

Integrity Diagnostics

Span Length Change Estimation: Parts I and II

Version #: <1.0>
Version Date: <11/27/2017>

Document Version Register

Version Number	Version Date	Details of Version
<1.0>	11/27/2017	Initial Document

Current Version: <1.0>

Completed by: [redacted]
Signature: _____ Date: _____

Reviewed by:
Signature: _____ Date: _____

Executive Summary

The probability of a span length increase on the East Line and West Line to be greater than 20 feet on clay-clay and 80 feet on sand-sand touchdown have been estimated using historical inspection results (2010-2016). The analysis is specific to ground condition (sand-to-sand and clay-to-clay) and location (East and West Line). The results are presented in Sect. 3.0, Table 2 and repeated below for convenience.

Ground Condition	Threshold	East	West
Sand-to-Sand	80 ft.	7.17e-9	3.6e-8
Clay to Clay	20 ft.	1.81e-6	2.40e-11

Table of Contents

1.0 Background 1

2.0 Methodology 1

3.0 Results 2

4.0 References 2

Appendix I: Distribution Fitting Details for Sand-Sand Ground Condition [2] 3

Appendix II: Distribution Fitting Details for Clay-Clay Ground Condition [2] 3

Appendix III: Cumulative Distribution Functions [2] 4

1.0 Background

A two year interval is proposed for span length inspections along the East and West Straits of Mackinac. To support the proposal, previous span length inspection results have been reviewed and a probability of exceedance (POE) analysis was used to estimate the likelihood of different span length growth amounts. The analysis was specific to sand to sand and clay to clay touchdown ground conditions and optimized for increases in span length.

2.0 Methodology

The estimation of the span length change was completed using a probability of exceedance calculation based on a distribution model of the inspection data. The data for the span lengths were from varying inspection periods. From 2010 to 2016, inspections were at two year intervals using sonar imagery to calculate span changes. However, from 2005-2007, the inspections were annual with no inspections between the period of 2007 to 2010. The data collected in this period were through visual analysis of remotely operated vehicle (ROV) video data, a method that was less precise than sonar imagery according to the underwater inspection contractor [1]. Therefore, only data from 2010 to 2016 was used for the likelihood estimates. Table 1 summarizes the statistical details of the datasets used in this analysis. Appendix 1 presents the total data used in the form of histograms.

Table 1. Summary statistics of historical datasets used in analysis

East / West	Ground Condition	# of Span Locations	# of Length Measured	Max Increase	Average Change	Standard Deviation of Change
East	Sand-to-Sand	29	72	22 ft.	2.06 ft. decrease	8.83 ft.
East	Clay to Clay	34	92	11 ft.	0.72 ft. decrease	4.47 ft.
West	Sand-to-Sand	37	93	28 ft.	0.51 ft. decrease	7.49 ft.
West	Clay to Clay	24	57	9 ft.	2.75 ft. decrease	9.61 ft.

The distribution fits were performed using @Risk™ software and optimized based on the upper tail to focus on positive span length changes. With the length change data modeled, the likelihood of exceeding a specified threshold value, q, can be estimated using the following expression,

$$P(X > q) = 1 - F(x = q)$$

where $F(x = q)$ is the cumulative distribution function of the modeled historical data evaluated at q. See Appendix I to III for distribution fitting details.

3.0 Results

In this work, two span length change thresholds have been assessed: 20 feet for clay to clay and 80 feet for sand to sand ground conditions. The probability of the span length change exceeding these distances are presented in Table 2 below.

Table 2. Likelihood estimates for span length changes exceeding threshold.

Ground Condition	Threshold	East	West
Sand-to-Sand	80 ft.	7.17e-9	3.60e-8
Clay to Clay	20 ft.	1.81e-6	2.40e-11

4.0 References

1. C.Bauer, "2016 Straits of Mackinac Pipeline Inspections and Maintenance Projects: Enbridge Energy Superior, WI", Report for Enbridge by Ballard Marine Construction, Inc., 2016.
2. Palisade Corporation, "@Risk User Guide: Risk Analysis and Simulation Add-In for Microsoft Excel", Version 6, 2013.

Appendix I: Distribution Fitting Details for Sand-Sand Ground Condition [2]

