the Energy to Lead

gti

ADDENDUM REPORT NUMBER 2
GTI PROJECT NUMBER 21874
Contract Number: DTPH56-15-T-00006

Characterization and Fitness for Service of Corroded Cast Iron Pipe

Addendum Report #2 – Geospatial Example

Report Issued
December 31, 2018

Prepared For
U.S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration
Office of Pipeline Safety
Chris McLaren
chris.mclaren@dot.gov

Technical Team
Daniel Ersoy
Ernest Lever
Oren Lever
Khalid Farrag
Brian Miller

Project Manager
Kristine Wiley
R&D Director, GTI
kristine.wiley@gastechnology.org

Technical Contact
Daniel Ersoy
R&D Executive Director, GTI
daniel.ersoy@gastechnology.org

Gas Technology Institute
1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018

SIGNATURE PAGE

			Date
CO-AUTHOR			
Daniel A. Ersoy		Daniel Ersoy//S//	12/31/2018
	Title:	R&D Exec. Dir. and PI	
CO-AUTHOR			
Ernest Lever		Ernest Lever//S//	12/31/2018
	Title:	R&D Dir.	
REVIEWED BY			
Kristine Wiley		Kristine Wiley//S//	12/31/2018
	Title:	R&D Dir. and PM	

LEGAL NOTICE

TABLE OF CONTENTS

Page

SIGNATURE PAGE i

LEGAL NOTICE ii

TABLE OF CONTENTS iii

LIST OF FIGURES iii

LIST OF TABLES iv

EXECUTIVE SUMMARY 1

Simulation of a Cast Iron Gas Distribution Network 2

Geospatial Database 2

References 16

LIST OF FIGURES

Page

Figure 1. Coastline extracted from GSSHS 2

Figure 2. Concentric coastal buffer zones: Coastal buffer, Sand, Loam, Clay, Rock 3

Figure 3. Rectangular pipeline grid 3

Figure 4. Allocation of pipe sizes 4

Figure 5. Distribution for input parameters 5

Figure 6. Coarse geographic regions 6

Figure 7. Geographic sub-regions 6

Figure 8. Average Stress Probe 7

Figure 9. Full system - calculated safety factors 9

Figure 10. 1% sampling of region – calculated safety factors 9

Figure 11. Simulation results 1% sampling left, 2% sampling right 10

Figure 12. Histogram of ave. flaw stress in [ksi] per segment (all segments) 11

Figure 13. Histogram of safety factor for ave. flaw stress 11

Figure 14. Histogram of lines with safety factor < 1.4 12

Figure 15. Histogram of strength class with safety factor < 1.4 12
Figure 16. Histogram of vintage with safety factor < 1.4........ 13
Figure 17. Histogram of sub-region with safety factor < 1.4 13
Figure 18. Histogram of region with safety factor < 1.4 14
Figure 19. Histogram of diameter with safety factor < 1.4........ 14
Figure 20. Histogram of diameter with 1.6 < safety factor ≤ 2.0........ 15

LIST OF TABLES

Page

Table 1. Allocation of Pipe Sizes: Counts per size and Totals 4

EXECUTIVE SUMMARY

The project final report, “Characterization and Fitness for Service of Corroded Cast Iron Pipe” dated February 15, 2018 provided a Cast Iron (CI) Fitness-For-Service (FFS) model, calculator, and method for operators to characterize and grade graphitic corrosion defects on cast iron natural gas pipe. The project deliverables will help make monitoring, repair, and replacement decisions, as well as prioritize their replacement program decisions leading to improved safety and supply stability.

The Technical Advisory Panel (TAP) suggested that the project expand the applicability of the calculator solution to include larger diameter pipe, 20-inch and larger, which several of them are currently using. Another suggestion was to provide a full geo-spatial implementation example showing the solution applied to a cast iron network with rankings for an accelerated mains replacement program.

