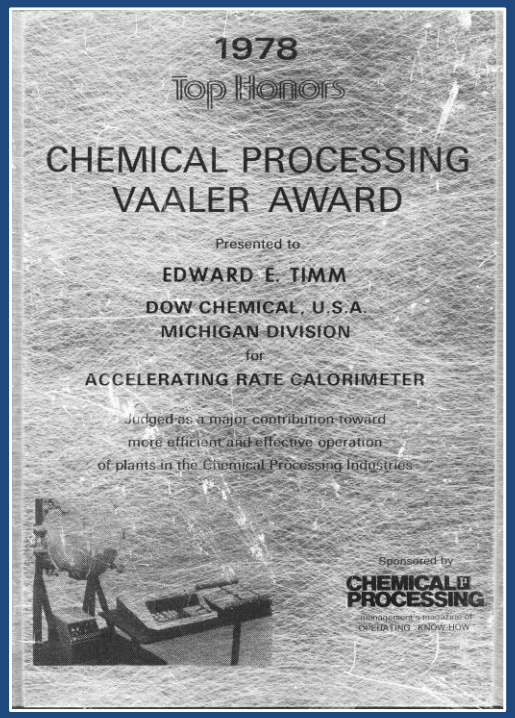
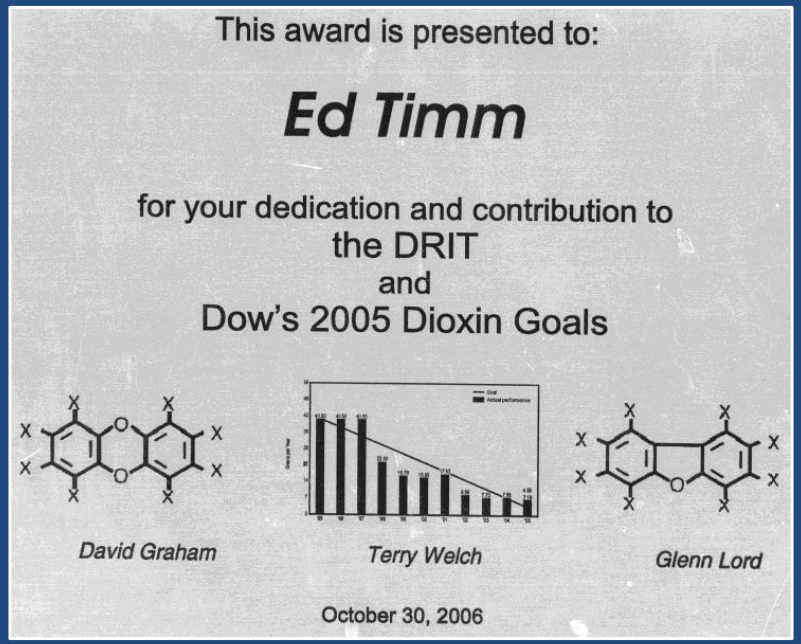
Enbridge Energy Partners, LLP
Straits Sections of Line 5
Technology Update

Edward E. Timm, PhD, PE

- BS, MS, PhD in Chemical Engineering from University of Michigan
- Licensed Professional Engineer, Michigan
- Retired as Senior Scientist, The Dow Chemical Company after 27 years
- 26 US Patents
- Expertise in all areas of chemical engineering with an emphasis on innovation, design, troubleshooting and new business analysis
- Hands on experience with most petrochemical and refinery processes
- Last years of Dow career devoted to Environmental Operations and cleanup technology

Enbridge Energy Partners Straits Sections of Line 5 Technology Update

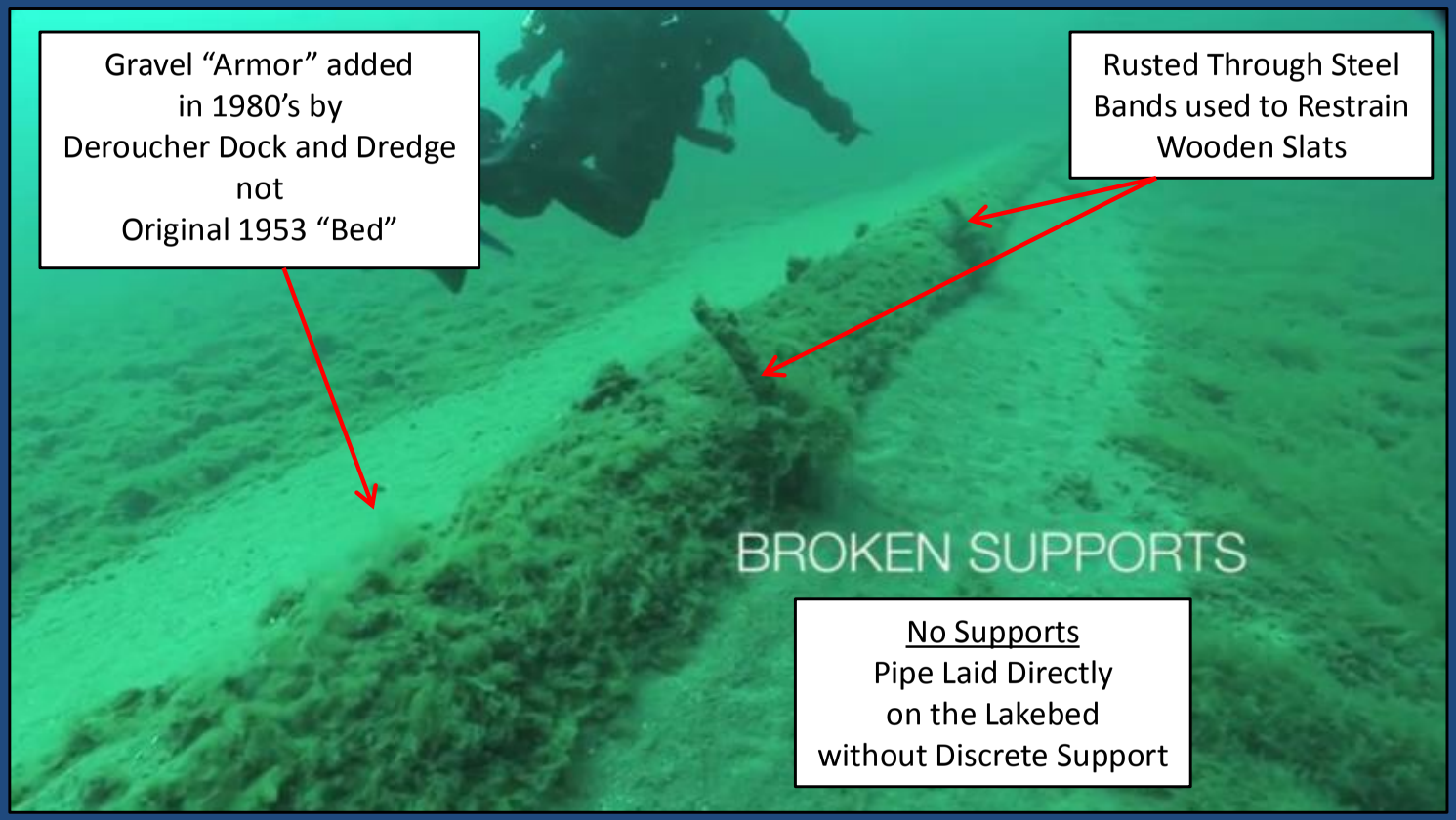




Enbridge Energy Partners
Straits Sections of Line 5
Technology Update

We have come a long way!

