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Enbridge Mackinac Straits ILI Review

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Safety Administration

NPS 20 Pipeline

Enbridge Line 5;

East and West Mackinac Straits

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Overview

The motivation of the ILI review was to provide a partial fitness-for-service assessment for the two Enbridge Line 5, 20" Mackinac Straits Crossings. It is a partial fitness-for-service because the inspections allow for the assessment of only metal loss (corrosion), circumferential cracking, deformation, pipe movement, and combinations thereof. The first step taken was to examine each inspection report and detail any anomalies that may require immediate attention. This was then followed by the alignment and comparison of all the inspections to examine for possible interacting anomalies and to examine for growth of metal loss. To be conservative, the maximum estimated growth rate in either segment, considering ILI tool tolerance, was then examined. During this process the criticality of any circumferential or girth weld crack-like anomalies was examined including potential interactions with metal loss or dents.

Data was provided for twenty in-line inspections, ten within each of the Line 5 - East and West Mackinac Straits sections. High resolution axial magnetic flux leakage (MFL) and geometry inspections have been conducted every 5 years since 1998. Both lines were inspected in 2014 with ultrasonic tools for circumferentially oriented cracking. These examined the full length of the crossings with particular attention given to the girth welds.

The high resolution MFL inspections cover the full pipe circumference to delineate the location and size of metal loss features both internal and external. Geometry ILI tools were employed to size dents or ovalities, examine deformation strain, as well as to determine the pipe physical location, and were high resolution as well. The Oceaneering PipeTech automated inspection system, employed in 2014, utilizes time of flight diffraction (TOFD) and phased array (PA) pulse-echo ultrasonic techniques. These complimentary techniques work together to provide improved detection and sizing accuracy for surface breaking and volumetric discontinuities in the weld and HAZ areas relative to a single mode. The NDT Global UCC tool, also run in 2014, is an ultrasonic tool employing shear wave sensors to examine the full length and circumference of the pipeline in high resolution for circumferentially oriented crack and crack-like anomalies.

Executive Summary

Data was provided for ten in-line inspections which have been conducted on each of the Line 5 - East and West Mackinac Straits sections. These 20" OD lines are 4.1 miles in length and are reported to transport up to 540,000 barrels per day (bpd) of light crude oil, light synthetic crude, and natural gas liquids (NGLs), including propane. The segments are comprised of API X-35, 0.5" Electric Resistance Weld (ERW) onshore, and 0.812" seamless pipe offshore. The metal loss inspection runs reviewed included the 1998, 2003, 2008 and 2013 magnetic flux leakage (MFL) inspections by GE/PII. Ultrasonic inspections (UT) for girth weld misalignment and weld cracking by the Oceaneering PipeTech automated UT (AUT) and circumferential cracking with the NDT Global UCC tool were conducted in 2014. As well as the GE/PII Calliper and BJ Geopig deformation and positioning inspections in 2003, 2005, 2008 and 2013.

All of the MFL in-line inspection (ILI) tools employed to size metal loss were considered high resolution with the flux field axially oriented. Similarly, the deformation ILI tools to size dents or ovalities, examine deformation strain, as well as to determine the pipe physical location, were high resolution as well. The Oceaneering PipeTech automated inspection system utilizes time of flight diffraction (TOFD) and phased array (PA) pulse-echo ultrasonic techniques. These complimentary techniques work together to provide improved detection and sizing accuracy for surface breaking and volumetric discontinuities in the weld and HAZ areas relative to a single mode. The NDT Global UCC tool is an ultrasonic tool employing shear wave sensors to examine the full length and circumference of the pipeline in high resolution for circumferentially oriented crack-like anomalies.

The motivation of this review was first to examine each inspection report and detail any anomalies that may require immediate attention. This was then followed by the alignment and comparison of all the inspections to examine for possible interacting anomalies and to examine for growth of metal loss. To be conservative, the maximum estimated growth rate in either segment, considering ILI tool tolerance, was then examined. During this process the criticality of any circumferential or girth weld crack-like anomalies was examined including potential interactions with metal loss or dents.

Metal Loss

The 2013 MFL inspections described all external metal loss as manufacturing related and all but 8 (all onshore) internal metal loss as manufacturing as well. All metal loss in the seamless heavy wall pipe (offshore) was characterized as manufacturing related. The distribution of the metal loss anomalies is quite dispersed and random in both location and orientation about the circumference of the pipe. This type of distribution is typical of manufacturing type anomalies. The following two tables detail the number of metal loss anomalies described by each MFL inspection.

	Inspection	# Ext. Metal Loss	# Int. Metal Loss	Total Metal Loss
EAST	1998 MFL (≥3%)	31	60	91
	2003 MFL (≥10%)/GEO	78	61	139
	2008 MFL (≥4%)/GE	78	61	139
	2013 MFL (≥1%)/GEO	71	70	141

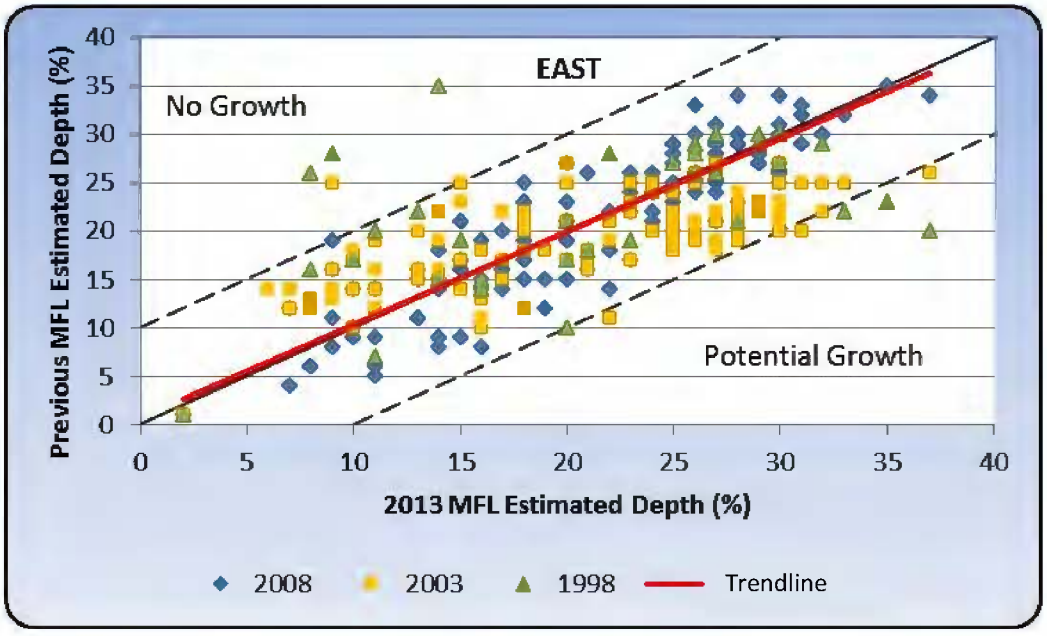
	Inspection	# Ext. Metal Loss	# Int. Metal Loss	Total Metal Loss
WEST	1998 MFL (≥3%)	20	32	52
	2003 MFL (≥10%)/GEO	186	95	281
	2008 MFL (≥4%)/GE	205	112	317
	2013 MFL (≥1%)/GEO	194	100	294

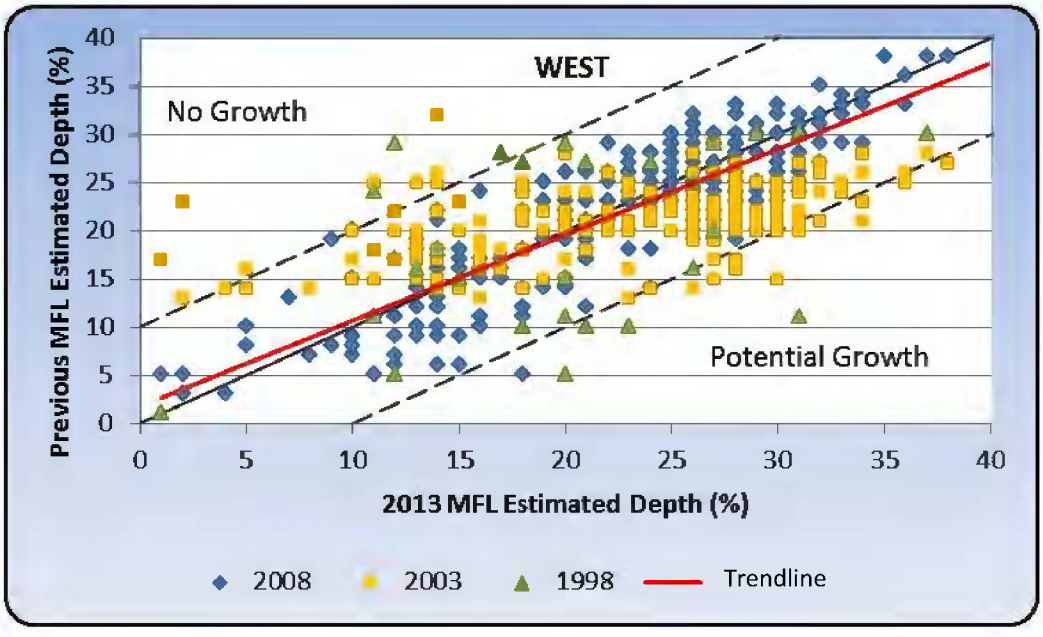
An anomaly matching analysis was then conducted between the 1998, 2003, 2008 and 2013 MFL inspections by aligning each of the runs. Note that the older 1998 MFL technology detailed many fewer metal loss features than the more recent technologies. The following table describes the number of metal loss anomalies that were aligned (considered the same anomaly) between particular inspections. The "percent possible" noted represents the percentage aligned of the maximum possible. It is intuitive that the greater the number of matches, the more informed is the determination of growth.