These revised and new project deliverables are provided in four additional files in addition to the previously distributed project Final Report:

1. DTPH56-15-T-00006_**FinalReport**_2018-02-15, original final report.
2. DTPH56-15-T-00006_**Addendum-01**_2018-12-31, which describes the expanded (larger diameter pipe inclusion) model development.
3. **[THIS REPORT]** DTPH56-15-T-00006_**Addendum-02**_2018-12-31, which uses the model solution and applies it to a geo-spatial scenario for accelerated mains replacement.
4. DTPH56-15-T-00006_**Model_Calculator_v0.3**_2018-12-31, which includes the expanded model use case range for larger diameters. The v0.3 is the first version released under the project.
5. DTPH56-15-T-00006_**Calculator_Training_Manual_v0.3**_2018-12-31, which explains how to use the calculator.

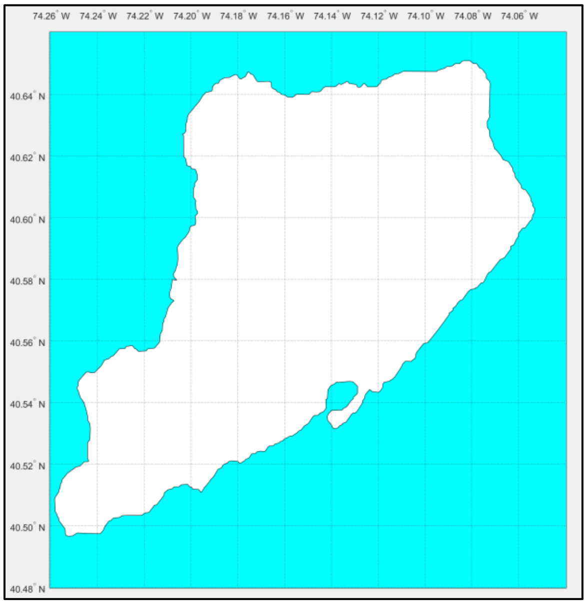
Simulation of a Cast Iron Gas Distribution Network

The Cast Iron Fitness-For-Service model described in the main body of this report forms an ideal basis for a simulation tool that can display aggregate system performance in a geospatial database. This simulation tool can provide the operator risk-informed geospatial input into their mitigation programs. The tool can also be extended to temporal consideration of future repair/replace programs.

Geospatial Database

Staten Island was chosen as a conveniently sized and well contained geographic region to build the synthetic database. The coastline of Staten Island was extracted from the Global Self-consistent, Hierarchical, High-resolution Shoreline (GSSHS) database compiled by Wessel et. al. [1]. The coastline is shown in Figure 1.

Figure 1. Coastline extracted from GSSHS

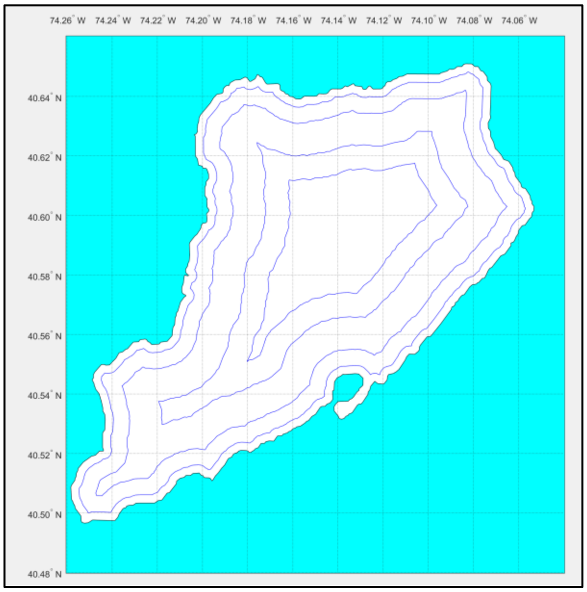


Several buffer-zones were generated internal to the shoreline prior to laying a synthetic gas distribution pipeline system:

1. A coastal buffer approximately 1000 feet from the shoreline
2. A sand zone,
3. A loam zone,
4. A clay zone, and
5. A rock zone.