Photo from NWF Report "Sunken Hazard", 2012



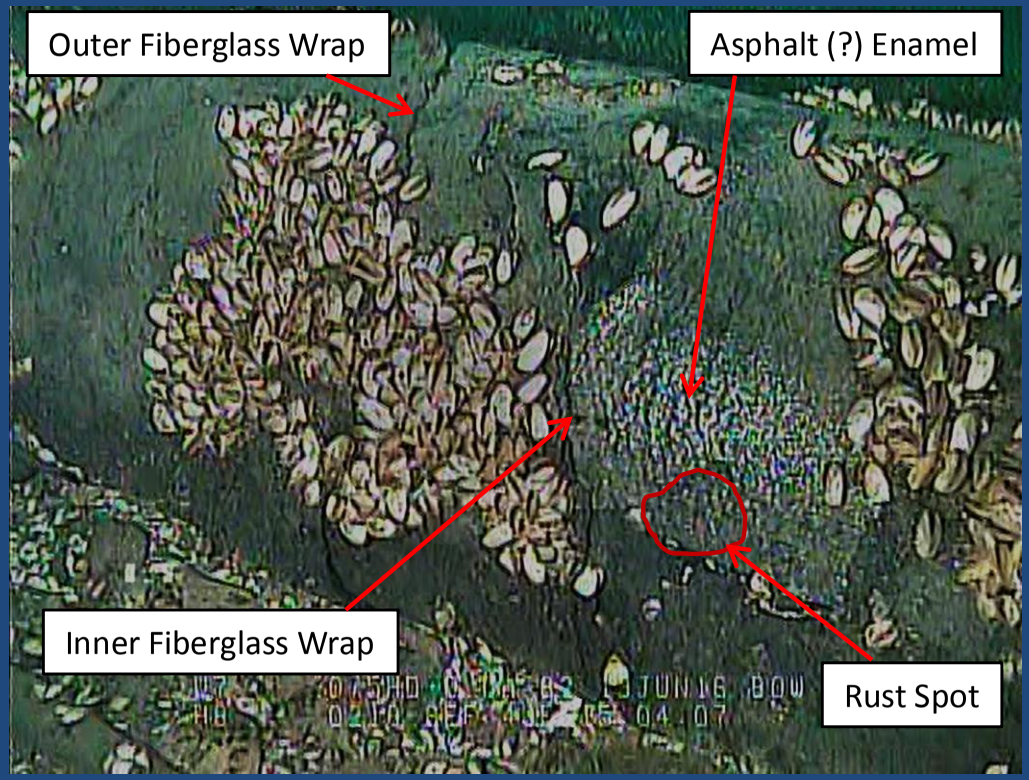
Enbridge Energy Partners
Straits Sections of Line 5
Technology Update

Outline

- Coatings, Holidays and Corrosion
- Cathodic Protection
- Currents and Stresses
  - Timm Report
  - Kiefner Report
  - LaMontagne Report
- Hydrotesting
- Upcoming Events
  - Proposed Consent Decree
  - Alternatives Analysis

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)



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

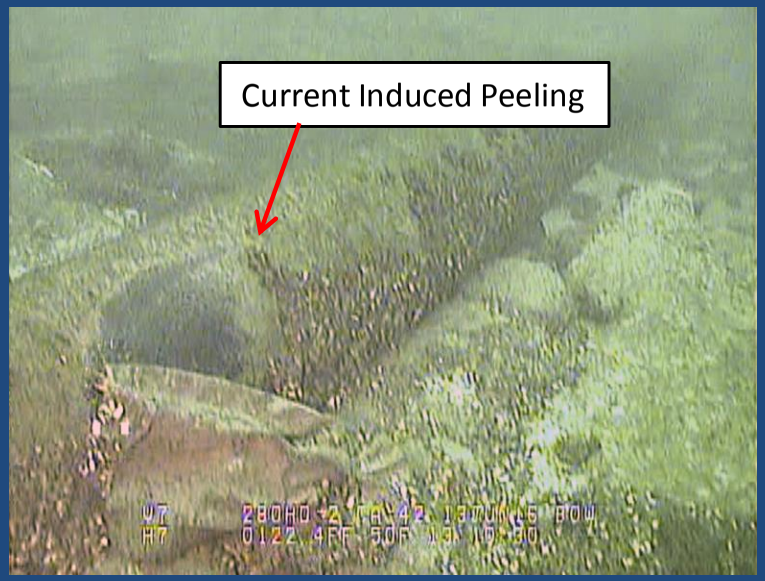
"The entire pipe line will be properly cleaned, primed, and coated with a single application of coal tar. The coating will be reinforced by a spiral wrap of glass material and covered by a spiral wrap of special glass outer wrap. Penetrations will be made for cathodic protection."

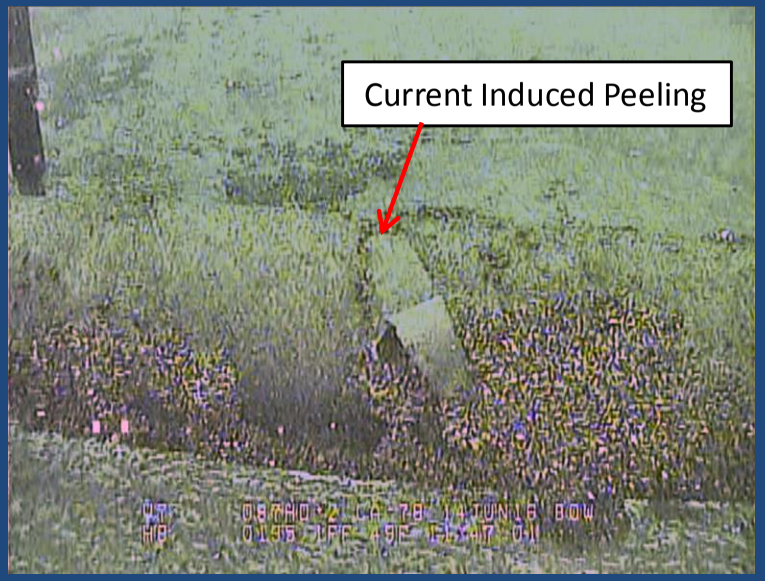
"Engineering and Construction Considerations for the Mackinac Pipeline Company's Crossing of the Straits of Mackinac" submitted by Mackinac Pipeline Company/Lakehead Pipeline Company to the Michigan Department of Conservation, January, 1953

"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.