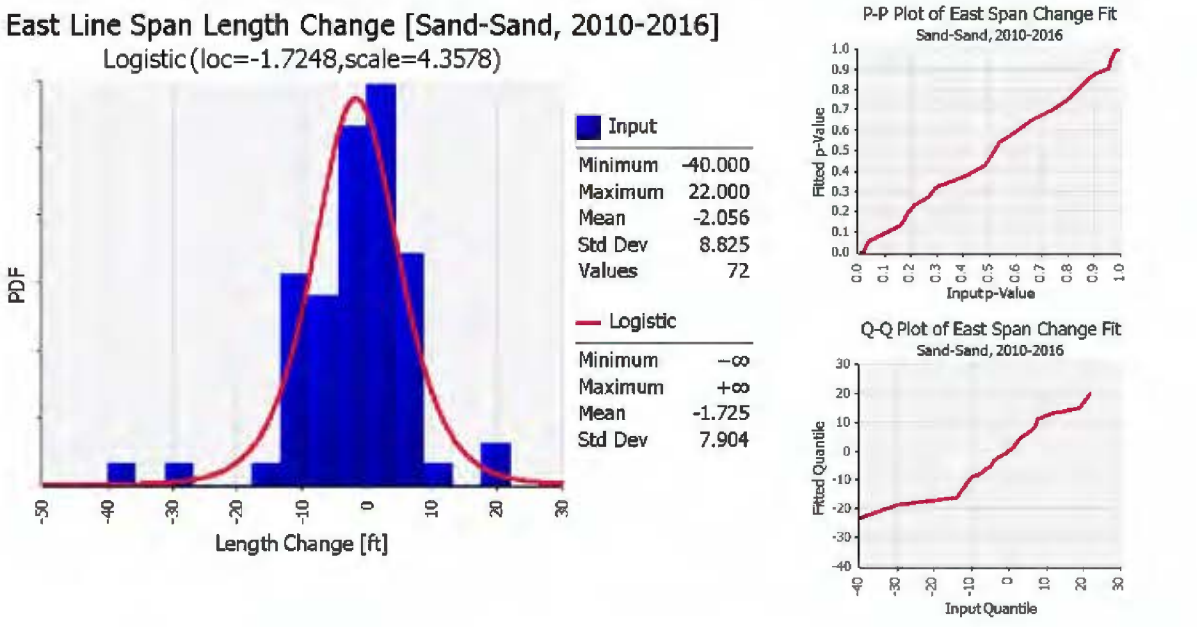


Figure 1. East Line span length change on sand-sand ground condition (2010-2016)

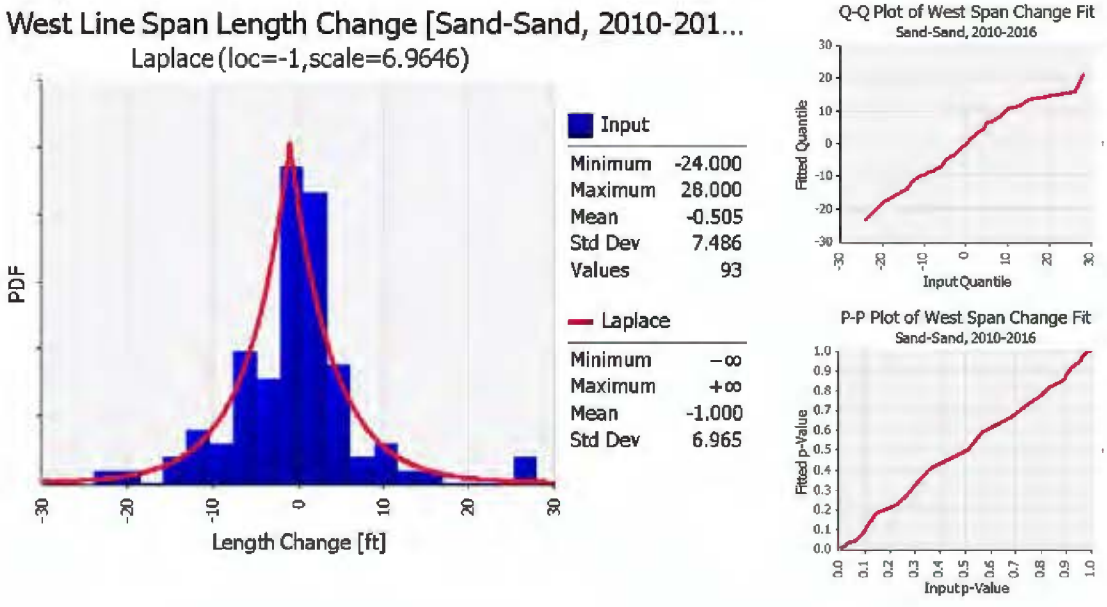


Figure 2. West Line span length change on sand-sand ground condition (2010-2016)

Appendix II: Distribution Fitting Details for Clay-Clay Ground Condition [2]