	ILI Runs Compared	# of Matches for External Metal Loss	# of Matches for Internal Metal Loss	Total # Anomaly Matches (% possible)
EAST	1998-2003	20	20	40 (44%)
	1998-2008	18	19	37 (41%)
	1998-2013	18	18	36 (40%)
	2003-2008	75	56	131 (94%)
	2003-2013	67	52	119 (86%)
	2008-2013	69	52	121 (87%)
WEST	1998-2003	13	19	32 (62%)
	1998-2008	13	18	31 (62%)
	1998-2013	13	16	29 (56%)
	2003-2008	155	85	240 (85%)
	2003-2013	144	62	206 (73%)
	2008-2013	190	79	269 (92%)

Corrosion growth rates were investigated by analyzing the growth of matched metal loss anomalies between the 2008 MFL and 2013 MFL inspections. All variances in depth were found to be within the ±10% error of the tool. Therefore considering tool error there is no growth as would be expected if these are all manufacturing anomalies. The trendlines for both the East and West segments approximate unity as seen in the following unity plots.

No excavations of metal loss were deemed necessary based on the 2013 MFL inspection sizing and no apparent corrosion growth. Even considering the greatest deviation in depths within all inspections and not allowing for tool tolerance, an extremely conservative growth rate of 0.019 in/yr was determined. Applying this extraordinary rate to the length and depth of each anomaly, the lowest estimated failure pressure of any anomaly after a 10 year growth period is 1350 psi (2.25 safety factor relative to the maximum operating pressure (MOP)).





Deformation Anomalies

Five deformation inspections within each crossing were examined with consideration to dent depth, location to welds and their association to corrosion and/or cracking. There were no dents >2% depth, no dents with metal loss or on girth welds. Two dents were found to be ≅1.5% depth, with one location potentially containing multiple dents. There were a few ID reduction / ovalities noted in each section. Estimated bend strains were calculated and all have a low estimated strain. The location of the highest noted strain (4.9%) was in a pipe replacement area that has a slight deviation from the original pipe and is not an actual strain near the West launcher. The ID restrictions in all but 2 cases have an ID ≥ 17.9", the

minimum value set by Enbridge. The two locations have ID's of 17.35" and 17.81". These diameters will not restrict future in-line inspections as is and can be continued to be monitored.

During the alignment of the various in-line inspections, locations of possible dents interacting with metal loss or crack-like indications were looked for. All of the MFL, UCC and deformation inspections were considered. To which, one possible location of a dent (1998) with metal loss (2003) was found. There are no further alignments at this location within any of the more recent inspections. Enbridge has reviewed this location and found that based on the subsequent 7 inspections that there is a manufacturing metal loss indication that has had no change in growth and that there are no indications of denting in the higher resolution deformation tools employed since then. This location is deemed acceptable based on this review.

A location noted in the 2013 Geopig ILI as a multiple dent with a maximum depth of 1.5% has been visually inspected by divers in 2014. At the location there were some markings on the pipe from the banding used during installation of the pipe, there was no corrosion observed within the disbonded area, and there was no denting, gouging, or scratching identified in the vicinity. Even though the term multiple dent was utilized in the ILI, there was no sign of multiple apex's by the tool and it is a well-known fact that seamless pipe has a harmless but undulating wall profile. A deflection of 1/3" is all that is required to register a 1.5% deflection.

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.

	Inspection	*Circumferential Crack-Like*
EAST	**2014 UCC (≥5%)**	14
WEST	**2014 UCC (≥5%)**	21

Girth Weld Anomalies

The 2014 Oceaneering AUT tool targeted girth welds having a minimum of 3.2mm misalignment. The inspection of both East and West segments found 2 girth welds with up to a 4.6mm misalignment. There are no absolute limits for misalignment in API 1104 provided that the misalignment is distributed evenly around the circumference. It appears to be as the misalignment high-low length is 400mm in length (1/4 of the circumference) and there is no measured ovality at the location. Considering DNV-RP-C203 (2010) "Fatigue Design Of Offshore Steel Structures" this deviation has a stress concentration factor of 1.01. Meaning

that the stress imparted on this misalignment from the operating pressure is 1% higher than a properly aligned butt weld, which is negligible.

Pipeline Movement

Pipeline positional information was provided by the BJ Geopig as captured during the deformation inspections. Submeter accurate inertial navigation units are within the ILI to capture the three dimensional movements of the tool. The information provided is a highly accurate geographic location (northing and easting) of specific points such as girth welds. The greatest horizontal displacement in the data was noted in the East segment at the end of the inspection and was 163mm (6.4") and in the West segment at the beginning of the inspection and was 172mm (6.8"). This amount of deviation has been determined to impart less than 0.02% strain as it acts over a long length. Both of these locations are onshore.

The vertical deviations are slightly greater. The greatest vertical deviation in the data was noted in the East segment at both ends of the inspection with the greatest being 370mm (14.6") and in the West segment at one third of the inspection length and was 214mm (8.4"). 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. Some of the underwater variations in height may have been corrected during 2014 maintenance in which both segments had new anchor points installed so as to have no unanchored spans greater than 75' in length.

No locations other than the one location having an aligned dent with metal loss were found to require attention or review at this time in the East or West Straits with respect to the ILI data supplied. The 5 year re-inspection interval is deemed satisfactory.

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Introduction

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The metal loss inspection runs reviewed included the 1998, 2003, 2008 and 2013 magnetic flux leakage (MFL) inspections by GE/PII. Ultrasonic inspections (UT) for girth weld misalignment and weld cracking by the Oceaneering PipeTech automated UT (AUT) and circumferential cracking with the NDT Global UCC tool were conducted in 2014. As well as the GE/PII Calliper and BJ Geopig deformation and positioning inspections in 2003, 2005, 2008 and 2013.

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Results and Discussion

Review of the Inspection Metal Loss Data

The distribution of the metal loss anomalies from the four inspections are detailed in Figures 1 through 4. Figures 1 and 2 detail the external and internal metal loss distributions along the length of the East Straits, respectively. Likewise, Figures 3 and 4 detail the external and internal metal loss distributions along the length of the West Straits, respectively.

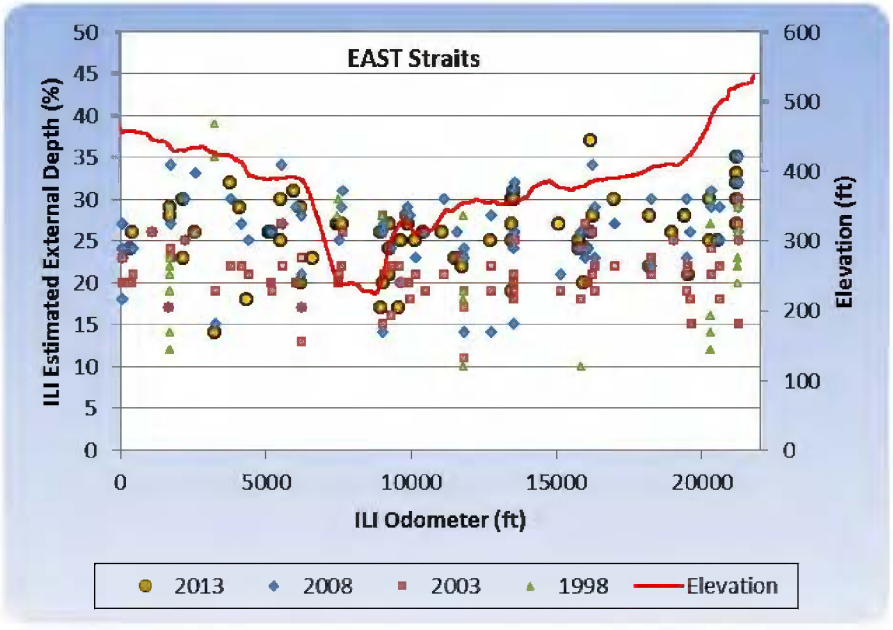


Figure 1. Distribution of external metal loss anomalies in the East Straits.