Current Induced Peeling of Protective Fiberglass Wrap

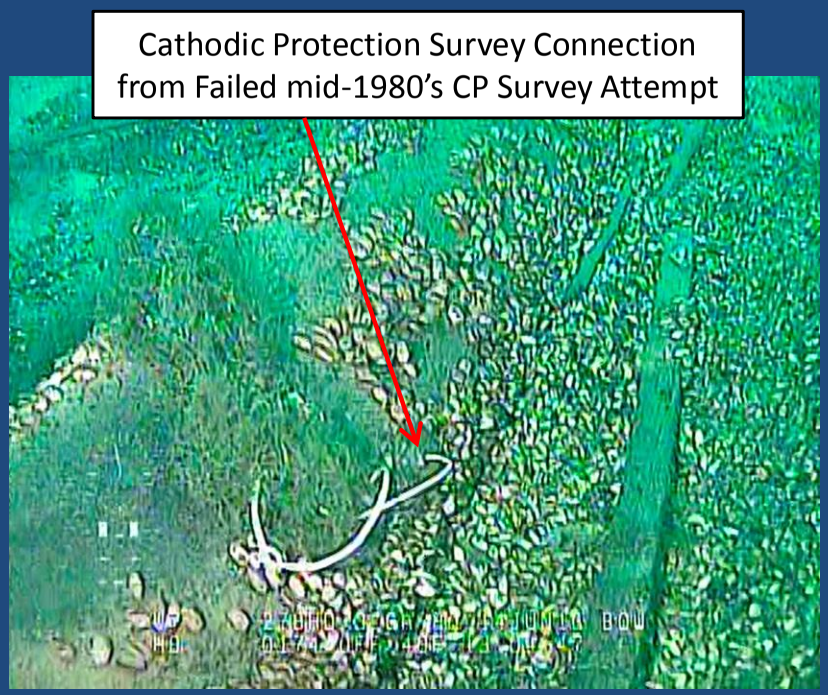




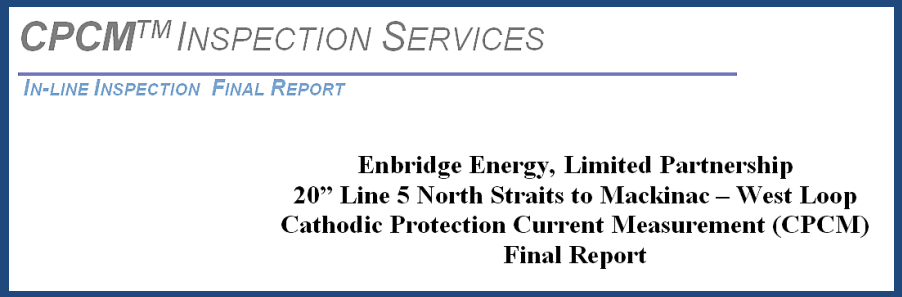
Rust Never Sleeps

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



Line 5 and Cathodic Protection – West Leg CPCM Survey 2016


CPCM™ INSPECTION SERVICES

IN-LINE INSPECTION FINAL REPORT

Enbridge Energy, Limited Partnership
20" Line 5 North Straits to Mackinac – West Loop
Cathodic Protection Current Measurement (CPCM)
Final Report

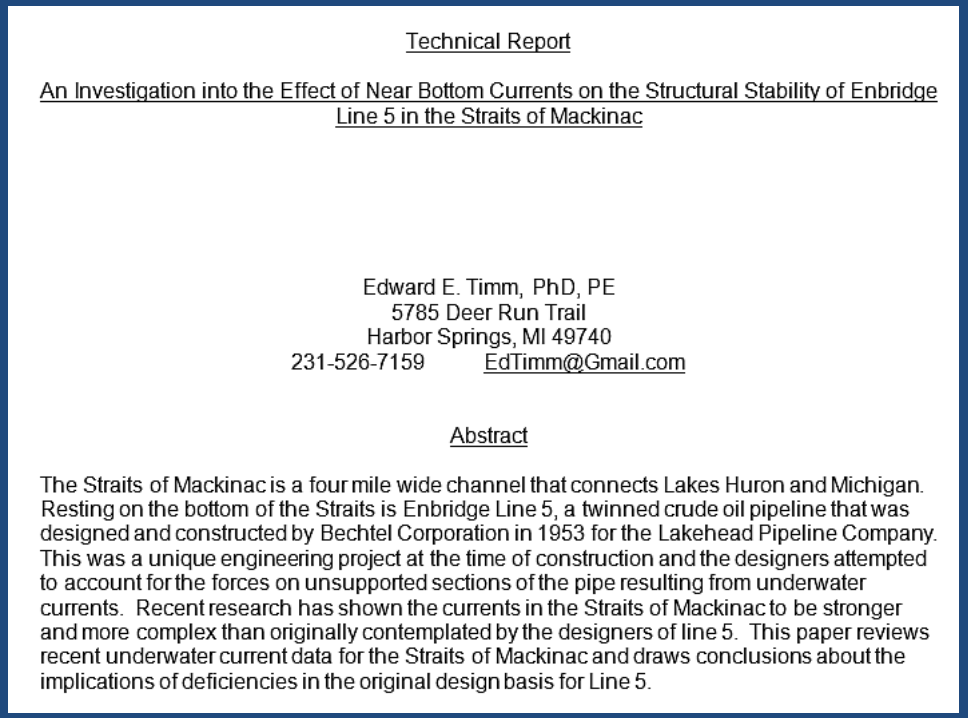
Significant findings in this CPCM inspection include:

- Based on the amount of DC current and the DC current density on the line it appears the line has an excellent coating system.
- There is very little total CP current on this line.
- The line has coal tar coating and it is not unusual to have low CP current density and low total CP current.
- There is noise in the CPCM data caused by speed variations, contact quality and pipe roughness and since the CP current is very low the noise level is a significant factor in data analysis.