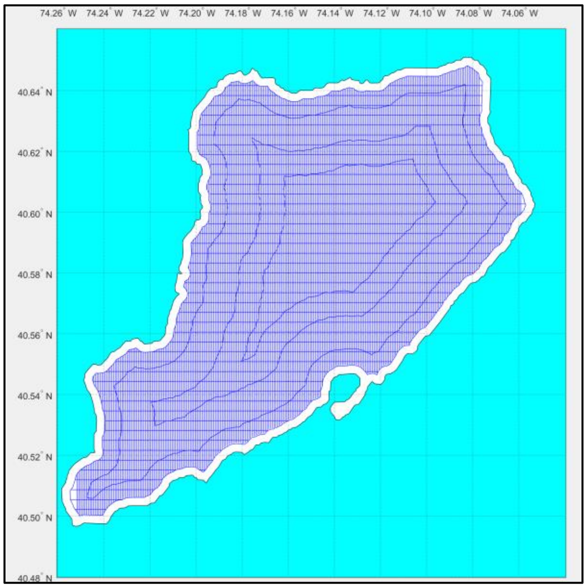
These zones are used to determine the soil density for the soil=loading calculations and to ensure that pipelines do not extend into the sea. The zones are shown in Figure 2.

Figure 2. Concentric coastal buffer zones: Coastal buffer, Sand, Loam, Clay, Rock



The entire island internal to the coastal buffer was divided into a rectangular grid utilizing the dimensions of a standard Manhattan city block, 264' x 900'. The resultant grid is shown in Figure 3.

Figure 3. Rectangular pipeline grid



The rough allocation of pipe sizes is shown in Figure 4. A large north-south main line shown as 32” in the figure was upsized to 36” in the final allocation. Smaller mains of 12” were allocated in the north-south direction with 6” for the remaining north-south lines. A 24” east-west main was allocated with the remaining lines a mixture of 8” and 4” sizes.

Table 1 summarizes the number of lines, segments and length per pipe size as well as the totals for each metric.

Figure 4. Allocation of pipe sizes

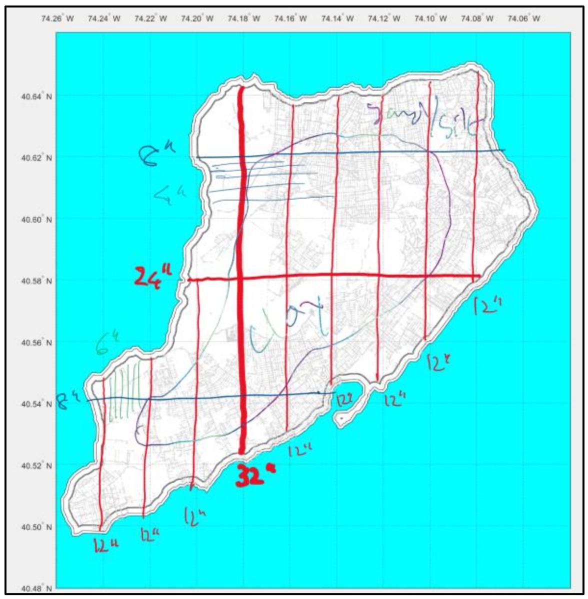


Table 1. Allocation of Pipe Sizes: Counts per size and Totals

	4 inch	6 inch	8 inch	12 inch	24 inch	36 inch	Totals
Lines	39	277	9	13	1	1	340
Segments	41,330	288,188	8,302	9,460	1,065	1,355	349,700
Length [ft]	495,960	3,458,256	99,624	113,520	17,040	21,680	4,206,080

Each segment was generated independently with the orientation in x- horizontal axis, y-depth axis varying randomly within specified tolerances. The nominal depth of cover was set to 4.5 feet with a tolerance of ± 1.5 foot.

Each pipe segment thus has a unique average depth of cover. The density of the soil cover was set in accordance with the calculator values for sand, clay and gravel in accordance with the soil type regions described above. Traffic loading was applied in accordance with the calculator values for rail, highway and none.

Probability distribution for the proportion of pipe with defects and the width, length and depth of the defects were generated and are shown in Figure 5. The defect size bounds correspond to the ranges for the calculator.

The pipes were grouped into 20 coarse geographic regions. The regions were assigned vintages in the range 1911 – 1960 with each region spanning 2 ½ years of vintage range. Tensile strength distributions were generated that accurately match the distributions covered in the main body of the report.

Values for each parameter were randomly drawn from the appropriate probability distribution on a segment by segment basis. Variability was introduced for specific lines in specific geographic regions. Corrosion rate was adjusted in a subset of 200 sub-regions. The geographic regions and sub-regions are shown in Figure 6 and Figure 7.