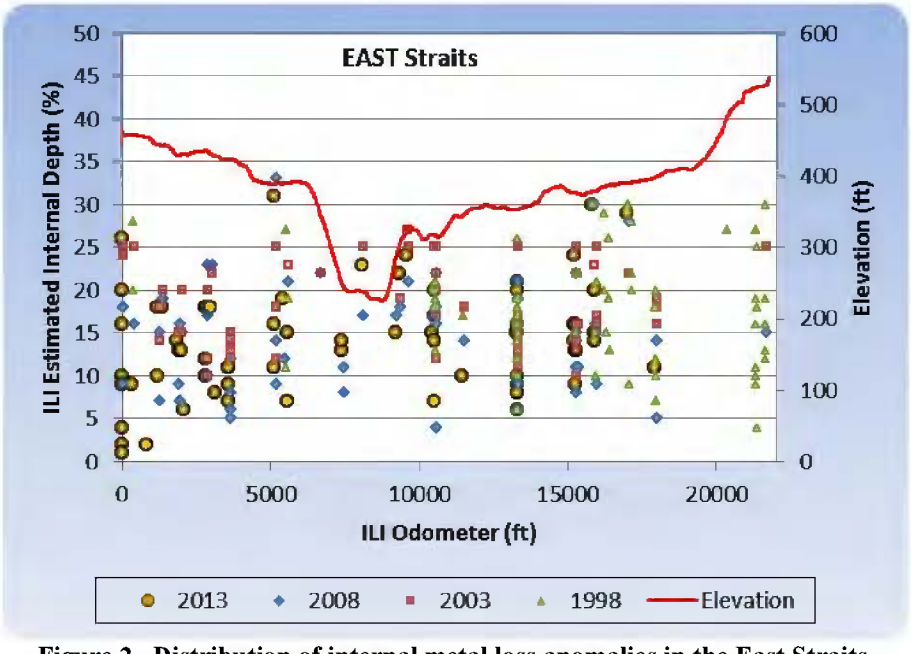


Figure 2. Distribution of internal metal loss anomalies in the East Straits.

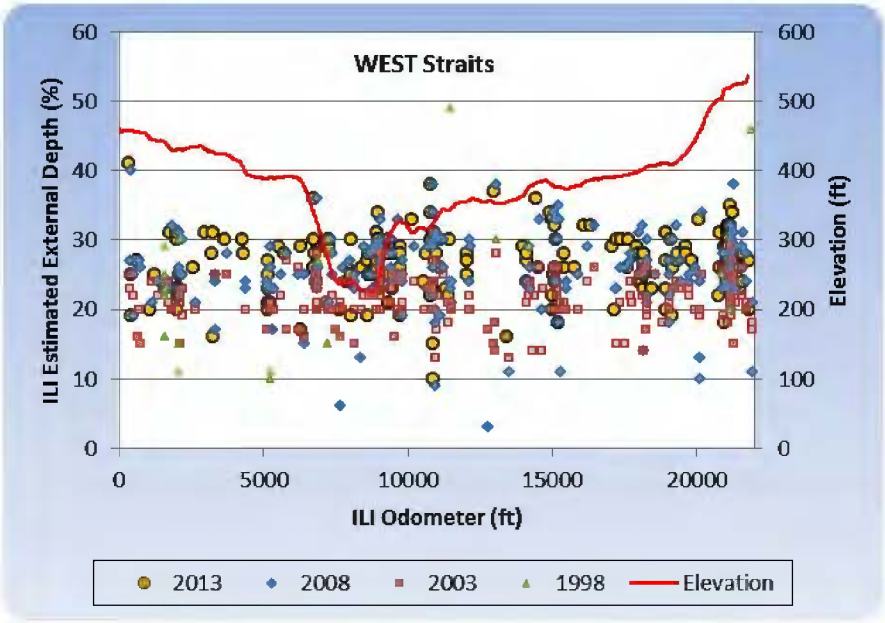


Figure 3. Distribution of external metal loss anomalies in the West Straits.

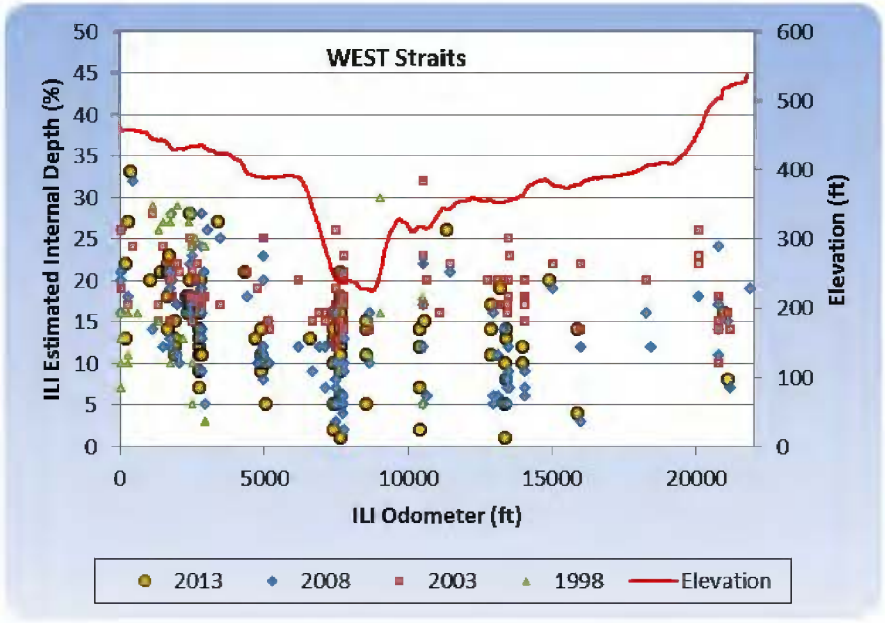


Figure 4. Distribution of internal metal loss anomalies in the West Straits.

Note that the older 1998 MFL technology detailed many fewer metal loss features than the more recent technologies. The average lengths are greater in the 2013 inspection than in 1998, verifying that the quantity of anomalies is not a result of interaction method variations. The quantities of anomalies are similar in the 2003, 2008 and 2013 inspections. The locations of higher densities of anomalies tend to agree between inspections. Also, there are a few discrepancies between metal loss being called either internal or external in the MFL inspections. Generally, this is typical and not of great concern as the remaining strength is not governed by the side of pipe the metal loss is on and the interaction of anomalies should not depend on this either. Many locations of higher density internal metal loss are at local low

elevation areas. This implies that there may have been corrosion at some point in time, particularly when there is more than one pipe joint included.

A check of the distribution of the metal loss anomalies by clock position in Figures 5 through 8, showed no distinct preferred orientations of external nor internal metal loss. Figures 5 and 6 detail the external and internal metal loss orientations along the length of the East Straits, respectively. Likewise, Figures 7 and 8 detail the external and internal metal loss orientations along the length of the West Straits, respectively.

The potential internal corrosion noted above would typically be seen to occur about a preferred orientation which is not the case. It is seen, particularly in Figure 8 that the metal loss orientation is spread throughout the full circumference of the pipe. This then signifies that it is a manufacturing issue. Seamless pipe is known to cause minor metal loss anomalies to be delineated in areas where the wall thickness is non-uniform due to the pipe manufacturing process.

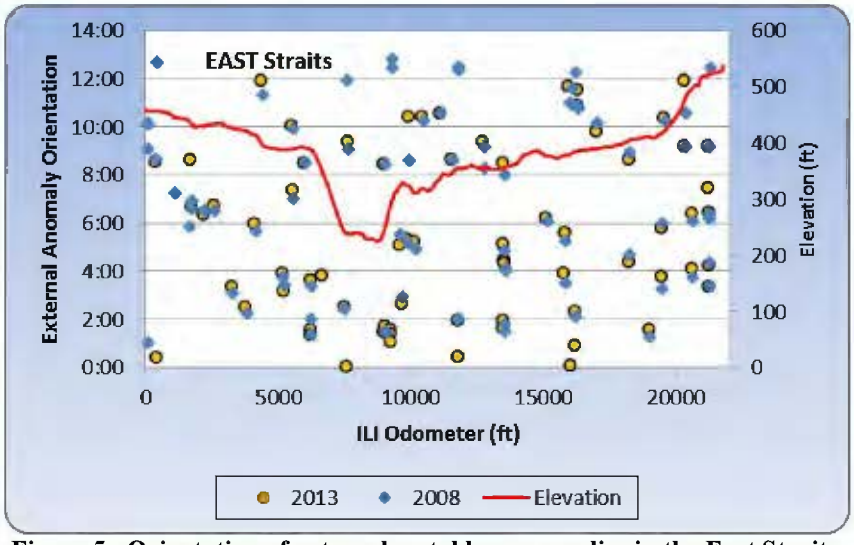


Figure 5. Orientation of external metal loss anomalies in the East Straits.

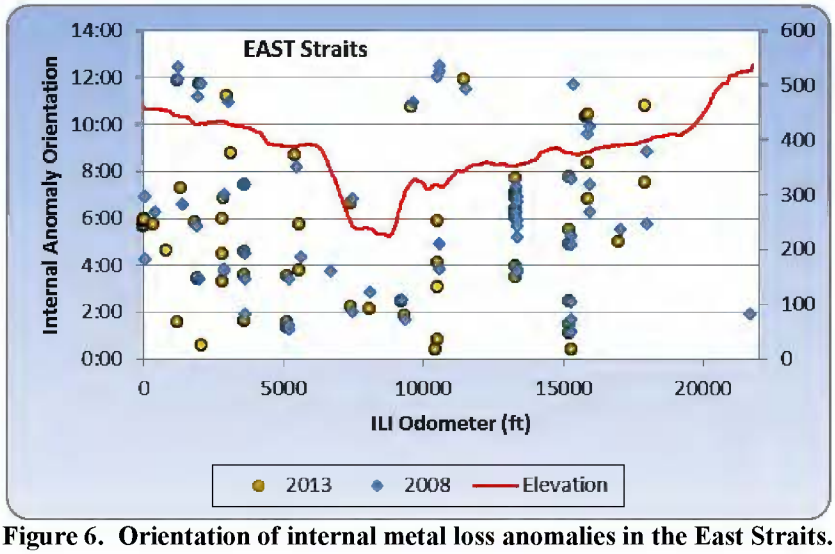


Figure 6. Orientation of internal metal loss anomalies in the East Straits.