Recommendations:

- Continue performing standard CP monitoring and Rectifier and Bond monitoring as required by state and federal regulations.
- Identify the CP Source locations at each end of the pipeline and if possible install electrical isolation and bonds with current measurement shunts for future CP testing and informational purposes.

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

Edward E. Timm, PhD, PE
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Harbor Springs, MI 49740
231-526-7159 EdTimm@Gmail.com

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.

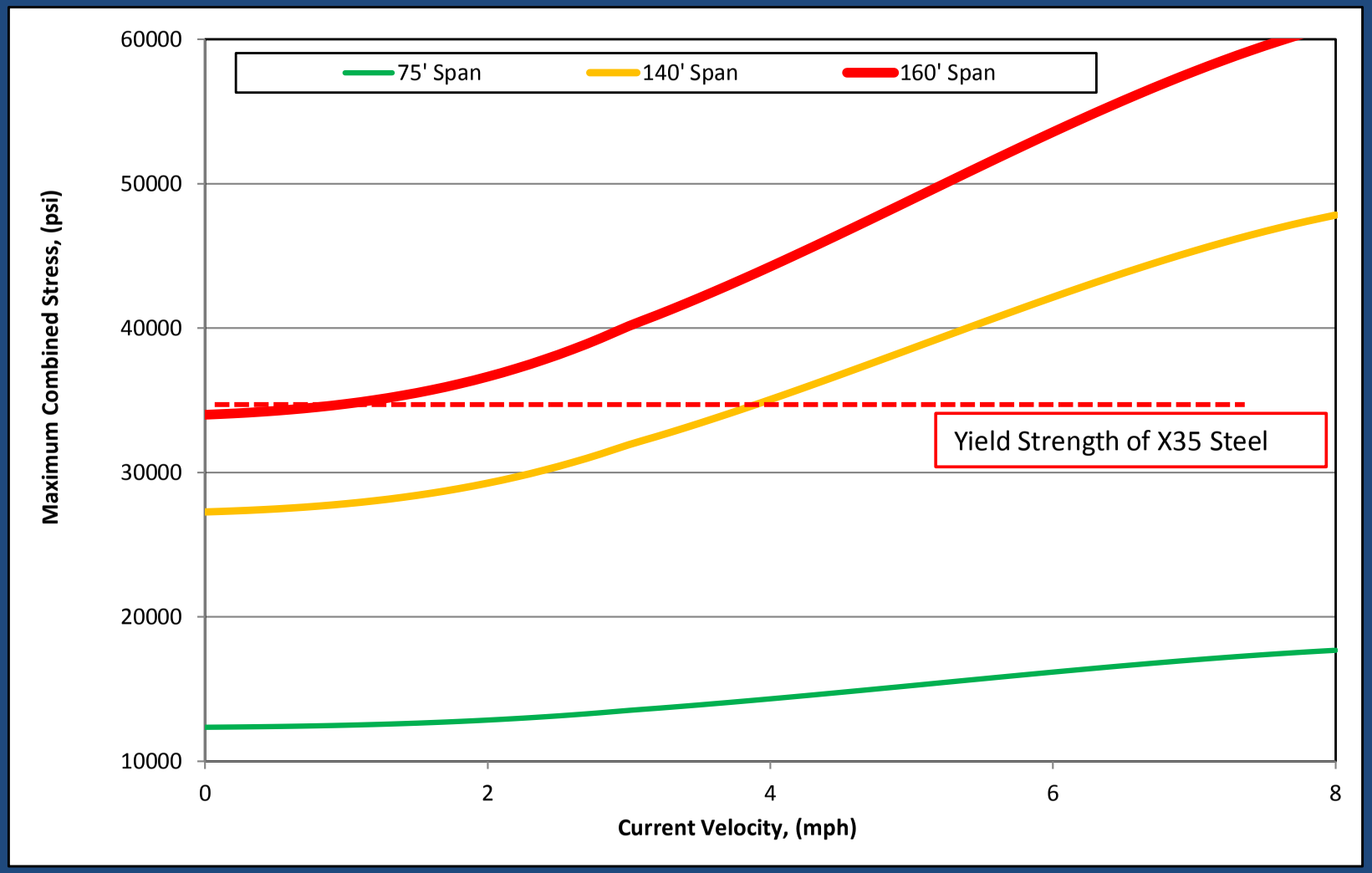
Conclusions

- 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 (DNV)
- Consideration should be given to requiring shutdown and inspection of the pipe following an extreme current event in the Straits

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." ( )

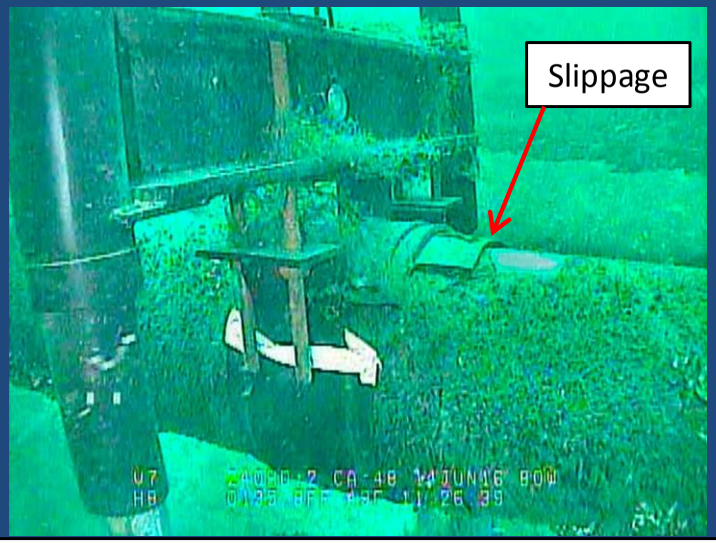
1953 Engineering Report: "Under no circumstance should the unsupported span exceed 140 feet." ( )