Figure 5. Distribution for input parameters

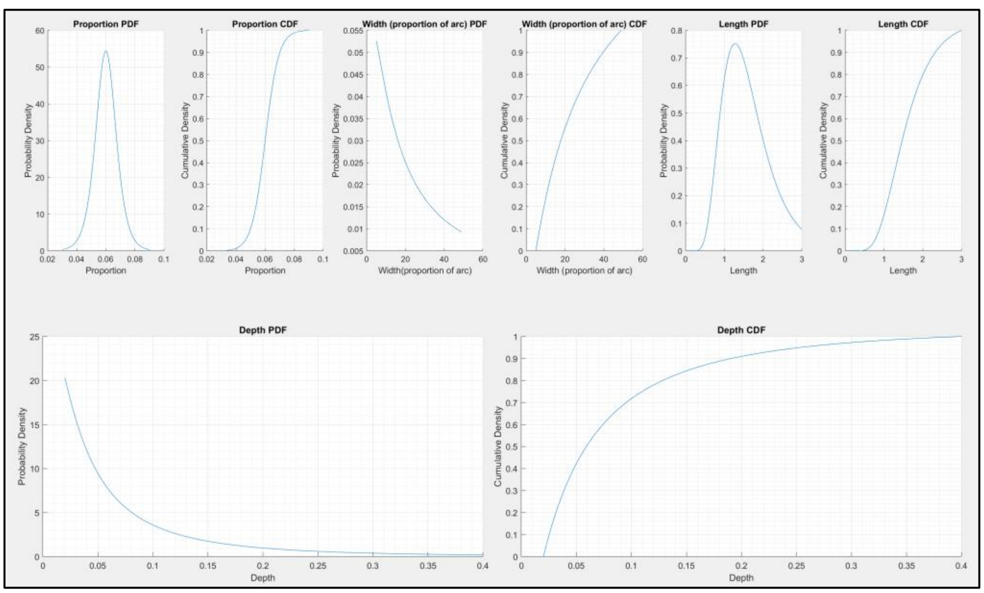


Figure 6. Coarse geographic regions

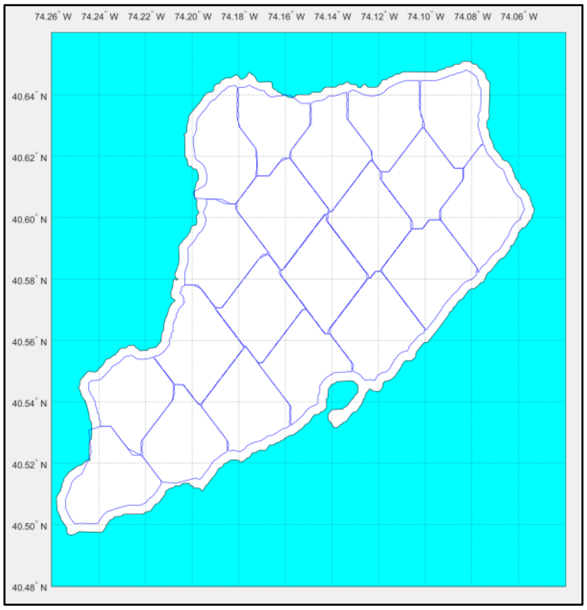


Figure 7. Geographic sub-regions

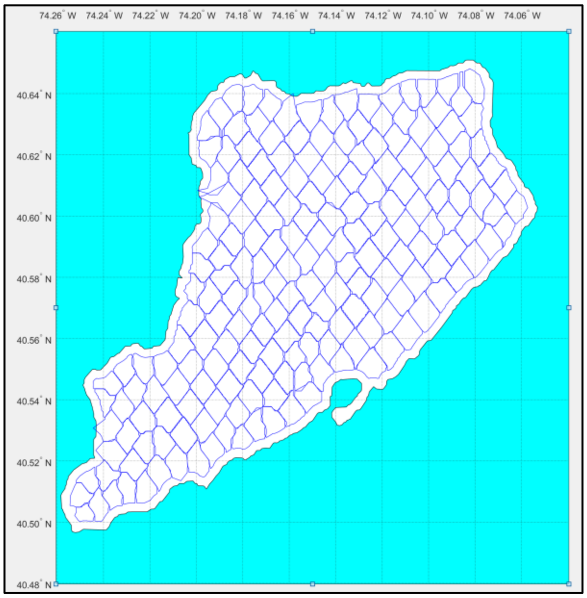
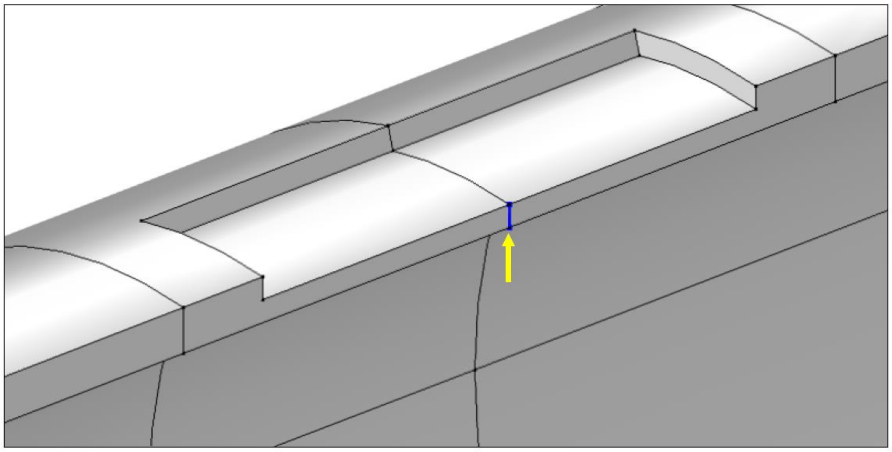


Figure 11 shows the results of a full simulation run. The plots show a 1% sampling of the 349,700 segments next to a 2% sampling of the same results. The results of separate samplings at each of the two sampling rates are shown overlaid on the soil type regions, geographic regions and geographic sub regions.

The result shown is the factor of safety relative to the average flaw stress as defined in the main report Figure 98, Figure 8.

Figure 8. Average Stress Probe



(Figure 98 in main report) - Radial line (highlighted in blue) at center of flaw for average stress probe (model cross-section shown for illustration)

The factor of safety is the average stress from the calculator model for free pipe ends divided by the segment tensile strength. The plots in Figure 9 show a large filled red circle for all segments with a factor of safety less than or equal to 1.4. Smaller orange filled circles depict a factor of safety in the range $1.4 < FS \leq 1.6$ and the smallest green filled circles depict a factor of safety in the range $1.6 < FS \leq 2.0$.