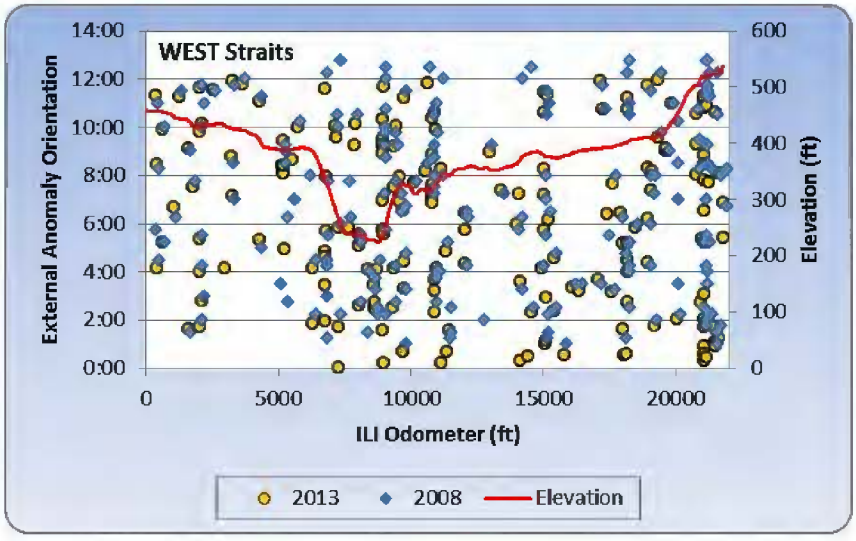


Figure 7. Orientation of external metal loss anomalies in the West Straits.

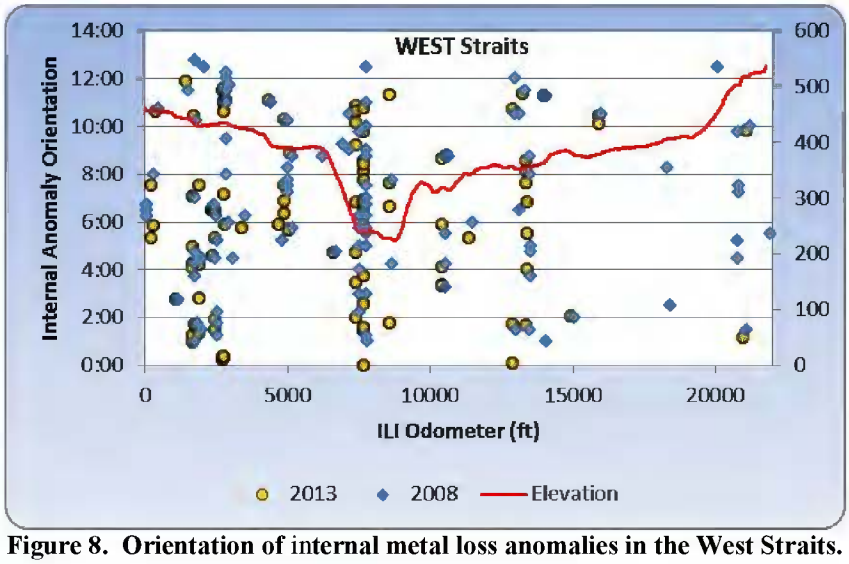


Figure 8. Orientation of internal metal loss anomalies in the West Straits.

In-Line Inspection Comparison and Growth Rate Estimation

The in-line inspection results from the 1998, 2003, 2008 and 2013 MFL runs where examined for potential metal loss growth. The 2013 MFL inspections described all external metal loss as manufacturing related and all but 8 (all onshore) internal metal loss' as manufacturing as well. All metal loss in the seamless heavy wall pipe (offshore) was characterized as manufacturing related. Table 1 details the number of metal loss anomalies described by each MFL inspection.

Table 1. Summary of in-line inspection anomalies.

	Inspection	*# Ext. Metal Loss*	*# Int. Metal Loss*	*Total Metal Loss*
EAST	**1998 MFL (≥3%)**	31	60	91
	2003 MFL (≥10%)/GEO	78	61	139
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	2003 MFL (≥10%)/GEO	**186**	95	281
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	2013 MFL (≥1%)/GEO	**194**	100	294

An anomaly matching analysis was then conducted between the 1998, 2003, 2008 and 2013 MFL inspections by aligning each of the runs. Table 2 describes the number of metal loss anomalies that were aligned (considered the same anomaly) between particular inspections. The "percent possible" noted represents the percentage aligned of the maximum possible. It is intuitive that the greater the number of matches, the more informed is the determination of growth.

Table 2. Anomaly matching results from ILI run alignment.

	ILI Runs Compared	*# of Matches for External Metal Loss*	*# of Matches for Internal Metal Loss*	*Total # Anomaly Matches (% possible)*
EAST	**1998-2003**	20	20	40 (44%)
	1998-2008	18	19	37 (41%)
	1998-2013	18	18	36 (40%)
	2003-2008	75	56	131 (94%)
	2003-2013	67	52	119 (86%)
	2008-2013	69	52	121 (87%)
WEST	**1998-2003**	13	19	32 (62%)
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	1998-2013	13	16	29 (56%)
	2003-2008	155	85	240 (85%)
	2003-2013	144	62	206 (73%)
	2008-2013	190	79	269 (92%)

Corrosion growth rates were investigated by analyzing the growth of matched metal loss anomalies between the 2008 MFL and 2013 MFL inspections. All variances in depth were found to be within the ±10% error of the tool. Therefore considering tool error there is no

growth as would be expected if these are all manufacturing anomalies. The trendlines for both the East and West segments approximate unity seen in Figures 9 and 10.

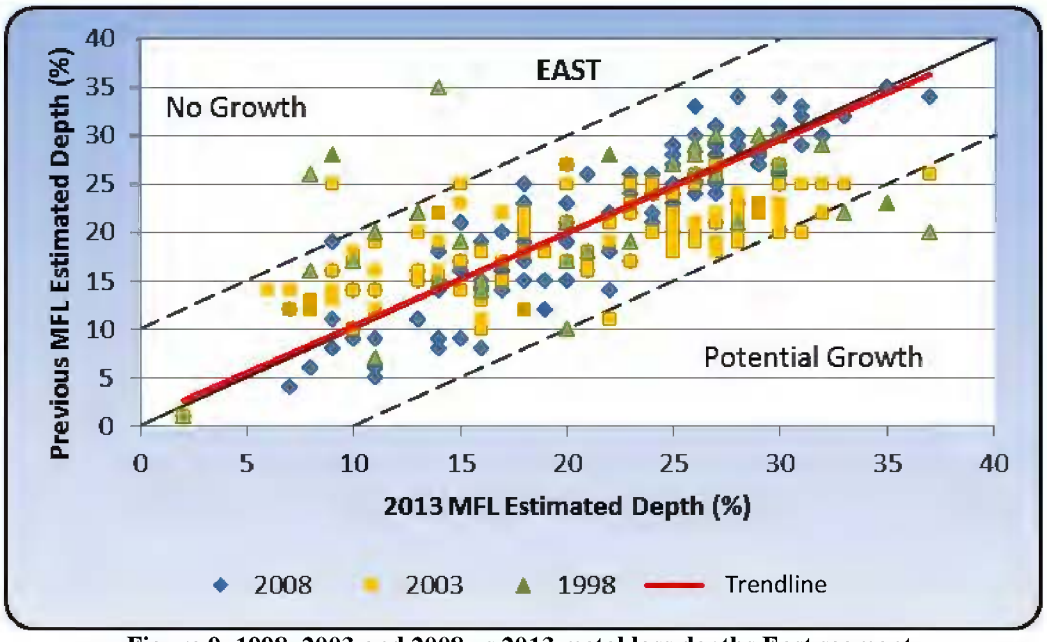


Figure 9. 1998, 2003 and 2008 vs 2013 metal loss depths East segment.

