma_b = \frac{MD}{2\,I} \quad , \quad \sigma_x = \frac{T}{A}$$

where

y = pipe deflection
C = tensioned beam coefficient

and all other variables are as defined above.

The relief of thermal expansion by sagging results in a significantly different relationship between span length and total pipe stress for spans longer than 120 ft compared to the situation where the differential temperature is negligible. Stresses increase with span length, but at a significantly lower rate. This is illustrated by the solid curves in Figure 3 for a temperature differential of +20 F. The span length corresponding to the tensile limit of 80% of SMYS is 195 ft. As with the case with no differential temperature, when the pipeline structural response is governed by catenary behavior the span length is governed by the tensile stress criterion rather than the biaxial stress criterion. The limit of 90% of SMYS on the biaxial stress then governs local curvatures, primarily in areas where the pipeline is already supported on the bottom soil and follows the bottom contours.

The results indicate that with negligible temperature differential, the pipe may begin yielding with spans longer than 170 ft, whereas with the maximum temperature differential the pipe does not begin to yield until spans are at least 225 ft long. The pipe does yield significantly beyond the elastic limit until spans are actually much longer than that amount. This seems to be consistent with the fact that spans longer than 250 ft have occurred without apparent damage to the line. Operating conditions having a differential temperature intermediate between 0 F and +20 F would be bounded by the solutions represented by the dashed and solid curves in Figure 3.

One potential concern with the catenary spans is for girth weld integrity. The pipeline was constructed using shielded metal arc welding (stick welding) using E6010 coated electrodes. While improved incrementally over time, this process is essentially similar to how the vast majority of pipelines are constructed today. The project-specific standards adopted for qualification of the welding procedures and welders, and for acceptance of workmanship in production welds, were not very different from those that are in use today as well, in accordance with API 1104. In order to minimize the chances for cracking, the welds were preheated. Finally, all girth welds were fully radiographed. Given these factors, one can have some confidence that the overall weld quality and integrity is comparable to those produced today using E6010 electrodes on a plain carbon steel pipe such as Grade B.

While fracture toughness characteristics of the welds were never measured, an engineering critical assessment in accordance with a proven methodology[11] indicates that with a minimally ductile weld (having a crack tip opening (CTOD) of 0.005 inch), the allowable workmanship flaw 2-inches long would be safe against brittle fracture even at tensile stress levels of 95% of SMYS, with a factor of safety of '2'. This is consistent with the fact that spans longer than 250 ft have occurred without incident and gives confidence that the proposed allowable span of 140 ft is a sound limit.

EFFECTS OF OPERATING CONDITIONS

New supports installed under an existing span will not relieve the spanning-induced stresses, only the additional stresses due to span extension (increase in length), unless the span is lifted prior to installing the supports or the supports have a jacking capability. Lifting the line prior to support installation, or jacking afterward, would preload the supports and make them at least partially effective in relieving present spanning-induced stresses. Without preload, the supports would carry only the added load caused by span length extension. As an alternative, a reduction in the amount of sag resulting from introducing different operating conditions such as reduced product temperature or reduced product specific gravity could achieve a similar effect to raising the pipe first or jacking the supports.

Four variables could be controlled to adjust the span sag when supports are being installed: line pressurized versus depressurized, flow shut-in versus normal flow, crude oil contents versus NGL contents, and line out-of-service versus in-service. These will be briefly reviewed to determine whether there are operating conditions that should be avoided because they could increase risks during the mitigation process, or that are preferred because they could make the supports more effective.

Pressure

The hoop stress due to the normal operating pressure (NOP) of 220 psig is only 9% of SMYS. The longitudinal stress in the pipe due to internal pressure is between 30% of this value for restrained portions of the line and 50% for unrestrained portions, or 3% to 4.5% of SMYS. It is unlikely that a longitudinal stress component this low could make a significant difference from a safety standpoint even when added to the spanning stresses. Thus it seems unnecessary to require that the line pressure be reduced from normal operation.

Flow

An analysis of the deflection and stresses in the spans considered that the pipes are in a state of compression caused by differential thermal expansion due to the crude oil product in the pipe being warmer than the water temperature of 40 F. This led to the finding that spans must exceed 120 ft in length in order to fully relieve the thermal compression. Longer spans develop catenary behavior from the thermally relieved sag configuration, with resistance to additional vertical sag developed through increased axial tension rather than additional bending stress. In fact, recognition of this phenomenon led to greater allowable spans than would be the case without any initial thermal compression on the pipeline. It follows that if the flow is shut-in for a sufficiently long period of time prior to the span correction, the lines would cool to the ambient water temperature and the thermal compressive stress would be lost. This would result in more tension in the spans and reduced sag. If the supports were to be installed with the line in this condition, then when product flow is restored and the pipe warms to the product temperature, the supports would become loaded by the additional sag induced by thermal expansion of the pipe.

It should be noted that the analysis also showed that without thermal expansion, spans of 140 ft are at the limit of acceptable lengths based on traditional Code stress criteria. This means that after cooling down, the existing long spans that are currently safe but longer than the 140-ft service lengths Enbridge plans to allow, would then be in excess of acceptable stress limits for the period of time between when the line cools down and when the supports are installed. It is likely that the longest spans could experience longitudinal stresses in excess of the yield strength. There are a number of reasons why this is probably not a real structural integrity concern but the safety margins are difficult to quantify with the information available. Thus shutting in the lines while they are full of product is not recommended even though doing so would lead to more effective span support. Shutting in the lines would also interrupt service for however long it takes to complete the support installation process.

Product

If both products are transported at the same temperature, the difference in net unit weight between the crude and NGL conditions would be expected to result in only a small difference in span sag owing to the thermal compression effect. If so, then it may make no significant difference whether the line is transporting crude oil or NGL during support installation. On the other hand, if the product temperature of NGL is lower than the temperature of the crude, there could be as much as a 20% reduction in sag measured from the top of the pipe at the ends of the span compared to when crude is in the line. In that case, it would be preferable to transport NGL while supports are being installed. Note that this would only relieve spanning–induced stresses at the present span lengths when crude oil is being transported, not when NGL is in the line. If the span length extends, then the supports become effective regardless of product.

Service

A fourth option is to take the line out of service completely, including clearing it of product by nitrogen displacement. In this condition, the reduced net weight of the pipe and the equalized pipe temperature would result in the least amount of span sag. This would be the optimal from the standpoint of the immediate effectiveness of the installed supports. However, this strategy would result in the line being out of service for the duration of the span mitigation process. However, with two line crossings this might be operationally feasible.

Summary

Some relief of span sag during the installation of supports would be beneficial because it would immediately transfer some load to the supports. Mechanically, relief is accomplished by lifting the line prior to support installation, or by installing supports that provide a jacking or lifting function after installation. Without some means of preloading, the supports do not become effective for reducing span-induced stresses until the spans extend in length through a continued bottom scour process. However, they will help mitigate vortex-induced vibration without preload.

There is no benefit to reducing the operating pressure during the support installation process from the standpoint of stresses due to internal pressure, because those stress components are too small to make a significant difference. Shutting in flow could reduce span sag due to the line cooling down, but this runs the risk of increasing stress levels in the spans until the supports are installed and flow is restored. Therefore, shutting in the line while the supports are being installed is not recommended. Switching over to NGL will yield only a relatively small change in the sag if the transporting temperature of the NGL is as warm as the crude oil. If the NGL runs cooler than the crude oil, the combination of lower pipe temperature and reduced span weight could reduce span sag making the supports at least partially effective at the present span lengths when crude oil is being transported. The optimal situation, solely from the standpoint of immediate effectiveness of the supports, is to take the line out of service, including clearing the pipe of product contents. This study does not evaluate the impact of this strategy on operation.

SPAN SUPPORTS

Pipe spans vary greatly in length. Enbridge has established that spans exceeding 140 ft will be corrected by the installation of supports, although spans of up to 195 ft meet conservative allowable stress limits conventionally applied to offshore pipelines. The 140-ft span limit is consistent with criteria for remediation employed on the lines previously, and allows for some continued extension over time without serious erosion of safety margins. Free span heights above the Straits bottom vary considerably.

A survey of offshore pipe span support methods was conducted on behalf of Enbridge by J. P. Kenny, Ltd. in 2002.[12] This review draws on the information available in that study. An important part of the survey was estimated costs for materials and installation.

Several methods of support for offshore pipeline spans are available, including:

- trenching;
- rock-dumping;
- mattresses, sandbags, and grout bags;
- mechanical support; and
- pipeline anchors.

The option of trenching is not recommended, since that can only be used in specific bottom soil conditions that may or may not be present consistently. The option of rock-dumping is the most effective long-term mitigation of the effects of scour. It has been used successfully on the Great Lakes Gas Transmission 36-inch Straits crossing, and other submerged pipelines in other offshore locations. If Enbridge wishes to consider a comprehensive span mitigation program, rock-dumping would warrant investigation. However, it may not be the most cost-effective solution for spot repairs of a few individual spans.

For spot repairs, three options remain. All may be effective for the required purposes, depending on the specific conditions.

The grout bags have a stack height of approximately 2 ft. Where the span clearance above the Straits bottom is large (for example 15 ft or more), grout bags may not be an optimal choice because it will be necessary to lay them in a tiered stack (pyramid fashion) for long-term stability resulting in a large number of bags to be placed. Also, grout bags do not offer a pipe-lifting capability in order to preload the supports.

Mechanical supports consist of a two-legged telescoping A-frame device that clamps around the pipeline and supports it off the bottom. They are relatively inexpensive and straightforward to install. Such devices may prove effective where continued scour is not anticipated. However, if the bottom elevation could be expected to continue to lower due to continued scour, they offer only temporary support and might be detrimental if they lose bottom contact.

Pipeline anchors consist of a structural support that is screwed or grouted into the bottom soil. They have been used successfully in similar circumstances to the Straits, including several major US river washouts. They may be the most reliable system where span clearances are large, as well as where current velocities are high (which does not appear to be the case here). The costs for anchor systems will be greater than for mechanical supports.

Recommendations for Mitigation of Spans

Recommendations are as follows for mitigating the spans on the Straits crossings:

- grout bags for low-clearance spans
- anchors for high-clearance spans
- rock-dumping for permanent system-wide mitigation

ANALYSIS OF LOCAL PIPE WALL STRESSES

At the request of Enbridge, an analysis was performed to estimate local stresses in the pipe wall associated with support structures installed to mitigate excessive span lengths. The purpose of the analysis was to address the requirement in 49 CFR 195.110(b):

> "The pipe and other components must be supported in such a way that the support does not cause excess localized stresses. In designing attachments to the pipe, the added stress to the wall of the pipe must computed and compensated for."

The local stresses were evaluated for a maximum span of 140 ft consistent with Enbridge's span mitigation objectives. The average support reaction of a multiple span installation is then 19.6 kips.

The support structures Enbridge has considered for installation are a commercially available system that have been installed successfully on other offshore and marine pipelines. The assembly consists of screw-anchored 4.5-inch OD posts positioned on each side of the pipeline and connected by an overhead 8-inch wide-flange support beam. Collars are used to adjust the support beam height. The pipeline is suspended below the support beam by a saddle bolted to the bottom of the beam. The saddle strap is 8-inches wide and 0.5-inch thick. A spacer is inserted between the top of the pipe and the bottom of the beam. A schematic of the support concept is shown in Figure 5.

The bending stresses on the gross pipe section associated with installation of a pipe support were accounted for in the development of the span limits and are not the subject of §195.110(b). The language of §195.110(b) refers instead to local stresses associated with the attachments. In order to evaluate the local stresses associated with the saddle, a theoretical model was used based on axisymmetric radial pressure around a cylinder.[13] This model was adjusted by recognizing that the bearing pressure at the interface between the pipe and the saddle is concentrated within an arc of between 60 and 120 degrees around the bottom of the pipe section. The local through-wall unit bending moment for this simple idealization is computed as $M=(q/2\lambda^2)(e^{-\lambda a}\sin\lambda a)$, where q is the bearing pressure at the interface, a is half the width of the saddle strap, λ is computed as $[3(1-v^2)/(Rt)^2]^{1/4}$, v is Poisson's Ratio, R is the mean radius of the pipe section, and t is the pipe wall thickness. The local bending stress is then computed as $\sigma=6M/t^2$. The local shear stress is computed as $\tau=qa/2t$, again with q adjusted to consider the limited arc of contact between the pipe and saddle. The results of the analysis are summarized in Table 1 below:

Table 1. Local Pipe Wall Stresses Resulted from Bearing Pressure at Support Locations

Interface Angle, deg	Local Bending Stress, ksi	Local Shear Stress, ksi
60	0.80	1.20
90	0.53	0.80
120	0.40	0.60

The local stresses are observed to be very low. Local stresses much larger than this are normally present within or adjacent to common features in pipelines such as branch connections, attachment welds, flanges, and fittings and are not of significant concern. These stresses, superimposed on the stresses due to normal operation and spanning, do not pose a threat to the integrity of the pipeline. Having determined that the local stresses associated with the support are so low, no further action to address them is recommended.

VIBRATION INDUCED BY VORTEX-SHEDDING

Introduction

The steady flow of fluid around a bluff body creates a wake. Under certain conditions, the wake is characterized by discrete vortices which form and then detach from the trailing surface of the body in an organized periodic fashion from alternating sides of the body. Such a wake is referred to as a vortex street. Examples of such vortices are shown in Figure 6 (laboratory generated on the left and computer generated on the right). As each vortex detaches, momentary hydrodynamic lift and drag forces are produced giving rise to alternating inertial forces acting on the cylinder. If the body is flexible and lightly damped, the alternating forces result in oscillation of the body. If the frequency of vortex shedding is close to the frequency of a fundamental mode of structural vibration, resonance and large oscillation amplitudes occur. Even if the vortex frequency and structural frequency are not closely matched, if the oscillations are large enough the phenomenon of "lock-on" can occur wherein the body and wake frequencies acquire the same value. This can cause structural failure and has done so in pipelines exposed to water or wind currents under these conditions.

The nondimensional shedding frequency is given by the Strouhal Number, St=fD/U, where *f* is the vortex shedding frequency, *D* is the bluff body diameter, and *U* is the mean stream velocity. The Strouhal Number is relatively constant and equal to approximately 0.2 at values of the Reynolds Number below $3.5x10^5$. The Reynolds Number is a dimensionless parameter that defines the flow regime, calculated as Re=ρD/μ, where *ρ* is the fluid density, *D* is the diameter of the cylinder, and *μ* is the fluid viscosity. The flow regimes that produce periodic vortices in the wake are indicated in Figure 7.

Vortex Shedding Limitations

The onset of motion of the span is characterized by the reduced velocity, V_r.[14,15] The reduced velocity is given by $V_r=U/(f_nD)$, where *U* is the velocity of steady flow normal to the pipeline, f_n is the natural frequency of the span, and D is the overall diameter of the coated pipeline. Susceptibility to vortex lock-on is considered significant with reduced velocities between 3.5 and 7.0. This occurs when the beam-mode fundamental frequency is within about 35% of the vortex shedding frequency f_s. The response peaks at a reduced velocity near 5.0, which occurs when the two frequencies acquire the same value. This is shown schematically in Figure 8. When the reduced velocity is between 4.0 and 7.0, oscillation of the pipe occurs crosswise to the current flow (i.e., vertically). At reduced velocities between 1.0 and 3.0, the vortices break off of both trailing surfaces simultaneously, resulting in oscillation in line with the current (i.e., horizontally). The magnitude of dynamic response in this mode is much lower than in the cross-current mode.

The natural frequency of the suspended pipeline span may be calculated, neglecting axial effects, from the formula:

$$f_i = \frac{X}{2\pi}\left[\frac{E}{m_e}\frac{I}{L^4}\right]^{1/2}$$

where *X* is the degree of end fixity constant (dimensionless), *E* is Young's Modulus of Elasticity, *L* is the span length, and *I* is the moment of inertia of the steel pipe section. The fixity constant, *X*, was assigned a value of 15.4, corresponding to a fixed-pinned beam (or propped cantilever). The effective mass, m_e, is the sum of the mass of pipe plus coating, the mass of contents inside the pipe, and the mass of water displaced by the pipeline (i.e., the "added mass").

By combining the equation for the reduced velocity with that giving the natural frequency of the suspended pipeline span, the critical span length can be obtained:

$$L_{cr} = \left[\frac{C D_c V_r}{U}\right]^{1/2}$$

where

$$C = \frac{15.4}{2\pi}\left[\frac{EI}{m_e}\right]^{1/2}$$

Current Velocity Data Analysis

Enbridge installed water current monitoring devices at four locations along their crossing in order to obtain better data concerning currents impinging on exposed spans. The devices were placed at representative water depths and locations in the Straits. Currents were monitored at 3-hour intervals between September 26, 2002 and August 8, 2004. Easting and Northing current velocities recorded by the four monitoring units are shown in Figure 9 through Figure 12. A sampling of current velocities in Easting and Northing coordinates is shown in Figure 13. The Easting current velocity component is about 3 times the Northing current velocity component. The velocities are seen to reverse direction every 2 to 3 days, and are predominately oriented in the ENE and WSW direction.

The seasonal variation in average and maximum current velocities is shown in Figure 14. The currents are somewhat lower in late summer months. Mean velocities ranged from 0.1 to 0.7 ft/sec. Maximum absolute velocities were 4 to 5 times the average, ranging up to 2.75 ft/sec. However, readings of this magnitude were actually extremely infrequent, as will be discussed subsequently.

Figure 15 is a plot of all 21,037 velocity measurements in both Easting and Northing directions. Each measurement unit is indicated by a different color. Figure 15 highlights several important observations. For one, the Easting velocity components are greater than the Northing velocity components by a factor of about 3. Currents tend to flow either ENE or WSW, though the degree to which headings were off-axis varied with the measurement station. With all four measurement units, the predominant current heading would be chiefly crosswise to the pipeline spans. Also, there is a significant amount of flow reversal suggested by the scatter. The two dashed gray boxes represent the boundaries of 2 and 3 standard deviations (2σ and 3σ) in the statistical scatter of the readings. (The 1σ box is hidden by the data points.)

Figure 16 and Figure 17 show the statistical distribution of velocity readings by magnitude, for the Easting and Northing coordinates, respectively. Both sets of readings were essentially normally distributed and centered about a velocity of zero as an effect of the flow reversal. The statistical parameters are summarized in Table 2 below. The analysis indicates that 95% of the readings for the Easting current velocities are within ±1.1 ft/sec.

Table 2. Summary of Flow Velocity Analysis

Parameter	Actual Velocity, ft/sec	
	Easting	Northing
Minimum	−2.02	−0.96
Maximum	2.76	0.95
Average	0.01	0.00
1SD (68%)	0.54	0.15
2SD (95%)	1.08	0.30
3SD (99.7%)	1.62	0.45

It may be misleading to evaluate the data in the manner described above in that the flow-reversal implies that the expected velocity would be zero. Therefore, the data was reanalyzed in terms of the absolute value of the velocity, as shown in Figure 18 and Figure 19. The distribution follows a gamma function. The statistical parameters are summarized in Table 3 below. The average current velocity is non-zero but relatively low, about ±0.4 ft/sec in the Easting direction. The mean plus 2-sigma velocity, which envelopes 95% of the readings, was 1.1 ft/sec, about the same as from the analysis using actual water current values.

Using either velocity distribution, the proportion of velocities above the 2.3 ft/sec threshold identified in the VIV discussion is very low. A velocity this high was observed only eight times in 21,037 measurements, or 0.038% of the time.

Table 3. Summary of the Flow Velocity Statistical Parameters

Parameter	Velocity Magnitude, ft/sec	
	Easting	Northing
Minimum	0.00	0.00
Maximum	2.76	0.96
Average	0.41	0.11
Std. Deviation	0.36	0.10
X+1SD (68%)	0.76	0.21
X+2SD (95%)	1.12	0.31
x+3SD (99.7%)	1.48	0.41

The mean plus 3-sigma velocity encompassing over 99% of measured values was approximately 1.5 ft/sec. Hence current velocities in excess of 1.5 ft/sec can be considered rare and infrequent events.

Results

The critical spans determined from the foregoing analysis are shown in Figure 20. The results indicate that as the current velocity increases, the VIV-allowable span length decreases. The allowable span length decreases to less than the 140 ft span length established on the basis of static analysis at current velocities of 2.3 ft/sec or greater. A velocity of 2.3 ft/sec happens to correspond to a Reynolds Number of $3.5x10^5$, above which the wake becomes disorganized and the vortex street is aperiodic. So velocities greater than 2.3 ft/sec would not be expected to limit spans to shorter lengths in consideration of VIV. Moreover, velocities approaching 2.3 ft/sec would be quite rare, and presumably of short duration.

As a conservative assumption, only the stiffness of the steel pipe has been considered in the calculations. The effects of catenary (or sag tension) would in all likelihood allow for slightly greater spans by increasing beam natural frequencies of vibration.

REFERENCES

1. API Specification 5L, *Specification for Line Pipe*, 12th Edition, 1951.
2. Mackinac Straits Pipe Line Specifications, 1953.
3. Straits of Mackinac Pipe Line Easement, Conservation Commission of the State of Michigan to Lakehead Pipe Line Company, Inc., April 1953
4. Subaquatic Surveys, Onyx Superior Special Services, Inc., 2001 (supplemented by data from Enbridge).
5. Code of Federal Regulations, Title 49 – Transportation, Part 195 – Transportation of Hazardous Liquids by Pipeline, 49 CFR 195, October 1, 2002.
6. ASME B31 *Code for Pressure Piping*, Section 4, Hazardous Liquid Pipeline Systems, B31.4, 1999.
7. ASA B31 *Code for Pressure Piping*, 1951 with 1953 Addenda.
8. ASME Boiler and Pressure Vessel Code, Section IX, *Welding and Brazing*, 1953.
9. API Standard 1104, *Welding of Pipelines and Related Facilities*, 1st Edition, January 1953.
10. Dr. Mario G. Salvadori, Dept. of Civil Engineering, Columbia University letter to Lake Head Pipe Line, Inc., with attached calculations.
11. CSA Z662, *Oil and Gas Pipelines*, Appendix J/K, 2000.
12. Analysis of Spans, J. P. Kenny report to Enbridge, 2003.
13. Young, W. C., *Roark's Formulas for Stress and Strain*, 6th Ed., 1989, McGraw-Hill.
14. Mousselli, A. H., *Offshore Pipeline Design, Analysis, and Construction*, PennWell Books, 1981.
15. Danish Hydraulic Institute, *Pipeline Free Span Design, Volume 1, Design Guideline*, PRCI PR-170-9522, January 1997.