Figure 9 is a plot of the entire system calculated safety factors. Figure 10 and Figure 11show the results from random samplings of the region using 1% and 2% sampling rates. It can clearly be seen in the plots that the sampling picks up the pre-1920 pit cast pipe, lines with reduced corrosion resistance due to morphology and sub-regions with corrosive environments due to local soil conditions.

The three factor of safety ranges can be used to prioritize mitigation programs. They also reflect the temporal aspect of corrosion: Red -current problem segments, Orange can be expected to be problematic in the short term, Green can be expected to be problematic in the medium term.

Figure 12 shows the histogram of the average flaw stress across all segments. It is clearly a complex distribution of stresses indicating that multiple factors are interacting to produce the result. Figure 13 shows the distribution of safety factors due to these stresses. The safety factors reflect the tensile strength of the individual segments. The distribution is highly skewed.

Figure 14 through Figure 19 show histogram plots of the likelihood of safety factor ≤ 1.4 conditioned on: line number, strength class, vintage, sub-region, region and diameter.

It is immediately apparent that strength class of 10 ksi, which is highly correlated with pre=1920 pit cast pipe, is the dominant risk factor. Four-inch diameter is pipe most likely to have a low safety factor. The regions that had pipe installed pre-1920 are obviously the riskiest regions. There are several sub-regions that can be identified as having more corrosive environments, and there is a well-defined set of lines that are high risk.