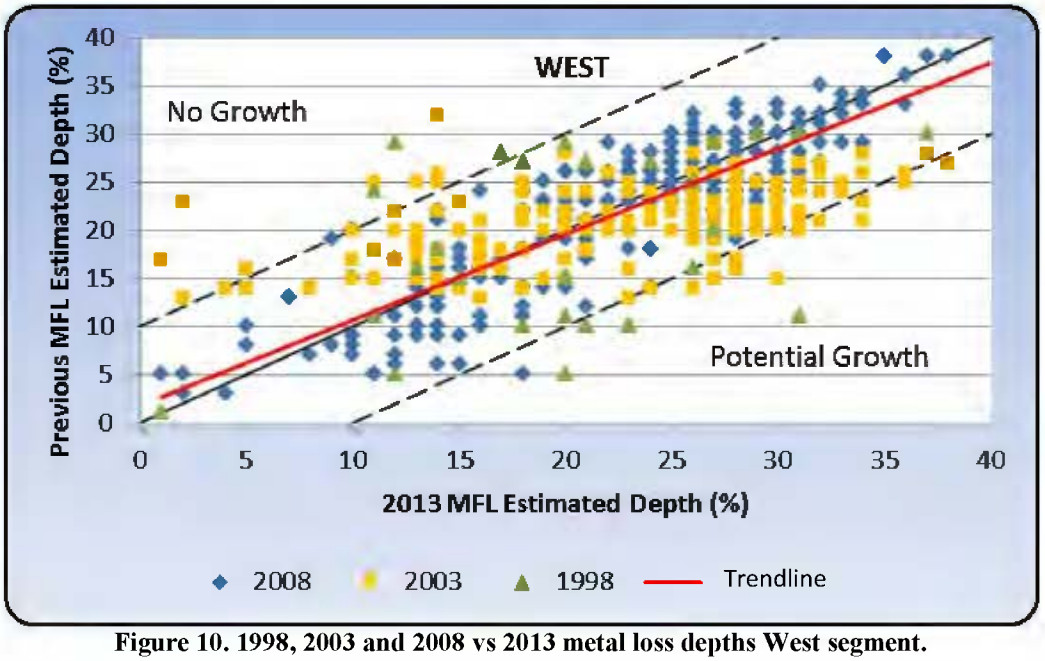


Figure 10. 1998, 2003 and 2008 vs 2013 metal loss depths West segment.

If tool error is not considered, the external growth was found to be between 0.0016 – 0.015 in/yr and the internal between 0.0016 – 0.019 in/yr. The corrosion rates for both the external and internal anomalies were calculated using a moving 95th percentile scale as presented in

Figures 11-14. All growth rates were determined to be the 95% confidence interval of growth. Again, the depth variances were within tool error and these rates noted cannot be stated as actual, just used as a worst case estimate.

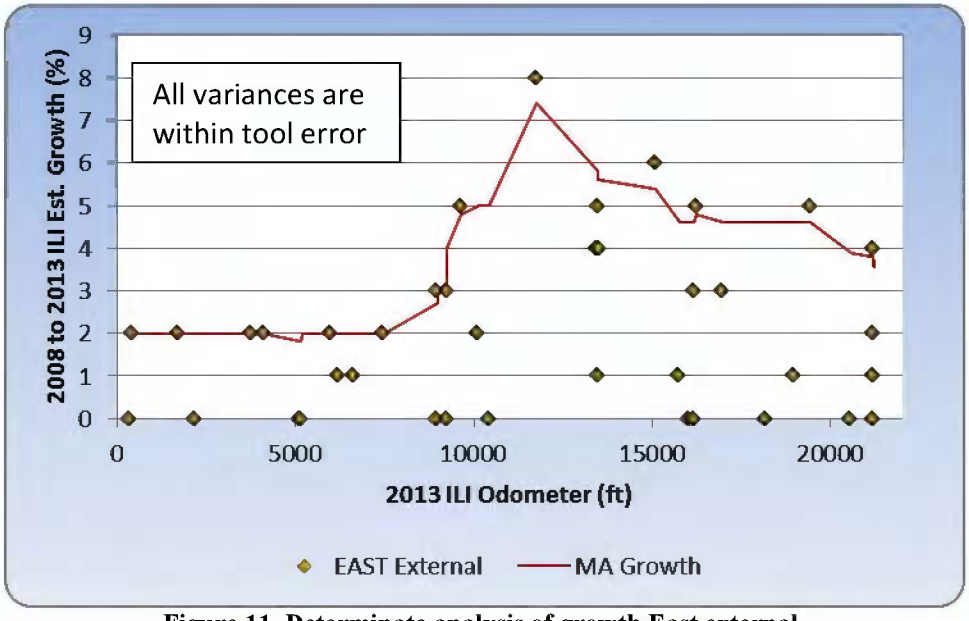


Figure 11. Determinate analysis of growth East external.

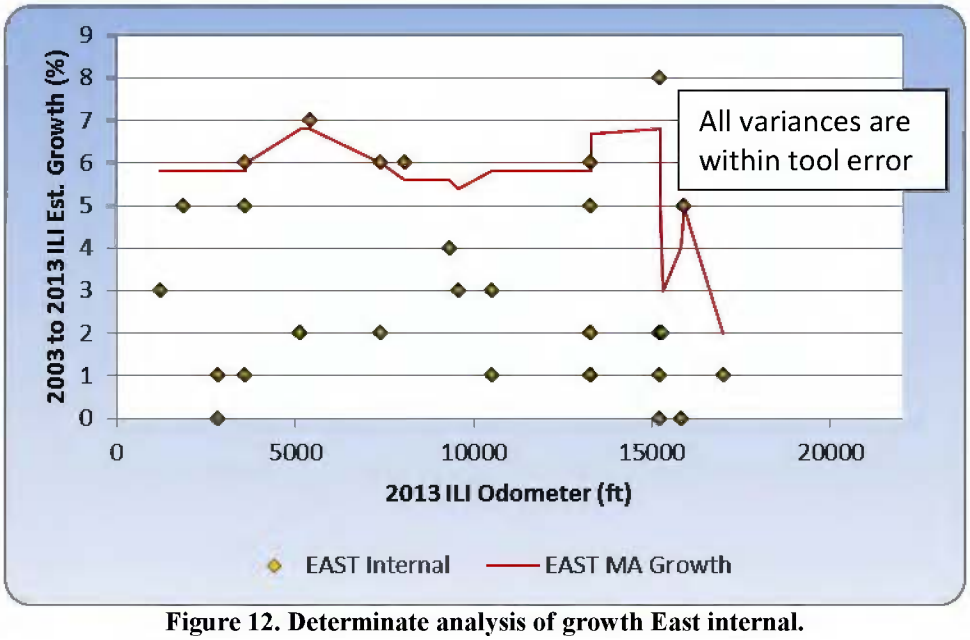


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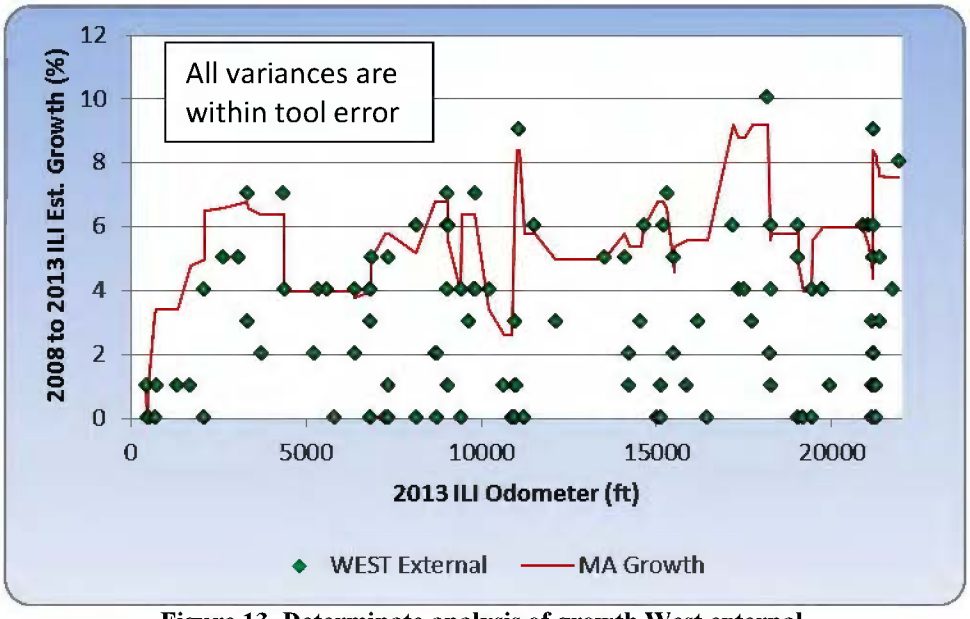


Figure 13. Determinate analysis of growth West external.

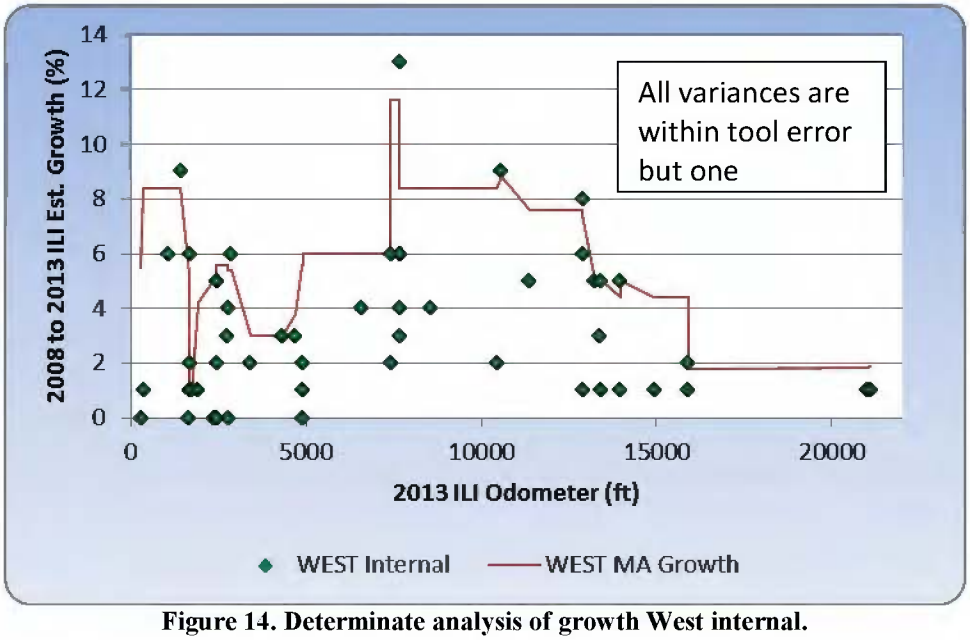


Figure 14. Determinate analysis of growth West internal.