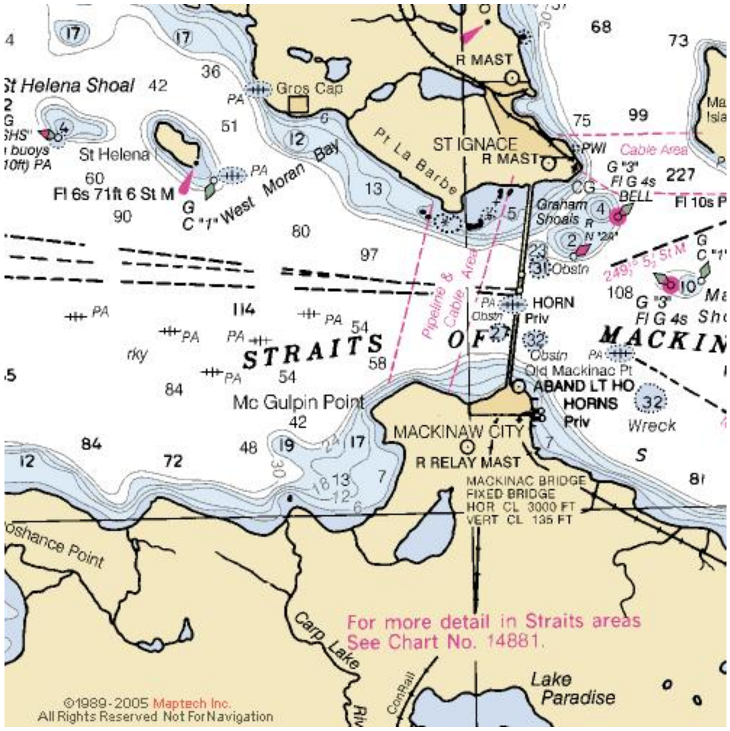

Figure 1. Location of Pipeline Crossing

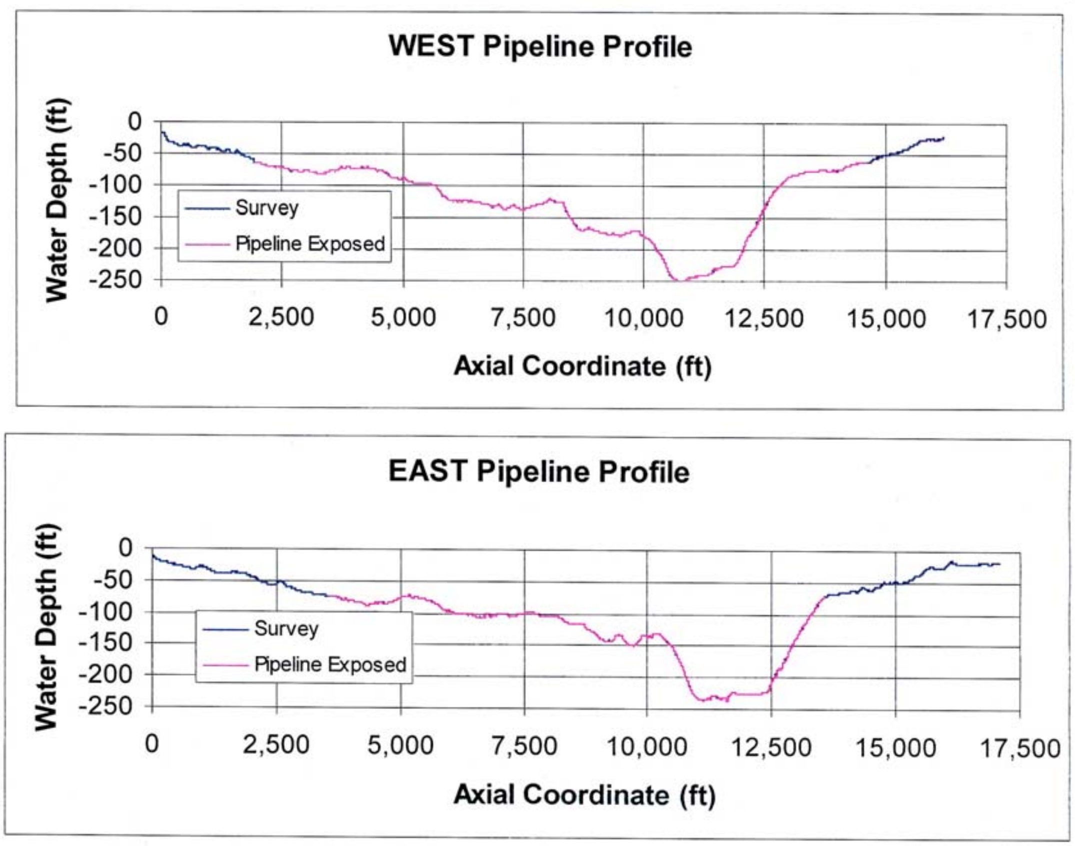

Figure 2. Crossing Bottom Elevation Profiles

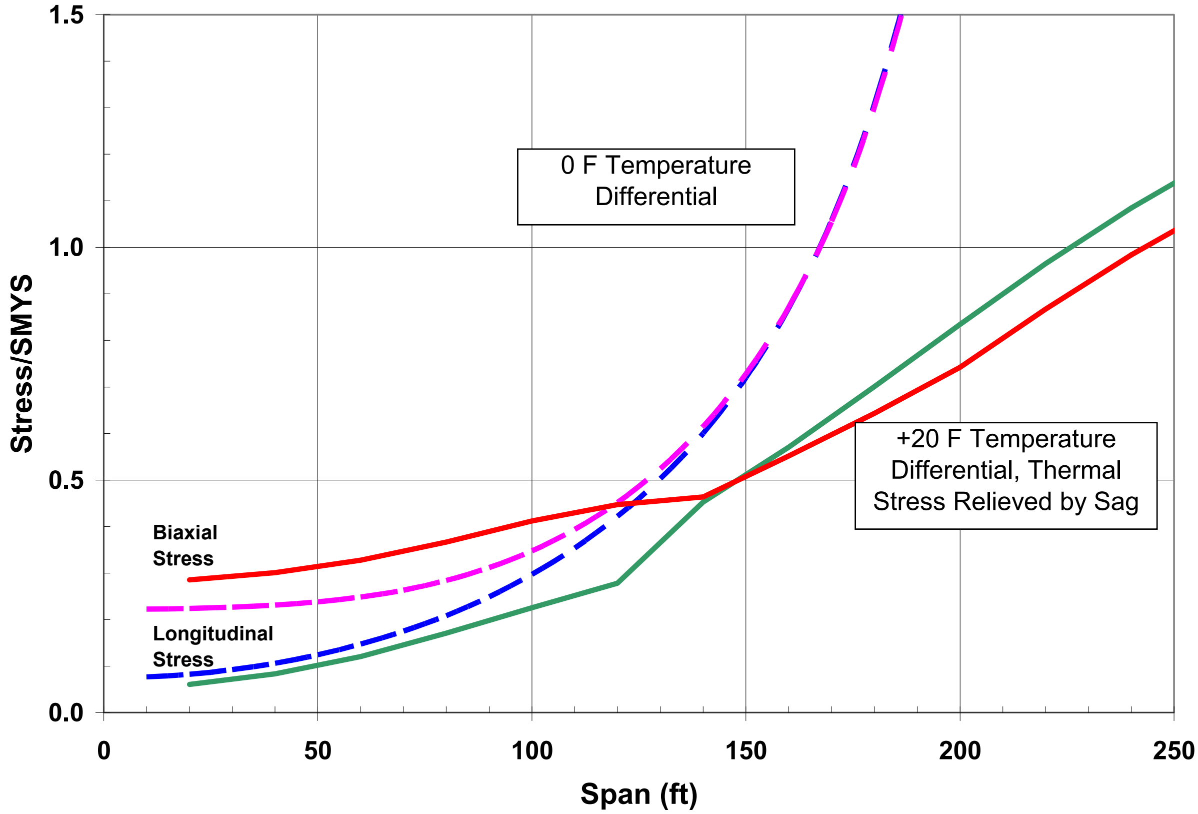

Figure 3. Relationship between Span and Stress

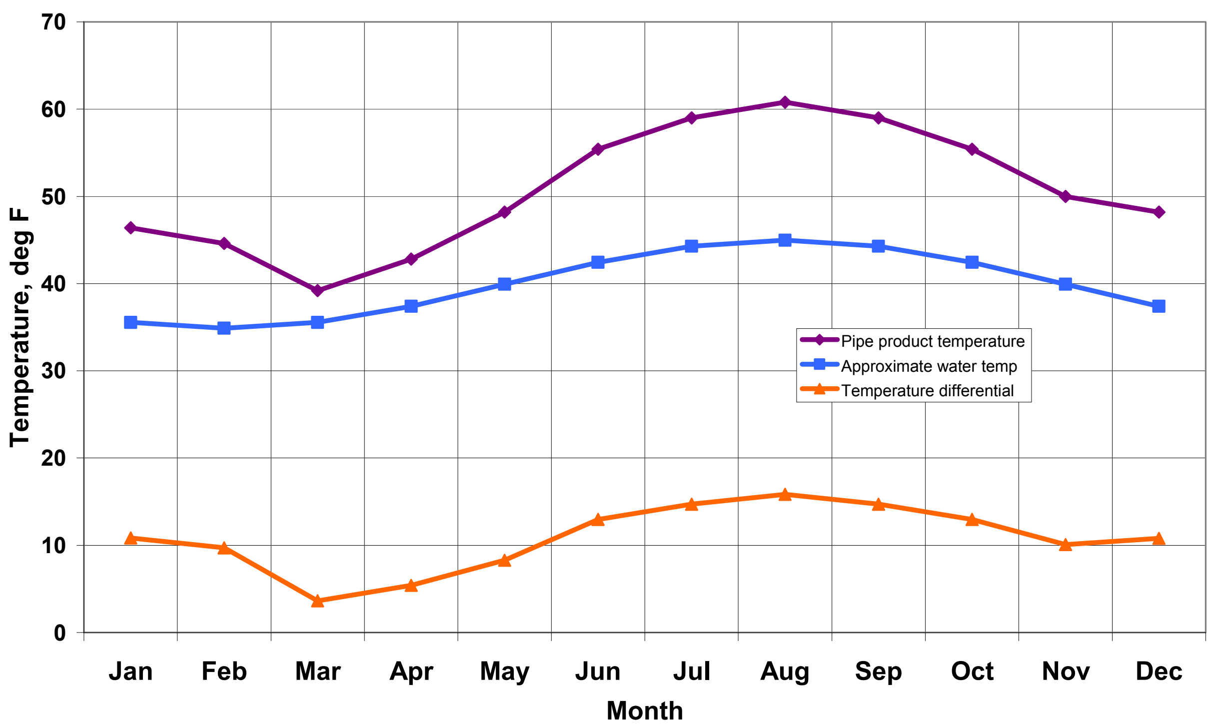

Figure 4. Annual Variation in Temperature

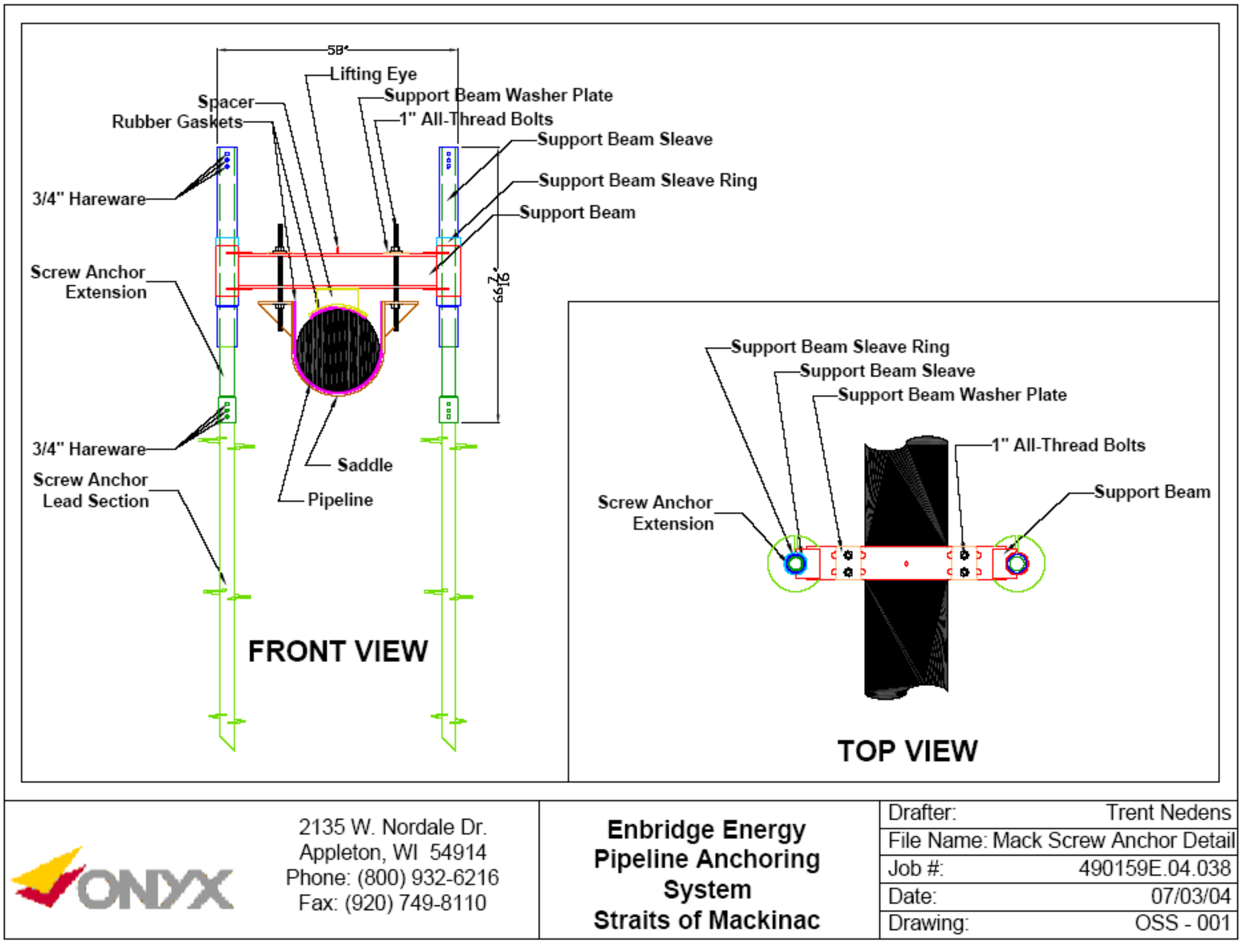

Figure 5. Pipe Support Arrangement

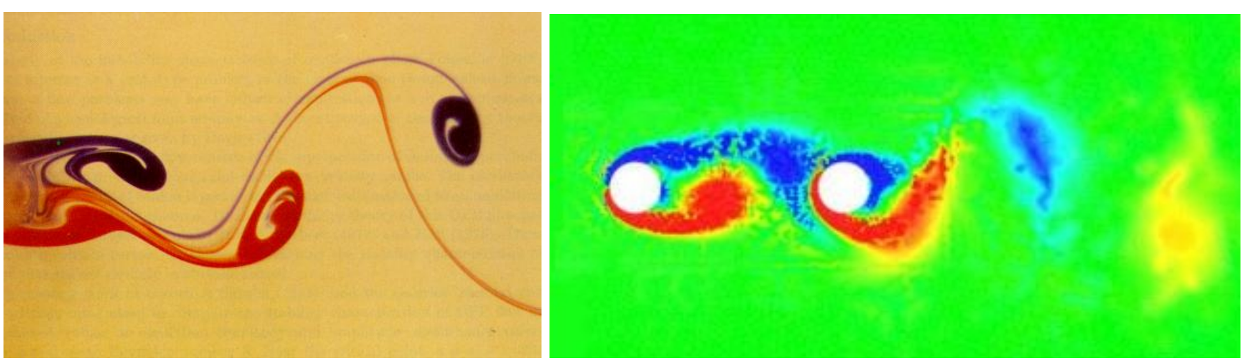

Figure 6. Examples of Periodic Vortex Shedding from Cylindrical Bodies

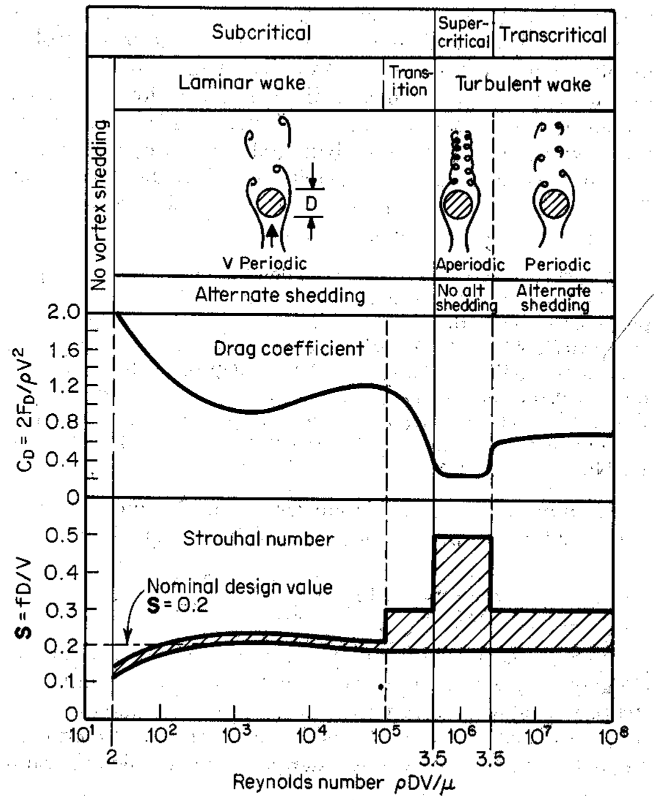

Figure 7. Flow Regimes Susceptible to Periodic Vortex Shedding

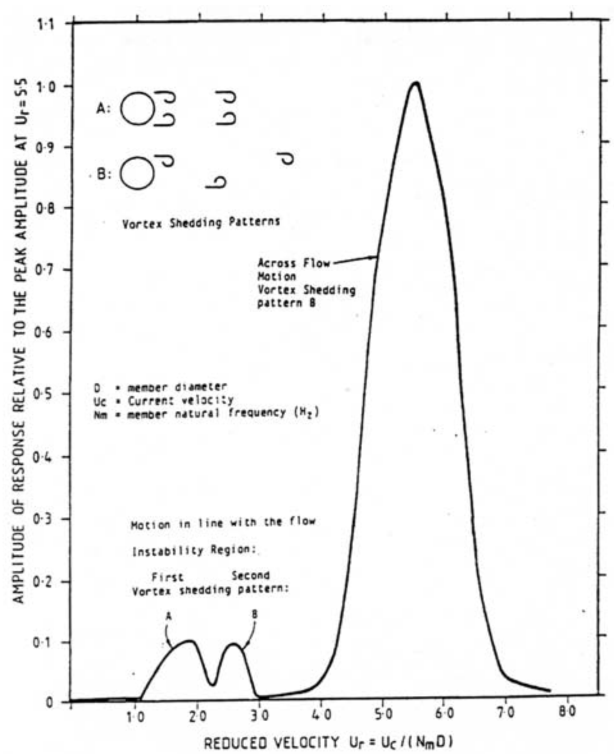

Figure 8. Influence of Reduced Velocity on Dynamic Response

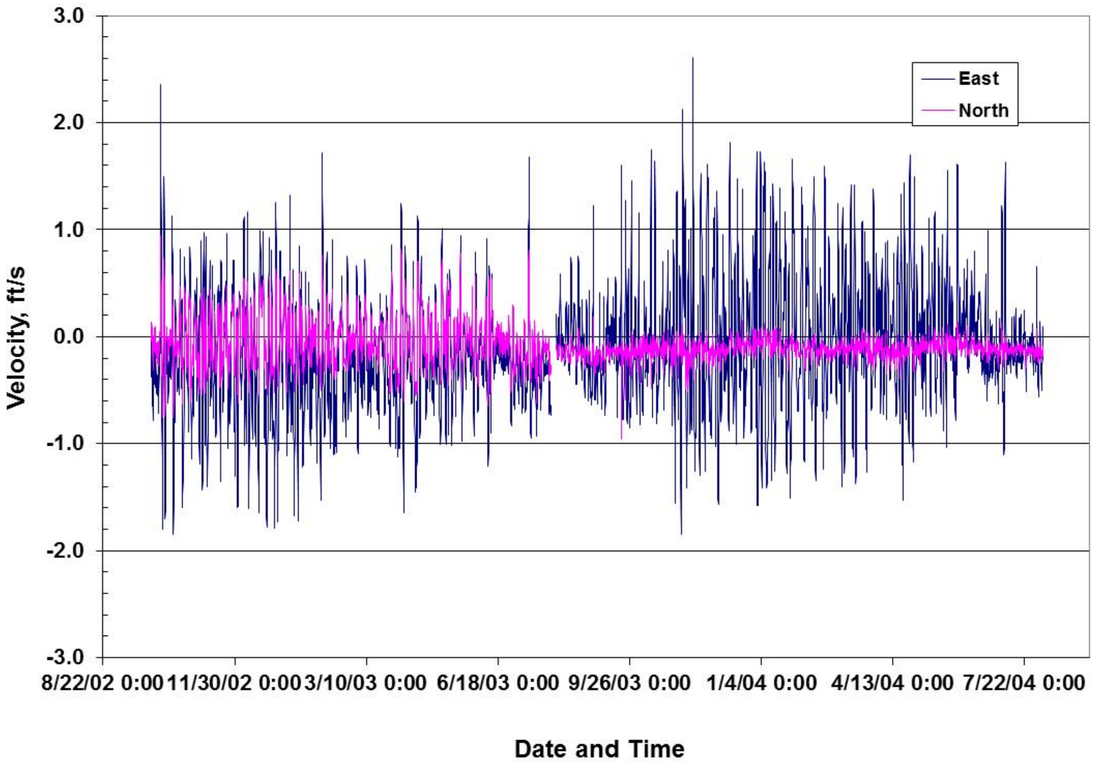

Figure 9. Current Velocity Measurement Unit 1

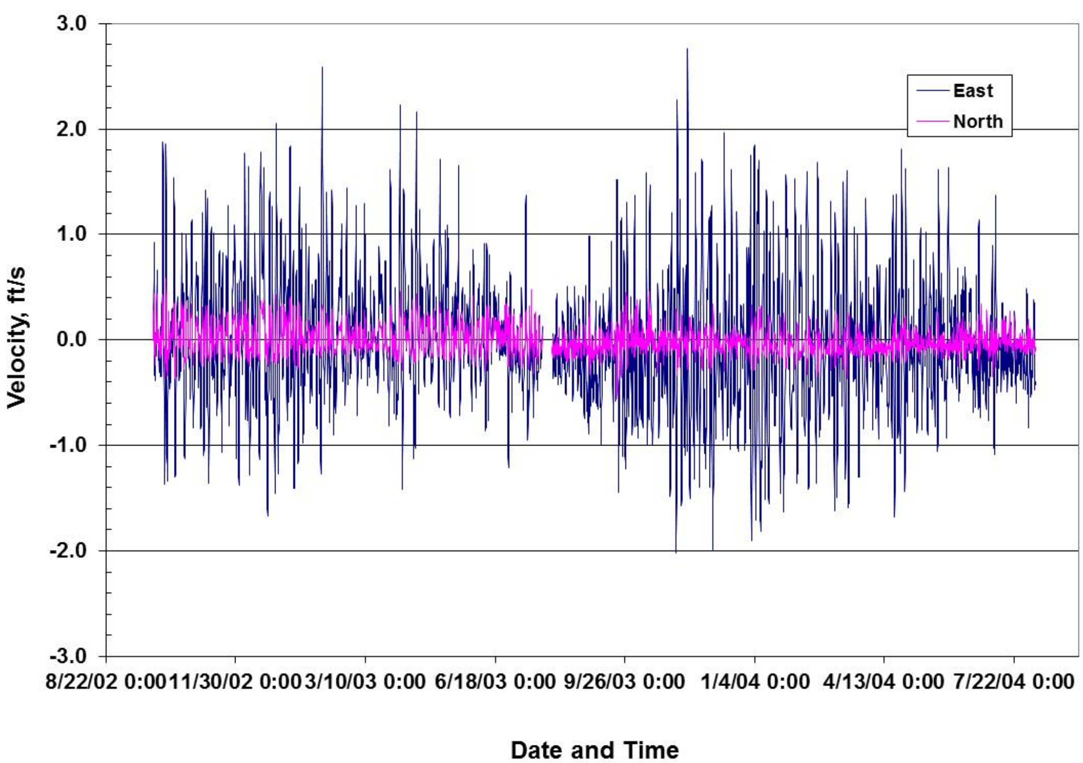

Figure 10. Current Velocity Measurement Unit 2

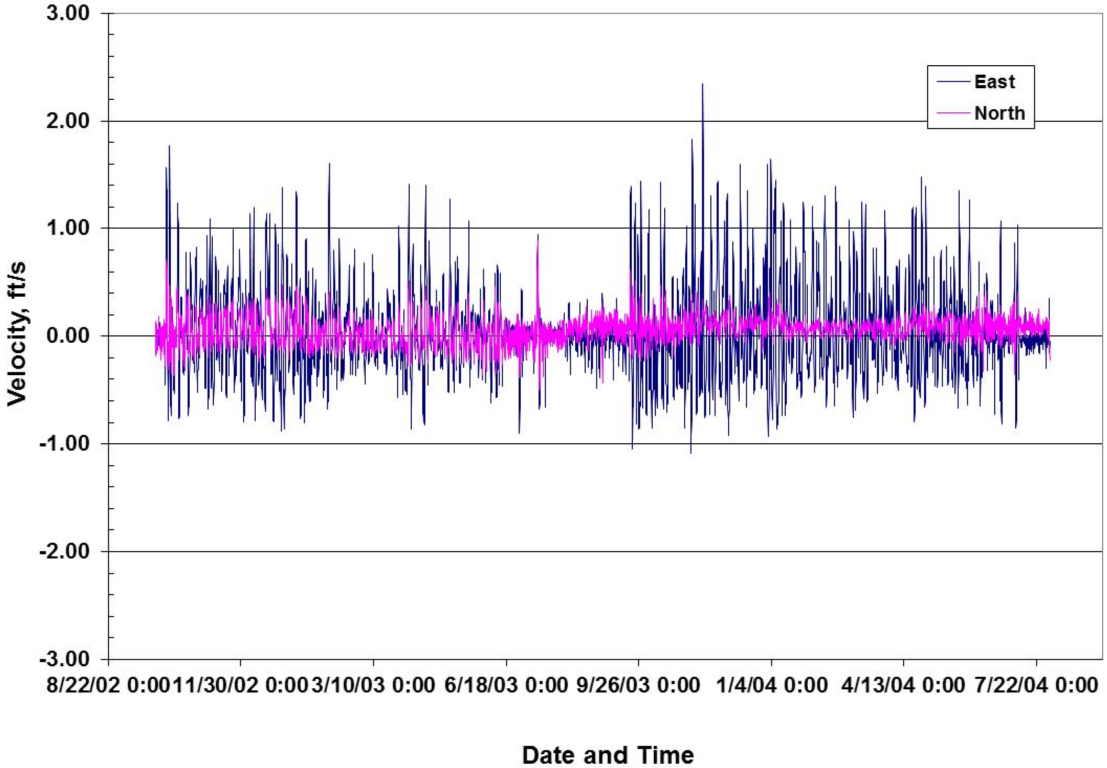

Figure 11. Current Velocity Measurement Unit 3

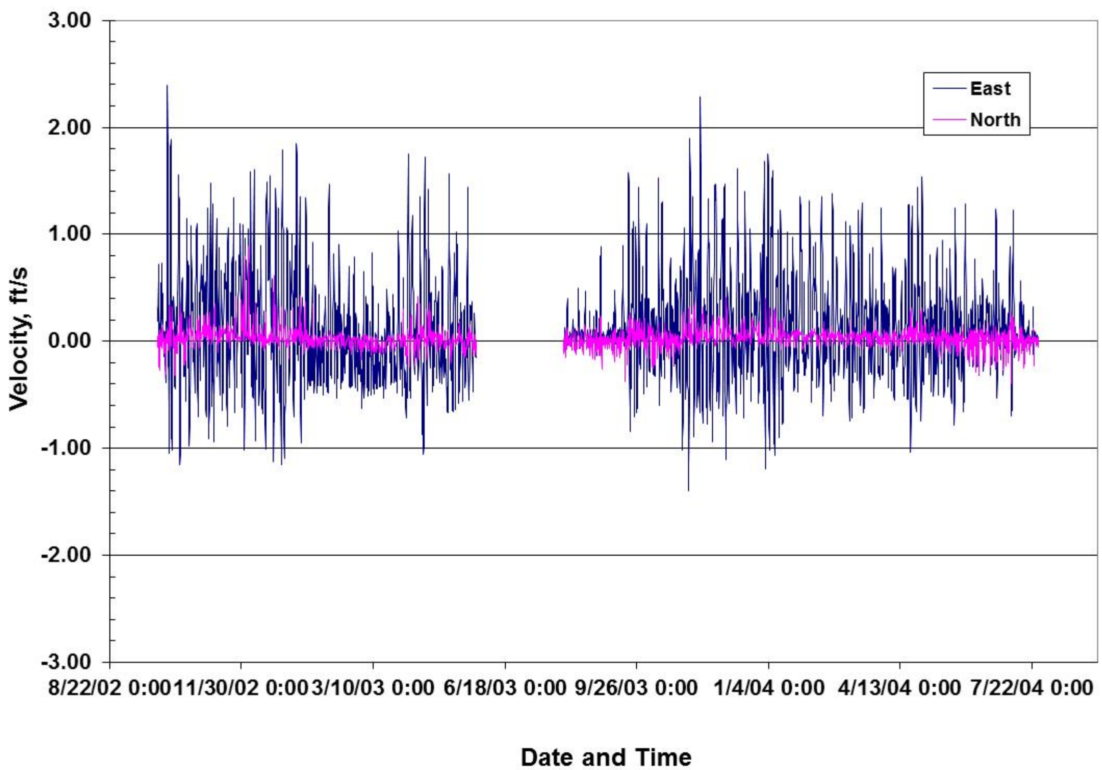

Figure 12. Current Velocity Measurement Unit 4

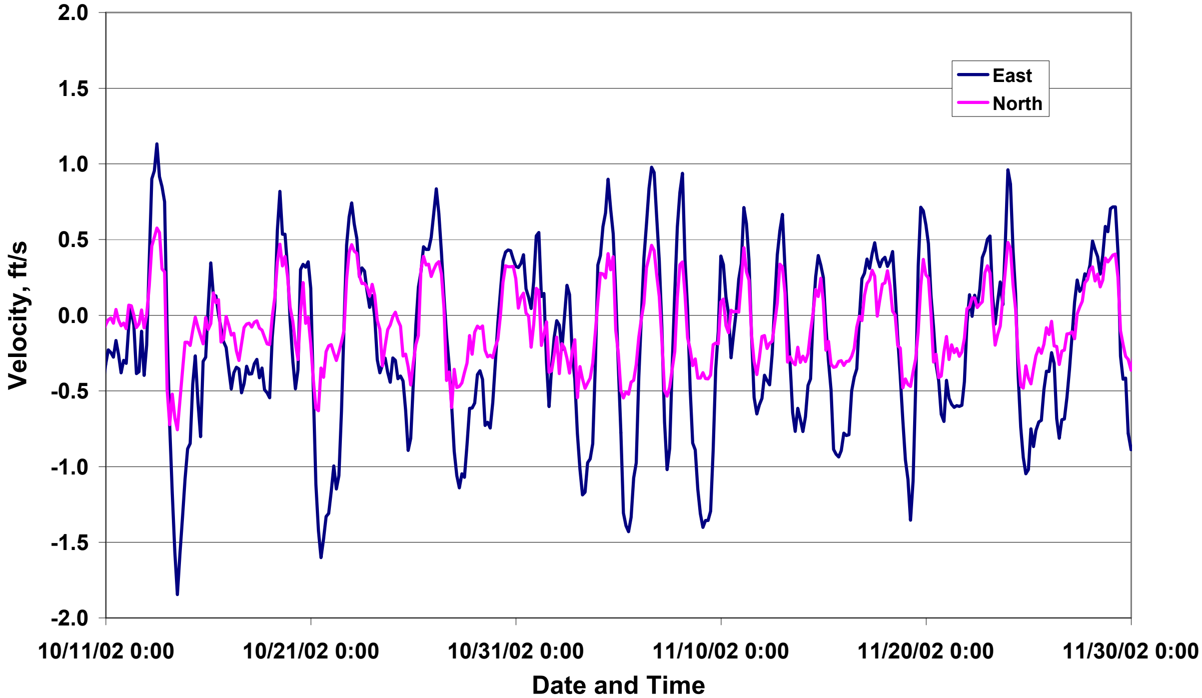

Figure 13. Current Velocity Sampling

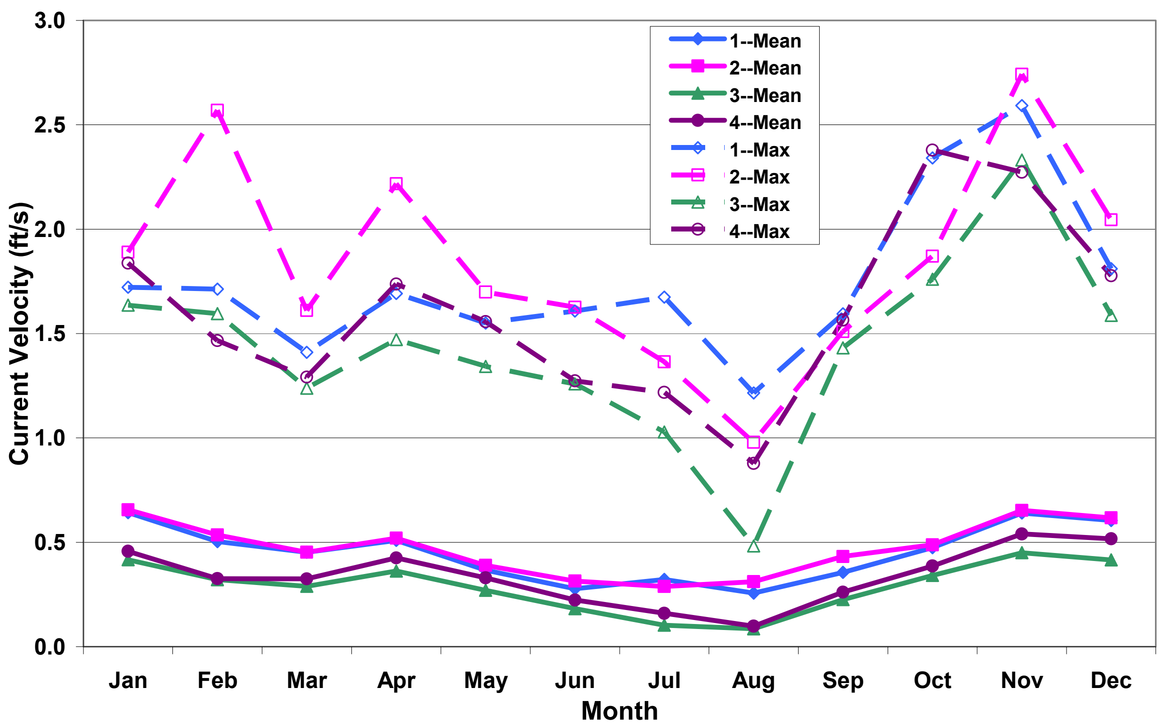

Figure 14. Seasonal Variation in Current Velocity

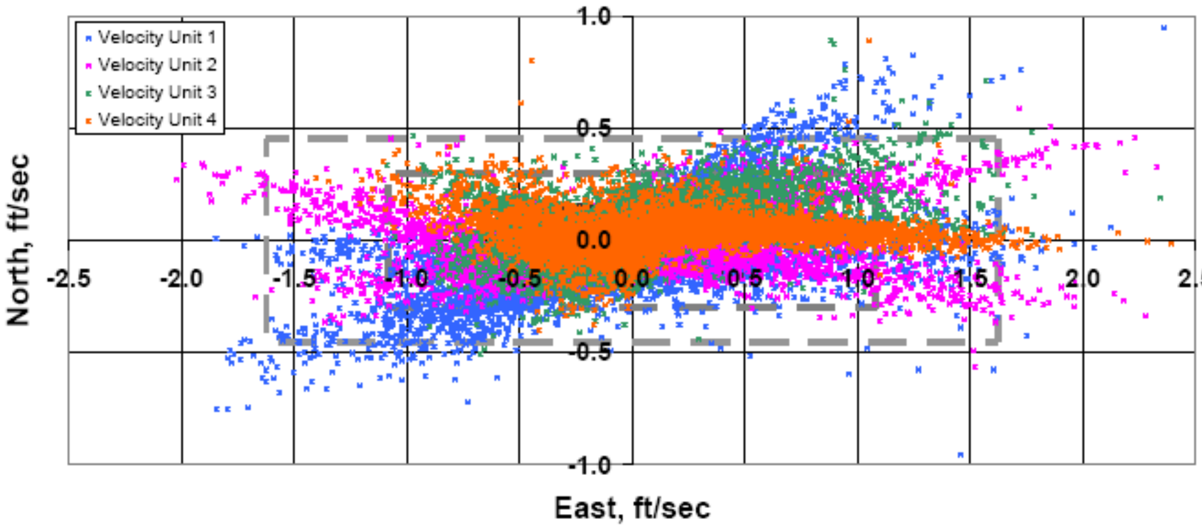

Figure 15. Distribution of Current by Heading and Velocity

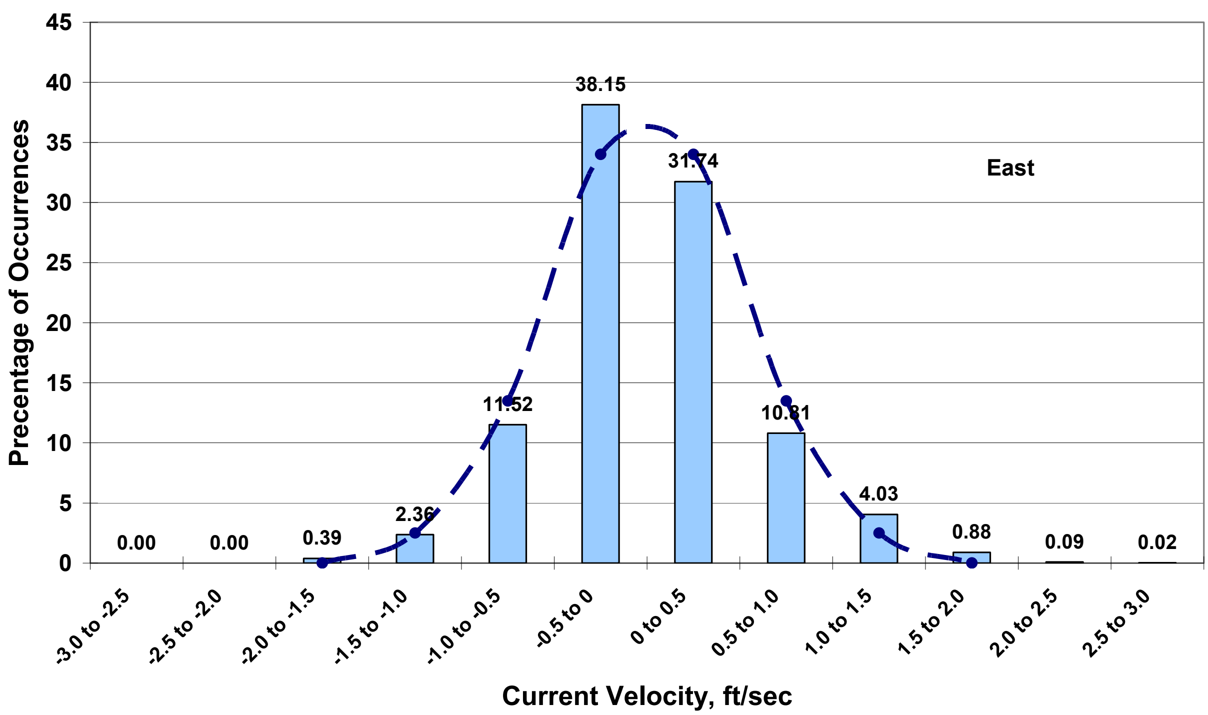

Figure 16. Distribution of Easting Velocity Occurrences

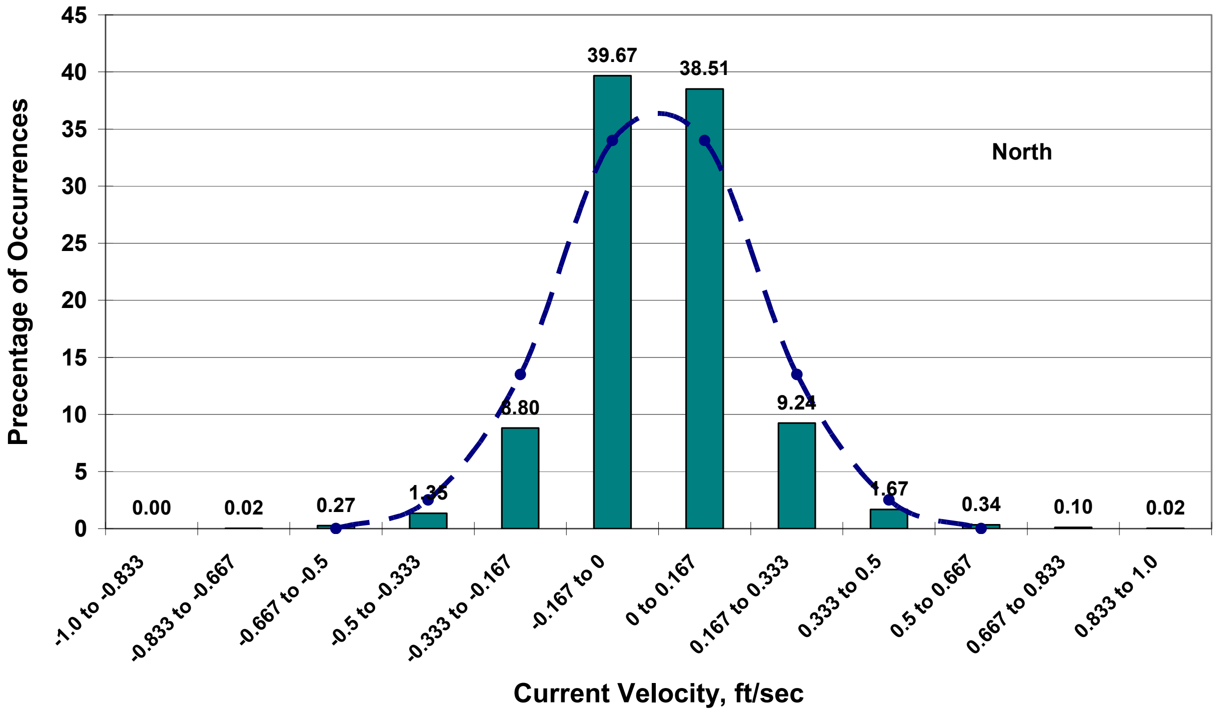

Figure 17. Distribution of Northing Velocity Occurrences

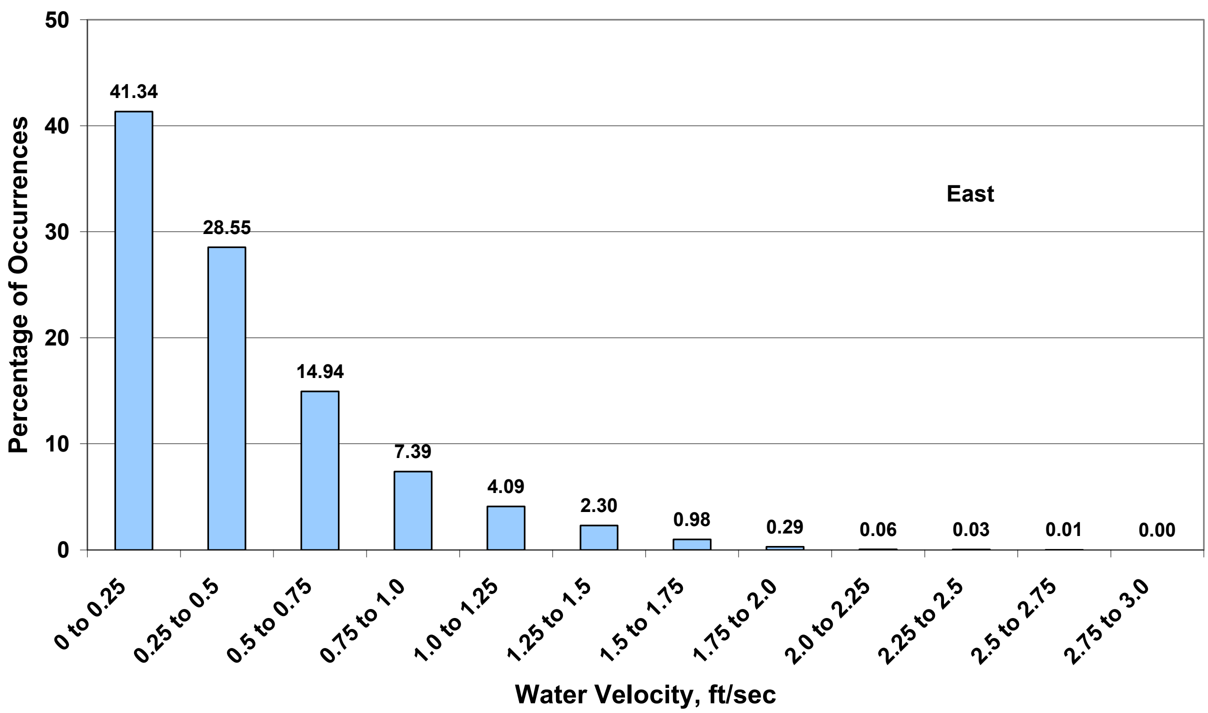

Figure 18. Distribution of Easting Velocity Magnitudes

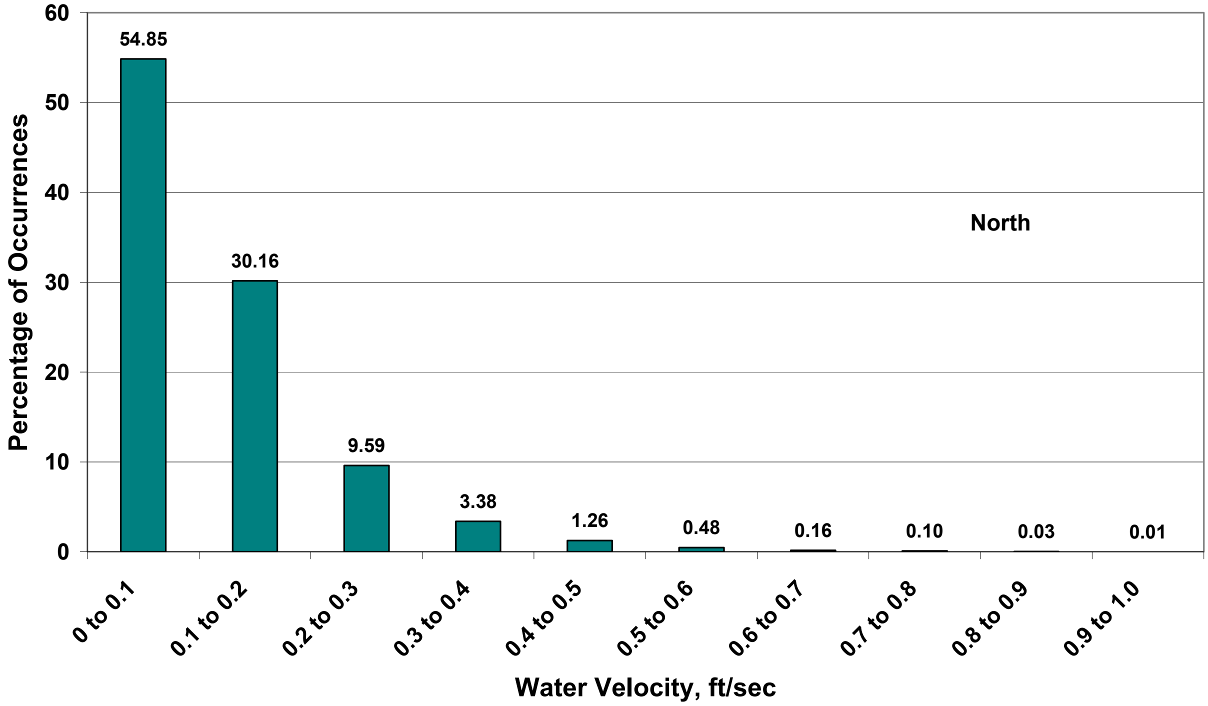

Figure 19. Distribution of Northing Velocity Magnitudes

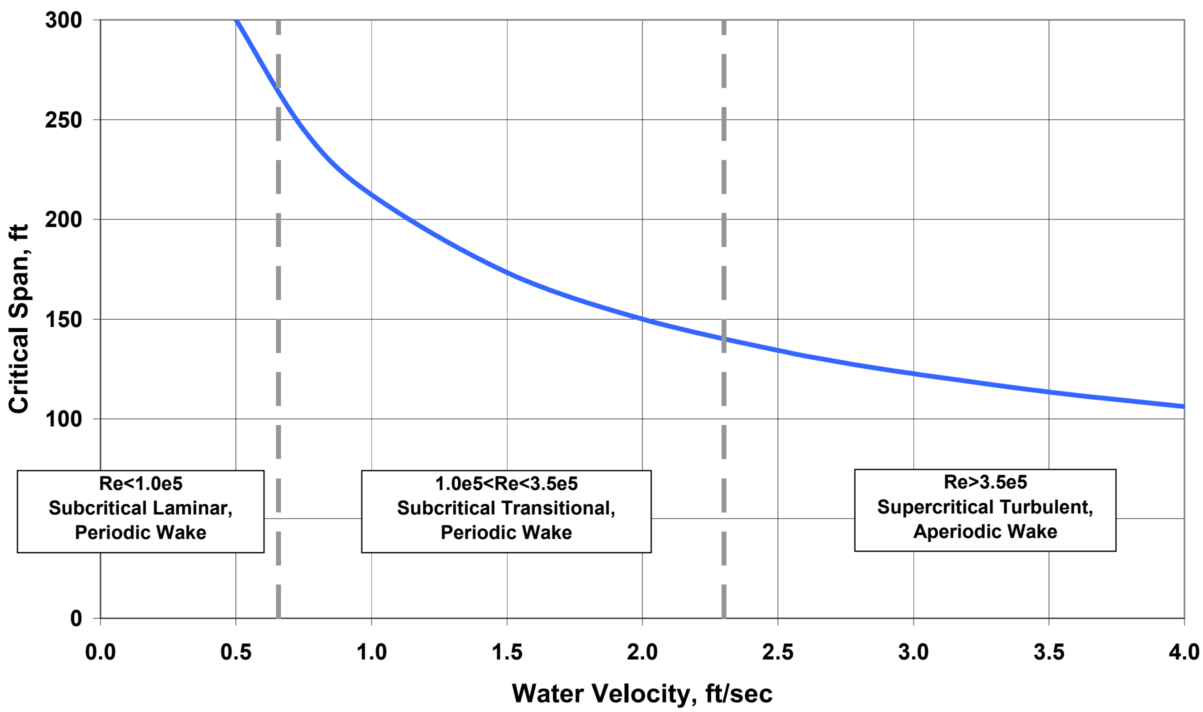

Figure 20. Critical Span Lengths for Vortex-Induced Vibration

Enbridge document shows years of noncompliance for pipeline supports

Arielle Breen (989) 732-1111 abreen@gaylordheraldtimes.com May 31, 2017

File Photo

STRAITS OF MACKINAC — Every 75 feet under the Straits of Mackinac there are supposed to be supports to hold the dual pipeline, known as Line 5, in place.

But according to an underwater inspection document from Enbridge Energy —the pipeline's owner and operating company— those supports have exceeded the length requirements more than 200 times in years past.

Jennifer McKay, Tip of the Mitt Watershed Council policy director and member of the Michigan Pipeline Safety Advisory Board, said the document shows the company to have been in violation of its easement agreement.

“Enbridge, since 1953 was supposed to have no (span) areas greater than 75 feet and if you look there’s a number — a quite substantial number — of spans that violated that requirement,” McKay said. “It means that Enbridge has essentially, at least according to the spreadsheet — been operating the pipeline in violation for a number of years.”

Line 5 is a twin pipeline that separately carries both light crude oil and natural gas liquids from Canada through the Upper Peninsula, Straits of Mackinac and Lower Peninsula, crossing out of the state to Ontario, Canada, beneath the St. Clair River.

The document resides in a collection of information requested by the state of Michigan after the attorney general, Michigan Department of Natural Resources and Michigan Department of Environmental Quality learned in February of documented examples of coating issues on the lines under the Straits in Enbridge’s Biota Investigation Work Plan dated to September 2016.

The 75-foot span regulation was a safety measure included in the original agreement, McKay said.

“So the question then becomes since it’s been operating essentially in violation of that safety measure, what was the actual impact to the integrity of the pipeline?” McKay said.

According to the Underwater Inspection spreadsheet document, most of the spans over 75 feet were listed from 2005 to 2010 with some still in 2012.

Out of any of the years listed on the document, the longest span from one support to the next was listed as 54 feet over the 75-foot limit in 2005, along the east pipeline. The next longest span was 50 feet over the limit in 2005, along the northern part of the east pipeline.

Some specific spans are shown to have been in violation, in some cases, for at least five consecutive inspection years which occur every two years.

In total, the document reports nearly 250 instances between the east and west lines of Line 5 over the years where sections have spanned longer than the required 75 feet.

Underwater Inspection Line 5 by Arielle Breen on Scribd

* All Measurements given in feet* Span Identifier	2016 Length	2016 Span Height (Approximate)	2016 Support Length	2014 Length	2012 Length	2010 Length	2007 Length	2006 Length	2005 Length	Touch Down Position and Type (Year Install)	Support Depth	Notes	Anchors Proposed in 2016 (not yet installed)
Southern Exposure Point	NA	NA	NA	NA	NA	NA	NA	NA	NA	Only/Sand	69		
E-75	NA	NA	NA	NA	Silted In	70	69	73	80	NA NA	NA NA		
E-74A	52	0.5	236 to Southern Exposure^^	50	80	61	67	67	71	South/Sand North/Anchor (2004)	72 73		
E-74B South	66	0.5	1 Shared Touch Down ^	70	56	109	100			South/Anchor (2004) North/Anchor (2010)	73 74	In excess of 65'. No need to mitigate. Anchors on both north and south ends	
E-74B North	46	0.5	1 Shared Touch Down ^	47	48					South/Anchor (2010) North/Anchor (2006)	74 73		
E-74C	18	1	1 Shared Touch Down ^	28	16	13	14			South/Anchor (2006) North/Sand	73 72		
E-71A	36	0.5	116 to E-74C^	30	76	87	86	86	84	South/Sand North/Anchor (2014)	74 74		
E-71B	47	0.5	1 Shared Touch Down ^	49						South/Anchor (2014) North/Anchor (2005)	74 75		
E-72	43	0.5	1 Shared Touch Down ^	44	40	40	38	36	48	South/Anchor (2005) North/Sand	75 75		
E-77	48	1	7 to E-72^	37	34	44	52	44	42	South/Sand North/Sand	75 75	18' increase but no history in excess of 52'. No other criteria meet.	
E-26	48	1	188 to E-77^	54	48	54	45	48	51	South/Clay North/Sand	79 79		
E-25A	60	0.5	39 to E-26^	38	87	91	85	84	96	South/Sand North/Anchor (2014)	84 83	22' increase and a history, before mitigation of original span, of lengths in excess of 96'	
E-25B	34	0.5	1 Shared Touch Down ^	48						South/Anchor (2014) North/Sand	83 82		
E-24	46	0.5	107 to E-25B^	44	44	50	45	46	37	South/Sand North/Sand	84 85		
E-23A South	25	0.5	95 to E-24^	28	86	85	81	86	84	South/Sand North/Anchor (2014)	86 88		
E-23A North	58	0.5	1 Shared Touch Down ^	58						South/Anchor (2014) North/Anchor (2003)	88 88		
E-23B South	60	0.5	1 Shared Touch Down ^	61	66	87	86	90	90	South/Anchor (2003) North/Anchor (2012)	88 87		
E-23B North	32	1	1 Shared Touch Down ^	31	26					South/Anchor (2012) North/Sand	87 86		
E-27	59	0.5	79 to E-23B North^	63	58	69	65	66	74	South/Sand North/Sand	85 84		
E-28A South	36	1	54 to E-27^	37	70	81	73	74	81	South/Sand North/Anchor (2014)	85 86		
E-28A North	34	1	1 Shared Touch Down ^	38						South/Anchor (2014) North/Anchor (2005)	86 86		
E-28B	58	1	1 Shared Touch Down ^	63	66	69	65	64	72	South/Anchor (2005) North/Sand	86 84		
E-29	57	1	32 to E-28B^	59	60	55	44	63	58	South/Sand North/Sand	84 82	Long Shadow to north and south indicating little support. Signs of consistent growth.	1
E-30A	39	1	17 to E-29^	38	72	83	82	82	89	South/Sand North/Anchor (2014)	81 80		
E-30B	38	1	1 Shared Touch Down ^	36						South/Anchor (2014) North/Sand	80 79		
E-38	36	1	81 to E-30B^	36	34	45	32	37	46	South/Sand North/Sand	76 75		
E-37	52	1	160 to E-38^	56	54	54	50	54	58	South/Sand North/Sand	77 77		
E-36	45	0.5	17 to E-37^	50	42	41	48	42	34	South/Sand North/Sand	76 76		
E-35A	32	0.5	38 to E-36^	36	60	67	66	67	63	South/Sand North/Anchor (2014)	76 78		
E-35B	38	0.5	1 Shared Touch Down ^	36						South/Anchor (2014) North/Sand	78 79		
E-34A	59	1	17 to E-35B^	58	58	62	54	61	59	South/Sand North/Anchor (2003)	80 82		
E-34B South	51	1	1 Shared Touch Down ^	58	73	80	82	74	75	South/Anchor (2003) North/Anchor (2014)	82 81		
E-34B North	26	1	1 Shared Touch Down ^	21						South/Anchor (2014) North/Sand	81 82		
E-33	50	1	109 to E-34B North^	48	46	52	47	45	39	South/Sand North/Sand	85 89		
E-32A-A	Silted In	NA	NA	6	Silted In	11	17			South/Clay North/Anchor (2006)	91 91		
E-32A South	41	1	20 to E-33^^	40	47	92	89			South/Anchor (2006) North/Anchor (2012)	91 95		
E-32A North	49	1.5	1 Shared Touch Down ^	47	40					South/Anchor (2012) North/Anchor (2003)	95 97		
E-32B South	66	1	1 Shared Touch Down ^	67	88	87	97	85	79	South/Anchor (2003) North/Anchor (2014)	97 99	In excess of 65'. No need to mitigate. Anchors on both north and south ends	
E-32B North	23	1	1 Shared Touch Down ^	22						South/Anchor (2014) North/Clay	99 98		
E-31	34	1	27 to E-32B North^	36	34	36	47	42	37	South/Clay	98		

Ryan Duffy, Enbridge's supervisor of regional communications, said the company is not in violation of the easement agreement in any support spans and said most sections are "well below" the 75 feet requirement.

Some sections from the 2016 inspection shown on the document report spans as low as 7 feet. And while 2016 and 2014 numbers generally show shorter span lengths — earlier years show a trend of longer lengths — particularly in 2005 and 2006.

Duffy said any time the span lengths had been discovered to be longer than 75 feet during the underwater inspections, the company had 90 days to fix the situation from the time of discovery.

He said so far, the company has always fixed the span supports within the allotted 90 days.

However, according to the spreadsheet, there are instances where a section of line has consistently had spans in excess of 75 feet for up to five inspection years in a row.

"There's been ongoing maintenance with the anchor supports. Every two years we inspect if we see that some have slipped to (have grown) wider, then we go in and put new anchor supports (in)," Duffy said. "The lakebed is a dynamic environment, there's a lot of currents that are shifting, there's erosion. So, where gaps open up we need to go in and reinforce those areas."

He said the company applied for 18 permits last year in places where the line does not immediately need supports.