Evidence of Lateral Pipe Movement from 2012 and 2016 Inspection Videos

Laterally Deflected Anchor from 2012 Inspection

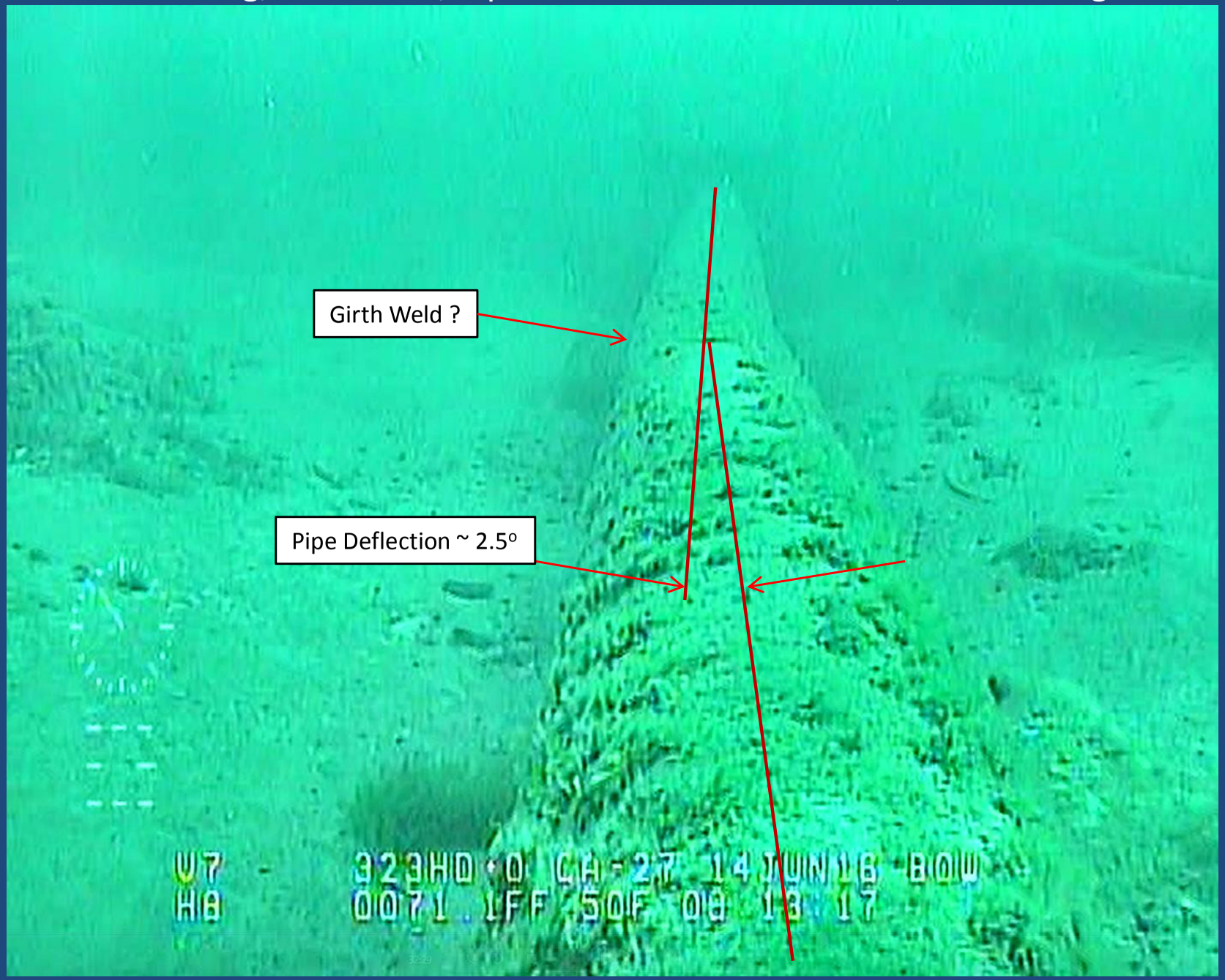
Laterally Deflected Anchor from 2016 Inspection



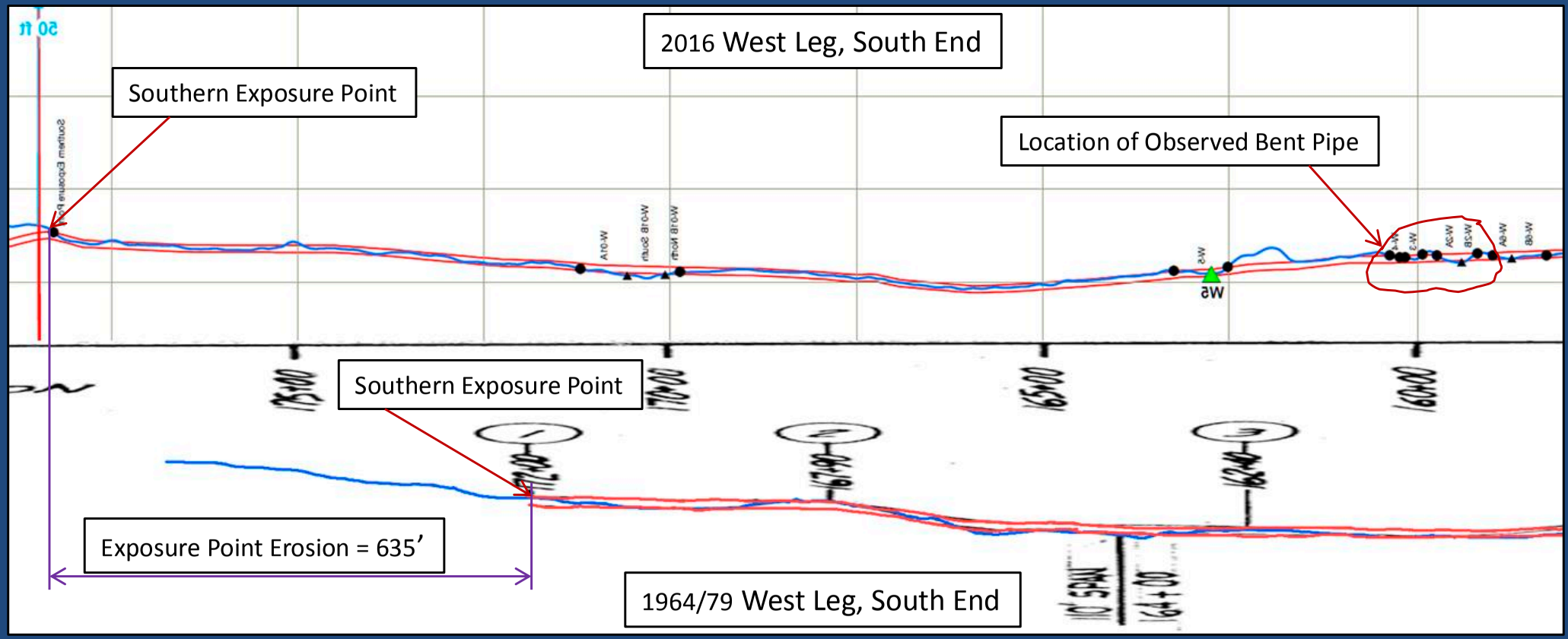
Evidence of Lateral Pipe Slippage through Anchor