Future Metal Loss Mitigation and MFL Re-inspection Interval

No excavations of metal loss were deemed necessary based on the 2013 MFL inspection sizing and no apparent corrosion growth. Even considering the greatest deviation in depths within all inspections and not allowing for tool tolerance, an extremely conservative growth rate of 0.019 in/yr was determined. Applying this extraordinary rate to the length and depth of each anomaly, the lowest estimated failure pressure of any anomaly after a 10 year growth period is 1350 psi (2.25 safety factor relative to the maximum operating pressure (MOP)). Presently, the 5 year re-inspection interval for metal loss is adequate.

Circumferential Crack Discussion

Ultrasonic (UT) in-line inspections were completed in the east and west segments in 2014 to examine for circumferentially oriented cracking or girth weld misalignment. The NDT UCc and the Oceaneering automated UT (AUT) tools were employed for this, respectively.

The NDT Global UCc tool employs shear wave UT sensors to examine the full length and circumference of the pipeline in high resolution for circumferentially oriented crack-like anomalies. The NDT UCc tool examined the entirety of each full crossing. The circumferential "crack-like" anomalies identified in 2014 were all at the minimum tool reporting depth of 5%, save one at 6%. There were 35 locations delineated, 14 in the East segment and 21 in the West. Sixteen were described as potential notches. Three were excavated for field interpretation and found to be innocuous manufacturing related marks on the pipe; one location is shown in Figure 15. None of these three were noted as possible notch-like.

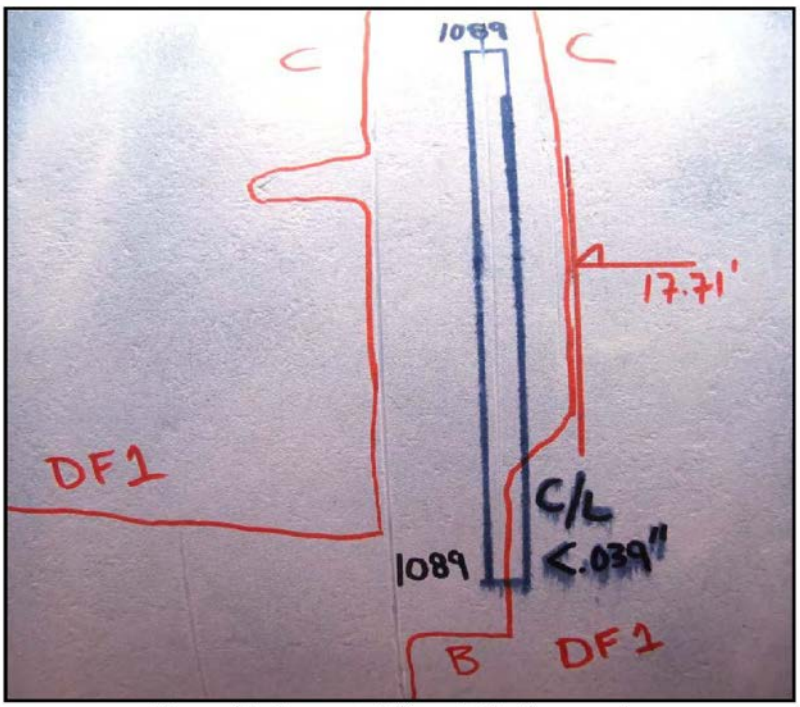


Figure 15. Excavated "crack-like" anomaly.

A fatigue analysis was made employing the most recent years' operating pressures (Figure 16) and considering the dimensions of the crack-like indications. All of the 35 delineated anomalies had a remaining life of greater than 50 years using ASME FFS/API 579. API Recommended Practice 579 (RP579), Fitness-For-Service, provides guidance for conducting Fitness-For-Service (FFS) assessments using methodologies specifically prepared for equipment in the refining and petrochemical industry. FFS assessments are quantitative engineering assessments which are performed to demonstrate the structural integrity of an in-service component such as pipe, containing a flaw or damage. The results of the ASME FFS/API 579 assessment are shown in the Failure Assessment Diagram in Figure 17. All of the anomalies are grouped in a tight area as a result of the similar dimensions, particularly depth, of each "crack-like" anomaly.

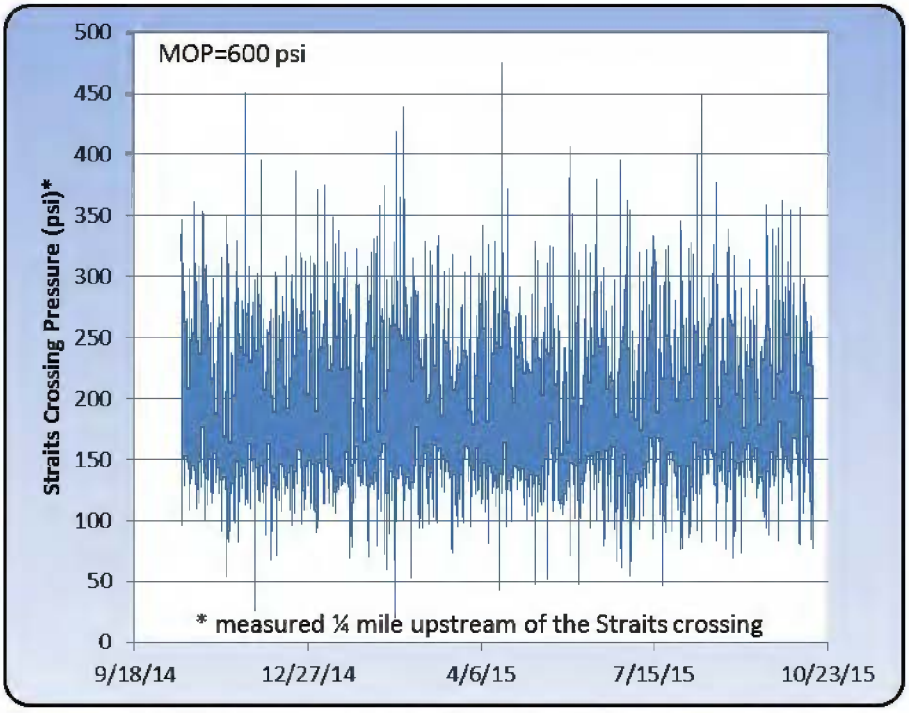


Figure 16. Actual operating pressure of both Straits lines for the period shown.

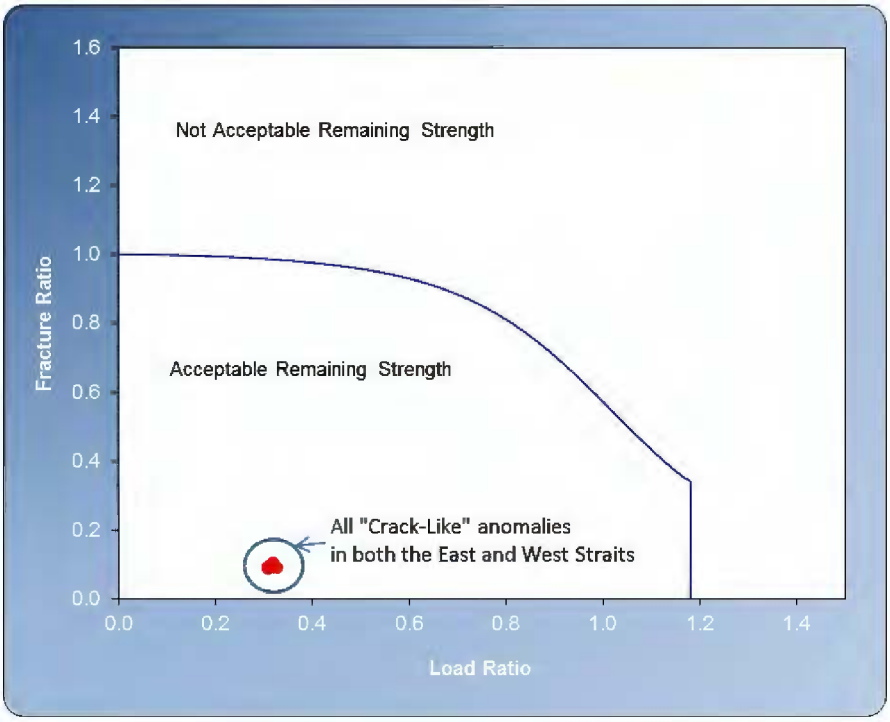


Figure 17. Failure Assessment Diagram of all 35 circumferential "Crack-Like" anomalies in the East and West Straits as identified by the NDT UCc tool.