The proactive supports were requested in an attempt to close the distance on spans that are nearing the 75-foot mark but were denied by the state.

Last year, the company applied for, and was granted, four supports for areas that were over the 75-foot requirement.

"Much of the pipeline through the Straits follows the bottom contours and rests on the lakebed," Duffy said in an email. "Since 2002, we have added 128 support anchors."

He said this year the company is applying for another 22 anchors for stability.

"Our goal is to complete this work in 2017, as part of our comprehensive maintenance program," Duffy said.

When asked about any potential repercussions of the violations shown in the document — the director of communications with the Michigan Attorney General's office, Andrea Bitely, said "The governor's pipeline risk and alternatives studies are due this summer. The engineering firms doing that work are taking everything into account."

The next Pipeline Safety Advisory Board meeting is scheduled for Monday, June 12 at Petoskey Middle School, 801 Northmen Drive. According to the Michigan Petroleum Pipelines website, the meeting is open for public comment from 9 a.m to noon.

The accompanying documents are available online at mipetroleumpipelines.com

March 29, 2017

The Honorable Bill Schuette
Attorney General
State of Michigan
Department of Attorney General
G. Mennen Williams Building, 7th Floor
525 W. Ottawa Street
Lansing, Michigan 48909

Ms. C. Heidi Grether
Director
Michigan Department of Environmental Quality
Constitution Hall
525 West Allegan Street
Lansing, MI 48933

Mr. Keith Creagh
Director
Michigan Department of Natural Resources
Executive Division
525 West Allegan Street
Lansing, MI 48933

Re: Response to Request for Information Regarding Line 5 Dual Pipelines at the Straits of Mackinac

Dear Attorney General Schuette, Director Grether and Director Creagh:

This letter and information are in response to the Request for Information transmitted to Enbridge with your letter dated March 8, 2017. Enbridge's Responses to the Request for Information are attached to the electronic version of this letter.

In addition to the attached narrative Responses, Enbridge is also providing certain documents and other materials requested as part of the Request for Information. A complete list of the material to be provided appears below. These materials in some cases are too large to be transmitted by email. As a result, I will be forwarding a hard drive with the materials in question by separate cover in the next day or so.

As for the request for information regarding future tests or inspections, Enbridge will inform you or your offices about future tests and inspections regarding the Straits, and in doing so discuss which reports or results the State wishes to receive once the tests or inspections are completed. Please let me know if you would like to discuss this approach going forward.

The materials to be provided separately consist of the following:

- BMC report summarizing findings of visual inspection;
- GEI report summarizing findings of biota survey;
- Line 5 Straits Biota Investigation Videos (6-13-16 East Line Video file, 6-14-16 West Line Video file);
- Line 5 Straits Supplemental Biota Work Plan, dated March 23, 2017;
- 2016 BH CPCM Inspection (East Straits);
- 2016 BH GeoPig Inspection (East Straits);
- 2016 BH CPCM Inspection (West Straits);
- 2016 BH GeoPig Inspection (West Straits);
- 2015 Acoustic Emission Inspection (East Straits); and
- 2015 Acoustic Emission Inspection (West Straits).

We look forward to any comments or questions you might have regarding the Responses.

Sincerely,

ENBRIDGE ENERGY, LIMITED PARTNERSHIP
By Enbridge Pipelines (Lakehead) LLC
Its General Partner

Bradley F. Shamla
Vice President, U.S. Operations

Enclosures

cc: Teresa Seidel, Division Chief, Department of Environmental Quality – WRD
Valerie Brader, Executive Director, Michigan Agency for Energy

Appendix C: East lateral report

Span Identifier	Preliminary 2016 Length	2014 Span Height	2014 Support Length	2014 Length	2012 Length	2010 Length	2007 Length	2006 Length	2005 Length	Touch Down Position and Type (Year Install)	Support Depth	Latitude	Longitude	Designated For Repair in 2016
Southern Exposure Point	NA	NA	NA	NA	NA	NA	NA	NA	NA	Only/Sand	66	45.79740051 N	84.76828612 W	No
E-75	NA	NA	NA	NA	Silted In	70	69	73	80	NA	NA	NA	NA	No
										NA	NA	NA	NA	
E-74A	52	0.5	240' to Bury	50	80	61	67	67	71	South/Sand	69	45.79803465 N	84.76803487 W	No
										North/Anchor (2004)	70	45.79817336 N	84.76798054 W	
E-74B South	68	0.5	Shared Touch Down ^	70	56	109	100			South/Anchor (2004)	70	45.79817336 N	84.76798054 W	No
										North/Anchor (2010)	71	45.79836191 N	84.76790185 W	
E-74B North	46	0.5	Shared Touch Down ^	47	48					South/Anchor (2010)	71	45.79836191 N	84.76790185 W	No
										North/Anchor (2006)	70	45.79848622 N	84.76785431 W	
E-74C	22	1	Shared Touch Down ^	28	16	13	14			South/Anchor (2006)	70	45.79848622 N	84.76785431 W	No
										North/Sand	69	45.79855919 N	84.7678226 W	
E-71A	33	0.5	111' to E74C North	30	76	87	86	86	84	South/Sand	71	45.79885179 N	84.76772027 W	No
										North/Anchor (2014)	71	45.79893197 N	84.76769084 W	
E-71B	49	0.5	Shared Touch Down ^	49						South/Anchor (2014)	71	45.79893197 N	84.76769084 W	No
										North/Anchor (2005)	72	45.79906039 N	84.76764254 W	
E-72	44	0.5	Shared Touch Down ^	44	40	40	38	36	48	South/Anchor (2005)	72	45.79906039 N	84.76764254 W	No
										North/Sand	72	45.79917455 N	84.76759603 W	
E-77	50	1	9' to E-72	37	34	44	52	44	42	South/Sand	72	45.79919654 N	84.76758791 W	No
										North/Sand	72	45.799292 N	84.76754813 W	
E-26	50	1	202' to E77	54	48	54	45	48	51	South/Clay	76	45.79982164 N	84.76734294 W	No
										North/Sand	76	45.7999639 N	84.76728235 W	
E-25A	36	0.5	42' to E-26	38	87	91	85	84	96	South/Sand	81	45.80007298 N	84.76724349 W	No
										North/Anchor (2014)	80	45.80017387 N	84.76720464 W	
E-25B	48	0.5	Shared Touch Down ^	48						South/Anchor (2014)	80	45.80017387 N	84.76720464 W	No
										North/Sand	79	45.80029924 N	84.76715103 W	
E-24	46	0.5	114' to E25B	44	44	50	45	46	37	South/Sand	81	45.80059751 N	84.76703994 W	No
										North/Sand	82	45.80071223 N	84.76699755 W	
E-23A South	26	0.5	96' to E-24	28	86	85	81	86	84	South/Sand	83	45.80096148 N	84.76690243 W	No
										North/Anchor (2014)	85	45.80103603 N	84.76687496 W	
E-23A North	58	0.5	Shared Touch Down ^	58						South/Anchor (2014)	85	45.80103603 N	84.76687496 W	No
										North/Anchor (2003)	85	45.80118708 N	84.7668158 W	
E-23B South	60	0.5	Shared Touch Down ^	61	66	87	86	90	90	South/Anchor (2003)	85	45.80118708 N	84.7668158 W	No
										North/Anchor (2012)	84	45.80134576 N	84.76674988 W	
E-23B North	32	1	Shared Touch Down ^	31	26					South/Anchor (2012)	84	45.80134576 N	84.76674988 W	No
										North/Sand	83	45.80142404 N	84.76671263 W	
E-27	59	0.5	78' to E23B North	63	58	69	65	66	74	South/Sand	82	45.80162764 N	84.76663722 W	No
										North/Sand	81	45.80179248 N	84.76657389 W	

E-28A South	37	1	52' to E-27	37	70	81	73	74	81	South/Sand	82	45.80193012 N	84.76652267 W	No
										North/Anchor (2014)	83	45.8020281 N	84.76649157 W	
E-28A North	35	1	Shared Touch Down ^	38						South/Anchor (2014)	83	45.8020281 N	84.76649157 W	No
										North/Anchor (2005)	83	45.80212884 N	84.76645585 W	
E-28B	56	1	Shared Touch Down ^	63	66	69	65	64	72	South/Anchor (2005)	83	45.80212884 N	84.76645585 W	No
										North/Sand	81	45.80229567 N	84.76639508 W	
E-29	66	1	25' to E28B	59	60	55	44	63	53	South/Sand	81	45.8023587 N	84.76636855 W	Yes
										North/Sand	79	45.80251327 N	84.76631514 W	
E-30A	38	1	22' to E29	38	72	83	82	82	89	South/Sand	78	45.80256885 N	84.76629197 W	No
										North/Anchor (2014)	77	45.80267125 N	84.76626081 W	
E-30B	38		Shared Touch Down ^	36						South/Anchor (2014)	77	45.80267125 N	84.76626081 W	No
										North/Sand	76	45.80276442 N	84.76622516 W	
E-38	36	1	86 to E-30B	36	34	45	32	37	46	South/Sand	73	45.80299189 N	84.76614415 W	No
										North/Sand	72	45.80308618 N	84.76611094 W	
E-37	51	1	155' to E-38	56	54	54	50	54	53	South/Sand	74	45.80349412 N	84.7659669 W	No
										North/Sand	74	45.80363883 N	84.76590965 W	
E-36	55	0.5	12' to E-37	50	42	41	48	42	34	South/Sand	73	45.80366947 N	84.76589995 W	No
										North/Sand	73	45.80380204 N	84.76585057 W	
E-35A	32	0.5	33' to E-36	36	60	67	66	67	63	South/Sand	73	45.80389819 N	84.76581718 W	No
										North/Anchor (2014)	75	45.80399347 N	84.7657808 W	
E-35B	35	0.5	Shared Touch Down ^	36						South/Anchor (2014)	75	45.80399347 N	84.7657808 W	No
										North/Sand	76	45.80408779 N	84.76574484 W	
E-34A	60	1	25' to E35B	58	58	62	54	61	59	South/Sand	77	45.80415409 N	84.76572209 W	No
										North/Anchor (2003)	79	45.80430605 N	84.76566353 W	
E-34B South	52	1	Shared Touch Down ^	53	73	80	82	74	75	South/Anchor (2003)	79	45.80430605 N	84.76566353 W	No
										North/Anchor (2014)	78	45.80444616 N	84.76561487 W	
E-34B North	23	1	Shared Touch Down ^	21						South/Anchor (2014)	78	45.80444616 N	84.76561487 W	No
										North/Sand	79	45.80450136 N	84.76558981 W	
E-33	45	1	109 to E34B North	43	46	52	47	45	39	South/Sand	82	45.80478655 N	84.76548042 W	No
										North/Sand	86	45.80490015 N	84.76543833 W	
E-32A-A	NA		21' to E-33	6	Silted in	11	17			South/Clay	88	45.80495542 N	84.76541633 W	No
										North/Anchor (2006)	88	45.80497238 N	84.76541225 W	
E-32A South	40	1	Shared Touch Down ^	40	47	92	89			South/Anchor (2006)	88	45.80497238 N	84.76541225 W	No
										North/Anchor (2012)	92	45.80507422 N	84.76536839 W	
E-32A North	47	1.5	Shared Touch Down ^	47	40					South/Anchor (2012)	92	45.80507422 N	84.76536839 W	No
										North/Anchor (2003)	94	45.80519687 N	84.76532216 W	
E-32B South	62	1	Shared Touch Down ^	67	88	87	97	85	79	South/Anchor (2003)	94	45.80519687 N	84.76532216 W	No
										North/Anchor (2014)	96	45.80537562 N	84.76525738 W	
E-32B North	23	1	Shared Touch Down ^	22						South/Anchor (2014)	96	45.80537562 N	84.76525738 W	No
										North/Clay	95	45.80543416 N	84.7652347 W	
E-31	32	1	22' to E32B North	36	34	36	42	42	37	South/Clay	95	45.80549271 N	84.76521037 W	No
										North/Clay	96	45.80558613 N	84.76517358 W	