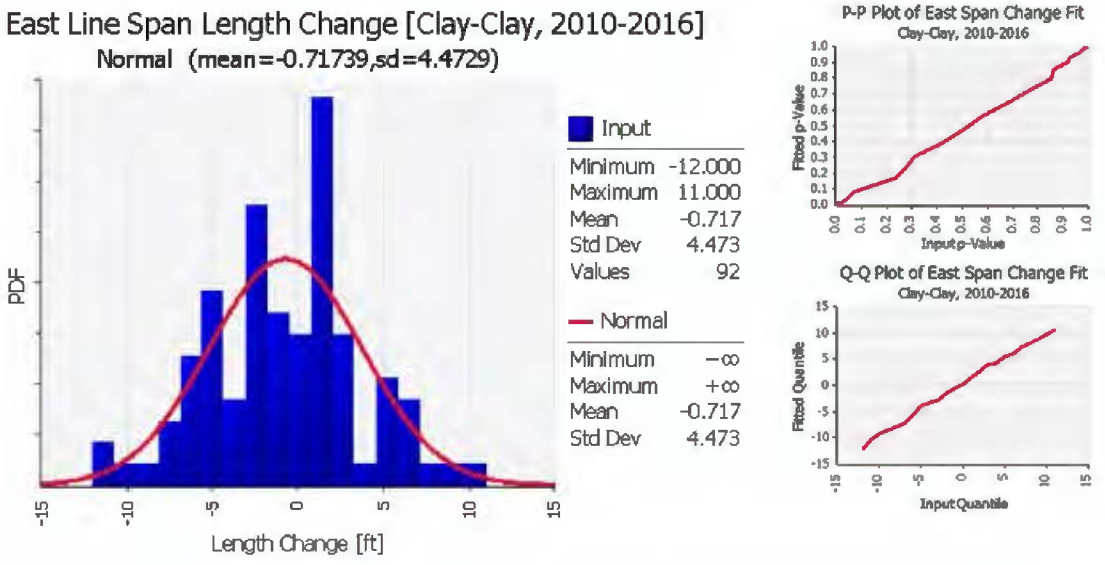


Figure 3. East Line span length change on clay-clay ground condition (2010-2016)

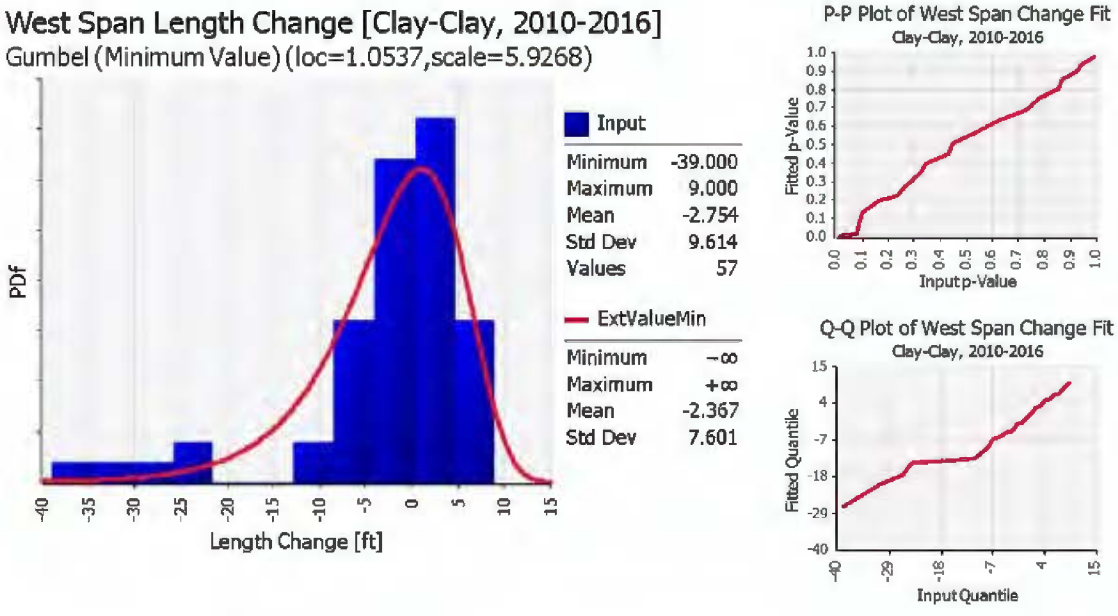


Figure 4. West Line span length change on clay-clay ground condition (2010-2016)

Appendix III: Cumulative Distribution Functions [2]

Normal

$$F(x) \equiv \Phi\left(\frac{x-\mu}{\sigma}\right) = \frac{1}{2}\left[\operatorname{erf}\left(\frac{x-\mu}{\sigma\sqrt{2}}\right) + 1\right]$$

μ = continuous location parameter

σ = continuous scale parameter

Logistic

$$F(x) = \frac{1 + \tanh\left(\frac{1}{2}\left(\frac{x-\alpha}{\beta}\right)\right)}{2}$$

α = continuous location parameter

β = continuous scale parameter

Laplace

$$F(x) = 1 - \frac{1}{2}\exp\left(-\sqrt{2}\left|\frac{x-\mu}{\sigma}\right|\right)$$

μ = continuous location parameter

σ = continuous scale parameter

Gumbel (Minimum Extreme Value)

$$F(x) = 1 - \exp\left(e^{(x-\alpha)/\beta}\right)$$

α = continuous location parameter

β = continuous scale parameter

<End of Document>