No further action is deemed necessary based on the NDT UCc findings. Should there be abrupt pipe movement in the future, imparting a high strain on the pipe, it would be prudent to re-inspect for circumferential cracking.

Girth Weld Misalignment

The 2014 Oceaneering AUT tool targeted girth welds having a minimum of 3.2mm misalignment. The inspection of both East and West segments found 2 girth welds with up to a 4.6mm misalignment. This amount of misalignment represents approximately 22% of the actual wall thickness. There are no absolute limits for misalignment in API 1104 provided that the misalignment is distributed evenly around the circumference. It appears to be as the misalignment high-low length is 400mm in length (1/4 of the circumference) and there is no measured ovality at the location. Considering DNV-RP-C203 (2010) "Fatigue Design Of Offshore Steel Structures" (equation 3.3.4) this deviation has a stress concentration factor of 1.01, Appendix A. Meaning that the stress imparted on this misalignment from the operating pressure is 1% higher than a properly aligned butt weld, which is negligible.

Weld misalignment is a function of pipeline construction and therefore is a stable non-growing feature. No further action is deemed necessary.

Deformation Discussion

Five deformation inspections within each crossing were examined with consideration to dent depth, location to welds and their association to corrosion and/or cracking. Table 3 summarizes the details of the five deformation inspections within each crossing. There were no dents >2% depth, no dents with metal loss or on girth welds as detailed in the inspections. Two dents were found to be ≅1.5% depth, with one location potentially containing multiple dents. There were a few ID reduction / ovalities noted in each section. Estimated bend strains were calculated and all have a low estimated strain. The location of the highest noted strain (4.9%) was in a pipe replacement area that has a slight deviation from the original pipe and is not an actual strain. The replacement section is above ground, 16' from the West launcher. The ID restrictions in all but 2 cases have an ID ≥ 17.9", the minimum value set by Enbridge. The two locations have ID's of 17.35" and 17.81". These diameters will not restrict future in-line inspections as is and can be continued to be monitored.

Table 3. Dent summary from previous deformation inspections.

	EAST			*WEST*		
Inspection	**ID Reduction /Ovality**	**# Dents**	**Highest Est. Strain (%)**	**ID Reduction /Ovality**	**# Dents**	**Highest Est. Strain (%)**
1998 PII	-	2	-	-	3	-
2003 BJ Geopig	4	-	0.331	9	-	1.100
2005 BJ Geopig	9	-	0.014	12	-	0.021
2008 GE Calliper	13	-	-	4	-	-
2013 BJ Geopig	5	2	-	12	-	4.900

The location noted in the 2013 Geopig ILI as a multiple dent with a maximum depth of 1.5% has been visually inspected by divers in 2014. At the location there were some markings on the pipe from the banding used during installation of the pipe, there was no corrosion

observed within the disbonded area, and there was no denting, gouging, or scratching identified in the vicinity. Even though the term multiple dent was utilized, there was no sign of multiple apex's by the tool and it is a well-known fact that seamless pipe has a harmless but undulating wall profile. A deflection of 1/3" is all that is required to register a 1.5% deflection.

During the alignment of the various in-line inspections, locations of possible dents interacting with metal loss or crack-like indications were looked for. All of the MFL, UCC and deformation inspections were considered. To which, one possible location of a dent (1998) with metal loss (2003) was found, Table 4. There are no further alignments at this location within any of the more recent inspections. Enbridge has reviewed this location along with the ILI vendor and found that based on the subsequent 7 inspections that there is a manufacturing metal loss indication that has had no change in growth and that there are no indications of denting in the higher resolution deformation tools employed since then. This location is deemed acceptable based on this review.

Table 4. Dent aligned with metal loss run over run.

1998 MFL East					2003 MFL East				
Distance (ft)	Length (in)	Depth %	Clock	Comments	Distance (ft)	Length (in)	Depth %	Clock	Comments
9571.492			8:45	DENT	9606.808	1.2	27	8:30	Int MFG

Pipe Movement Discussion

Pipeline positional information was provided by the BJ Geopig as captured during the deformation inspections. Submeter accurate inertial navigation units are within the ILI to capture the three dimensional movements of the tool. The information provided is a highly accurate geographic location (northing and easting) of specific points such as girth welds.

Comparing previous Geopig inspections to the 2013 data it was found that the greatest horizontal displacement in the data was noted in the East segment (Figure 17) at the end of the inspection and was 163mm (6.4") and in the West segment (Figure 18) at the beginning of the inspection and was 172mm (6.8"). This amount of deviation has been determined to impart less than 0.02% strain as it acts over a long length. Both of these locations are onshore. The 2013 odometers for the greatest deviations are noted in the figures.

The vertical deviations are slightly greater. The greatest vertical deviation in the data was noted in the East segment (Figure 19) at both ends of the inspection with the greatest being 370mm (14.6") and in the West segment (Figure 20) at one third of the inspection length and was 214mm (8.4"). 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. Some of the underwater variations in height may have been corrected during 2014 maintenance in which both segments had new anchor points installed so as to have no unanchored spans greater than 75' in length.

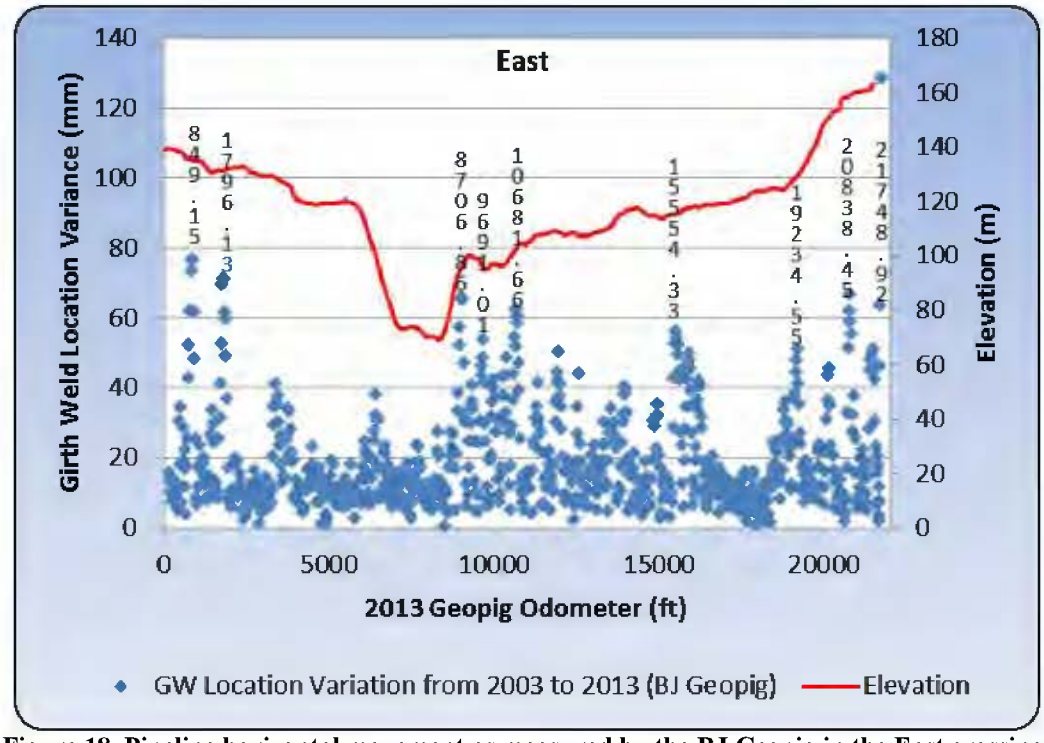


Figure 18. Pipeline horizontal movement as measured by the BJ Geopig in the East crossing.

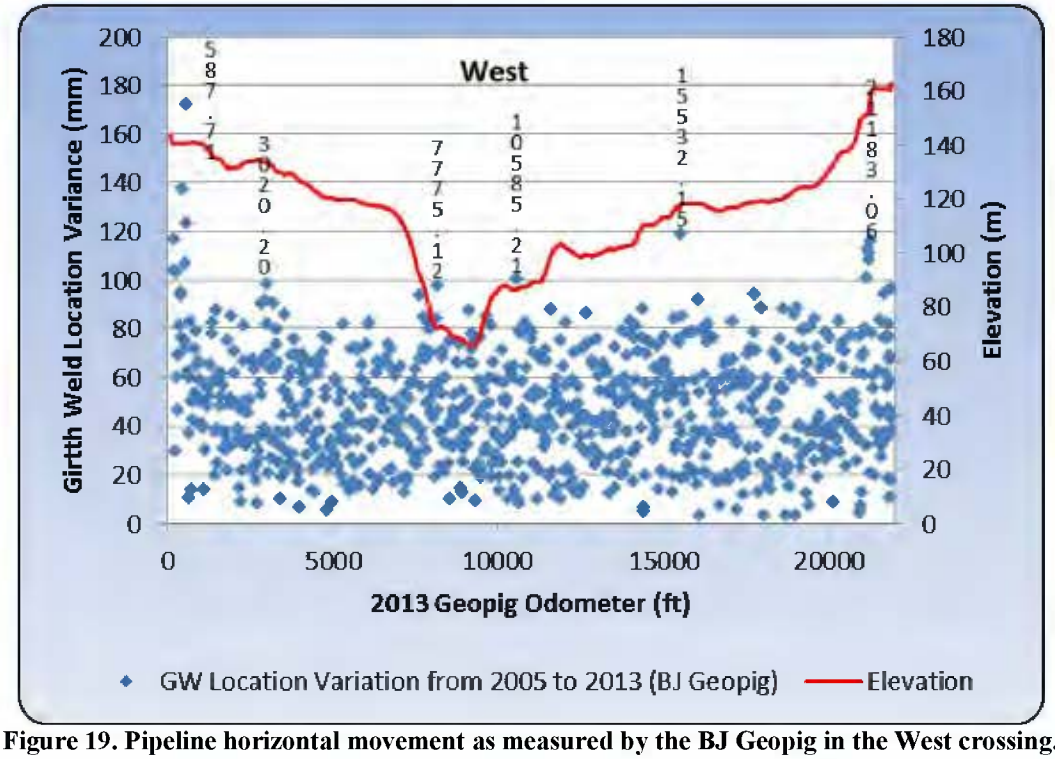


Figure 19. Pipeline horizontal movement as measured by the BJ Geopig in the West crossing.