2016 Enbridge Inspection Video

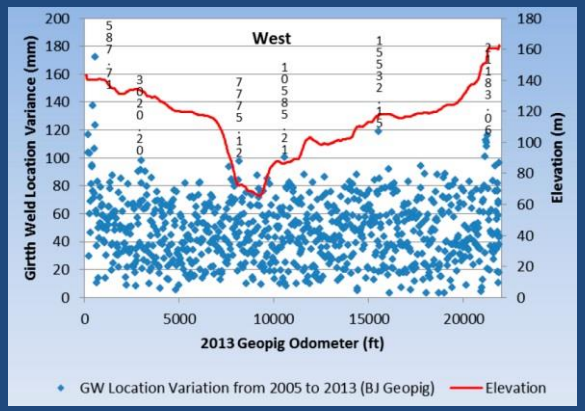
West Leg, South End, Pipe Bend to the West at 15,900’ Chainage



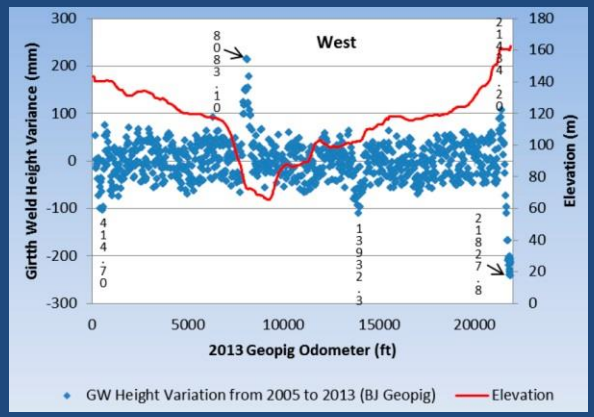
Comparison of Line 5 Bottom Profile Drawing from 2016 with 1964/79 Drawing



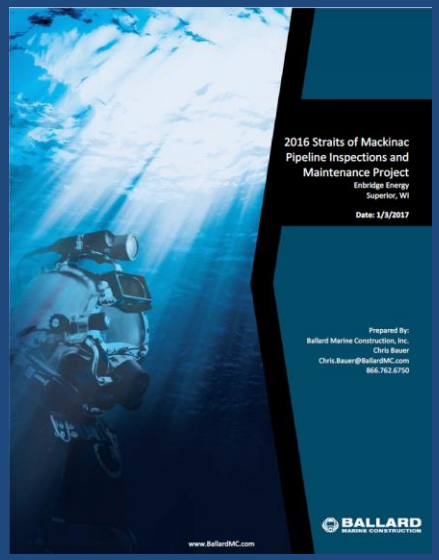
Pipe Movement Plots from LaMontagne ILI Summary Report



Conclusion:
Bent pipe observed on 2016 Video occurred before the 2005 inspection



Enbridge 2012 and 2016 Underwater Inspection Video



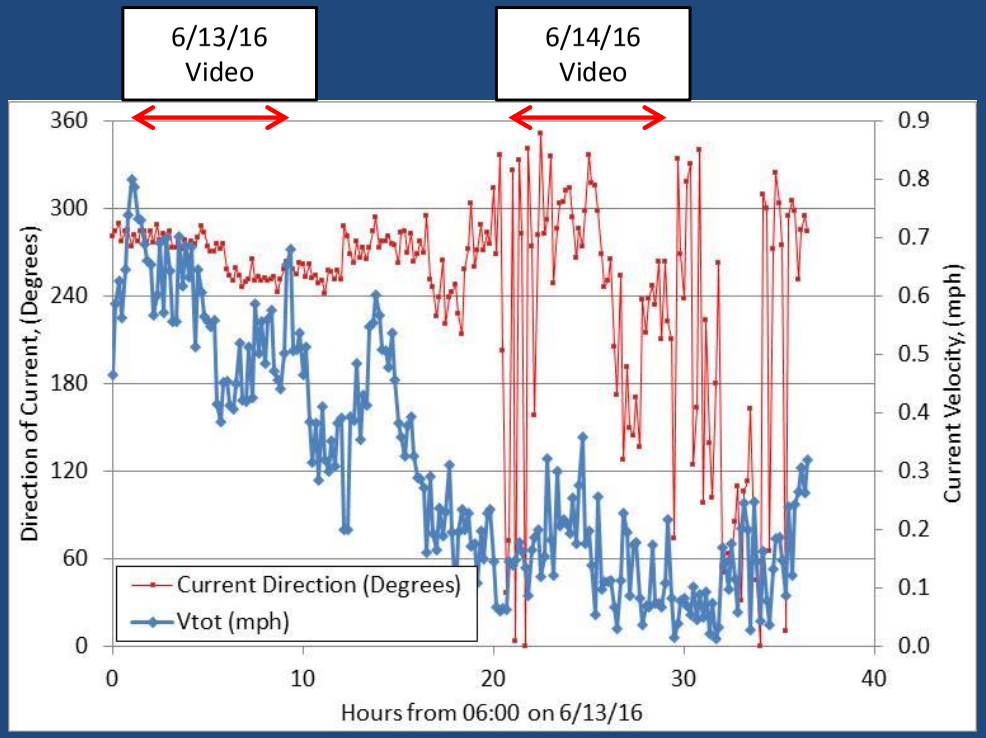
- At times, stronger currents (2-3 ft/s) hampered dive operations but never became a problem during survey operations
- Furthermore ROV video inspection and AUV data collection shows that the pipeline currently appears to be in stable condition with minimal coating delamination or nearby obstruction concerns
- Anchors to be added to a pre existing engineering bend in one of the pipelines. No mention of this in previous Ballard inspection reports