E-39	77	1	58' to E-31	63	74	83	67	78	66	South/Clay	98	45.80573967 N	84.76511784 W	Yes
										North/Sand	98	45.80590475 N	84.76505337 W	
E-40A	20	1	370' to E39	22	85	82	80	90	97	South/Sand	103	45.80688466 N	84.7646828 W	No
										North/Anchor (2014)	104	45.80694103 N	84.7646623 W	
E-40B	63	1	Shared Touch Down ^	60						South/Anchor (2014)	104	45.80694103 N	84.7646623 W	No
										North/Sand	104	45.80709655 N	84.76459532 W	
E-46	46	1	220' to E40B	46	86	93	82	72	58	South/Sand	104	45.80767814 N	84.76437691 W	No
										North/Anchor (2006)	104	45.80780151 N	84.76433045 W	
E-45A	59	1	Shared Touch Down ^	58	53	50	49	62	72	South/Anchor (2006)	104	45.80780151 N	84.76433045 W	No
										North/Anchor (2014)	104	45.80795517 N	84.76427079 W	
E-45B	28	1	Shared Touch Down ^	28						South/Anchor (2014)	104	45.80795517 N	84.76427079 W	No
										North/Clay	102	45.80802708 N	84.76423847 W	
E-44	43	1	144' to E45B	45	45	37	33	40	37	South/Clay	100	45.80840536 N	84.76408996 W	No
										North/Clay	98	45.8085226 N	84.76403879 W	
E-43	52	1	67' to E44	56	54	54	59	54	54	South/Clay	102	45.80870068 N	84.76397628 W	No
										North/Clay	103	45.80884836 N	84.76391865 W	
E-42 South	46	1.5	41' to E43	39	45	91	97	97	103	South/Clay	103	45.80895719 N	84.76388102 W	No
										North/Anchor (2012)	103	45.80906046 N	84.76384057 W	
E-42 North	46	1.5	Shared Touch Down ^	46	52					South/Anchor (2012)	103	45.80906046 N	84.76384057 W	No
										North/Clay	101	45.80917946 N	84.7637909 W	
E-41	70	1	130' to E42 North	71	70	74	77	68	84	South/Clay	98	45.80952345 N	84.76366022 W	Yes
										North/Clay	97	45.80971147 N	84.76358754 W	
E-47A	39	1	141 to E41	45	76	75	75	74	75	South/Clay	98	45.81007932 N	84.76344236 W	No
										North/Anchor (2014)	100	45.81019925 N	84.76339755 W	
E-47B	33	1	Shared Touch Down ^	28						South/Anchor (2014)	100	45.81019925 N	84.76339755 W	No
										North/Clay	100	45.8102734 N	84.76336643 W	
E-48A	56	1.5	20' to E47	55	48	59	48	55		South/Clay	100	45.81032483 N	84.76334545 W	No
										North/Anchor (2005)	102	45.81047222 N	84.76329119 W	
E-48B South	56	1	Shared Touch Down ^	60	67	66	82	68		South/Anchor (2005)	102	45.81047222 N	84.76329119 W	No
										North/Anchor (2014)	101	45.81063345 N	84.7632324 W	
E-48B North	15		Shared Touch Down ^	14						South/Anchor (2014)	101	45.81063345 N	84.7632324 W	No
										North/Clay	101	45.81066737 N	84.76321778 W	
E-79	NA	NA	NA	NA	NA	Filled In	19	13		NA	NA	NA	NA	No
										NA	NA	NA	NA	
E-70	51	1	380' to E48B	52	53	54	53	47	52	South/Clay	110	45.81167843 N	84.76283521 W	No
										North/Clay	111	45.81181537 N	84.76278221 W	
E-66A South	21	1	3' to E70	22	22	97	89	97		South/Clay	111	45.81182421 N	84.76277945 W	No
										North/Anchor (2012)	111	45.81188319 N	84.7627559 W	
E-66A North	72	0.5	Shared Touch Down ^	72	77					South/Anchor (2012)	111	45.81188319 N	84.7627559 W	No
										North/Anchor (2005)	113	45.81207618 N	84.76267988 W	
E-66B	50	1	Shared Touch Down ^	52	56	89	89	81		South/Anchor (2005)	113	45.81207618 N	84.76267988 W	No
										North/Clay	113	45.81221358 N	84.76262661 W	

E-56A	39	1.5	32' to E66B	44	45	44	33			South/Clay North/Anchor (2006)	113 114	45.81229737 N 45.81241142 N	84.76259107 W 84.76254418 W	No
E-56B	43	2	Shared Touch Down ^	46	44	42	48			South/Anchor (2006) North/Clay	114 112	45.81241142 N 45.81253217 N	84.76254418 W 84.76250017 W	No
E-55	42	1	35' to E56B	46	45	46	41	50	43	South/Clay North/Clay	113 114	45.8126226 N 45.81274368 N	84.76246303 W 84.76241929 W	No
E-54A	60	3	11' to E55	57	58	62	59	66		South/Clay North/Anchor (2005)	114 121	45.81277307 N 45.81292344 N	84.76240561 W 84.76234556 W	No
E-54B	32	2.5	Shared Touch Down ^	33	32	37	39	29		South/Anchor (2005) North/Grout Bag (2001)	121 122	45.81292344 N 45.8130088 N	84.76234556 W 84.76231479 W	No
E-53A	44	3	Grout Bags ^	44	44	38	33	43		South/Grout Bag (2001) North/Anchor (2005)	122 124	45.8130088 N 45.81312414 N	84.76231479 W 84.76226755 W	No
E-53B	64	3	Shared Touch Down ^	60	57	64	71	63		South/Anchor (2005) North/Clay	124 127	45.81312414 N 45.8132822 N	84.76226755 W 84.76221172 W	No
E-52A	10	2.5	11' toE53B	10	9	15	14	18		South/Clay North/Anchor (2012)	127 128	45.81330927 N 45.81333405 N	84.76220265 W 84.76219074 W	No
E-52B	8	3	Shared Touch Down ^	8	8					South/Anchor (2012 North/Clay	128 128	45.81333405 N 45.81335562 N	84.76219074 W 84.76218435 W	No
E-49C	50	2	8 to E-52	51	48	46	36	53	44	South/Clay North/Anchor (2004)	129 133	45.81337589 N 45.81351091 N	84.76217535 W 84.76212131 W	No
E-49B South	50	2	Shared Touch Down ^	42	86	85	82	87	101	South/Anchor (2004) North/Anchor (2014)	133 136	45.81351091 N 45.81362344 N	84.76212131 W 84.76208421 W	No
E-49B North	39	2	Shared Touch Down ^	45						South/Anchor (2014) North/Anchor (2004)	136 139	45.81362344 N 45.81374064 N	84.76208421 W 84.76203766 W	No
E-49A South	64	1	Shared Touch Down ^	67	87	75	93	95	86	South/Anchor (2004) North/Anchor (2014)	139 140	45.81374064 N 45.81391998 N	84.76203766 W 84.76197483 W	No
E-49A North	23	1	Shared Touch Down ^	23						South/Anchor (2014) North/Clay	140 141	45.81391998 N 45.81397636 N	84.76197483 W 84.7619502 W	No
E-58	66	3	87 to E49A North	62'	60	51	66	61	61	South/Clay North/Clay	141 144	45.81420665 N 45.81436938 N	84.76187126 W 84.76180643 W	No
E-61A-A	52	3	196' to E58	57	52	47	59			South/Clay North/Anchor (2006)	137 145	45.81488776 N 45.81503694 N	84.76160874 W 84.76155307 W	No
E-61A	66	4	Shared Touch Down ^	63	65	61	68	120	129	South/Anchor (2006) North/Anchor (2004)	145 145	45.81503694 N 45.81520235 N	84.76155307 W 84.76149042 W	No
E-61B South	46	4	Shared Touch Down ^	46	52					South/Anchor (2004) North/Anchor (2012)	145 148	45.81520235 N 45.81532105 N	84.76149042 W 84.76144352 W	No
E-61B North	68	3	Shared Touch Down ^	70	62	114	113	115	125	South/Anchor (2012) North/Anchor (2004)	148 147	45.81532105 N 45.81550142 N	84.76144352 W 84.76137607 W	No
E-61C South	54	3	Shared Touch Down ^	57	61	85	90	83	78	South/Anchor (2004) North/Anchor (2012)	147 142	45.81550142 N 45.81564713 N	84.76137607 W 84.76132398 W	No
E-61C North	29	2.5	Shared Touch Down ^	29	31					South/Anchor (2012) North/Clay	142 139	45.81564713 N 45.81572031 N	84.76132398 W 84.76129539 W	No

E-62	40	1.5	41' to E61C	39	37	32	29	38	34	South/Clay	135	45.81582864 N	84.76125214 W	No
										North/Clay	130	45.81593382 N	84.76121499 W	
E-63	21	1	9' to E61	21	18	23	22	22	15	South/Clay	129	45.81595831 N	84.76120677 W	No
										North/Clay	130	45.81601262 N	84.7611857 W	
E-64	49	1	20' to E63	49	52	47	51	48	52	South/Clay	132	45.81606385 N	84.76116825 W	No
										North/Clay	132	45.81619121 N	84.76111823 W	
E-22A	67	4	38 to E64	70	76	80	74	76	79	South/Clay	130	45.81629124 N	84.76108022 W	No
										North/Anchor (2014)	130	45.81647888 N	84.76100317 W	
E-22B	12	1	Shared Touch Down ^	7						South/Anchor (2014)	130	45.81647888 N	84.76100317 W	No
										North/Clay	130	45.81649739 N	84.76099431 W	
E-21	50	0.5	40' to E22	53	50	43	48	52	51	South/Clay	128	45.81660352 N	84.76095383 W	No
										North/Clay	129	45.81674293 N	84.7608986 W	
E-20	NA	NA	NA	NA	NA	Filled In	23	25		NA	NA	NA	NA	No
										NA	NA	NA	NA	
E-19A South	23	0.5	67 to E21	23	75	87	76	78	107	South/Clay	133	45.81692151 N	84.76083215 W	No
										North/Anchor (2014)	136	45.8169808 N	84.76080731 W	
E-19A North	60	0.5	Shared Touch Down ^	60						South/Anchor (2014)	136	45.8169808 N	84.76080731 W	No
										North/Anchor (2003)	140	45.81714033 N	84.7607472 W	
E-19B South	59	1	Shared Touch Down ^	58	82	75	80	81	73	South/Anchor (2003)	140	45.81714033 N	84.7607472 W	No
										North/Anchor (2014)	144	45.81729393 N	84.76068901 W	
E-19B North	23	0.5		24						South/Anchor (2014)	144	45.81729393 N	84.76068901 W	No
										North/Clay	145	45.81735826 N	84.76066463 W	
E-18B	24	0.5	33'to E19B North	22	23	25	22	25	16	South/Clay	148	45.81744163 N	84.76063246 W	No
										North/Clay	151	45.81749679 N	84.76061139 W	
E-18C	8	0.5	6' to E18B	15	Silted in	16				South/Clay	151	45.81750978 N	84.7606076 W	No
										North/Clay	154	45.81754778 N	84.760593 W	
E-18A	16	0.5	4' to E18C	17	16	21	22	18	29	South/Clay	154	45.8175558 N	84.76058925 W	No
										North/Clay	156	45.81759883 N	84.76057257 W	
E-17	32	0.5	33' to E18A	38	39	36	40	31	44	South/Clay	161	45.81768298 N	84.76054041 W	No
										North/Clay	167	45.81778351 N	84.7605004 W	
E-16	38	2.5	58' to E17	42	38	48	36	38	47	South/Clay	175	45.81793523 N	84.76044082 W	No
										North/Clay	184	45.81804614 N	84.76039472 W	
E-15A	25	1	4' to E16	28	31	29	25	28		South/Sand	184	45.81805592 N	84.76039102 W	No
										North/Anchor (2005)	192	45.81812989 N	84.7603635 W	
E-15B	50	1	Shared Touch Down ^	50	52	52	51	47		South/Anchor (2005)	204	45.81812989 N	84.7603635 W	No
										North/Grout Bag (2001)	203	45.81826147 N	84.76031158 W	
E-08A	56	1	Grout Bags ^	58	56	54	65	56	62	South/Grout Bag (2001)	203	45.81826147 N	84.76031158 W	No
										North/Anchor (2003)	216	45.81841688 N	84.7602534 W	
E-8B	71	2	Shared Touch Down ^	69	70	71	66	73		South/Anchor (2003)	216	45.81841688 N	84.7602534 W	No
										North/Anchor (2005)	224	45.81859712 N	84.76018457 W	
E-08C/D South	51	3	Shared Touch Down ^	58	76	39	79	97		South/Anchor (2005)	224	45.81859712 N	84.76018457 W	No
						20				North/Anchor (2014)	227	45.81875079 N	84.7601283 W	

E-08C/D North	35	2	Shared Touch Down ^	18						South/Anchor (2014)	227	45.81875079 N	84.7601283 W	No
										North/Sand	227	45.8187984 N	84.76010964 W	
E-09	33	0.5	25 to E08C/D North	35	41	33	33	40	39	South/Sand	229	45.81886442 N	84.76009022 W	No
										North/Sand	230	45.81895739 N	84.76005737 W	
E-10	47	2	72 to E09	47	52	50	49	44		South/Clay	229	45.81914977 N	84.75998662 W	No
										North/Clay	230	45.81927332 N	84.75993637 W	
E-11	70	2	4' to E10	66	63	70	74	69		South/Clay	230	45.81928482 N	84.75993198 W	Yes
										North/Clay	228	45.819459 N	84.75986295 W	
E-12	34	1	58' to E11	34	39	41	88	81	81	South/Clay	228	45.81963584 N	84.75979216 W	No
										North/Clay	227	45.81972489 N	84.75975827 W	
E-13A	29	1	65' to E12	29	27	32	40	34	36	South/Clay	228	45.81989427 N	84.75969496 W	No
										North/Anchor (2004)	230	45.81997078 N	84.75966271 W	
E-13B South	56	1	Shared Touch Down ^	58	56	106	116	112	115	South/Anchor (2004)	230	45.81997078 N	84.75966271 W	No
										North/Anchor (2010)	228	45.82012417 N	84.75960843 W	
E-13B North	56	1	Shared Touch Down ^	57	56					South/Anchor (2010)	228	45.82012417 N	84.75960843 W	No
										North/Anchor (2004)	226	45.82027847 N	84.75955349 W	
E-13C South	53	1.5	Shared Touch Down ^	51	48	107	105	99	102	South/Anchor (2004)	226	45.82027847 N	84.75955349 W	No
										North/Anchor (2010)	225	45.82041043 N	84.75949691 W	
E-13C North	52	1.5	Shared Touch Down ^	52	56					South/Anchor (2010)	225	45.82041043 N	84.75949691 W	No
										North/Clay	216	45.82055076 N	84.75944415 W	
E-3A	26	1	133' to E13C North	27	87	76	68	90	62	South/Clay	217	45.82090248 N	84.75931622 W	No
										North/Anchor (2014)	221	45.82097424 N	84.75928534 W	
E-3B	43	1	Shared Touch Down ^	53						South/Anchor (2014)	221	45.82097424 N	84.75928534 W	No
										North/Anchor (2005)	217	45.82111266 N	84.75922939 W	
E-76A	12	1	11' to E3B	58	58	10	18			South/Clay	217	45.82114141 N	84.75921794 W	No
E-76B	56									North/Clay	217	45.82129123 N	84.75915826 W	
E-02A South	20	0.5	238' to E76A/B	15	76	80	80			South/Sand	218	45.82192295 N	84.75892028 W	No
										North/Anchor (2014)	218	45.82195983 N	84.75890383 W	
E-02A North	45	0.5	Shared Touch Down ^	55						South/Anchor (2014)	218	45.82195983 N	84.75890383 W	No
										North/Anchor (2006)	218	45.82210278 N	84.75884748 W	
E-02B	28	0.5	Shared Touch Down ^	26	32	30	33			South/Anchor (2006)	218	45.82210278 N	84.75884748 W	No
										North/Sand	216	45.82217149 N	84.75882614 W	
E-01A South	22	2.5	20' to E02B	28	81	85	84	88	88	South/Sand	216	45.82222505 N	84.75880875 W	No
										North/Anchor (2014)	217	45.82229766 N	84.75878027 W	
E-01A North	62	2	Shared Touch Down ^	53						South/Anchor (2014)	217	45.82229766 N	84.75878027 W	No
										North/Anchor (2003)	217	45.82244184 N	84.7587229 W	
E-01B-A South	53	3	Shared Touch Down ^	53	39	100	96	96	107	South/Anchor (2003)	217	45.82244184 N	84.7587229 W	No
										North/Anchor (2012)	212	45.82258353 N	84.75866685 W	
E-01B-A North	43	2	Shared Touch Down ^	43	53					South/Anchor (2012)	212	45.82258353 N	84.75866685 W	No
										North/Anchor (2004)	206	45.82269559 N	84.75862499 W	
E-01B-B	53	2	Shared Touch Down ^	48	82	62	74	68	65	South/Anchor (2004)	206	45.82269559 N	84.75862499 W	No
										North/Sand	197	45.82282173 N	84.75857538 W	

E-04A South	13	1	83' to E-01B-B	17	84	82	84	101		South/Sand	186	45.82304007 N	84.75848688 W	No
										North/Anchor (2014)	185	45.82308056 N	84.7584657 W	
E-04A North	64	1	Shared Touch Down ^	59						South/Anchor (2014)	185	45.82308056 N	84.7584657 W	No
										North/Anchor (2006)	176	45.8232365 N	84.75840367 W	
E-04B	20	1	Shared Touch Down ^	19	20	26	23	101		South/Anchor (2006)	176	45.8232365 N	84.75840367 W	No
										North/Sand	173	45.82328669 N	84.75838476 W	
E-05A South	12	1	37' to E04B	27	80	75	82	77	74	South/Sand	169	45.82338631 N	84.75834799 W	No
										North/Anchor (2014)	166	45.82345562 N	84.75831776 W	
E-05A North	61	1	Shared Touch Down ^	55						South/Anchor (2014)	166	45.82345562 N	84.75831776 W	No
										North/Anchor (2003)	157	45.82360285 N	84.75826104 W	
E-05B	60	1	Shared Touch Down ^	67	65	63	62	57	61	South/Anchor (2003)	157	45.82360285 N	84.75826104 W	No
										North/Sand	146	45.8237806 N	84.75819081 W	
E-06	58	1	228' to E-05B	52	60	60	76	65	67	South/Sand	116	45.8243827 N	84.75795786 W	No
										North/Sand	111	45.82452008 N	84.75790456 W	
E-07	60	0.5	54' to E06	52	62	72	74	69	70	South/Sand	104	45.82465949 N	84.75784771 W	No
										North/Sand	97	45.82479445 N	84.75779612 W	
E-65A	56	0.5	458' to E07	62	64	67	67	59		South/Sand	66	45.82600507 N	84.75733017 W	No
										North/Anchor (2005)	66	45.82617024 N	84.75726365 W	
E-65B	58	1	Shared Touch Down ^	61	61	60	65	64		South/Anchor (2005)	66	45.82617024 N	84.75726365 W	No
										North/Sand	66	45.8263332 N	84.75720272 W	
Northern Exposure Point	NA	NA	148' to E-65B	NA	NA	NA	NA	NA	NA	Only/Sand	62	45.82672766 N	84.75706154 W	No

Appendix C: West lateral report

Span Identifier	Prelim 2016 Length	2014 Span Height	2014 Support Length	2014 Length	2012 Length	2010 Length	2007 Length	2006 Length	2005 Length	Touch Down Position and Type (Year Install)	Support Depth	Latitude	Longitude	Designated For Repair in 2016
Southern Exposure Point		NA	NA	NA	NA	NA	NA	NA	NA	Only/Sand	65	45.79570801 N	84.77389377 W	No
W-01A	60	2.5	760' to pipe bury	66	65	79	63	66	71	South/Sand	74	45.79772369 N	84.77314096 W	No
										North/Anchor (2003)	75	45.79789806 N	84.77307274 W	
W-01B South	62	2.5	Shared Touch Down ^	59	80	79	83	77	80	South/Anchor (2003)	75	45.79789806 N	84.77307274 W	No
										North/Anchor (2014)	75	45.79805619 N	84.7730173 W	
W-01B North	21		Shared Touch Down ^	21						South/Anchor(2014)	75	45.79805619 N	84.7730173 W	No
										North/Sand	75	45.79810962 N	84.77299804 W	
W-5	78	1	651' to W01B	71	70	81	83	80	74	South/Sand	75	45.79983894 N	84.77235059 W	Yes
										North/Sand	71	45.80002695 N	84.77228089 W	
W-77	NA	----	----	NA	Silted in	37	25	24	11	NA	NA	NA	NA	No
										NA	NA	NA	NA	
W-4	13	1	215' to W5	12	16	13	18	18	14	South/Sand	70	45.8005966 N	84.77206933 W	No
										North/Sand	70	45.80062778 N	84.77205516 W	

W-3	43	1.5	3' to W4	42	43	39	41	31	22	South/Sand	71	45.8006356 N	84.77205235 W	No
										North/Sand	71	45.80074826 N	84.77201133 W	
W-2A	57	1.5	4' to W3	53	52	54	54	53		South/Sand	70	45.80076595 N	84.77200487 W	No
										North/Anchor (2006)	72	45.80090546 N	84.77195411 W	
W-2B	12	1.5	Shared Touch Down ^	12	14	10	10	10		South/Anchor (2006)	72	45.80090546 N	84.77195411 W	No
										North/Sand	70	45.80093427 N	84.77193985 W	
W-6A	37	2	11'to W2B	40	72	83	82	72	68	South/Clay	70	45.80096456 N	84.7719274 W	No
										North/Anchor (2014)	70	45.80107298 N	84.77189363 W	
W-6B	35		Shared Touch Down ^	32						South/Anchor(2014)	70	45.80107298 N	84.77189363 W	No
										North/Clay	72	45.80115633 N	84.77185761 W	
W-7	52	2	84' to W6	47	46	Merged 50	34	22	33	South/Clay	70	45.8013792 N	84.77176906 W	No
W-8							22	17	23	North/Clay	70	45.80150413 N	84.77171663 W	
W-9	52	2.5	40' to W7-8	51	53	53	65	55	57	South/Clay	66	45.80160803 N	84.77167766 W	No
										North/Clay	72	45.80174235 N	84.77162408 W	
W-11	52	2.5	114' to W-9	48	52	47	40	46	49	South/Sand	72	45.80204636 N	84.77152015 W	No
										North/Sand	77	45.80216995 N	84.77145889 W	
W-10	65	3	183' to W-11	66	64	69	63	63	53	South/Sand	79	45.80265731 N	84.77128597 W	No
										North/Sand	83	45.80283001 N	84.77120879 W	
W-12A	33	1.5	133' to W10	35	43	91	94	95	97	South/Sand	88	45.80318394 N	84.77107992 W	No
										North/Anchor (2012)	88	45.80327592 N	84.7710389 W	
W-12B	54	1.5	Shared Touch Down ^	56'	46					South/Anchor (2012)	88	45.80327592 N	84.7710389 W	No
										North/Sand	88	45.80342375 N	84.77098542 W	
W-13A	28	3	65'to W12 North	28'	83	87	90	76	75	South/Sand	86	45.80359866 N	84.7709303 W	No
										North/Anchor (2014)	90	45.80367382 N	84.77090546 W	
W-13B	46		Shared Touch Down ^	54						South/Anchor (2014)	90	45.80367382 N	84.77090546 W	No
										North/Sand	91	45.8038143 N	84.7708486 W	
W-14	49	1.5	31' to W13	51	54	51	74	62	48	South/Sand	92	45.803895 N	84.77081842 W	No
										North/Sand	94	45.80402656 N	84.7707635 W	
W-16	44	0.5	24' to W14	40	44	45	42	48	36	South/Sand	94	45.8040894 N	84.77073743 W	No
										North/Sand	95	45.80419549 N	84.77069364 W	
W-15	40	0.5	260' to W-16	37	37	38	39	45	37	South/Sand	96	45.80488293 N	84.7704441 W	No
										North/Sand	97	45.80498015 N	84.77040304 W	
W-17	NA				NA	Filled in	23	36	26	NA	NA	NA	NA	No
										NA	NA	NA	NA	
W-18A_A	12	2	162' to W-15	8	14	15	15	16		South/Sand	105	45.80541373 N	84.77023722 W	No
										North/Anchor (2006)	106	45.80543625 N	84.77022891 W	
W-18A South	46	2.5	Shared Touch Down ^	42	42	41	100	99		South/Anchor (2006)	106	45.80543625 N	84.77022891 W	No
										North/Anchor (2010)	113	45.80554847 N	84.7701857 W	
W-18A North	52	2	Shared Touch Down ^	55	55	55				South/Anchor (2010)	113	45.80554847 N	84.7701857 W	No
										North/Anchor (2004)	117	45.80569713 N	84.77013121 W	
W-18B South	56	1	Shared Touch Down ^	62	82	91	93	87	95	South/Anchor (2004)	117	45.80569713 N	84.77013121 W	No

										North/Anchor (2014)	120	45.80586207 N	84.77007142 W	
W-18B North	26		Shared Touch Down ^	24						South/Anchor (2014)	120	45.80586207 N	84.77007142 W	No
										North/Sand	120	45.80592331 N	84.77004434 W	
W-20	34	0.5	48' to W18B	22'	27	47	45	46	49	South/Sand	122	45.80605223 N	84.77000235 W	No
										North/Sand	122	45.80610853 N	84.76997572 W	
W-24A	12	2.5	38' to W-20	12	17	90	82	86	87	South/Sand	122	45.80620743 N	84.76993569 W	No
										North/Anchor (2012)	123	45.80623916 N	84.76992226 W	
W-24B	68	2	Shared Touch Down ^	70	69					South/Anchor (2012)	123	45.80623916 N	84.76992226 W	Yes
										North/Sand	122	45.80642502 N	84.76984642 W	
W-23A	60	0.5	21' to W-24 North	49	63	63	62	61	68	South/Sand	123	45.80648154 N	84.76982185 W	No
										North/Anchor (2004)	124	45.80661144 N	84.76977471 W	
W-23B	36	1	Shared Touch Down ^	36	23	57	57	56	56	South/Anchor (2004)	124	45.80661144 N	84.76977471 W	No
										North/Sand	124	45.80670768 N	84.76973934 W	
W-22	34	2	66' to W-23B	30	33	34	31	37	39	South/Sand	124	45.80688201 N	84.76967483 W	No
										North/Sand	123	45.80696092 N	84.76964449 W	
W-21	53	2	61' to W-22	51	50	60	58	65	59	South/Sand	124	45.80712413 N	84.76958849 W	No
										North/Sand	126	45.80725987 N	84.76954174 W	
W-25	NA			NA	Silted in	9	30	34	41	NA	NA	NA	NA	No
										NA	NA	NA	NA	
W-26	68	1	226' to W-21	54	53	66	71	72	64	South/Sand	126	45.8078569 N	84.76930883 W	No
										North/Sand	128	45.8079986 N	84.76925521 W	
W-27	NA		NA	NA	Silted in	12	17	23	19	NA	NA	NA	NA	No
										NA	NA	NA	NA	
W-30	62	1.5	160 to W-26	54	57	62	62	62	60	South/Sand	130	45.80842054 N	84.76909002 W	No
										North/Sand	132	45.80856243 N	84.76903767 W	
W-28A South	10	3	156' to W-30	6	70	77	77	84	73	South/Clay	132	45.80897784 N	84.76888725 W	No
										North/Anchor (2014)	133	45.80899415 N	84.76888196 W	
W-28A North	64		Shared Touch Down ^	65						South/Anchor (2014)	133	45.80899415 N	84.76888196 W	No
										North/Anchor (2003)	135	45.80916534 N	84.76881592 W	
W-28B	54	2	Shared Touch Down ^	59	67	70	50	58	58	South/Anchor (2003)	135	45.80916534 N	84.76881592 W	No
										North/Clay	133	45.80932154 N	84.76874888 W	
W-28	33	1	15' to W28B	35	30	34	34	30	28	South/Clay	133	45.80936143 N	84.76873716 W	No
										North/Clay	133	45.80945076 N	84.76870155 W	
W-76	NA				Silted in	20	16	18		NA	NA	NA	NA	No
										NA	NA	NA	NA	
W-31A South	46	0.5	116' to W-28	38	90	90	89	92	92	Clay	132	45.80975754 N	84.76858567 W	No
										North/Anchor (2014)	134	45.80985984 N	84.76855131 W	
W-31A North	42		Shared Touch Down ^	51						South/Anchor (2014)	134	45.80985984 N	84.76855131 W	No
										North/Anchor (2004)	134	45.80999344 N	84.76849255 W	
W-31B South	42	0.5	Shared Touch Down ^	54	78	75	86	83	84	South/Anchor (2004)	134	45.80999344 N	84.76849255 W	No
										North/Anchor (2014)	135	45.81014042 N	84.7684405 W	

W-31B North	35		Shared Touch Down ^	25						South/Anchor (2014)	135	45.81014042 N	84.7684405 W	No
										North/Grout Bags (2001)	134	45.81020833 N	84.76841199 W	
W-34A	29	0.5	14' to W-31B North	26	Silted in	17	10	17		South/Sand	134	45.81024645 N	84.76840035 W	No
										North/Anchor (2006)	134	45.81031762 N	84.76836946 W	
W-34B South	63	1	Shared Touch Down ^	64	64	97	108	110		South/Anchor (2006)	134	45.81031762 N	84.76836946 W	No
										North/Anchor (2010)	133	45.81048695 N	84.76830706 W	
W-34B North	36	1	Shared Touch Down ^	38	35					South/Anchor (2010)	133	45.81048695 N	84.76830706 W	No
										North/Sand	130	45.81058605 N	84.76827156 W	
W-37A	47	1	37' to W-34B North	43	79	76	79	101		South/Sand	129	45.81068589 N	84.76823233 W	No
										North/Anchor (2014)	130	45.8108011 N	84.76819354 W	
W-37B	34		Shared Touch Down ^	36						South/Anchor (2014)	130	45.8108011 N	84.76819354 W	No
										North/Sand	130	45.81089642 N	84.76815787 W	
W-36A	36	1.5	29' to W37	37	37	38	39	38		South/Sand	127	45.81097249 N	84.76812596 W	No
										North/Anchor (2006)	127	45.81107112 N	84.76809122 W	
W-36B	53	1.5	Shared Touch Down ^	54	50	51	53	49		South/Anchor (2006)	127	45.81107112 N	84.76809122 W	No
										North/Grout Bags (2001)	126	45.81121511 N	84.76804264 W	
W-35A	29	0.5	Shared Touch Down ^	27	32	33	25	31	33	South/Grout Bags (2001)	126	45.81121511 N	84.76804264 W	No
										North/Anchor (2004)	125	45.81128571 N	84.76801092 W	
W-35B South	66	0.5	Shared Touch Down ^	61	79	89	90	90	87	South/Anchor (2004)	125	45.81128571 N	84.76801092 W	No
										North/Anchor (2014)	121	45.81144798 N	84.76795339 W	
W-35B North	17		Shared Touch Down ^	24						South/Anchor (2014)	121	45.81144798 N	84.76795339 W	No
										North/Sand	119	45.81150905 N	84.76792436 W	
W-38	66	1	68' to W35B	59	Merged 53	47	36	31	34	South/Sand	120	45.81168887 N	84.76784301 W	No
W-39						26	27	31	17	North/Anchor (2005)	122	45.81184558 N	84.76778121 W	
W-40	44	1	Shared Touch Down ^	45	44	50	46	44	54	South/Anchor (2005)	122	45.81184558 N	84.76778121 W	No
										North/Sand	124	45.81196638 N	84.76774431 W	
W-41A South	38	1.5	170' to W40	37	42	90	87	88	87	South/Sand	131	45.8124196 N	84.76757785 W	No
										North/Anchor (2012)	138	45.8125168 N	84.76753502 W	
W-41A North	46	1.5	Shared Touch Down ^	48	49					South/Anchor (2012)	138	45.8125168 N	84.76753502 W	No
										North/Anchor (2004)	143	45.8126456 N	84.76748895 W	
W-41B	67	1	Shared Touch Down ^	69	66	73	73	68	65	South/Anchor (2004)	143	45.8126456 N	84.76748895 W	Yes
										North/Sand	150	45.81282522 N	84.76741618 W	
W-43A	65	2	32 to W-41B	64	64	63	59	64	68	South/Sand	154	45.81290732 N	84.7673873 W	Yes
										North/Anchor (2003)	162	45.81307278 N	84.76732484 W	
W-43B	65	2	Shared Touch Down ^	65	68	67	69	64	62	South/Anchor (2003)	162	45.81307278 N	84.76732484 W	No
										North/Clay/Mountain	169	45.81324384 N	84.76726106 W	
W-42A	70	1.5	18' to W43B	71	70	72	67	73	73	South/Clay/Mountain	169	45.81329129 N	84.76724157 W	No
										North/Anchor (2003)	168	45.81348091 N	84.76717734 W	
W-42B	69	1	Shared Touch Down ^	67	71	71	77	69	75	South/Anchor (2003)	168	45.81348091 N	84.76717734 W	Yes
										North/Sand	164	45.81366089 N	84.76711461 W	
W-45	29	0.5	9' to W42B	35	27	25	27	26	24	South/Sand	163	45.81368538 N	84.76710678 W	No