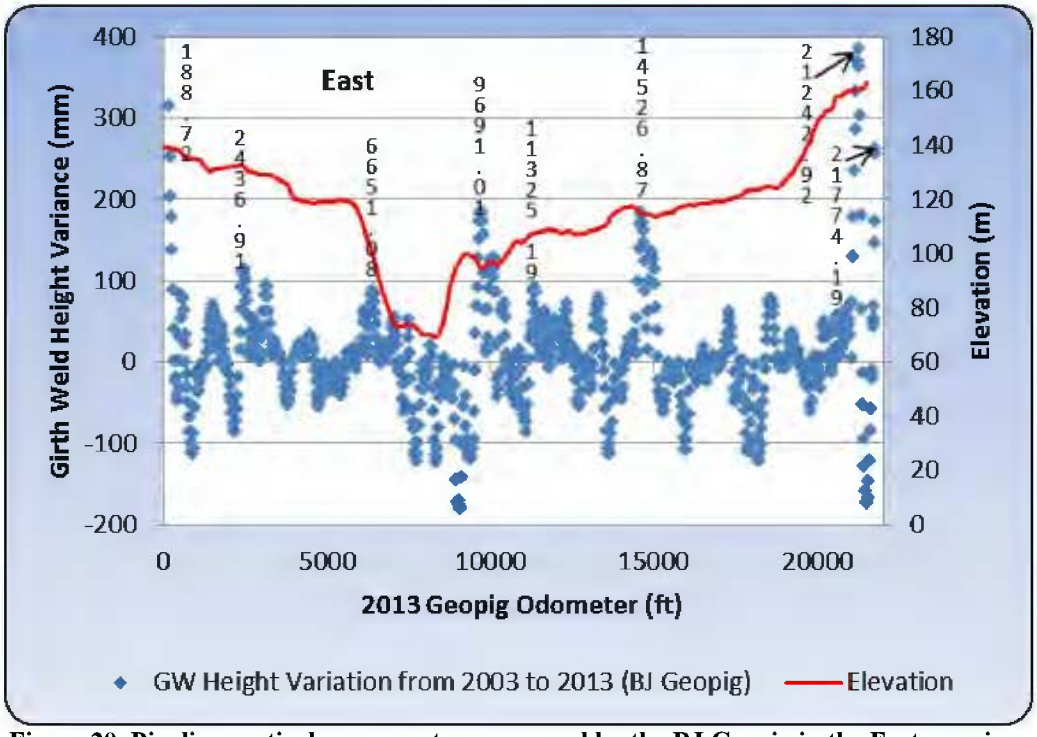


Figure 20. Pipeline vertical movement as measured by the BJ Geopig in the East crossing.

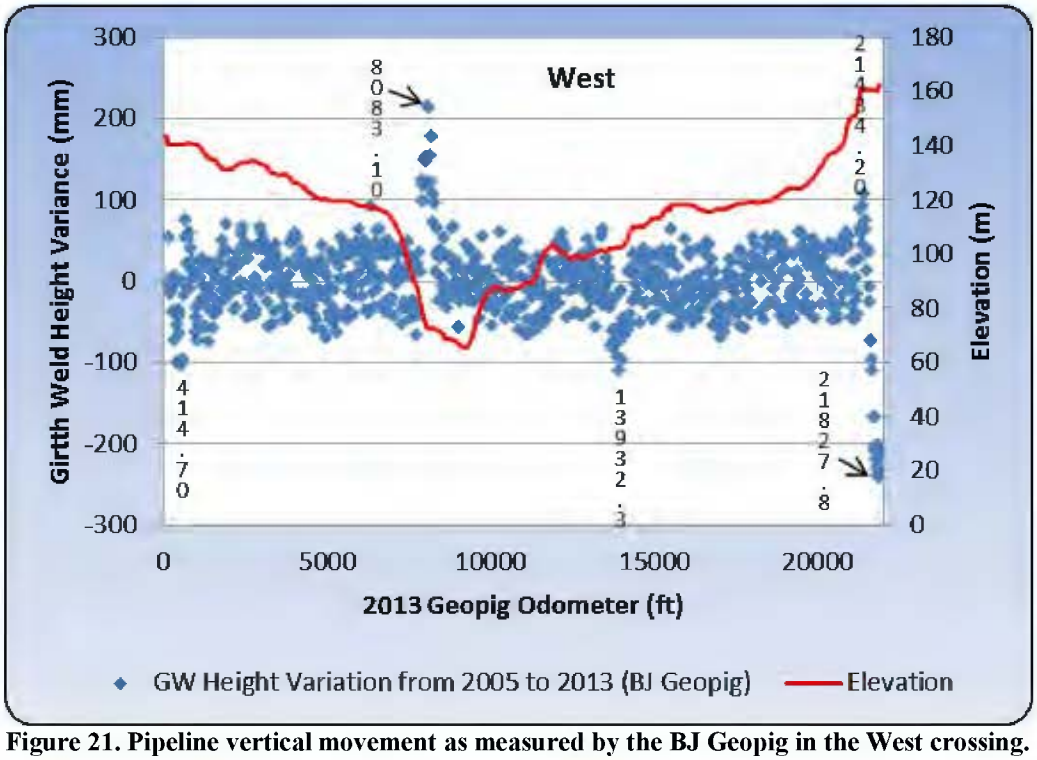


Figure 21. Pipeline vertical movement as measured by the BJ Geopig in the West crossing.

Continued vigilance with respect to pipe movement is warranted. Unless a specific event occurs which may cause pipe movement, the present inspection frequency is appropriate.

Further Discussion to Note

The following points should be considered as they relate to the preparation of this report:

1. A re-inspection for metal loss, deformation and pipe movement is due in 2018. If a specific event occurs which may cause pipe movement or damage, then it may be prudent to inspect prior to 2018 and also include circumferential cracking as a threat to examine for.

2. Specified interaction criteria and remaining strength analysis should continue to be made on all metal loss anomalies including those defined as manufacturing related.

3. No other locations were found to require attention at this time in the East or West Straits with respect to the information supplied.

This review considers anomalies as delineated by MFL, deformation and specific UT tools; no other threats outside the scope of the ILI tools utilized or areas of possible concern were considered. The threats that the ILI tools considered in this report are metal loss (corrosion), deformations including dents, buckles and ovalities, pipe movement, circumferential crack-like anomalies, and girth weld misalignment.

Please refer again to the disclaimers noted on page 2.

APPENDIX A – Girth Weld Misalignment Stress Calculation

DNV-RP-C203 (2010) "Fatigue Design Of Offshore Steel Structures" (equation 3.3.4)

$$SCF = 1 + \frac{6(\delta_t + \delta_m - \delta_0)}{t} \cdot \frac{1}{1 + \left(\frac{T}{t}\right)^{\beta}} e^{-\alpha}$$

$SCF = Stress\ Concentration\ Factor$
$\delta_t = Pipe\ wall\ transition\ thickness\ variance = 0\ in\ this\ case$
$\delta_m = Misalignment\ depth = 4.6mm = 0.181"$
$\delta_0 = 0.1\,t = 0.1\,(0.812) = 0.0812"$
$t = Wall\ thickness = 0.812"$
$T = Thicker\ pipe\ wall\ thickness\ if\ this\ were\ a\ transition\ \therefore in\ this\ case\ \left(\frac{T}{t}\right)^{\beta} = 1$
$D = Diameter$
$L = Misalignment\ Length = 400mm = 15.75"$

$$\alpha = \frac{1.82L}{\sqrt{Dt}} \cdot \frac{1}{1 + \left(\frac{T}{t}\right)^{\beta}}$$

Solving for SCF

$$SCF = 1 + \frac{6(0 + 0.181 - 0.0812)}{0.812} \cdot \frac{1}{1+1} e^{-\frac{1.82(15.75)}{\sqrt{20(0.812)}} \frac{1}{1+1}}$$

$$SCF = 1.01$$