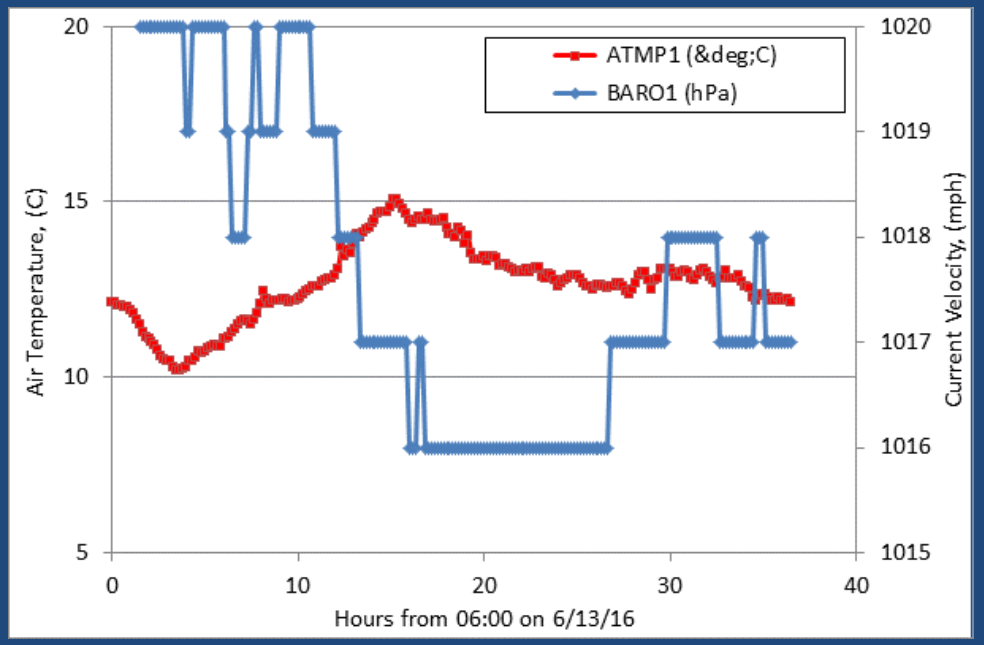
Enbridge 2012 and 2016 Underwater Inspection Video - 2

"The exposed portion of the pipeline is heavily covered in zebra mussel growth, making a detailed analysis of the coating and actual pipe condition impossible"
William Scheutte, Hydrographics Manager, Veolia ES Special Services, Inc., 2012.

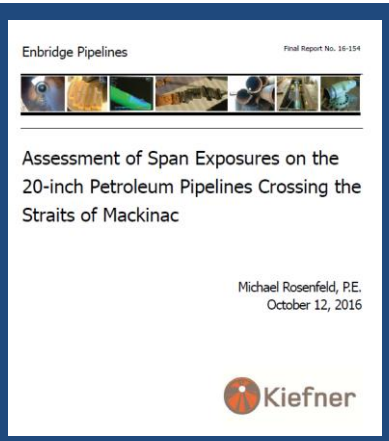
ET Conclusion: About 20% of the 20" line can be visibly inspected and Scheutte's comments apply to that 20%

A current velocity of 0.6 mph is in the top 10% of current events





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 discuss the "overturning moment" caused by currents on long spans

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

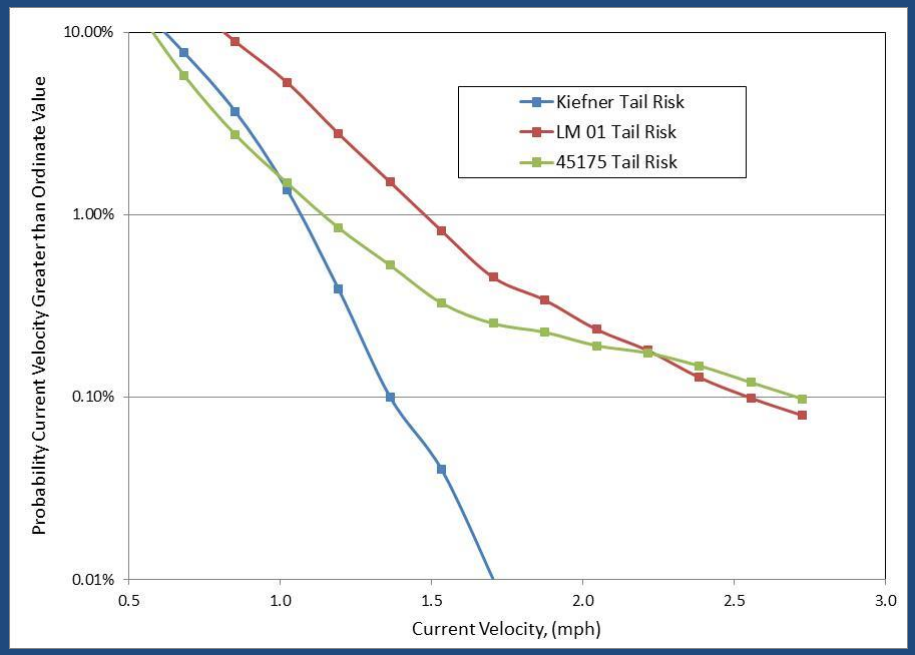
Conclusions

Vortex Induced Vibrations Section

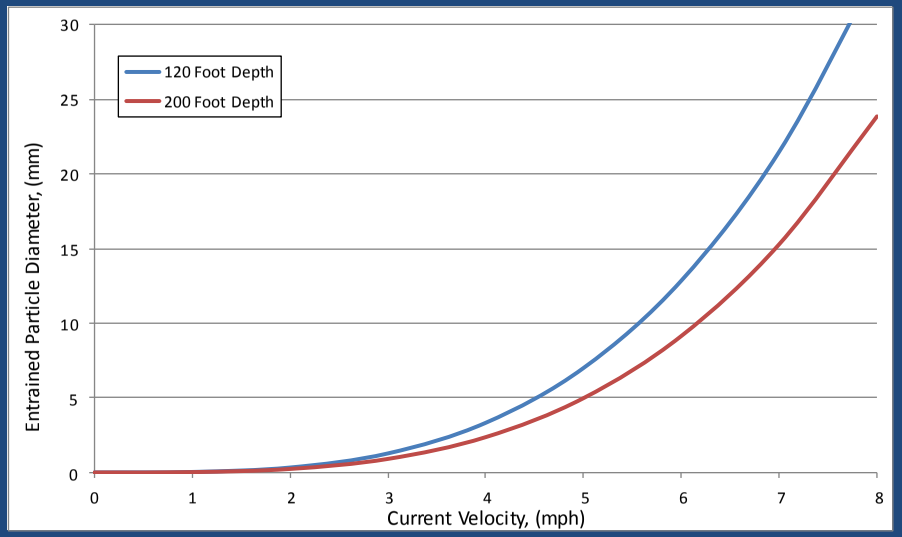
Questionable analysis of Enbridge supplied current data
- No discussion of turbulent flow field in Straits
- No discussion of the importance of instantaneous current velocity data and the masking effect of averaging time
- Fails to recognize and quantify the importance of extreme current events as documented 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"
- 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)

Kiefner Report on Currents and Stresses in Line 5
Kiefner Analysis Discussion - 3



Tail Risk as a Function of Current Velocity



Particle Entrainment Velocity Computed from the Levillain Equation

Flawed Conclusion from 2016 LaMontagne ILI Review

LAMONTAGNE
Pipeline Assessment Corporation

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

"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."