										North/Sand	163	45.81377639 N	84.76707143 W	
W-46	48	1	50' to W45	54	44	53	82	82	77	South/Sand	163	45.81390759 N	84.76701534 W	No
										North/Sand	163	45.81405037 N	84.76696836 W	
W-47	41	1.5	150' to W46	41	37	61	69	67	62	South/Clay	172	45.81444824 N	84.76681747 W	No
										North/Clay	170	45.81455828 N	84.76677736 W	
W-51A	16	1.5	20' to W47	16	14	14	11	20		South/Clay	170	45.81461201 N	84.76675686 W	No
										North/Anchor (2006)	170	45.81465648 N	84.7667401 W	
W-51B South	57	1	Anchor	58	82	84	81	80		South/Anchor (2006)	170	45.81465648 N	84.7667401 W	No
										North/Anchor (2014)	174	45.81481348 N	84.76668449 W	
W-51B North	26			24						South/Anchor (2014)	174	45.81481348 N	84.76668449 W	No
										North/Clay	172	45.81487608 N	84.76665789 W	
W-50	13	0.5	38' to W51B	20	Filled in	23	18	26	12	South/Clay	172	45.81497406 N	84.76661907 W	No
										North/Clay	172	45.81502565 N	84.76660073 W	
W-49	50	1.5	29' to W50	50	54	52	61	47	47	South/Clay	172	45.81510113 N	84.76656607 W	Yes
										North/Clay	170	45.81523798 N	84.76652427 W	
W-48A	58	1	3' to W49	54	61	57	60	59	63	South/Clay	170	45.81524574 N	84.76652191 W	Yes
										North/Anchor (2003)	177	45.81539218 N	84.76646868 W	
W-48B	65	1	Shared Touch Down ^	63	67	79	59	72	66	South/Anchor (2003)	177	45.81539218 N	84.76646868 W	Yes
										North/Clay	176	45.81555569 N	84.76639198 W	
W-52	62	1	14' to W48B	59	60	91	61	63	66	South/Clay	175	45.81559247 N	84.76637538 W	No
										North/Clay	174	45.81574877 N	84.76632003 W	
W-53A	77	1	96' to W52	69	67	77	67	75		South/Clay	169	45.8160056 N	84.76622468 W	Yes
										North/Anchor (2005)	169	45.81618886 N	84.76615963 W	
W-53B	32	0.5	Shared Touch Down ^	26	25	31	42	39		South/Anchor (2005)	169	45.81618886 N	84.76615963 W	No
										North/Clay	170	45.81625886 N	84.76613285 W	
W-70 A	44	0.5	109' to W53B	42	43	114	100	109		South/Clay	172	45.81654866 N	84.76602166 W	No
										North/Anchor (2010)	175	45.81666162 N	84.76597665 W	
W-70 B	24	0.5	Shared Touch Down ^	36	25					South/Anchor (2010)	175	45.81666162 N	84.76597665 W	No
										North/Clay	175	45.81675578 N	84.76594127 W	
W-69	77	0.5	55' to W70B	64	70	96	98	81	88	South/Clay	178	45.81690174 N	84.76588593 W	Yes
										North/Clay	182	45.81707239 N	84.76582266 W	
W-68A South	13	1	105' to W69	11	77	85	75	83	69	South/Clay	190	45.81735651 N	84.7657183 W	No
										North/Anchor (2014)	192	45.8173852 N	84.76570621 W	
W-68A North	65		Shared Touch Down ^	66						South/Anchor (2014)	192	45.8173852 N	84.76570621 W	No
										North/Anchor(2003)	191	45.81756257 N	84.7656429 W	
W-68B	45	1	Shared Touch Down ^	62	60	43	48	41	50	South/Anchor (2003)	191	45.81756257 N	84.7656429 W	No
										North/Clay	196	45.81772359 N	84.76557989 W	
W-71A	27	1	88' to W68B	26	77	84	81	84	67	SouthClay	217	45.81795369 N	84.76549024 W	No
										North/Anchor (2014)	224	45.81802422 N	84.76546477 W	
W-71B	45		Shared Touch Down ^	55						South/Anchor (2014)	224	45.81802422 N	84.76546477 W	No
										North/Anchor (2003)	232	45.81816946 N	84.76541244 W	

W-72A South	50	1.5	Shared Touch Down ^	57	57	105	107	108	108	South/Anchor (2003)	232	45.81816946 N	84.76541244 W	No
										North/Anchor (2012)	232	45.81831983 N	84.76535345 W	
W-72A North	55	1	Shared Touch Down ^	47	47					South/Anchor (2012)	232	45.81831983 N	84.76535345 W	No
										North/Anchor (2004)	238	45.81844653 N	84.76530393 W	
W-72B South	32	1.5	Shared Touch Down ^	35	36	100	100	98	99	South/Anchor (2004)	238	45.81844653 N	84.76530393 W	No
										North/Anchor (2012)	242	45.81854156 N	84.76526921 W	
W-72B North	65	1.5	Shared Touch Down ^	61	61					South/Anchor (2012)	242	45.81854156 N	84.76526921 W	No
										North/Anchor (2004)	246	45.81870788 N	84.76521301 W	
W-72C	54	2	Shared Touch Down ^	54	59	56	65	52	56	South/Anchor (2004)	246	45.81870788 N	84.76521301 W	No
										North/Clay	244	45.81885056 N	84.76516087 W	
W-75	59	1	19' to W72C	61	52	77	57	54	44	South/Clay	243	45.81890246 N	84.76513828 W	No
										North/Clay	241	45.819066 N	84.76508084 W	
W-56	54	1	72' to W75	57	59	67	58	60	61	South/Clay	237	45.81925852 N	84.76501189 W	No
										North/Clay	238	45.81940715 N	84.76495466 W	
W-78	NA				NA	Filled in	16	15		NA	NA	NA	NA	No
										NA	NA	NA	NA	
W-54A	57	1	172' to W56	56	56	55	53	60		South/Clay	234	45.81986479 N	84.7647835 W	No
										North/Anchor (2005)	232	45.82001287 N	84.76473484 W	
W-54B	51	1.5	26' to W54A	51	49	88	87	86		South/Clay	232	45.82008325 N	84.76470314 W	No
										North/Clay	232	45.8202238 N	84.76465785 W	
W-57A	47	2.5	65' to W54B	43	79	77	67	78	75	South/Clay	230	45.82040018 N	84.76459954 W	No
										North/Anchor (2014)	230	45.8205126 N	84.76455633 W	
W-57B	30		Shared Touch Down ^	40						South/Anchor (2014)	230	45.8205126 N	84.76455633 W	No
										North/Clay	228	45.82061962 N	84.76451859 W	
W-59A-A	NA				Silted in	6	33			NA	NA	NA	NA	No
										NA	NA	NA	NA	
W-59A South	37	2.5	319' to W-57	36	45	90	91	130		South/Anchor (2006)	221	45.82146702 N	84.76420828 W	No
										North/Anchor (2012)	221	45.82156234 N	84.76416991 W	
W-59A North	47	2.5	Shared Touch Down ^	53	47					South/Anchor (2012)	221	45.82156234 N	84.76416991 W	No
										North/Anchor (2003)	219	45.82170276 N	84.76412053 W	
W-59B South	41	3	Shared Touch Down ^	41	52	104	97	100		South/Anchor (2003)	219	45.82170276 N	84.76412053 W	No
										North/Anchor (2012)	219	45.82180891 N	84.7640712 W	
W-59B North	57	3	Shared Touch Down ^	56	45					South/Anchor (2012)	219	45.82180891 N	84.7640712 W	No
										North/Anchor (2003)	212	45.82195831 N	84.76401066 W	
W-58A South	61	2	Shared Touch Down ^	62	62	126	132	131		South/Anchor (2003)	212	45.82195831 N	84.76401066 W	No
										North/Anchor (2010)	207	45.82212511 N	84.76395711 W	
W-58A North	70	2.5	Shared Touch Down ^	70	70					South/Anchor (2010)	207	45.82212511 N	84.76395711 W	No
										North/Anchor (2003)	190	45.82230838 N	84.7638836 W	
W-58B	36	1.5	Shared Touch Down ^	35	36	38	30	28		South/Anchor (2003)	190	45.82230838 N	84.7638836 W	No
										North/Clay	183	45.8224028 N	84.76385368 W	
W-60A	58	1.5	137' to W58B	56	58	55	52	60	62	South/Clay	165	45.82276582 N	84.76370893 W	No

										North/Anchor (2003)	160	45.82291533 N	84.7636541 W	
W-60B South	51	2	Shared Touch Down ^	50	70	90	91	86	89	South/Anchor (2003)	160	45.82291533 N	84.7636541 W	No
										North/Anchor (2012)	155	45.82304668 N	84.76359861 W	
W-60B North	32	2	Shared Touch Down ^	33	20					South/Anchor (2012)	155	45.82304668 N	84.76359861 W	No
										North/Clay	148	45.82313538 N	84.76356789 W	
W-79	NA				Silted in	15	16			NA	NA	NA	NA	No
										NA	NA	NA	NA	
W-61A	30	1	83' to W60B	27	72	80	85	79	84	South/Clay	135	45.82335415 N	84.76349054 W	No
										North/Anchor (2014)	132	45.82342456 N	84.76346306 W	
W-61B	46		Shared Touch Down ^	45						South/Anchor (2014)	132	45.82342456 N	84.76346306 W	No
										North/Clay	125	45.82354201 N	84.76341513 W	
W-62	46	1	351 to W61	44	46	49	45	44	38	South/Sand	91	45.82447624 N	84.76309011 W	No
										North/Sand	89	45.82459253 N	84.76304185 W	
W-63A	56	1.5	282 to W-62	54	66	57	49	57	55	South/Sand	78	45.82534041 N	84.76275039 W	No
										North/Anchor (2004)	78	45.82548661 N	84.7626958 W	
W-63B	55	1.5	Shared Touch Down ^	53	50	54	54	49	51	South/Anchor (2004)	78	45.82548661 N	84.7626958 W	No
										North/Sand	76	45.8256262 N	84.76264017 W	
W-65A	43	1.5	185' to W-63B	50	77	90	82	86	80	South/Sand	74	45.82611694 N	84.76246404 W	No
										North/Anchor (2014)	74	45.82624713 N	84.76241517 W	
W-65B	26		Shared Touch Down ^	26						South/Anchor (2014)	74	45.82624713 N	84.76241517 W	No
										North/Sand	74	45.82631462 N	84.76238826 W	
W-64A	18	1	8' to W-65	18	20	90	89	90	80	South/Sand	73	45.82633776 N	84.76238098 W	No
										North/Anchor (2012)	73	45.82638189 N	84.76235928 W	
W-64B South	52	1	Shared Touch Down ^	29	71					South/Anchor (2012)	73	45.82638189 N	84.76235928 W	No
										North/Anchor (2014)	73	45.8264624 N	84.7623333 W	
W-64B North	26		Shared Touch Down ^	46						South/Anchor (2014)	72	45.8264624 N	84.7623333 W	No
										North/Sand	72	45.82658693 N	84.76228562 W	
W-67A	52	2'	98' to W-64N	41	89	87	89	100	86	South/Sand	72	45.8268466 N	84.76218543 W	No
										North/Anchor (2014)	72	45.82695668 N	84.762151 W	
W-67B	40		Shared Touch Down ^	50						South/Anchor (2014)	72	45.82695668 N	84.762151 W	No
										North/Sand	70	45.82708749 N	84.76210055 W	
W-66	42	1.5	196' to W-67	43	67	41	45	45	44	South/Sand	70	45.82760434 N	84.76191151 W	No
										North/Sand	70	45.82771752 N	84.76186138 W	
Northern Exposure Point		NA	100' to W-66	NA	NA	NA	NA	NA	NA	Only/Sand	65	45.82798472 N	84.76176355 W	No

Enbridge Response to Request for Information

A. Information currently available to Enbridge

1. Underwater Inspections- Please provide copies of all information available to Enbridge, including, without limitation, documents, reports, photographs, and video recordings, relating to any and all underwater inspections of the dual pipelines conducted after the completion of 2014 inspections performed by Ballard Marine Construction. This includes, but is not limited to, the 2016 underwater inspections referenced in the Plan.

Please find attached (1) a report prepared by Ballard Marine Construction ("BMC") summarizing the findings of the visual inspection of the Line 5 Dual Pipelines conducted for Enbridge in the Straits of Mackinac in 2016 and the repair work done following the inspection and (2) a report prepared by GEI Consultants ("GEI") summarizing the findings of the biota survey of the Dual Pipelines that the firm conducted for Enbridge based on the visual inspection conducted by BMC. These reports were previously submitted to the EPA on January 4, 2017. Also attached is a Supplemental Biota Work Plan submitted by Enbridge to EPA on March 23, 2017. Photographs of areas identified in both the original and supplemental Biota Work Plans are contained in the reports themselves.

BMC conducted a visual inspection of the portion of Line 5 that crosses the Straits in June 2016 and the results were analyzed in July 2016. The attached BMC report explains how the inspection was conducted and summarizes the findings of the inspection.

The attached GEI report describes a survey of biota undertaken based on the visual inspection made of the Dual Pipelines. The Enbridge biota work plan, currently pending approval by EPA, is based in part on the attached GEI report, which is referenced in the Enbridge Biota Work Plan.

Associated video files from the 2016 BMC underwater inspection are also being provided.

The materials provided constitute the key documents relating to the latest underwater inspection, which was performed by BMC in 2016.

2. Clarification and Documentation of Conditions referred to in the Plan- Please:

a. List and explain the criteria used by Enbridge to identify the "holiday" areas referred to in the Plan.

The 18 areas referred to in the Biota Work Plan were identified based on review of the video recording of the 2016 inspection. The areas identified included (i) areas where Biota was not present and (ii) areas where Biota was not present and the pipelines' outer wrap appeared to have anomalies. Enbridge intends to inspect all 18 locations, as per the Biota Work Plan and its supplement, in order to gather any relevant additional data about these areas. Depending on the results of these inspections, Enbridge will make a determination on whether a review of additional areas of the Dual Lines where there are similar or other potential anomalies in biota presence or the outer wrap would yield any additional useful data.

b. For each such identified "holiday" area or "locations with potential delaminated coatings" referred to in the Plan, including, but not limited to those designated in Figures 4 and 5,

i. Provide Enbridge's best estimate of the size of the "holiday" area

The estimated size of the each of the areas identified below in response to Request # A.2.b.v is between 2 – 10 ft2 (with <100ft2 total).

Execution of the Biota Work Plan may allow Enbridge to further assess and refine these estimates.

ii. Indicate whether, and to what extent, bare metal is exposed

Enbridge has seen no evidence that any of the areas identified in the Biota Work Plan as "holiday" areas or areas with "potential delaminated coating" have bare metal exposed. In addition, a CPCM inline inspection was completed and local cathodic protection currents were measured to determine if any bare metal was present. This inspection has not indicated that there are any holidays in the coating.

iii. Describe the "delamination" or other condition that has been observed, e.g., whether and to what extent one or more layer of pipeline wrap and/or coating is missing

In 8 of the identified areas, there is a lack of Biota, but no visible indication of anomalies to the coating and specifically to the outer wrap. In the remaining 10 identified areas, there is a lack of Biota and some indication of anomalies in the outer wrap. In all cases, all other layers of coating appear to be intact and unaffected, including the enamel layer that covers the pipeline.

iv. Indicate whether, and to what extent, "delaminated pipeline coatings" referred to in the Plan have been observed on the lake floor

There is one location (W-12A) among the 18 areas identified in the Biota Work Plan where the outer layer wrap was observed on the lake floor. See also Response to # A.2.c.iv below (regarding second area not referred to in the Biota Work Plan).

v. Identify the time or other frame markings on the 2014 and 2016 underwater video recordings that Enbridge used to identify the holiday area, and if photographs of that specific area are available, provide them.

In the supplied video from the 2016 visual inspection, the 18 identified areas can be seen at the following frame times.

Label	**2016 Frame Markings**
Between E-74 & E-71	9:27:25
Between E-77 & E-26	9:44:30
Between E-24 & E-25	9:56:50
E-30	10:36:10
E-35	10:47:20
Between E-33 & E-34B	11:02:45
E-39	11:40:04
Near E-48	12:36:44
Near E-70	12:43:44

Between E-02 & E76	14:59:08
E-01B-B	15:21:32
Between W-10 & W-11	9:38:15
W-12A	9:47:55
Between W-15 & W-16	10:33:00
W-35	12:15:23
W-70	13:28:50
W-68	13:46:40
Between W-56 & W-54	14:27:25

Photographs of these areas are contained in both the September 2016 Work Plan and the Supplemental Work Plan. Enbridge has utilized the most recent 2016 data as it provides the best picture of pipeline coating condition.

vi. Provide any document(s), graphs, or figures correlating the visual observations of that area with the results of previous in-line inspections of the same area.

When comparing the identified locations with past In-line Inspection data from corrosion tools, there is no evidence of external corrosion found at any of the locations.

The Cathodic Protection in-line inspection tool deployed on September 27, 2016, found that the coating was protecting the pipe at all locations including the 18 locations identified in the Biota Plan.

c. Indicate whether, in addition to the areas referred to in the Plan and covered in item 2.b., above, Enbridge or its contractors have observed any other areas on the dual pipelines where the external pipeline coating is damaged or absent. If any such other areas have been observed, for each such area, provide the information listed in 2.b. (i.)- (vi.)

i. Provide Enbridge's best estimate of the size of the "holiday" area

The estimated size of the each of the areas identified below in response to Request # A.2.c.v is between 0 – 20 ft2 (with <100ft2 total).

ii. Indicate whether, and to what extent, bare metal is exposed

Enbridge has seen no confirmed locations of bare metal exposed at any point on the lines as shown by inline inspection results, including at the areas addressed in response to Request A.2.b.ii above. Three areas identified in the Supplemental Biota Work Plan will be inspected to determine if any bare metal is exposed. Also, as mentioned previously, our 2016 CPCM inline inspection has not identified any areas of increased usage of cathodic protection indicating that our coating is performing as designed.

iii. Describe the "delamination" or other condition that has been observed, e.g., whether and to what extent one or more layer of pipeline wrap and/or coating is missing

Some areas seen in the 2016 inspection exhibit only a lack of Biota – no visible indication of anomalies to the coating and specifically to the outer wrap. There are also a number of areas where there is a lack of Biota plus some indication of anomalies in the outer wrap. The locations of the areas in the second category are listed in the table provided in response to Request A.2.c.v below. In all cases, all other layers of coating appear to be intact and unaffected.

iv. Indicate whether, and to what extent, "delaminated pipeline coatings" referred to in the Plan have been observed on the lake floor

There is one other location (E-02B) seen in the 2016 Inspection where the outer layer wrap was observed on the lake floor. As noted above, W-12A also has outer coating on the lake floor.

v. Identify the time or other frame markings on the 2014 and 2016 underwater video recordings that Enbridge used to identify the holiday area, and if photographs of that specific area are available, provide them.

In the supplied video for the 2016 visual inspection, the additional areas where the coating appears to have an anomaly can be seen at the following frame times.

Label	2016 Frame Markings, TIME
Between E-25 & E-24	9:54:23
Between E-39 & E-40	11:46:35
E-45	12:08:17
E-48B	12:34:20
E-52	13:17:00
E-61A-A	13:35:18
Between E-12 & E-13A	14:39:04
E-13C	14:48:40
Between E-13C & E-3	14:52:17
E-76B	14:57:15
Between E-76B & E-02A	15:01:21
Between E-76B & E-02A	15:02:44
Between E-76B & E-02A	15:03:37
E-02B	15:11:01
E-01B-A	15:20:10
E-04B	15:28:32
Between E-04B & E-05A	15:29:16
Between E-05B & E-06	15:36:32
Between E-05B & E-06	15:37:17
Between E-05B & E-06	15:37:58
E-07	15:42:18
Between E-07 & E-65A	15:48:21
Between E-65B & Burial	15:55:58
W-01A	8:33:04
Between W01B & W-5	8:40:15
Between W-15 & W-16	10:32:22

Between W-15 & W-16	10:33:41
Between W-15 & W-18	10:38:37
Between W-18B & W-20	10:51:50
W-24	10:56:45
W-24	10:58:38
W-23A	11:00:14
W-23B	11:04:08
Between W-22 & W-21	11:06:48
Between W-22 & W-21	11:07:25
Between W-25 & W-26	11:12:36
Between W-26 & W-27	11:16:54
W-27	11:18:17
W-28	11:36:30
W-31A	11:46:48
W-53A	13:15:03
W-53A	13:17:06
Between W-64 & W-67	15:59:57

vi. Provide any document(s), graphs, or figures correlating the visual observations of that area with the results of previous in-line inspections of the same area.

When comparing the identified locations with past In-line Inspection data from corrosion tools, there is no external corrosion found at any of the locations.

The Cathodic Protection in-line inspection tool deployed on September 27, 2016, found that the coating was protecting the pipe at all locations including the areas listed in the preceding response.

3. Any Other Pipeline Inspection Results or Reports Not Previously Provided to the State- To the extent, if any, that Enbridge has available to it the results or reports of any other inspections of the dual pipelines, including, but not limited to any in-line inspections, conducted after 2013, that have not previously been provided to the State please provide copies of any such inspection results or reports.

Reports or summaries of all in-line inspections of the dual pipelines conducted after 2013 other than those previously provided are attached. These reports include:

- 2016 BH CPCM Inspection (East Straits)
- 2016 BH GeoPig Inspection (East Straits)
- 2016 BH CPCM Inspection (West Straits)
- 2016 BH GeoPig Inspection (West Straits)
- 2015 Acoustic Emission Inspection (East Straits)
- 2015 Acoustic Emission Inspection (West Straits)

Part B: Information Available to Enbridge in the Future. Please provide as soon as possible, and in any event, not later than ten (10) days after the date that each becomes available to Enbridge:

1. The Final, EPA-Approved Work Plan for the Biota Investigation required under Paragraph 69.b. of the proposed Consent Decree.

Enbridge will provide a copy of the approved Work Plan when available.

2. The Final Report of the Biota Investigation and, if applicable, the proposed work plan to address actual or threatened impairments to the dual pipelines required under Paragraph 69.c. of the proposed Consent Decree.

Enbridge will provide a copy of the Final Biota Report when available.

3. Underwater Inspections- Please provide copies of all information that becomes available to Enbridge, including, without limitation, documents, reports, photographs, and video recordings, relating to any and all underwater inspections of the Dual Pipelines conducted after the completion of the 2016 inspection and not already provided in response to Item A.1., above.

Enbridge will inform the State of future visual inspections as they occur.

4. Any Other Pipeline Inspection and Test Results- Please provide copies of all information that becomes available to Enbridge regarding the results or reports of any other inspections or tests of the integrity of the Dual Pipelines, including, but not limited to any in-line inspections, hydrostatic tests, or pipeline movement investigation required under Paragraphs 70 through 73 of the proposed Consent Decree.

Enbridge will inform the State of future inspections or tests of the integrity of the Dual Pipelines as they occur.

June 18, 2017 Supplemental Addendum to Technical Note

Regarding Enbridge Line 5 Non-Compliance with 1953 Easement Requirements A Mechanistic Analysis of Straits Pipeline Washout Phenomena

Edward E. Timm, PhD, PE
5785 Deer Run Trail, Harbor Springs MI 49740
EdTimm@Gmail.com

The Technical Note "Regarding Enbridge Line 5 Non-Compliance with 1953 Easement Requirements, A Mechanistic Analysis of Straits Pipeline Washout Phenomena"[1] released on 8/20/16 details the history of unsupported spans for the Straits portions of Enbridge Energy Partners Line 5 and suggests insight into the mechanism behind the reoccurring washouts that have resulted in nearly continuous non-compliance with State mandated support requirements since its construction in 1953. A recently released report by Kiefner and Associates entitled "Assessment of Span Exposures on the 20-inch Petroleum Pipelines Crossing the Straits of Mackinac"[2] includes information requiring this addendum to my original report. The Kiefner report documents work done for Enbridge beginning in 2003. The report was issued to Enbridge in draft form in 2005 and re-issued as a final report on October 12, 2016. This report contains information about previously unreported spans as of 2003 as well as information about a contracted study of current velocities in the vicinity of the pipeline done for Enbridge during the period 2002-2004.

The Technical Note of 8/20/16 resulted from a study of old blueprints released by Governor Snyder's Pipeline Task Force. Table 1 is taken from this document.

Table 1. Summary of Spans and Supports as of the 1979 Underwater Inspection of Line 5

1. Data taken from Lakehead Pipeline Company, Inc. drawings released by Michigan Attorney General
2. Drawing originally dated 4/14/64 and noted as being traced from Bechtel, Inc. drawing dated 11/63
3. Drawing updated through 1980 including revisions following 1972, 1975 and 1979 underwater inspections
4. Unsupported spans over 75 feet are prohibited by 1953 easement agreement with the State of Michigan
5. Unsupported spans over 140 feet were calculated to be dangerous to line integrity by original designers at Bechtel

Summary of non-Compliant Unsupported Spans as of 1980

Location	Spans > 75 feet	Spans > 140 feet
West Leg	10	3
East Leg	7	0

The longest unsupported span found in this work was 160 feet on the west leg.

The Kiefner report, which is mostly a calculational study of the stresses imposed on the pipe by gravity due to long unsupported spans, contains the following data about span lengths as of 2003. "The 2003 survey identified 7 spans longer than140 feet in the east leg, with the longest being 224 feet, and 9 spans longer than 140 feet in the west leg, with the longest being 286 feet (due to a failed grout bag support)."

Table1a, Summary of Spans as of 2003 from the Kiefner Report

Summary of non-Compliant Unsupported Spans as of 2003

Location	Spans > 140 feet	Maximum Span, feet
West Leg	7	224
East Leg	9	286

Table 2 is a history of Enbridge's efforts to provide support under Line 5 taken from my Technical Note.

Table 2 ROV Inspection and Span Support Installation History of Line 5 Straits of Mackinac

Year of ROV Inspection	Follow up Actions (Anchor Support Installation)	Type of Support Installed
1963	None	
1972	None	
1975	3	Grout Bags
1979	None	
1982	None	
1987	7	Grout Bags
1989	None	
1990	None	
1992	6	Grout Bags
1997	None	
2001	8	Grout Bags and mechanical support
2003	16	Mechanical Screw Anchors
2004	16	Mechanical Screw Anchors
2005	14	Mechanical Screw Anchors
2006	12	Mechanical Screw Anchors
2007	None	
2010	7	Mechanical Screw Anchors
2012	17	Mechanical Screw Anchors

Table 2 shows that Enbridge made two efforts to add mandated supports under Line 5 in the period from 1980 through 2000. In 1987, Enbridge added seven grout bag supports and in 1992 Enbridge added six grout bag supports. Beginning in 2001 a more significant effort was made to support the pipe using both grout bags and screw anchors. Assuming that the significant support efforts made in 2003 were done after the survey data reported in Table 1a, it is clear that spans exceeding those reported in this table must have occurred in the years 1980 through 2002 because supports were added to spans not revealed in Table 1a. The overall picture that emerges from this data is that the Straits portions of Line 5 did not comply with the State easement's requirement of no unsupported spans over 75 feet as constructed in 1953. This situation grew steadily worse for lack of maintenance through 2003 and was not rectified until very recently. More seriously, very long unsupported spans in excess of the recommended elastic limit of 140 feet have commonly occurred and some spans grew to such lengths that the pipe was plastically deformed by both the forces of gravity and currents until it either went into catenary mode or the sagging of the pipe was arrested by touching down on the lakebed. Some implications of these conclusions were reported by Timm[3] before the data revealed in the Kiefner report were known and the possibility of metal fatigue caused by the combined forces of gravity and the bi-directional currents that flow through the Straits is made much more likely by the extreme unsupported spans revealed in the Kiefner report.

The Kiefner report also reveals that Enbridge contracted an unknown firm to make current measurements in the vicinity of the pipe during the period from 2002 through 2004. Very little information is revealed about the details of these measurements in the Kiefner report but understanding this data is critical to the understanding of the hydrodynamic forces acting on Line 5 as it differs significantly from the four high quality data sets discussed in the Timm report. Following is a description of the Enbridge current data set taken from the Kiefner report. No information about the location or type of current sensors is included in this report

> Enbridge installed water current monitoring devices at four locations along their crossing in order to obtain better data concerning currents impinging on exposed spans. The devices were placed at representative water depths and locations in the Straits. Currents were monitored at 3-hour intervals between September 26, 2002 and August 8, 2004.

A full discussion of the current data Enbridge has relied on to draw conclusions about the hydrodynamic forces on Line 5 is beyond the scope of this document, however, the following summary of this data set taken from the Kiefner report is indicative that there are problems with the Enbridge current velocity data set.

> The mean plus 3-sigma velocity encompassing over 99% of measured values was approximately 1.5 ft/sec. Hence current velocities in excess of 1.5 ft/sec can be considered rare and infrequent events.

In this statement, the author of the Kiefner report concludes that current velocities in excess of 1.5 ft/sec (1 mph) are rare and infrequent events. Reference to Figure 1, taken from my original Technical Note[1], shows that a current velocity of 1 mph is only sufficient to mobilize and entrain soil particles with a diameter of less than 1 mm. It is extremely unlikely that the severe washouts that have affected Line 5 since its construction would be a factor if the currents under the Straits were only able to entrain very fine soil particles. It is much more probable that the extreme current events associated with extreme weather events in the Great Lakes basin documented in the Timm report and dismissed by the author of the Kiefner report as “rare and infrequent”, are the main factor posing a threat to the long term structural integrity of Line 5 under the Straits. In general, structures are far more likely to be damaged by weather extremes than average conditions and the failure of the author of the Kiefner report to statistically examine the Enbridge data set for extreme values or “Black Swan Events” is a major shortcoming of this work.

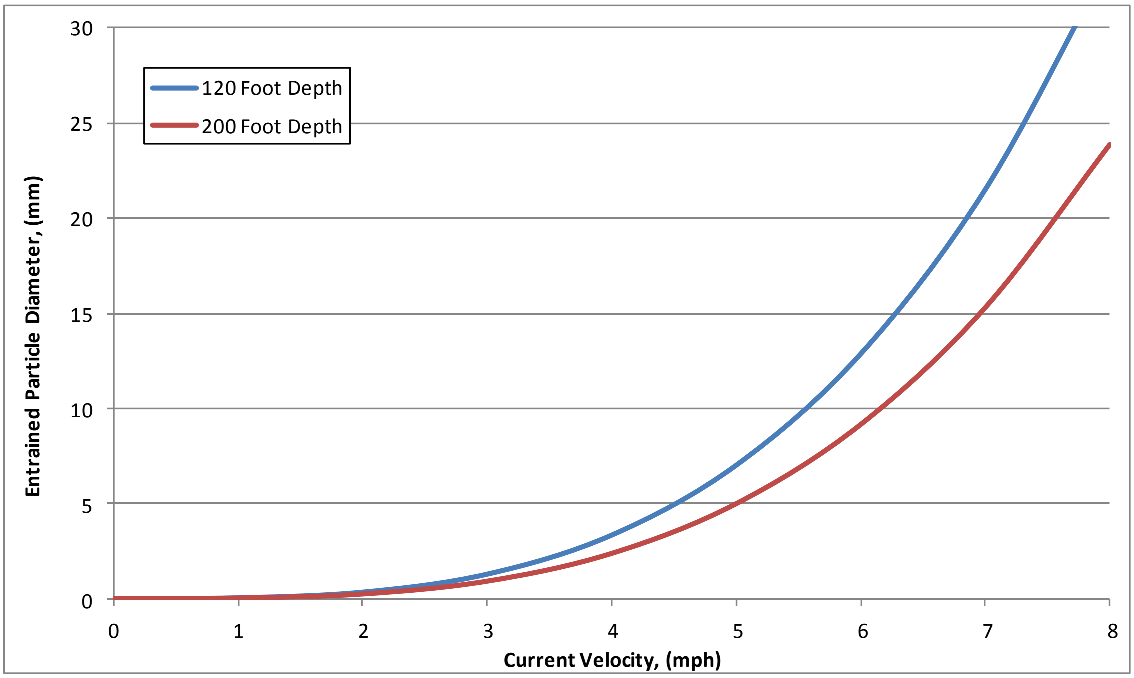

Figure 1. Soil Particle Entrainment Velocity as a Function of Underwater Current Velocity from Reference 1

Another shortcoming of the Enbridge current data set as reported and analyzed in the Kiefner report can be found in the following statement by Brad Shamla, Enbridge VP of US Operations, in a letter[4] to the State of Michigan:

> Four (4) current profilers were deployed to collect the current data, two (2) near the pipeline at the East crossing and two (2) near the pipeline at the West crossing. The current profilers were placed about 2 ft off the lake bottom. In the current velocity calculation, the average current over the elevations of 2 ft – 6 ft above the bottom was used where good quality current data was collected. Currents below 2 ft were calculated using known equations.

It should be obvious to those skilled in the art of fluid mechanics that drag and other forces imposed on a submerged bluff body respond virtually instantaneously to changes in current velocity. In this context, the statement by Enbridge that average (probably 3 hour average) current data was used to analyze hydrodynamic impacts on the stability of Line 5 illustrates another major problem with the conclusions drawn in the Kiefner report. As discussed in the Timm report, the use of average current velocity data and the dismissal of the extreme current events that are likely to impose the greatest forces on Line 5 and its environment make Enbridge's statements about the lack of current induced effects on Line 5 extremely suspect. Another area of discussion where a lack of fluid mechanical understanding has resulted in a flawed conclusion involves sections discussing Vortex Induced Vibration (VIV) in both references 2 and 4. This subject is far beyond the scope of this addendum but Enbridge's dismissal of the possibility that Line 5 has been compromised by VIV is incorrect. Given the importance of this subject and the fact that the extreme spans revealed in the Kiefner report make VIV effects more likely, it is recommended that further investigation of this subject is warranted.

A final observation drawn from Reference 4 and related materials submitted to the State of Michigan in Enbridge's application for a permit to allow placement of 22 additional screw anchors under Line 5 dated 5/9/17 regards a section of the West Leg located in the vicinity of the 15,500 foot chainage measurement. It is noted without further discussion that this section of the pipe includes five bends and two ovaled sections of pipe as revealed by numerous Enbridge ILI runs. Five of the 22 proposed screw anchors requested in the 5/9/2017 permit application are located in this area of what appears to be pipe damaged by unknown circumstances. It is recommended that a full examination of the circumstances leading to the observed damage on the West Leg of Line 5 be conducted before granting permission to place these anchors.

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[1] "Technical Note: Regarding Enbridge Line 5 Non-Compliance with 1953 Easement Requirements A Mechanistic Analysis of Straits Pipeline Washout Phenomena", Timm, E. E., August 2016, found as Appendix 1 in Reference 3

[2] "Assessment of Span Exposures on the 20-inch Petroleum Pipelines Crossing the Straits of Mackinac", Rosenfeld, M., Kiefner and Associates, Columbus, OH, October 2016

[3] "Technical Report: An Investigation into the Effect of Near Bottom Currents on the Structural Stability of Enbridge Line 5 in the Straits of Mackinac", Timm, E. E., March 2017, http://blog.nwf.org/wp-content/blogs.dir/11/files/2017/03/2017-Edward-Timm-Currents-and-Stresses-Report.pdf

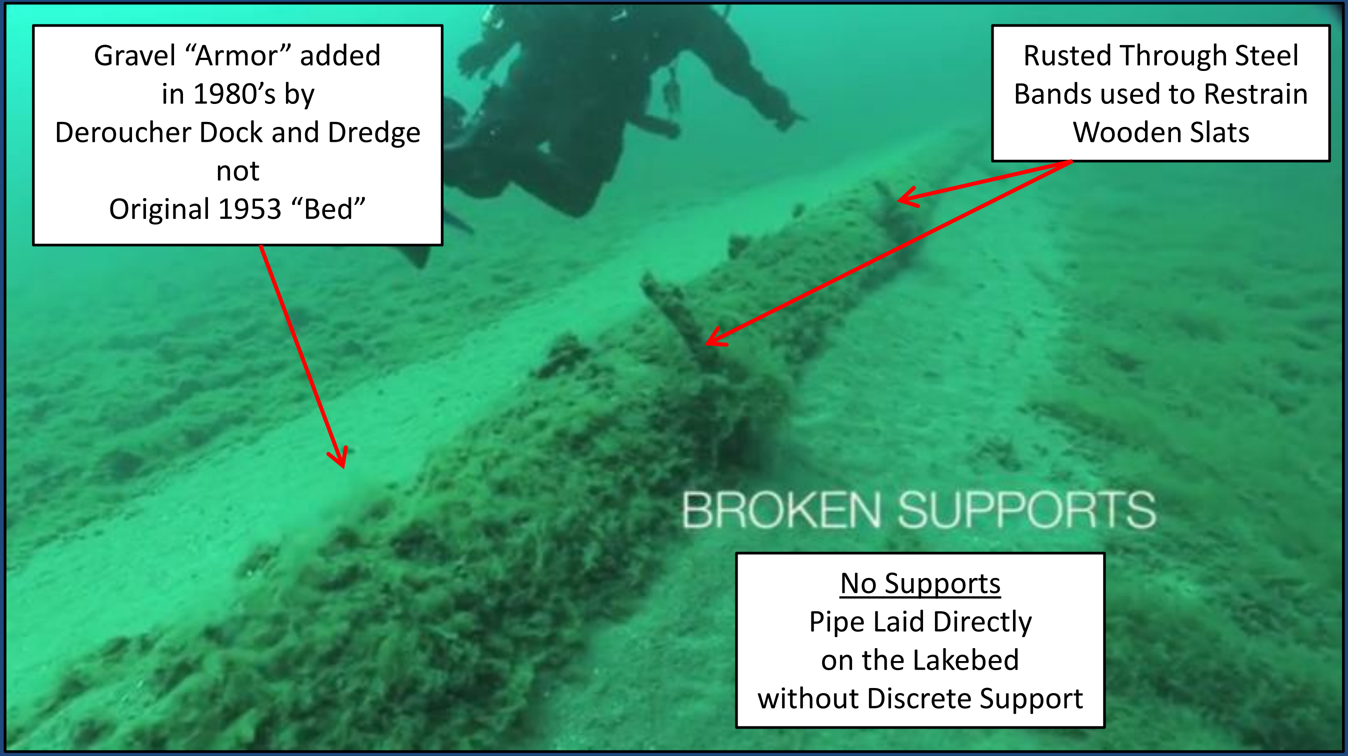
[4] Letter from Brad Shamla to the State of Michigan entitled "Response to Follow-Up Questions Concerning Enbridge's Forthcoming Application to Install Screw Anchor Supports on the Line 5 Dual Pipelines at the Straits of Mackinac", 4/13/2017

Enbridge Energy Partners, LLP
Straits Sections of Line 5
Summary Technology Update
6/9/17

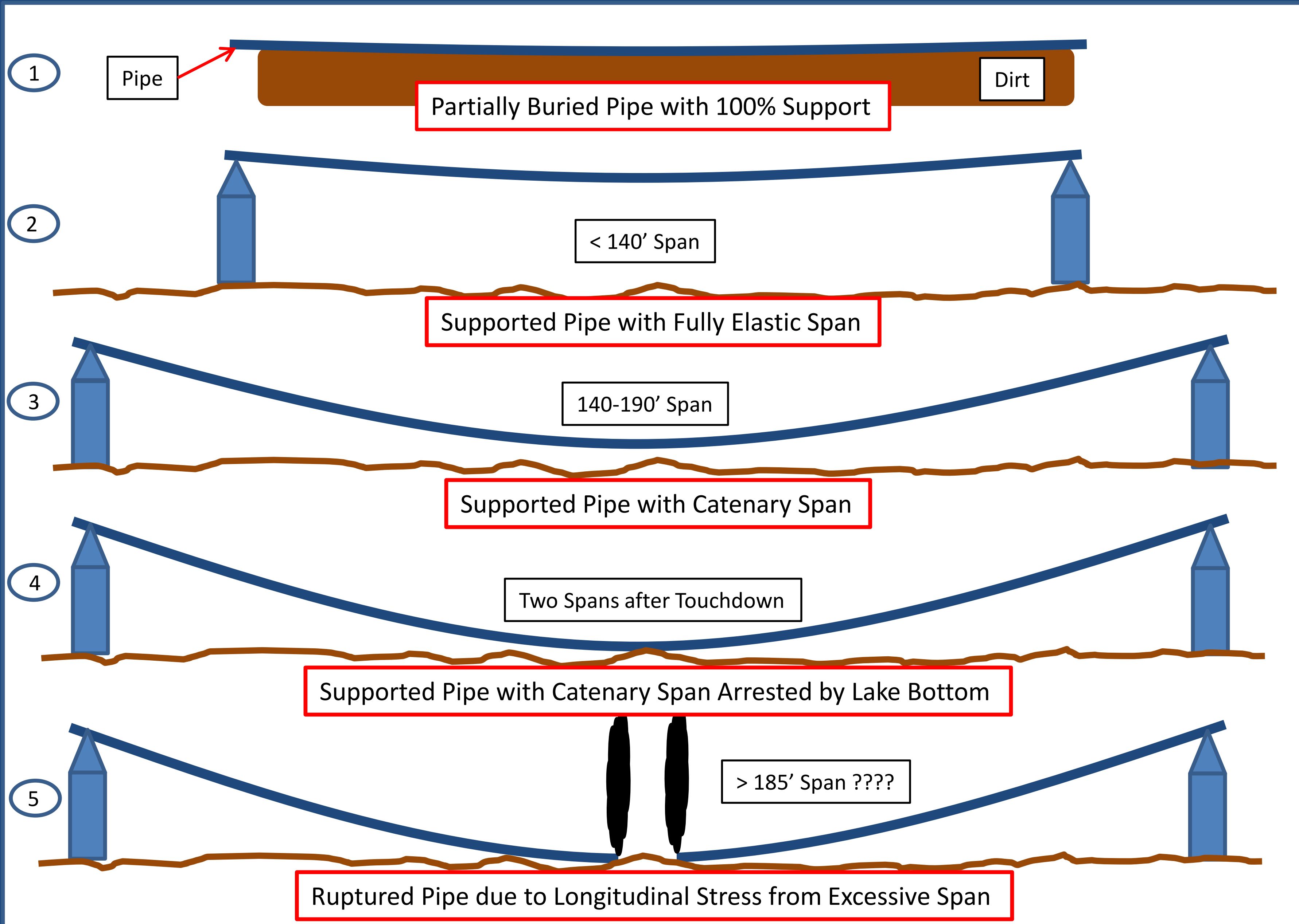
Enbridge Energy Partners
Straits Sections of Line 5
Technology Update

We have come a long way!

Photo from NWF Report “Sunken Hazard”, 2012



Issues Regarding the Straits Sections of Line 5 – Unsupported Spans and Failure



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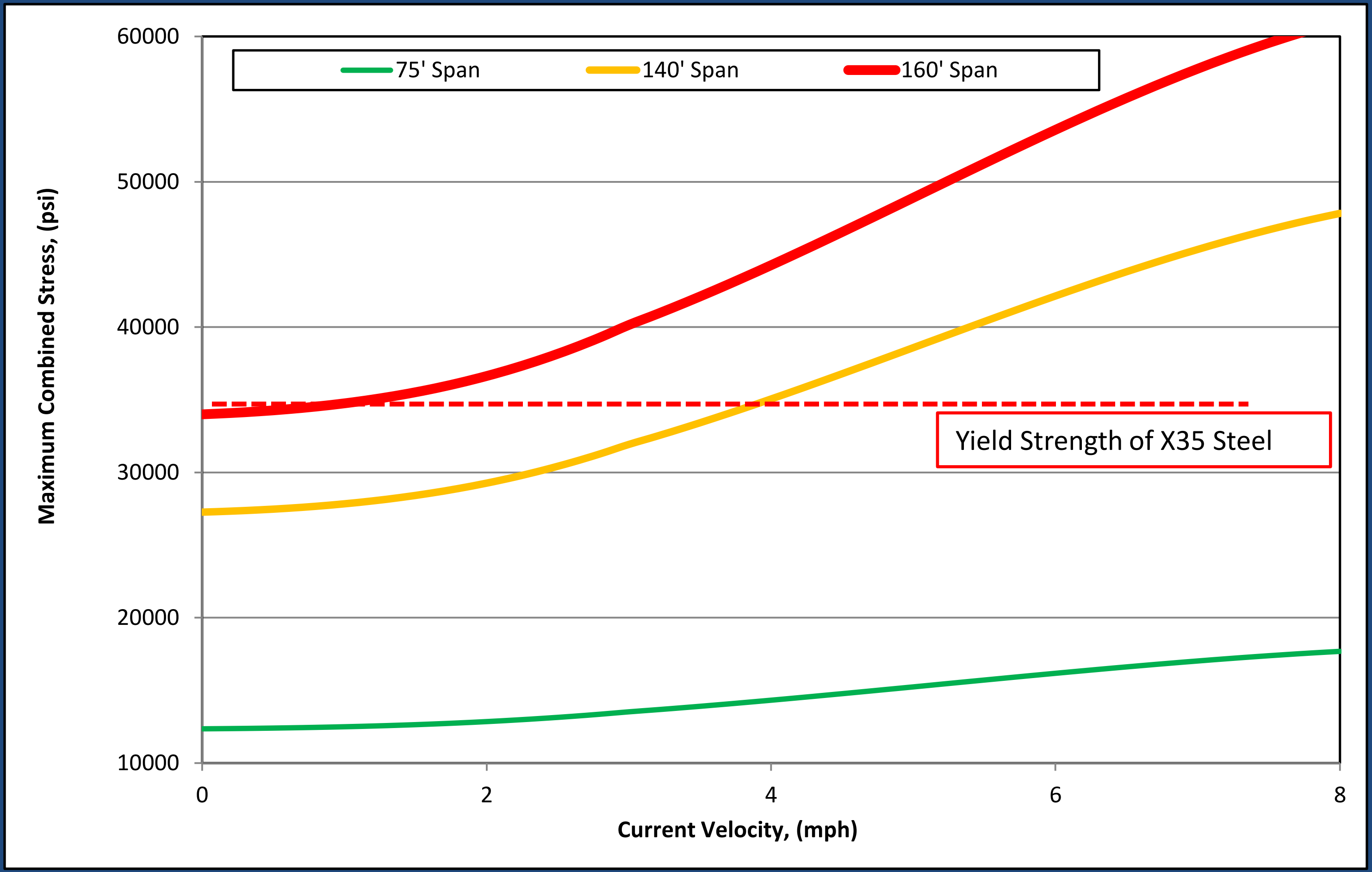
Issues Regarding the Straits Sections of Line 5 – Stress Due to Current

1953 Easement: "(10) The maximum span or length of pipe unsupported shall not exceed seventy-five (75) feet." (——)

1953 Engineering Report: "Under no circumstance should the unsupported span exceed 140 feet." (——)



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Currents and Stresses, Timm Report

Technical Report

An Investigation into the Effect of Near Bottom Currents on the Structural Stability of Enbridge Line 5 in the Straits of Mackinac

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Harbor Springs, MI 49740
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Abstract

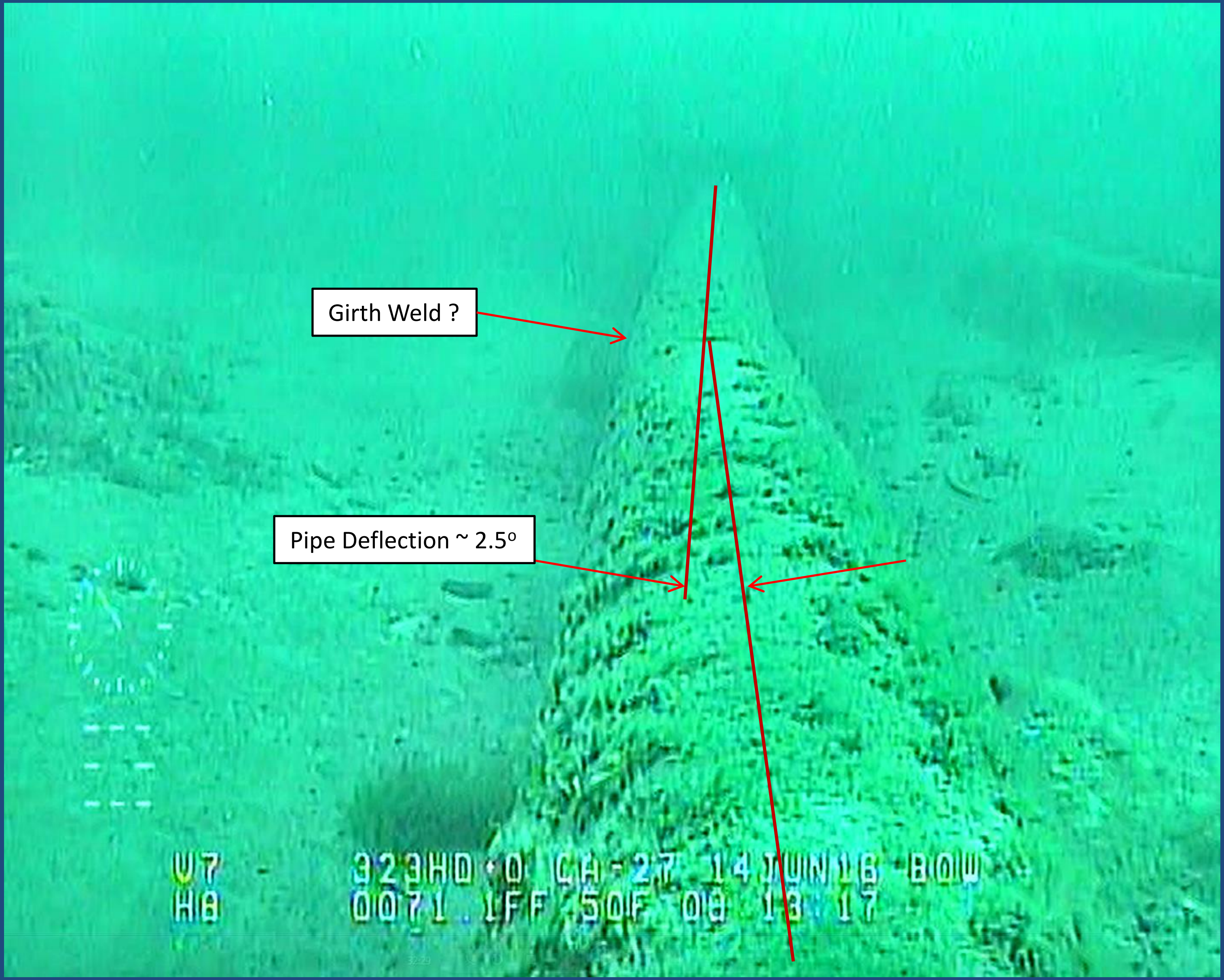
The Straits of Mackinac is a four mile wide channel that connects Lakes Huron and Michigan. Resting on the bottom of the Straits is Enbridge Line 5, a twinned crude oil pipeline that was designed and constructed by Bechtel Corporation in 1953 for the Lakehead Pipeline Company. This was a unique engineering project at the time of construction and the designers attempted to account for the forces on unsupported sections of the pipe resulting from underwater currents. Recent research has shown the currents in the Straits of Mackinac to be stronger and more complex than originally contemplated by the designers of line 5. This paper reviews recent underwater current data for the Straits of Mackinac and draws conclusions about the implications of deficiencies in the original design basis for Line 5.

Conclusions

- Currents stronger than the Line 5 design basis and previously unrevealed long, unsupported spans may have seriously fatigued the metal in the pipe (>160')
- The Straits sections of Line 5 cannot be considered fit for service until this subject has been thoroughly considered by experts in underwater pipeline integrity
- Consideration should be given to requiring shutdown and inspection of the pipe following an extreme current event in the Straits

<u>2016 Enbridge Inspection Video</u>

West Leg, South End, Pipe Bend to the West at 15,900' Chainage



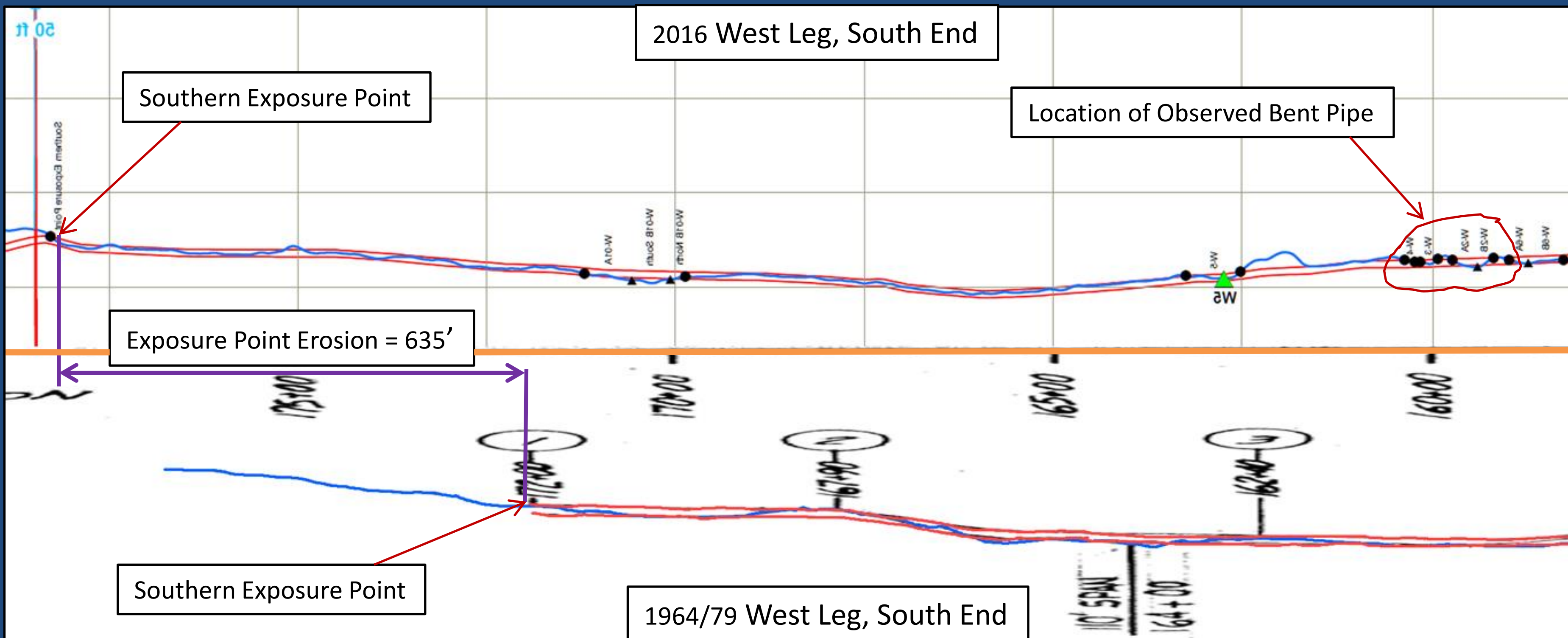
Evidence of Lateral Pipe Movement from 2012 and 2016 Inspection Videos

Laterally Deflected Anchor from 2012 Inspection

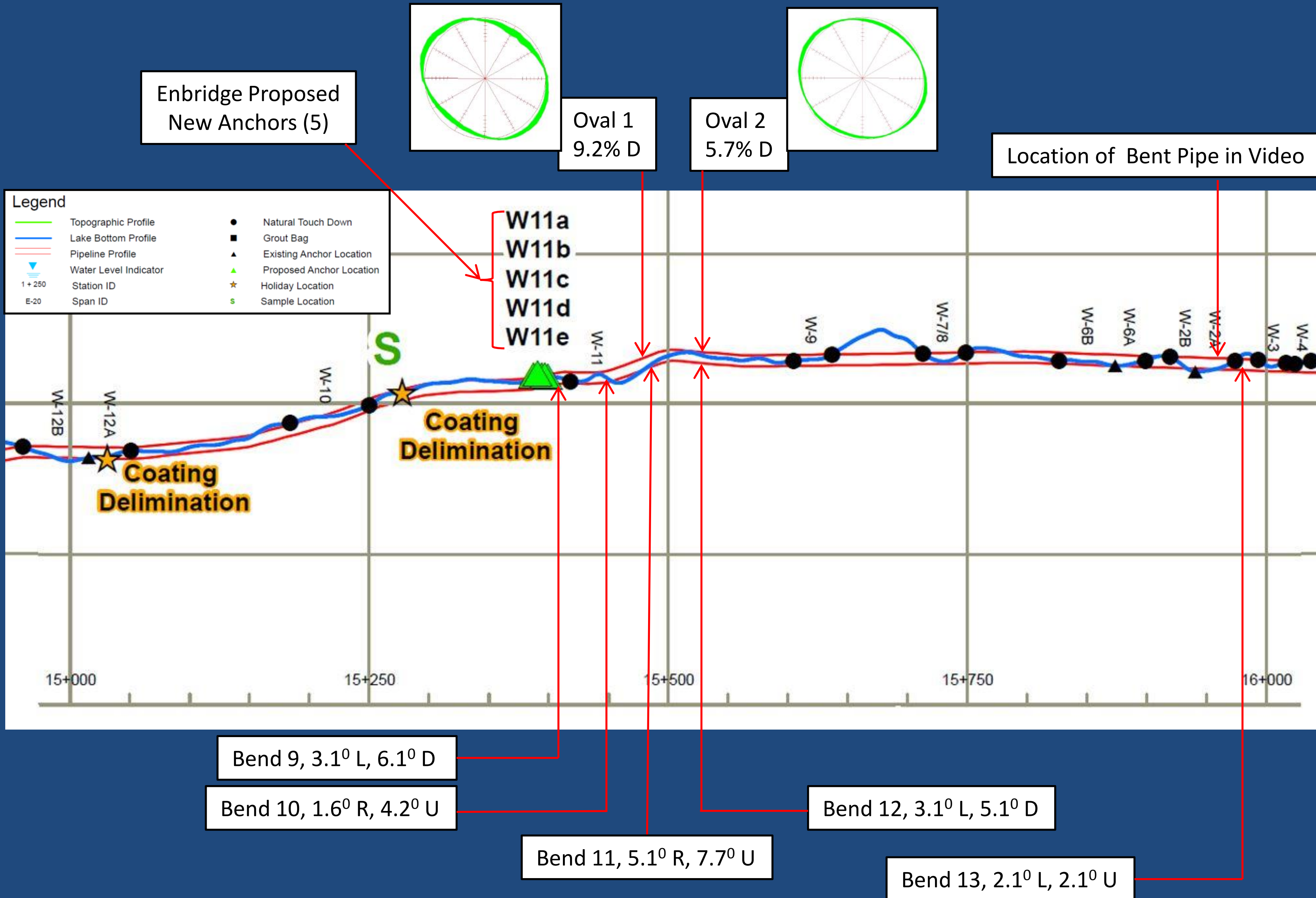
Laterally Deflected Anchor from 2016 Inspection

Evidence of Lateral Pipe Slippage through Anchor

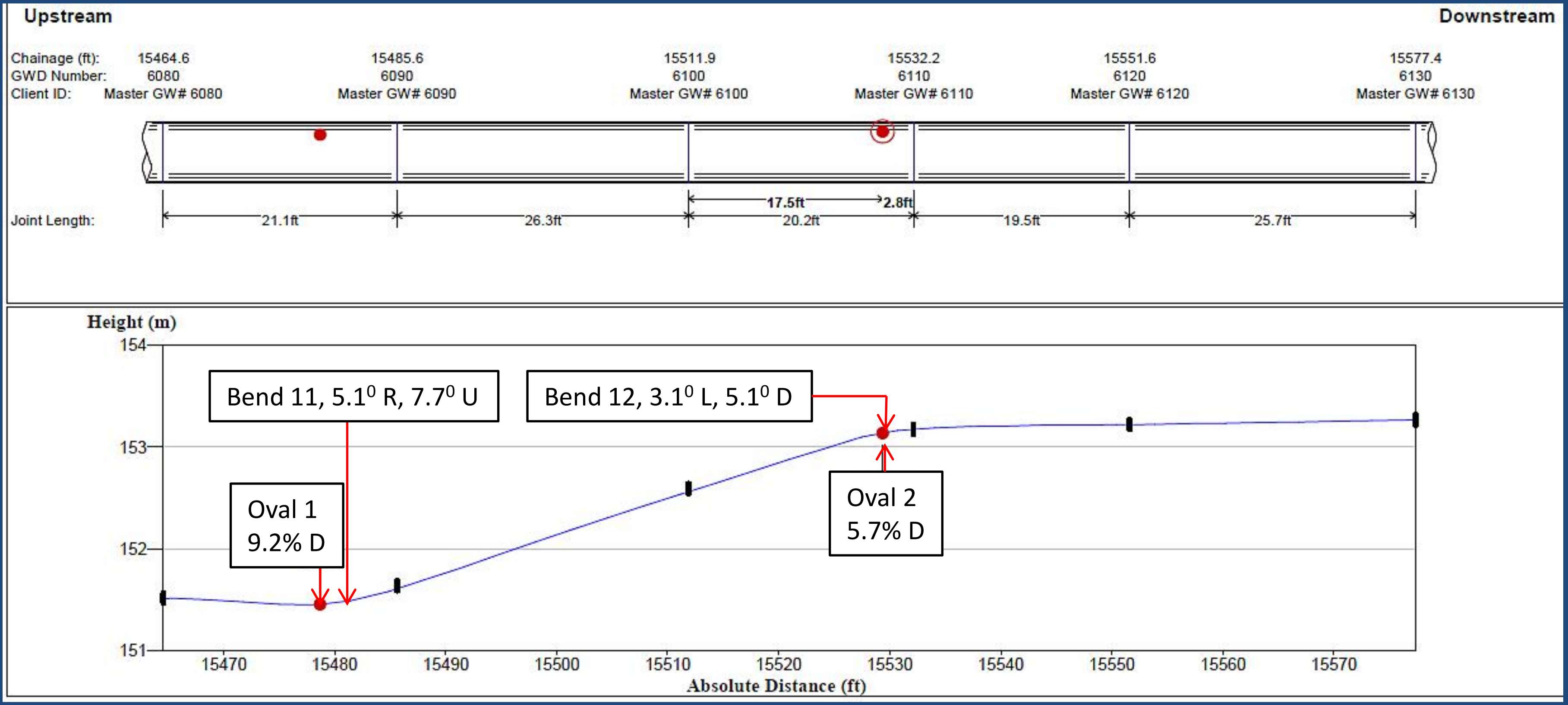
Comparison of Line 5 Bottom Profile Drawing from 2016 with 1964/79 Drawing

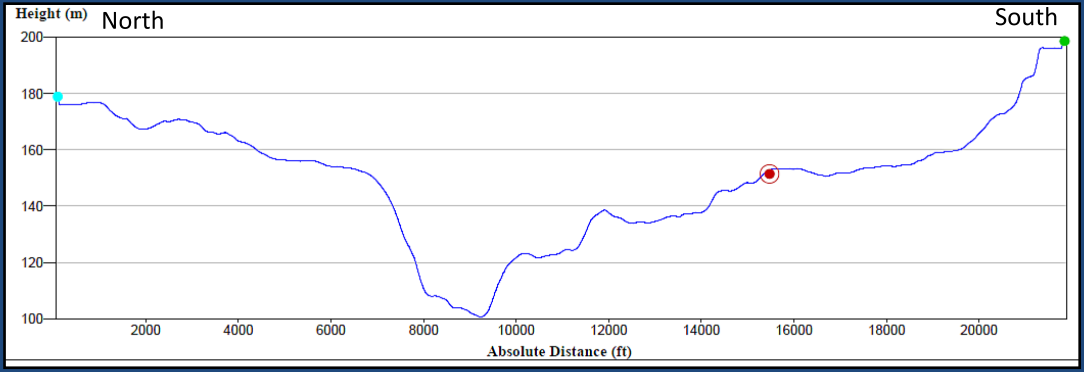


Line 5, West Leg, Pipe Deformities



Line 5, West Leg, Pipe Deformities





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Flawed Conclusion from 2016 LaMontagne ILI Review

LAMONTAGNE
Pipeline Assessment Corporation

ILI Review – Enbridge Line 5;
East and West Mackinac Straits

Analysis of all ILI data taken from 1998 through 2013 that finds very little metal loss or pitting and only small pipe movements since 2005. The report disclaims being a "Fitness for Service" report.