Flawed Conclusion from 2016 LaMontagne ILI Review - 2

Note that all of the horizontal and vertical deviations include many pipe joints. These are smooth transitions as many joints over 100's of feet are moving. The pipe therefore has negligible added stress or strain imparted.

E. E. Timm, PhD, PE Conclusion

1. Because the LaMontagne ILI review only looked at pipe position data from the period 2005 through 2013 and did not reconcile this with any underwater inspection data they missed pipe movement that occurred before 2005

2. Because the visual inspection data shows the pipe was bent before the ILI data was taken, LaMontagne's conclusion that pipe deflection has added negligible stress or strain to this portion of Line 5 is flawed.

3. The approximate 2.5^{o} deflection shown in the 2016 inspection video occurs over a small length of pipe. This deflection has added a significant amount of stress and strain to the pipe and, especially if there is a girth weld near the apex of this deflection, this situation requires detailed analysis to prove fitness for service

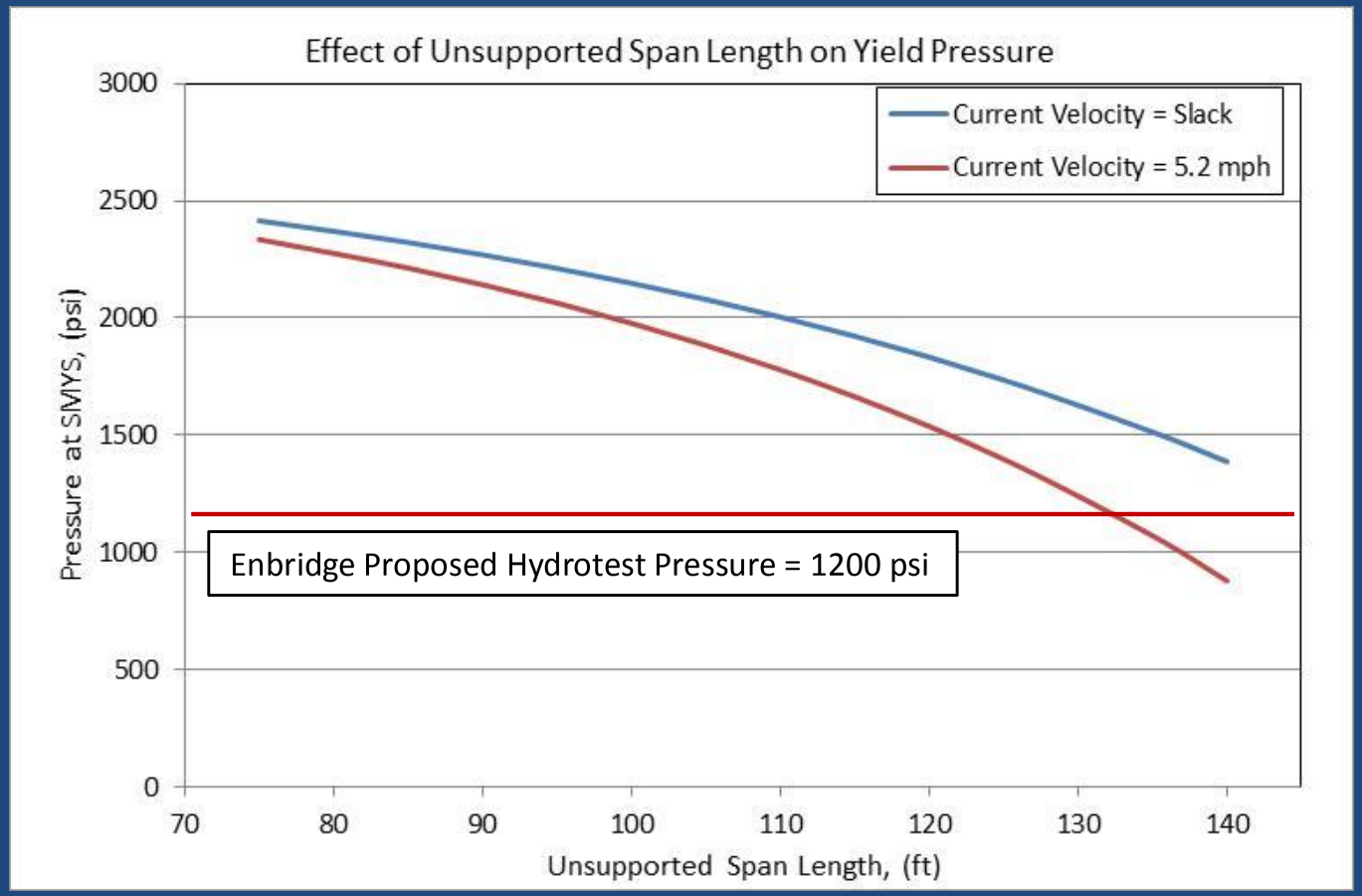
Comments Regarding Hydrotesting

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 atthe Straits. The analysis will include the following:

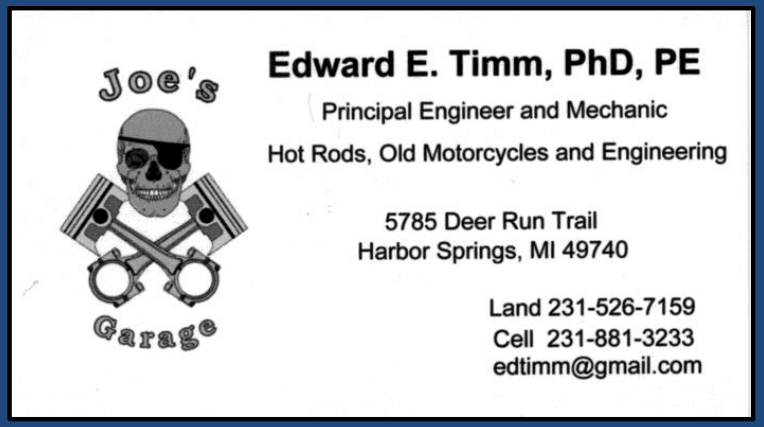
• An allowable suspended span length of the pipeline will be calculated to include the biomass along with operating loads, drag forces, buoyant weight, etc. A sensitivity analysis will be also completed on the impact of the biota mass to allowable span length.

• 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.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