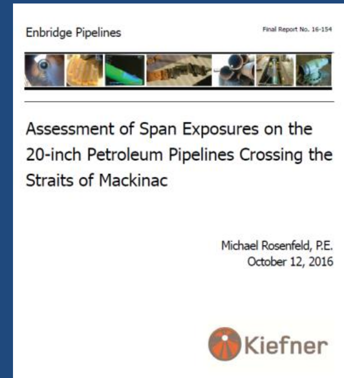
"Crack-Like Anomalies

The 2014 ultrasonic inspection for circumferential "crack-like" anomalies identified 39 that were all at the minimum tool reporting depth of 5%, save one at 6%. Sixteen were described as potential notches. Three were excavated for field interpretation and found to be innocuous manufacturing related marks on the pipe. A fatigue analysis was made employing the most recent years' operating pressures. All of the delineated anomalies had a remaining life of greater than 50 years."

Conclusion from Timm Report on Stresses and Currents

"It is clear from this report that the possibility of metal fatigue from bending stresses due to current velocities that exceed the design basis of the pipeline were not considered when determining that this pipe has a remaining fatigue life of greater than 50 years."

Kiefner Report on Currents and Stresses in Line 5


Enbridge Pipelines

Final Report No. 16-154

Assessment of Span Exposures on the 20-inch Petroleum Pipelines Crossing the Straits of Mackinac

Michael Rosenfeld, P.E.
October 12, 2016

Kiefner

DISCLAIMER

This document presents findings and/or recommendations based on engineering services performed by employees of Kiefner and Associates, Inc. The work addressed herein has been performed according to the authors' knowledge, information, and belief in accordance with commonly accepted procedures consistent with applicable standards of practice, and is not a guaranty or warranty, either expressed or implied.

The analysis and conclusions provided in this report are for the sole use and benefit of the Client. No information or representations contained herein are for the use or benefit of any party other than the party contracting with Kiefner. The scope of use of the information presented herein is limited to the facts as presented and examined, as outlined within the body of this document. No additional representations are made as to matters not specifically addressed within this report. Any additional facts or circumstances in existence but not described or considered within this report may change the analysis, outcomes and representations made in this report.

This report issued as a Final Report in 2016 describes work performed by Kiefner in 2003 and 2004 and reported in Draft form in January 2005. Data, regulations, and other input discussed herein were the most recent available at the time the work was performed. Data, regulations, and other input developed or revised subsequent to the 2005 Draft report are not accounted for and could change the analysis, outcomes, and representations made in this report.

Kiefner Report on Currents and Stresses in Line 5
Enbridge Current Velocity Data

Current Velocity Data Analysis

Enbridge installed water current monitoring devices at four locations along their crossing in order to obtain better data concerning currents impinging on exposed spans. The devices were placed at representative water depths and locations in the Straits. Currents were monitored at 3-hour intervals between September 26, 2002 and August 8, 2004. Easting and Northing current velocities recorded by the four monitoring units are shown in Figure 9 through Figure 12. A sampling of current velocities in Easting and Northing coordinates is shown in Figure 13. The Easting current velocity component is about 3 times the Northing current velocity component. The velocities are seen to reverse direction every 2 to 3 days, and are predominately oriented in the ENE and WSW direction.

Conclusions Regarding Enbridge Current Data

- Location of current velocity sensors unknown
- Type of current velocity sensors unknown
- Current sampling averaging time unknown
- Data is not referenced in report
- Quality of data is unknown
- Contractor responsible for project is unknown
- Reference 12 looks interesting!

12. Analysis of Spans, J. P. Kenny report to Enbridge, 2003.

Kiefner Report on Currents and Stresses in Line 5
Kiefner Analysis Discussion

Conclusions

Codes, Standards and Regulations Section

Pipeline is considered an Offshore Pipeline under the offshore sections of ASME B31.4

Engineering Analysis of Spans Section

Static analysis of span stresses, does not consider stresses added by currents!

Recommends that spans greater than 75’ could be safely permitted

Discloses and supports Enbridge 140’ threshold for taking support action

Concludes that spans of 155’ to 195’ may be safe with disclaimers

Reveals that Enbridge has allowed unsupported spans of up to 286’ in the past.

> The 2003 survey identified 7 spans longer than 140 ft in the east leg, with the longest being 224 ft, and 9 spans longer than 140 ft in the west leg, with the longest being 286 ft (due to a failed grout bag support).

1964/79 “As Built” blueprint only revealed three spans longer than 140’

Does not reconcile calculations with video and ILI data to reveal damaged pipe!

Effects of Operating Conditions Section

Raises some new concerns about how the line will accommodate thermal expansion in supported sections

Support Options Section

Recommends screw anchor supports where there is clearance to install them and grout filled bags where there is no clearance for screw anchor installation

Considers option of burying the entire line in rock.......!

Kiefner Report on Currents and Stresses in Line 5
Kiefner Analysis Discussion - 2

Conclusions

Vortex Induced Vibrations Section

Questionable analysis of Enbridge supplied current data

- No discussion of turbulent flow field in Straits
- No discussion of the importance of instantaneous current velocity data and the masking effect of averaging time
- Fails to recognize and quantify the importance of extreme current events as documented by Schwab (2013) and many other authors
- Fails to recognize the meteorological events that drive extreme currents
- Does not use appropriate statistical methodology for hunting "Black Swans"
- Discounts the possibility of VIV based on misunderstood lab scale data
- If the report's conclusions about the current velocities under the Straits are correct Line 5 would not be suffering from washout problems!

Questionable Analysis of Fluid Phenomena and Resulting Bending and Fatigue

- No discussion of the possibility that extreme current events could plastically deform (bend) long unsupported spans
- No recognition that reversing currents could bend the line back and forth causing metal fatigue over 50 years (The word fatigue does not appear in the report)
- Author is obviously weak in his fluid mechanical understanding about bluff body flow in a turbulent flow field (Author doesn't recognize flow in the Straits is turbulent)

Pipeline Coating Integrity is Critical for Minimization of External Corrosion Damage

1953 Easement Restrictions Regarding Corrosion Protection

"(8) Cathodic protection shall be installed to prevent deterioration of the pipe

(9) All pipe shall be protected by asphalt primer coat, by inner wrap and outer wrap composed of glass fiber fabric material and one inch by four inch (1" x 4") slats prior to installation."

1953 MPSC Order Regarding Corrosion Protection

"The entire pipe line will be properly cleaned, primed, and coated with a single application of coal tar. The coating will be reinforced by a spiral wrap of glass material and covered by a spiral wrap of special glass outer wrap. Penetrations will be made for cathodic protection."

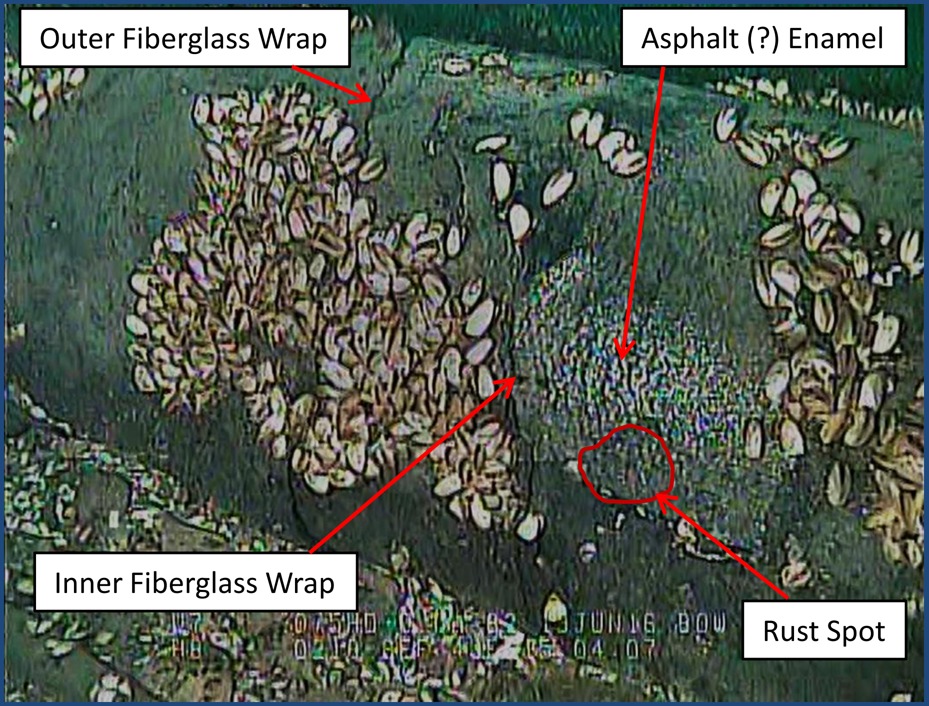
"Engineering and Construction Considerations for the Mackinac Pipeline Company's Crossing of the Straits of Mackinac" submitted by Mackinac Pipeline Company/Lakehead Pipeline Company to the Michigan Department of Conservation, January, 1953

"After coating with asphalt primer, fiberglass inner wrap and an asbestos felt outer wrap, and after attaching 1" x 4" wood slats to the full circumference of the pipe, it will be lowered onto a previously prepared "bed" on the floor of the Straits."

- Enbridge documentation claims that the coating is a coal tar based in some documents and asphalt based in others. Terminology changed from "coal tar" to "enamel" recently.
- Enbridge documentation makes no mention of slats or lagging.
- Bechtel probably based design life of line on probable coating life.

Coating Protective Fiberglass Wrap Delamination (Insert Noun Here) Enamel Primer/Coating and Rust

- Documentation regarding coating type is not definitive
- Enbridge has changed terminology from “Coal Tar” to “Enamel”
- It really makes a difference if it is coal tar or asphalt based
- Salvadori says “Asphalt”
- Failing coatings are the #1 problem of the vintage pipeline operator
  Jeff Didas, Colonial Pipeline company (Material Performance 3/1/17)



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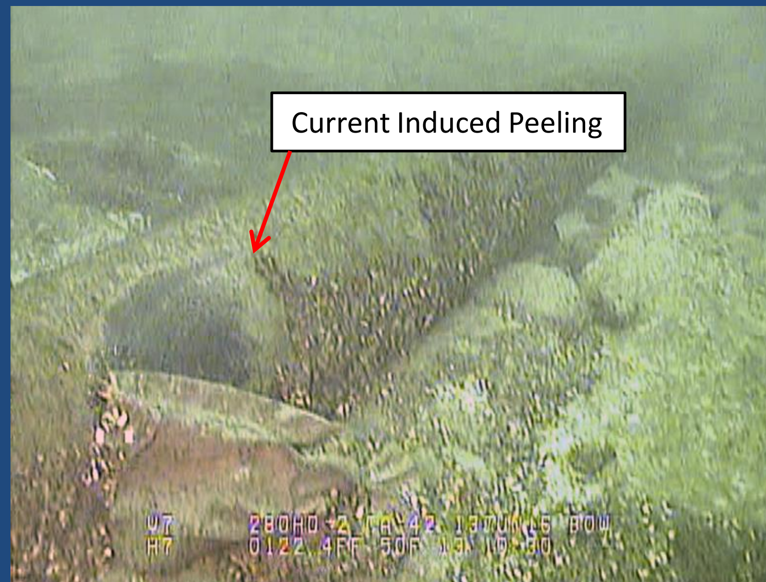
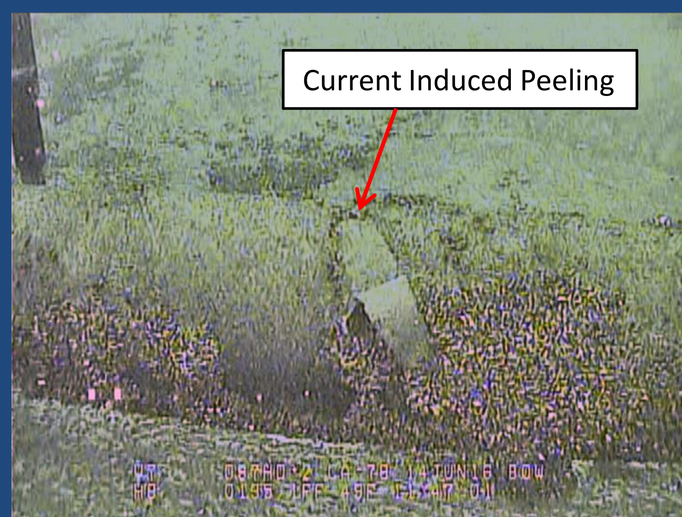
Current Induced Peeling of Protective Fiberglass Wrap





Line 5 and Cathodic Protection

- All pipelines installed since 1970 have Cathodic Protection systems as required by CFR
- It would not be possible to build pipelines out of steel without CP systems
- Effective CP is a tricky business and lines must be surveyed to assure efficacy
- Even a well surveyed underground pipeline can rupture (eg. Enbridge Line 6b)
- Cathodic protection of an underwater pipeline in low conductivity fresh water presents unique challenges
- Apparently, the Straits sections of Line 5 has never had an effective CP survey
- Baker Hughes CPCM inspection tools are a developing technology
- Little is known about the limits of detection of this technology
- Even less is known about the ability of this technology to detect coating breeches in low conductivity fresh water

Cathodic Protection Survey Connection from Failed mid-1980's CP Survey Attempt

BAKER HUGHES

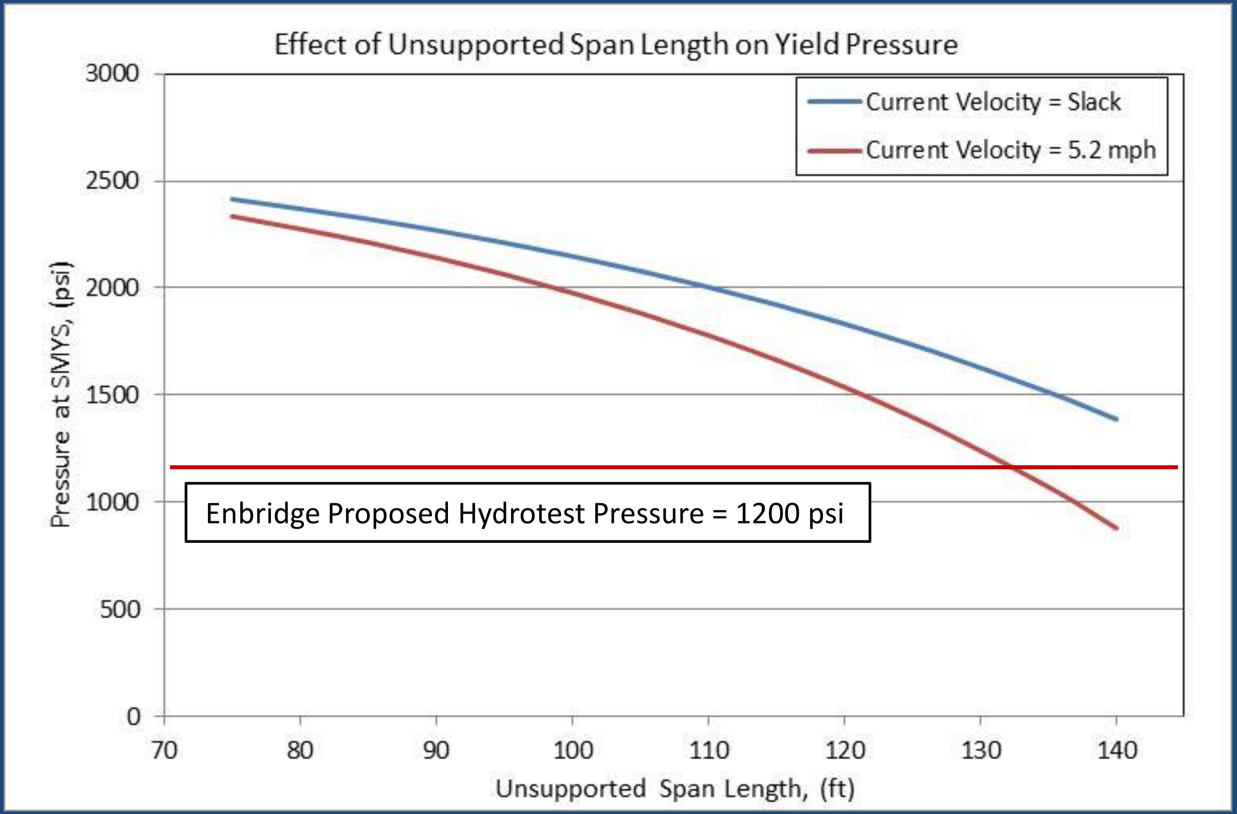
Comments Regarding Hydrotesting

Reference: "The Benefits and Limitations of Hydrotesting", Kiefner, J. F. and Maxey, W. A. , 2013

Industry Expert Opinion

For a pipeline of this criticality, a volumetric hydrotest to yield is the best way to assure integrity

Question from Anabel Drywer, Esq regarding the proposed Enbridge hydrotest of the Straits sections of Line 5: "Should Enbridge be required to hydrotest Line 5 during an extreme current event ?



Upcoming Events

Task 3.4 from the Biota Report for the Consent Decree

3.4 Engineering Stress Analysis
A structural engineering firm will be engaged to conduct an engineering stress analysis considering the impact of biota on the integrity of the pipelines suspended above the floor at the Straits. The analysis will include the following:

• An allowable suspended span length of the pipeline will be calculated to include the biomass along with operating loads, drag forces, buoyant weight, etc. A sensitivity analysis will be also completed on the impact of the biota mass to allowable span length.

• Vortex induced vibration ("VIV") assessment will be also performed to determine the mode shape and associated vibration periods of pipe free spans with various lengths and the assessed biomass. A sensitivity analysis will also be completed on the impact of the biota mass to allowable span length as part of the VIV assessment

Michigan PSAB Alternatives Analysis, Option 5

5. Maintaining the existing Straits Pipelines, including an analysis of the effective life of the existing pipelines.

   The analysis shall consider maintaining the current Straits Pipelines. This analysis shall include a comprehensive engineering analysis of the current condition and operation of the existing pipelines. The comprehensive engineering analysis of current conditions shall include operator's identified integrity standards for the pipeline and protocols for detecting and responding to departures from those standards. The analysis shall also consider how long the existing pipelines can reasonably be operated without replacement as well as the course of action for replacement based on the estimated useful life of existing pipelines.

Open Questions???

1. Specifications of pipe coating system
2. Video time stamp – geolocation correlation information
3. Complete history of long, unsupported spans including location of spans in Kiefner report
4. J. P. Kenny 2003 report entitled "Analysis of Spans"
5. Enbridge contractor report on 2002-2004 current velocity study
6. Bechtel and Merritt, Chapman and Scott contracts and engineering documents
7. Enbridge field reports leading to emergency ACE permit applications
8. Contracts and reports regarding the mid '80's gravel "armoring" project
9. Other reports regarding the use of a manned submersible for early inspections
10. Any reports or information about cathodic protection surveys
11. Information about the sensitivity of the Baker-Hughes CPCM cathodic protection survey tool
12. Disclosure of all Enbridge materials submitted to Dynamic Risk or DNV for Risk and Alternatives Analysis

Geometry Inspection Report prepared for:

Enbridge Energy Limited Partnership

20" GEOPIG™ Geometry Inspection

NPS20 Line 5 Straights of Mackinac - West Loop

Total Distance: 4.15mi

Pipeline Inspection Date: July 30, 2013

Issue Number: J2008-13 Issue #1

Baker Hughes Pipeline Inspection

4839 – 90th Ave S.E. Calgary, Alberta, Canada, T2C 2S8

Signature Block	Name	Date	Initial
Project Coordinator (QA Analyst) Level III Data Analyst *	Vicky Chan	Oct. 30, 2013.	VC
Inertial Analyst Level III Data Analyst *	for Tao Hu	Oct 30, 2013	TH
Caliper Analyst Level III Data Analyst *	Joshua Joseph	OCT. 29, 2013	JJ

*** As per ILI PQ 2005**

Issue Number	Release Date	Issue Date	Client Data Verified	Description of Changes
J2008-13 - Issue #1	October 29, 2013			Initial Issue

Note:

This report has been specifically prepared for Enbridge Energy Limited Partnership (hereinafter called "Enbridge"). Any use which a third party makes of this report, or any sole reliance on or decisions to be made based on the information contained herein, are the sole responsibility of such third parties. Baker Hughes Pipeline Inspection accepts no responsibility for the damages, if any, suffered by any third party as a result of decisions made or actions based on the information contained in this report.

Information provided herein represents the best efforts of Baker Hughes Pipeline Inspection to evaluate the described lines. Judgements concerning pipe condition are left entirely to Enbridge. All information herein represents only Baker Hughes Pipeline Inspection's opinion of the meaning of the GEOPIG™ information, and shall not be construed as a warranty or guarantee of the structural condition of the pipeline, its fitness for use, or any other condition.

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1 EXECUTIVE SUMMARY

Baker Hughes Pipeline Inspection has successfully completed an Inertial Geometry survey of Enbridge's 4.15mi NPS20 Oil pipeline, running from St. Ignace to Mackinaw. The successful run was performed on July 30, 2013. The purpose of the inspection was to determine pipeline geometry, which includes plan, profile, bends, weld tally, and pipe wall deformations.

The analysis of the caliper data has identified no dents greater than 2% O.D., and 2 ovalities greater than 5% O.D. No dents were found greater than 1% O.D., which met the criteria of "Dents in Close Proximity" or "Multiple Apex". The largest anomaly is a 1.750in (8.75 % OD) ovality located at absolute chainage 15,478.71ft. The complete anomaly listing is included in Appendix 2.

11 internal diameter restrictions, where the I.D. was less than 90% O.D., were identified during the caliper analysis. The largest minimum I.D. reached 17.35in (86.76%) and was located at absolute chainage 15,478.82ft on an ovality. The internal diameter restriction listing is included in Appendix 3.

The analysis of the inertial data has identified 25 bends with an angle larger than 1.5° and a radius of curvature less than 100D. No bends are tighter than 5D. The bends with are listed in Appendix 5.

GPS coordinates for the receive valve were provided by Enbridge. This information was integrated with the pipe centerline coordinates obtained from the inertial survey, providing a means for locating pipeline anomalies and a foundation for a Geographic Information System (GIS). A listing of the UTM coordinates based on the WSG84 datum appears in Appendix 1.

1 area of pipe replacement since the 2005 survey has been identified spanning the first 209.08ft (up to Master GWD#200) at the launch valve.

The line was analyzed for pipeline movements between the current inspection and 2005 GEOPIG™ Inspection. The reporting threshold is to report pipeline movements with differential bending strain exceeding 0.1%. No areas of pipeline movement, except the rerouted section, meeting the reporting threshold were identified in this line. It is listed in Appendix 4.

One copy of the survey data and the BHI software for viewing is stored on the enclosed DVD. The complete pipeline tally including girth welds, pipe fittings, wall thickness transitions, bends and anomalies can be displayed in BHI's software together with the caliper and inertial data. This information is also available in the Microsoft Excel file "BHI 2013 GEOPIG Survey NPS20 Straights of Mackinac - West Loop.xls", which is located in the directory "\BHI\ NPS20_Line5_StIgnace-Mackinaw-West_Loop\2013_GEOPIG_FINAL REPORT Issue #1" on the DVD. Also included on the DVD-ROM is the pipe tally provided in "comma delimited file" (csv) format for ISAS GIS System.

A hard copy of Enbridge ILI Reporting Profile Standard is included in Appendix 13.

2 Inspection Summary

2.1 Operational Details

Baker Hughes Pipeline Inspections has mobilized equipment and a qualified crew to perform in-line inspections of the following system:

BHI Job Number	J2008-13
Pipeline Operator	Enbridge Energy Limited Partnership
Segment Name	Line 5 Straights of Mackinac - West Loop
Launch Site	907 Boulevard Drive, St. Ignace, Michigan 49781
Receive Site	580 Wilderness Park Drive, Mackinaw City, Michigan 49701
Section Age/Date Constructed	1953
Pipeline Nominal Diameter	20''
Product	Oil
Section Length	4.15mi
Date of GEOPIG™ Inspection	July 30, 2013
Duration of GEOPIG™ Inspection	31 minutes
Field Project Manager	Blaine Titterington

Table 1. Operational Details

After passing all of the Baker Hughes pre-run inspection procedures, the GEOPIG™ was launched at 17:14 on July 30, 2013. The tool entered the receive trap at 17:45 the same day. The GEOPIG™ emerged relatively clean with no visible mechanical damage.

2.2 Reporting threshold

The reporting criterion is to report the anomalies greater than 2% of the nominal O.D. of the pipeline, the ovalities greater than 5% of the nominal O.D. of the pipeline and all dents including those greater than or equal to 1% O.D. in depth, which meet the criteria of "Dents in Close Proximity" or "Multiple Apex". In addition, areas with either vertical or horizontal bending strain difference exceeding 0.1% with pipeline movement and spanning more than 1 pipe joint are included in this report. The anomaly size definition varies by feature type and is provided in Section 5.4.

3 SURVEY RESULTS

The GEOPIG™ inertial survey provides pipeline plan, profile and bending strain, allowing one to locate the pipeline in the GPS mapping projection, and to detect pipeline movement between runs. The positional information is derived from the onboard strapdown inertial unit, the odometer readings and the GPS coordinates of selected tie points obtained from a GPS survey.

The caliper survey provides the information on the internal diameter and shape of the pipe, allowing for detection and measurement of pipe wall anomalies (dents, ovalities and wrinkles), wall thickness changes, valves, tees and girth welds.

3.1 Chainage

The GEOPIG™ chainage is the distance measured by the GEOPIG's odometers along the pipeline and is denoted as SCh (slack chainage) on the plots. It starts from 76.0ft at the pig launch trap and ends at 21,888ft in the receive trap. A separate client chainage that correlates the GEOPIG™ slack chainage to the Enbridge's As-built chainage has been created. A one-page sample of the BHI – Enbridge chainage correlation listing is included in Appendix 8. The horizontal chainage is also available, and it represents the true horizontal distance of the surveyed pipeline.

3.2 GPS Tie Points

GPS coordinates for the receive valve were provided by Enbridge. This information was integrated with the pipe centerline coordinates obtained from the inertial survey, providing a means for locating pipeline anomalies and a foundation for a Geographic Information System (GIS). A listing of the UTM coordinates based on the WSG84 datum appears in Appendix 1.

3.3 Pipe Anomalies

The caliper data was used for detecting and sizing diameter restrictions and pipe wall anomalies, such as ovalities, dents, and wrinkles. The anomaly size definition is provided in Section 5.4.

The analysis of the caliper data has identified no dents greater than 2% O.D., and 2 ovalities greater than 5% O.D. No dents were found greater than 1% O.D., which met the criteria of “Dents in Close Proximity” or “Multiple Apex”. The largest anomaly is a 1.750in (8.75 % OD) ovality located at absolute chainage 15,478.71ft. The complete anomaly listing is included in Appendix 2.

Summary of Pipewall Deformations

Deformations		Dents				Ovalities	Inward Wrinkles	Outward Wrinkles
		All (≥ 1%)	≥ 6%	Top of Pipe	Near GWD			
Total Number		0	0	0	0	2	0	0
Largest	Size (%OD)					8.75		
	Chainage (ft)					15,478.71		

Appendix 10 contains inspection sheets for the largest anomaly. There are three inspection sheets per anomaly: a dig sheet showing the position of the feature in a pipe joint together with the adjacent joints, a plot of pipeline plan and profile between the nearest u/s and d/s reference points, and a plot showing 3 views of the anomaly: 3-D view, pipe cross-section and diameter profile. The 3-D view scale is exaggerated 3 times. The pipe diameter profile consists of 25 lines showing the pipe internal diameter at different clock positions measured by the 25 pairs of opposing caliper arms. The clock positions of these caliper arms are colour coded according to the spectrum displayed on the left side of the plot.

11 internal diameter restrictions, where the I.D. was less than 90% O.D., were identified during the caliper analysis. The largest minimum I.D. reached 17.35in (86.76%) and was located at absolute chainage 15,478.82ft on an ovality. The internal diameter restriction listing is included in Appendix 3.

3.4 Bends

The analysis of the inertial data has identified 25 bends with an angle larger than 1.5° and a radius of curvature less than 100D. No bends are tighter than 5D. The bends with are listed in Appendix 5. Each bend is described in terms of absolute chainage, bend radius and angle, as well as change of direction in horizontal and vertical plane.

3.5 Pipeline Movements

The inertial data from the current and the 2005 GEOPIG™ surveys have been compared in order to identify areas of strain difference greater than 0.1% associated with pipeline movement. No such areas have been identified in this line. 1 area of pipeline replacement has been identified spanning 209.1ft at the launch barrel.

3.6 Pipe Tally

The pipe internal diameter measured by the calipers is used for calculation of pipe wall thickness assuming a constant pipe O.D. The list of valves and tees are included in Appendix 7.

The GEOPIG™ has also detected all the girth welds in the pipeline. They are listed in the worksheet “Weld Log”, which contains the information on the length and start chainage of each pipe joint. The weld log combined with all the other features in the pipeline (valves, tees, wall thickness transitions, anomalies and bends) are listed in the worksheet “Pipe Tally”. A one-page sample of the pipe tally listing is included in Appendix 9.

All the listings included in Appendices 1 to 8 as well as the full pipe tally are available in electronic form in the MS Excel spreadsheet “BHI GEOPIG Survey 2013 NPS20 Straights of Mackinac - West Loop.xls”.

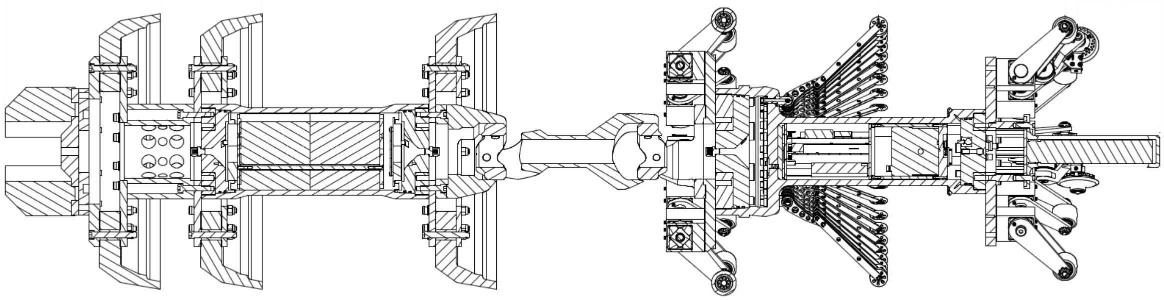
3.7 Plan and Profile

The first plot in Appendix 12 shows the plan, profile, internal diameter and pig velocity, and valves of the entire pipeline. The remaining 8 plots show the pipeline plan, profile, internal diameter and location of selected features, such as valves, tees, anomalies, internal diameter restrictions, and wall thickness transitions at 3,000ft per page.

4 GEOPIG DESCRIPTION

4.1 System Description

The GEOPIG™ is designed to meet a large variety of user requirements using a modular system that integrates a variable number of different sensors. The design of the NPS20 GEOPIG™ consists of two pig carriers, as illustrated bellow.



20" Mechanical Caliper GEOPIG™

A Strapdown Inertial Navigation System is the heart of the GEOPIG™ and delivers position and attitude of the pig along its trajectory within the pipe. Due to the nature of inertial measurements regular "updates" of attitude, position, and velocity are required. External position and attitude are taken from GPS results or alignment sheets.

The GEOPIG™ is suspended in the pipeline by urethane disks at front and rear of the carrier. This restricts the GEOPIG™ to move close and parallel to the pipe centre line. Mechanical calipers are mounted in the middle of the rear carrier and they scan the wall of the pipeline and generate a full picture of the shape of the pipeline. Here the information on dents, ovalities, wrinkles and other features is extracted.

The GEOPIG™ is completed by some other sensors and devices: odometers, which measure the distance travelled, tracking transmitter for location of the GEOPIG™, and finally, storage device and power supply which allow independent operation for long measurement periods.

4.2 Strapdown Inertial Navigation System

The strapdown INS ultimately produces 3-dimensional measurement of inertial acceleration and angular rate directly from orthogonal triads of accelerometers, and single degree of freedom gyros. In the case of a pair of two degree of freedom gyros, a redundant or combined axis measurement is available, and is dealt with appropriately to produce 3 axis orthogonal angular rates. The strapdown accelerometers and gyros are complementary sensors which when coupled deliver the measurements for computing pipeline curvature, orientation of the curvature, and the positioning capability for location of the curvature or other detected features.

4.3 Caliper

One ring of mechanical calipers scans the wall of the pipe. The caliper arms are spaced at precisely machined constant angles around the ring on the pig. An accurate offset was added to these ranges to give the actual distance from the centre of the carrier to the pipe wall. There are 50 mechanical caliper arms mounted in the middle of the carrier.

4.4 Other Sensors and Components

Other sensors and components integrated in the GEOPIG™ are:

- Odometer wheels providing direct measurements of distance traveled (chainage). Velocity is derived from these time tagged distances.
- Temperature and pressure sensors
- A flash memory system
- Interface electronics
- Batteries
- Micro-processor controllers
- Power management module
- Pig Tracking Module (Electromagnetic)

4.5 Survey Accuracy Specifications

The accuracy of the GEOPIG™ measurements are as follows:

- Pipeline position 1:2,000
- Bending strain +/- 0.02%
- Bend angle +/- 0.1 °
- Anomaly size +/- 0.1”
- Temperature +/- 0.1 Deg C
- Pressure 0.1% or +/- 3 PSI (0.2 BARSG)

5 DATA ANALYSIS PROCEDURES

The primary function of the GEOPIG™ inertial survey is to determine the pipeline plan, profile and bending strain. This is achieved by computing the GEOPIG's trajectory during the run using the data collected by the onboard strapdown inertial unit and the odometers. Due to a tight fit of the GEOPIG™ cups into the pipe the tool rides practically along the pipe centreline. The only exception from this is the deviation of the tool trajectory from the pipe centerline due to serious pipe wall deformations, as well as "smoothing out the corners" over the transition length (equal to the distance between the cups) at the bend boundaries and at the girth welds exhibiting noticeable out-of-straightness, i.e. sudden change of direction due to the weld misalignment. That data it is then rotated into the GPS co-ordinates of the selected tie-points along the line (usually a few km apart) to obtain the desired location accuracy in a given UTM mapping projection.

The following paragraphs outline the methods used for processing the odometer and inertial data in order to obtain the pipeline slack and horizontal chainage, client chainage, pipeline position and bending strain.

5.1 Chainage

The following types of chainages are used for referencing the GEOPIG™ data:

- slack chainage - the distance measured by the GEOPIG's odometers along the pipeline.
- horizontal chainage - the true distance along the pipeline projection on the horizontal plane. Not required by the client in this survey.
- client chainage - the reference system used by the pipeline operator (e.g. station number used on the as-built drawings, or KP location from the ROV survey).

5.1.1 Slack Chainage

The GEOPIG™ slack chainage is the distance measured by the GEOPIG's odometers along the pipeline. It starts from zero at the reducer on the pig launcher and ends at the receive trap. The odometer accuracy is 0.1 %.

The chainage from the first run is used as the baseline for all the subsequent runs. The preliminary chainage from the subsequent runs derived from the odometer data is scaled to match the distance between the girth welds from the baseline survey. Therefore any change of pipeline length between runs, e.g. elongation due to temperature differential, is disregarded.

5.1.2 Absolute Chainage

The GEOPIG™ absolute chainage is the distance along the pipeline corresponding to the upstream edge of defects and the centre of other features, measured from the start of the run. The usage of such distance is as per client specifications.

5.1.3 Horizontal Chainage

The GEOPIG™ horizontal chainage represents the true horizontal distance of the surveyed pipeline. It is computed from the slack chainage by projecting it on the horizontal plane first, and then scaling it to match the horizontal distance based on the GPS co-ordinates (Northing and Easting). The scaling is performed between the same tie-points that are used for rotating the inertial survey data into its final position.

5.1.4 Client Chainage

The purpose of a client chainage is to represent any one-dimensional information used by the client, which could be correlated to the slack chainage. Usually the client chainage corresponds to the chainage shown on the as-builts, or to the chainage recorded during another in-line inspection. It can be incorporated into the data at any time after the DVD is issued to the client.

5.2 Pipeline Position

The pipeline position is provided in terms of Northing, Easting and Height as a function of the chainage, in a selected mapping projection (usually UTM) and a specified datum.

5.2.1 Tie Points

Inertial data is translated, rotated and scaled to the "tie points" with known co-ordinates. Those points are typically selected at traps, valves, welds, bends, wall thickness transitions, or any other pipeline features that can be detected directly or indirectly by the GEOPIG™ sensors. The co-ordinates of those points are usually obtained from GPS survey.

This procedure provides correction for long term drifts that can introduce an absolute position error in the inertial survey over time. By transforming the GEOPIG™ trajectory into the tie points, the Northing, Easting, and Height are obtained for any point along the pipe.

The specified accuracy of the inertial survey is 1:2,000 of the distance from the tie points; therefore for the following sample distances between the tie points the following absolute accuracy is obtained:

Distance Between Tie Points [m]	Absolute Accuracy [m]
20,000	5.0
10,000	2.5
5,000	1.25
3,000	0.75

For example, if the data from two GEOPIG™ run have been tied to the points that are 3km apart, then the allowable error in-between the ties points can reach 0.75m, which corresponds to up to 1.5m difference between two runs. To reduce the relative difference between two runs, a procedure described in the next section is applied, which ensures that the actual pipeline movement is measured with centimeter accuracy. There is practically no difference in the pipeline position between the runs in the areas where the pipeline did not move.

5.2.2 Pipeline Movement

Once preliminary processing has been completed, the data from the current and the previous GEOPIG™ surveys are compared in order to identify the areas of strain differences associated with the pipeline movement. Then the current data is reprocessed using the coordinates of the tie points extracted from the baseline GEOPIG™ survey at 100m intervals, except for the previously determined pipeline movement areas. This procedure improves the accuracy of the local pipeline movement measurement by reducing the relative error between two runs. A noticeable error would result from the absolute position accumulation error when only the original tie points (from the GPS survey, at about 1km spacing) were used for scaling and rotating the inertial survey data.

5.3 Bending Strain

The bending strain is computed directly from the curvature of the GEOPIG™ trajectory, typically averaged over the distance of three pipe diameters. The specification for the bending strain measurements from the GEOPIG™ survey is +/- 0.02% strain. When the strain difference between two runs is compared that specification is usually exceeded in the originally straight sections of the line, and the accuracy of +/- 0.005% strain is achieved. The following subsections contain the description of the bending strain measurement and general remarks on interpretation of strain data.

5.3.1 Computation Method

There are two main components of the strain tensor in a pipe wall: the longitudinal strain (in the direction of the pipe axis) and the hoop strain (in the circumferential direction). The longitudinal strain is further separated into the axial component and the bending component that changes linearly along the pipe cross-section (see Figure 5.1).

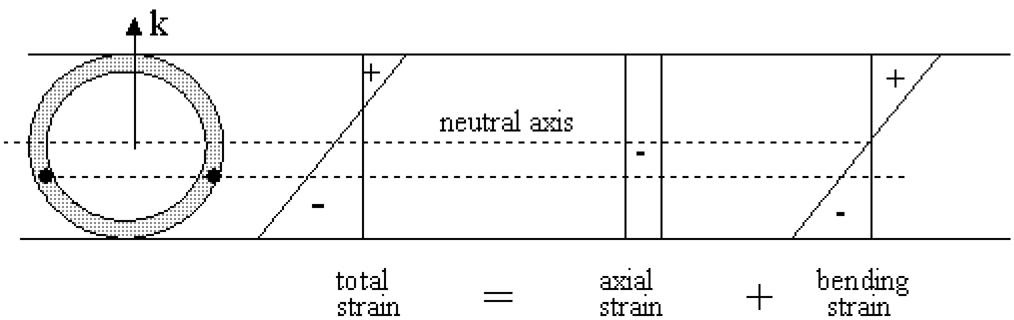


Figure 5.1 Distribution of Axial and Bending Components of Longitudinal Strain in Pipe Cross-section

The bending component of the longitudinal strain at any location in the pipe cross-section can be computed based on the bending strain at two points, e.g. at the top of the pipe (0 o'clock position) and on a right side (3 o'clock position). The bending strain at the bottom of the pipe is called the vertical strain ε_V, because it is induced by bending in the vertical plane (the bending strain at the top of the pipe has the same absolute value, but the opposite sign, i.e. - ε_V). For a similar reason the bending strain on the right side of the pipe is called the horizontal bending strain ε_H (the bending strain on the left side is equal to -ε_H). The maximum bending strain ε in the entire pipe-cross-section is equal to:

$$\varepsilon = \sqrt{\varepsilon_v^2 + \varepsilon_h^2} \; . \qquad (5.1)$$

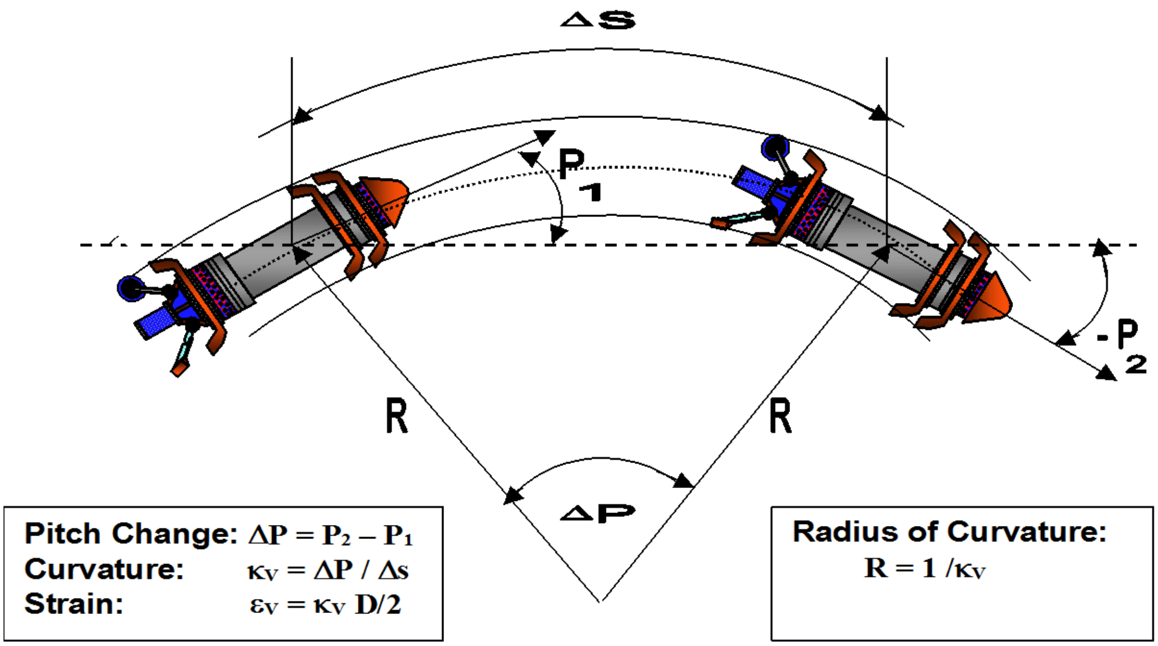


Figure 5.2 Computation of Pipeline Vertical Curvature and Strain from GEOPIG Pitch

Both the vertical and horizontal bending strains are computed from the GEOPIG™ survey using the measurements of the pipe centerline curvature. The curvature of a line in a 3-D space is defined as the change of direction (in radians) over the distance. The distance is measured by the odometers, and the direction of the pipe centerline is computed from the inertial system in terms of azimuth and pitch. The pitch P(s) describes the pipeline tilt with respect to the horizontal plane at chainage s, while the azimuth A(s) specifies the angle between the pipe direction and the north. The horizontal component of the curvature is proportional to the change of the azimuth, and the vertical component is proportional to the change of pitch. The following formulas are used for computation of the pipeline total curvature κ and its vertical κ_V and horizontal κ_h components based on the changes ΔP and ΔA of pitch and azimuth over a distance Δs along the pipe centerline:

$$\kappa = \sqrt{\kappa_v^2 + \kappa_h^2}, \qquad \kappa_v = \frac{\Delta P}{\Delta s}, \qquad \kappa_h = -\frac{\Delta A}{\Delta s}\cos(P) \qquad (5.2)$$

The relationship between curvature and bending strain is as follows:

$$\varepsilon = \frac{D}{2}\kappa \qquad \varepsilon_v = \frac{D}{2}\kappa_v \qquad \varepsilon_h = \frac{D}{2}\kappa_h \qquad (5.3)$$

where D is the pipe outside diameter.

The curvature radius is the inverse of the curvature. The BHI software reports strain in percents and the radius of curvature in pipe diameters. Strain is a unitless value that can be expressed in percents by multiplying it by 100%; e.g. 0.45% corresponds to 0.0045 strain.

5.3.2 Smoothing Curvature Data

The curvature can be computed according to formula (5.2) using the change of azimuth or pitch over the chainage increment as small as the distance between two inertial samples. The inertial data is collected at the rate of 100 samples per second. If the tool travels at the speed of 2 m/s then the distance between two samples is only 2 cm. The raw curvature computed this way would exhibit a significant level of noise, e.g. due to tool vibrations. In order to reduce that noise the curvature is typically averaged over a distance of 3 – 5 pipe diameters, i.e. 2-3m for 16" diameter pipe. For computational efficiency, instead of calculating the actual average, the curvature is computed using formula (5.2), where the increments ΔP and ΔA of pitch and azimuth are taken over a distance of 2m. This is practically equivalent to averaging curvature over the same distance - if the data are equally spaced, i.e. when the tool velocity is stable. The longer is the averaging length the smoother are the results.

Another smoothing technique is a regression line fit to the pitch or azimuth considered as functions of chainage. That method fits a line to all of the pitch values (or azimuth) over a specified length. This is practically equivalent to fitting a circle to all of the points along the GEOPIG™ trajectory over the specified length, but again much more computationally efficient than actually doing it. The radius of that circle is equal to the radius of curvature of the pipeline. The regression line fit produces smoother results than a regular moving average applied over the same length.

When estimating the bending strain induced by pipe-soil interaction, the curvature can be smoothed out over a length longer than 5 pipe diameters, usually over 5 - 10m. This approach significantly reduces the effect of weld misalignment, pipe wall imperfections and tool dynamics on the computed curvature, and at the same time it doesn't underestimate the bending strain induced by pipeline movement. This approach is particularly suited for calculation of strain difference between two runs. However, averaging over too long distance is not proper for computation of curvature of short features, such as bends or buckles. The bending strain of a feature would be underestimated if the feature was shorter than the effective averaging distance, which includes both the length used in curvature computation and the tool length, i.e. the distance between the cups supporting the pig body (i.e. the inertial canister in case of multi-body tools).

5.3.3 Interpretation of Bending Strain Data

The GEOPIG™ measures the total pipeline bending strain at the time of inspection, which includes strain induced during manufacturing, construction and operation. While pipeline is in operation the strain may be caused by the operating conditions (temperature and pressure differential) or by the external forces affecting the pipeline as the results of sea-bottom scouring, sub-sea currents, slope instability, soil settlement and erosion, etc. As the GEOPIG™ measures the total bending strain, including the plastic component induced during the whole history of loading, the current shape of the pipe and its bending strain cannot be fully explained by taking into consideration only the forces acting on the pipe during the inspection, e.g. the gravity, buoyancy and support reaction.

The GEOPIG™ measures the curvature of the pipe centerline with all its imperfections, including the out-of-straightness at welds that is theoretically described by infinite curvature, although it does not correspond to any bending strain in the pipe wall. When such curvature is measured by the GEOPIG™ is obviously not infinite due to the finite length of the tool and some additional smoothing applied during data processing, but it may still show up as spikes of significant amplitude in the curvature data.

When analyzing the bending strain induced during operation the high residual plastic strain present in the field bends should be disregarded. The main features distinguishing the bending strain induced during operation from the field bends are briefly discussed below. The bending strain in the field bends is usually in the range from 1 to 2% strain and is confined to one pipe joint and is characterized by an abrupt change of strain at the beginning and the end of a bend. The bending strain induced during operation is usually of smaller amplitude, spans more than one pipe joint and undergoes gradual change over longer transition sections.

5.4 Pipewall Anomaly Calculation

The caliper information is processed to provide the internal shape and diameter of the pipeline. The anomaly size D (depth) is calculated as follows:

(1) **Without Ovality**: $D = D_{Rstr} - 2*O_V$ for dents;

(2) **CSAZ662 (Ovality)**: $D = D_{Max} - D_{Min}$ for ovalities;

$D_{Rstr} = D_{Nom} - D_{Min}$

$O_V = (D_{Max} - D_{Nom})/2$

where:

- D_{Rstr} - total diameter restriction
- O_V - pipe ovality
- D_{Nom} - inner nominal pipe diameter
- D_{Min} - inner pipe diameter at the feature
- D_{Max} - inner pipe diameter 90° from the feature

The dent length and width are calculated as the axial distance and the circumferential distance between points of zero radial deflection respectively. The ovality length and width are calculated as the axial distance and the circumferential distance over which the feature depth exceeds 50% of its peak value respectively. A dent with the width larger than its length is called an inward wrinkle. The outward wrinkle is characterized by a local increase of pipe diameter.

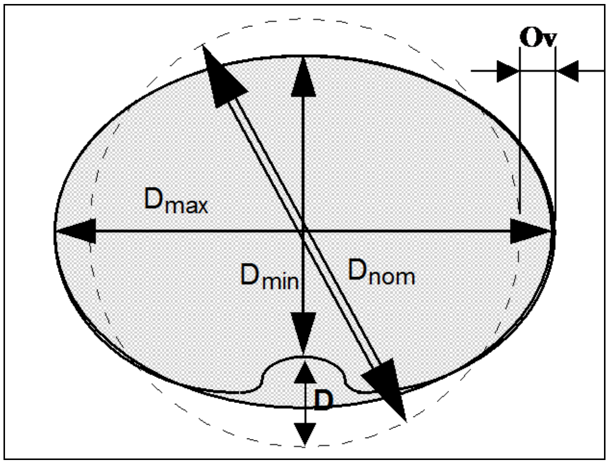


Figure 5.3 Anomaly Sizing

6 BHI Software Installation

The report is accompanied by a DVD-ROM containing the BHI display software and the data from the present survey. The data can be viewed using the GeminiView and GeoDisplay programs running in Microsoft Windows operating system. GeminiView is used to display the 3-D view of the pipe and the inner pipe wall shape measured by the calipers. GeoDisplay is used for displaying the inertial, odometer, weld, caliper, and other data bases (if available).

The directory structure on the DVD is as follows:

\BHI\NPS20_Line5_StIgnace-Mackinaw-West_Loop\2013_GEOPIG, which contains:

- several subdirectories with the GEOPIG™ data from the run
- environment file 2013_GEOPIG_NPS20_St_Ignace-Mackinaw-West_Loop_Issue1.env with the information on the location of the data files from the run. (%RootDir% specifies the path, and %BaseName% - the name)
- configuration file GD.cfg for Geodisplay

\BHI\BHI_Software	with the software stored on two subdirectories:
\GeminiView	with the GeminiView program (GEMINIVIEW.EXE)
\GD	with the GeoDisplay program (GDWIN.EXE)

The entire content of the DVD can be copied to a network drive, or a local hard drive for faster access of the data and the ability to save configurations files with customized displays. The programs can be also stored on the local hard drive while the data is accessed from the DVD or a network drive. In this case only the \BHI_Software subdirectory needs to be copied on the local hard drive.

Geminiview:

To setup the GeminiView program for the first time on a computer:

- Run the setup.exe program in the BHI\BHI_Software\GeminiView directory.

To launch the GeminiView program:

- Double click Geminiview_3.17.0.0.exe

Jobs can then be loaded using the File ⇒ Open menu

GeoDisplay:

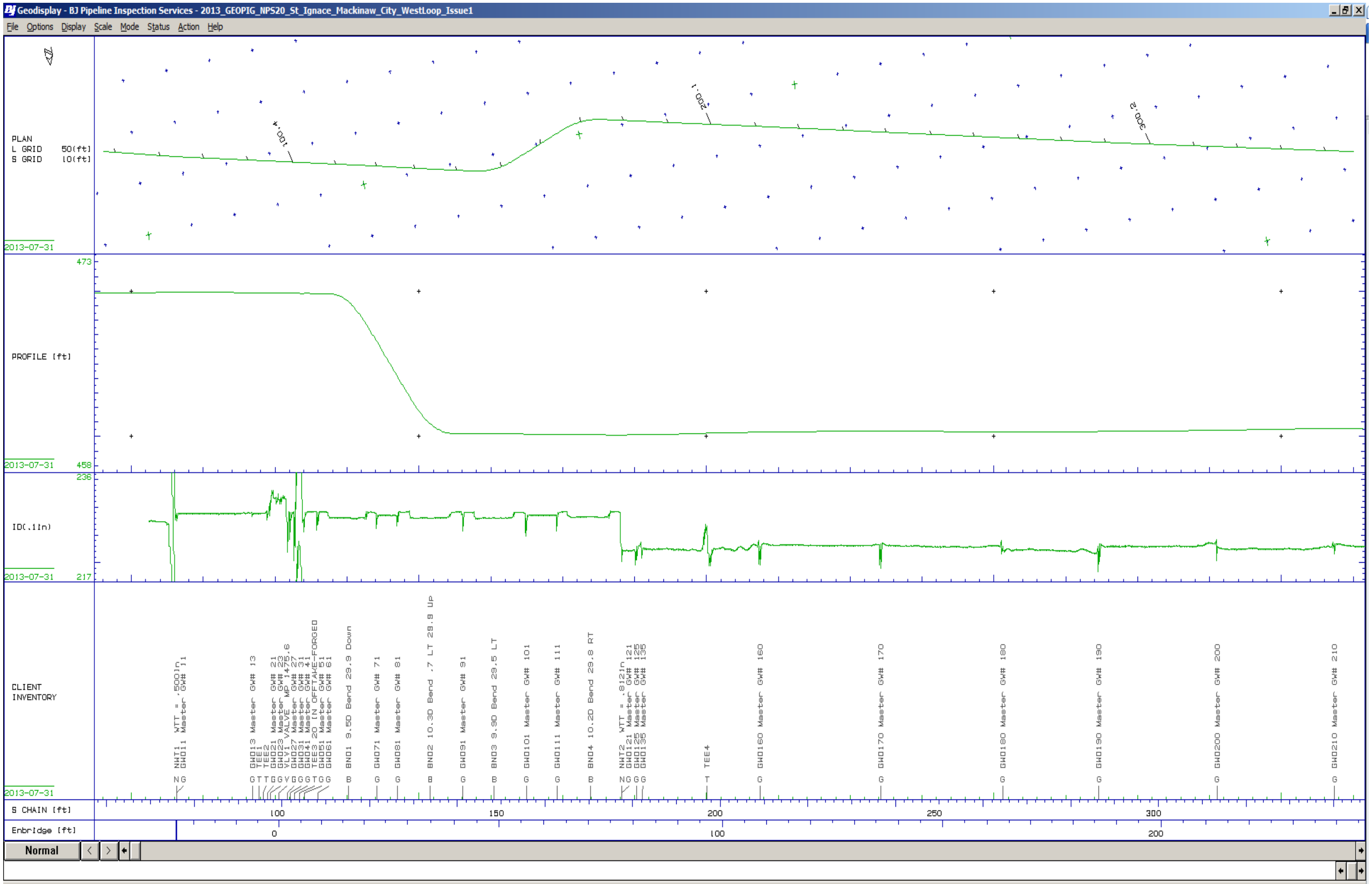
The simplest way to launch GeoDisplay from the DVD is to double click on the application program (GDWIN.EXE) using Windows Explorer.

The recommended way to launch GeoDisplay is to copy the “Geodisplay 2013 GEOPIG NPS20_Line5_StIgnace-Mackinaw-West_Loop” icon onto the computer desktop using the procedure outlined below. It is assumed that the subdirectory \BHI\BHI_Software is stored on the **C:** drive, and the data directory \BHI\NPS20_Line5_StIgnace-Mackinaw-West_Loop is on the **D:** drive. However, the proper drive letters for the DVD, network or hard drive corresponding to the actual location of those directories have to be used.

1) Go to directory C:\BHI\BHI_Software\GD using the Windows Explorer and drag the shortcut icon “Geodisplay NPS20_Line5_StIgnace-Mackinaw-West_Loop (with the blue and white BHI logo) to the desktop.
2) Right click on this new icon and left click on “Properties”.

3) Click on the “Shortcut” tab and make sure the “Target” and “Start in” are set to **C:**BHI\BHI_Software\GD\GDWIN.exe and **D:** \BHI\NPS20_Line5_StIgnace-Mackinaw-West_Loop respectively.
4) Click on the “General” tab and uncheck the “Read-only” box.
5) To start the program, double click on the icon.

Appendix 9. Pipe Tally – Sample Plot



Appendix 12. Plots of Pipeline Plan, Profile, Internal Diameter and Features

PipeWall Anomaly Listing

Client: Enbridge Energy Limited Partnership | Run Date: July 30, 2013 | Projection: UTM | Zone: 16

Project: NPS 20 GEOPIG Geometry Inspection | Location: Line 5 Straights of Mackinac - West Loop | Datum: WGS 84 | C.M.: -87

BAKER HUGHES

Feature Identifier	Absolute Chainage	Enbridge Chainage	Nearest U/S GWD	Dist to U/S GWD	Dist to D/S GWD	Clock Position	Depth		Length	Width	MinID	Ovality	MSP Position	Half Peak Height Position: US Shoulder	DS Shoulder	Circ Start Shoulder	Circ End Shoulder	Multi Apex	Dent Oriented off Axis	Assoc. Girth Weld	Dent in Close Proximity	Northing	Easting	Height	Comments
	(ft)	(ft)		(ft)	(ft)	h:mm	(in)	(%)	(in)	(in)	(in)	(%)	(ft)	(in)	(in)	(in)	(in)	(Y/N)	(Y/N)	(Y/N)	(Y/N)	(m)	(m)	(m)	
OVL 1	15,478.71	15,259.83	6080	14.14	6.92	1:00	1.750	8.75	40.52	10.44	-	-	-	-	-	-	-	-	-	-	-	5,074,486.56	673,176.81	116.22	
OVL 2	15,529.34	15,309.89	6100	17.43	2.81	12:45	1.090	5.45	40.33	9.99	-	-	-	-	-	-	-	-	-	-	-	5,074,471.87	673,172.54	117.92	

Bend Listing

Client: Enbridge Energy Limited Partnership
Project: NPS 20 GEOPIG Geometry Inspection
Run Date: July 30, 2013
Location: Line 5 Straights of Mackinac - West Loop
Projection: UTM
Datum: WGS 84
Zone: 16
C.M.: -87

Feature Identifier	Absolute Chainage (ft)	Enbridge Chainage (ft)	Nearest U/S GWD	Dist to U/S GWD (ft)	Bend Rad. (D)	Bend Angle (deg.)	Azimuth Change (deg).	Azimuth Dir.	Pitch Change (deg).	Pitch Dir.	Northing (m)	Easting (m)	Height (m)
BND 1	115.19	16.40	61	7.08	9.5	29.9	.3	Right	29.9	Down	5,078,865.97	674,354.97	143.02
BND 2	133.80	34.82	81	7.42	10.3	29.9	.7	Left	29.9	Up	5,078,867.16	674,350.06	140.47
BND 3	148.42	48.91	91	7.12	9.9	29.5	29.5	Left	.0	Up	5,078,868.02	674,345.72	140.26
BND 4	170.41	70.55	111	7.59	10.2	29.8	29.8	Right	.3	Down	5,078,866.47	674,339.22	140.25
BND 5	577.74	479.07	300	14.81	24.9	19.4	19.4	Left	.3	Up	5,078,893.83	674,218.13	140.40
BND 6	598.57	500.17	310	10.86	24.9	21.5	21.5	Left	.3	Up	5,078,893.14	674,211.85	140.38
BND 7	625.53	527.24	320	12.62	26.1	24.0	24.0	Left	.9	Down	5,078,889.25	674,204.68	140.43
BND 8	649.24	550.82	330	10.89	23.1	23.3	23.3	Left	1.5	Up	5,078,883.54	674,200.32	140.44
BND 9	15,173.89	14,957.63	5960	14.34	63.4	1.7	.8	Right	1.5	Up	5,074,576.80	673,198.24	113.24
BND 10	15,419.37	15,201.29	6050	25.81	51.5	3.7	1.7	Left	3.3	Down	5,074,504.28	673,180.18	117.00
BND 11	15,425.66	15,207.51	6060	5.69	49.6	2.7	.9	Left	2.5	Down	5,074,502.41	673,179.80	116.96
BND 12	15,447.98	15,229.55	6070	5.67	47.5	4.4	1.5	Right	4.1	Up	5,074,495.72	673,178.64	116.39
BND 13	15,481.28	15,262.43	6080	16.71	29.6	9.3	5.2	Right	7.7	Up	5,074,485.78	673,176.61	116.25
BND 14	15,529.24	15,309.99	6100	17.33	25.0	6.0	3.1	Left	5.2	Down	5,074,471.85	673,172.53	117.93
BND 15	15,982.22	15,760.13	6280	3.96	45.9	3.0	2.2	Left	2.1	Up	5,074,337.55	673,140.44	117.98
BND 16	20,938.68	20,666.54	8190	15.41	24.2	8.1	.0	Left	8.1	Down	5,072,867.29	672,797.69	148.75
BND 17	21,176.43	20,901.71	8280	21.33	28.8	4.3	.2	Right	4.3	Up	5,072,796.87	672,780.80	151.30
BND 18	21,190.22	20,915.22	8290	7.16	30.0	5.1	.0	Right	5.1	Up	5,072,792.82	672,779.78	151.72
BND 19	21,218.57	20,943.80	8300	11.17	24.4	11.1	10.0	Left	5.2	Up	5,072,784.57	672,777.72	153.26
BND 20	21,251.17	20,976.05	8310	17.53	23.7	18.9	19.6	Left	1.3	Up	5,072,775.01	672,777.08	155.82
BND 21	21,274.86	20,998.75	8320	12.51	22.4	24.2	25.0	Left	2.0	Down	5,072,768.39	672,778.99	157.86
BND 22	21,300.66	21,024.32	8330	14.18	25.0	23.6	22.8	Left	7.6	Down	5,072,762.57	672,783.82	159.83
BND 23	21,323.06	21,046.58	8340	9.72	25.1	15.3	14.2	Left	5.8	Down	5,072,759.36	672,789.74	160.71
BND 24	21,841.93	21,560.09	8620	8.38	25.5	11.4	.3	Right	11.4	Up	5,072,723.10	672,943.70	160.44
BND 25	21,877.64	21,596.42	8640	12.45	27.4	12.4	.6	Left	12.4	Down	5,072,720.62	672,954.08	162.55