The breakdown remains essentially unchanged for 1.4 < safety factor ≤ 1.6. The first noticeable difference can be seen in the range 1.6 < safety factor ≤ 2.0, where the histogram for likelihood by diameter is distinctly different as shown Figure 20. In this safety factor range 6” pipe has the greatest probability of being present.

The analyses presented here are a small sub-set of the possible analyses that can be conducted on database generated by the simulation. It is clear that the results match actual system behavior quite well and that combining this simulation approach with historical leak and repair histories will provide a powerful tool for forensically understanding past events and improving the predictive capabilities of the analysis for future system states.

Figure 9. Full system - calculated safety factors

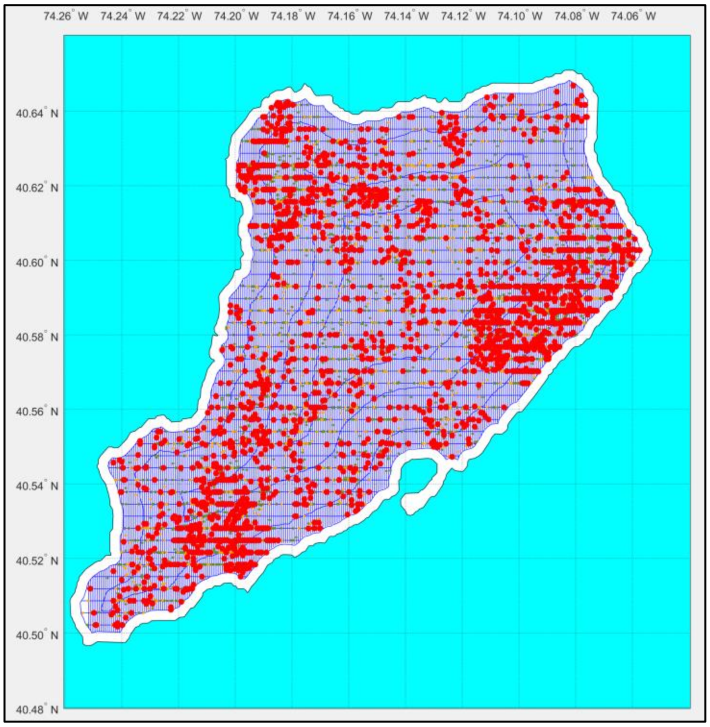


Figure 10. 1% sampling of region – calculated safety factors

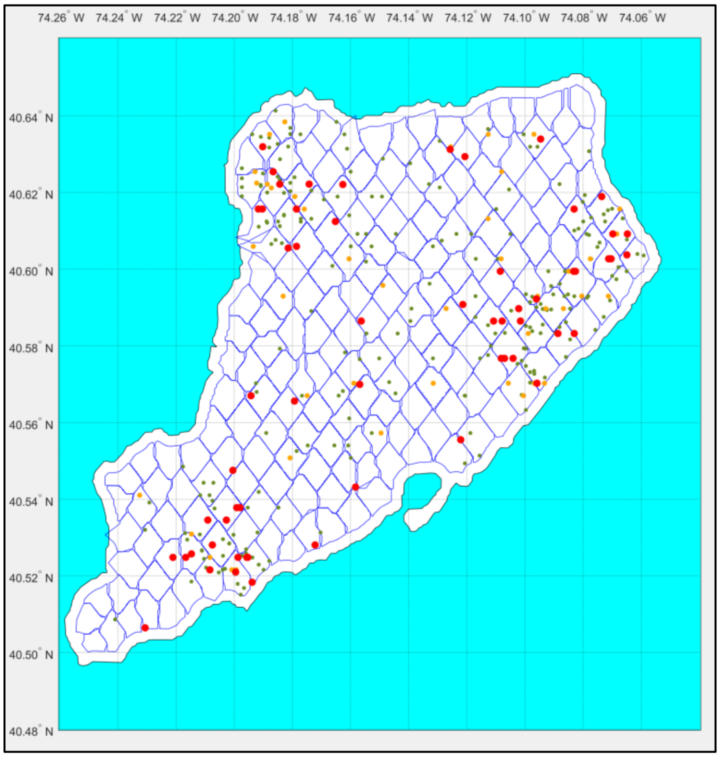


Figure 11. Simulation results 1% sampling left, 2% sampling right

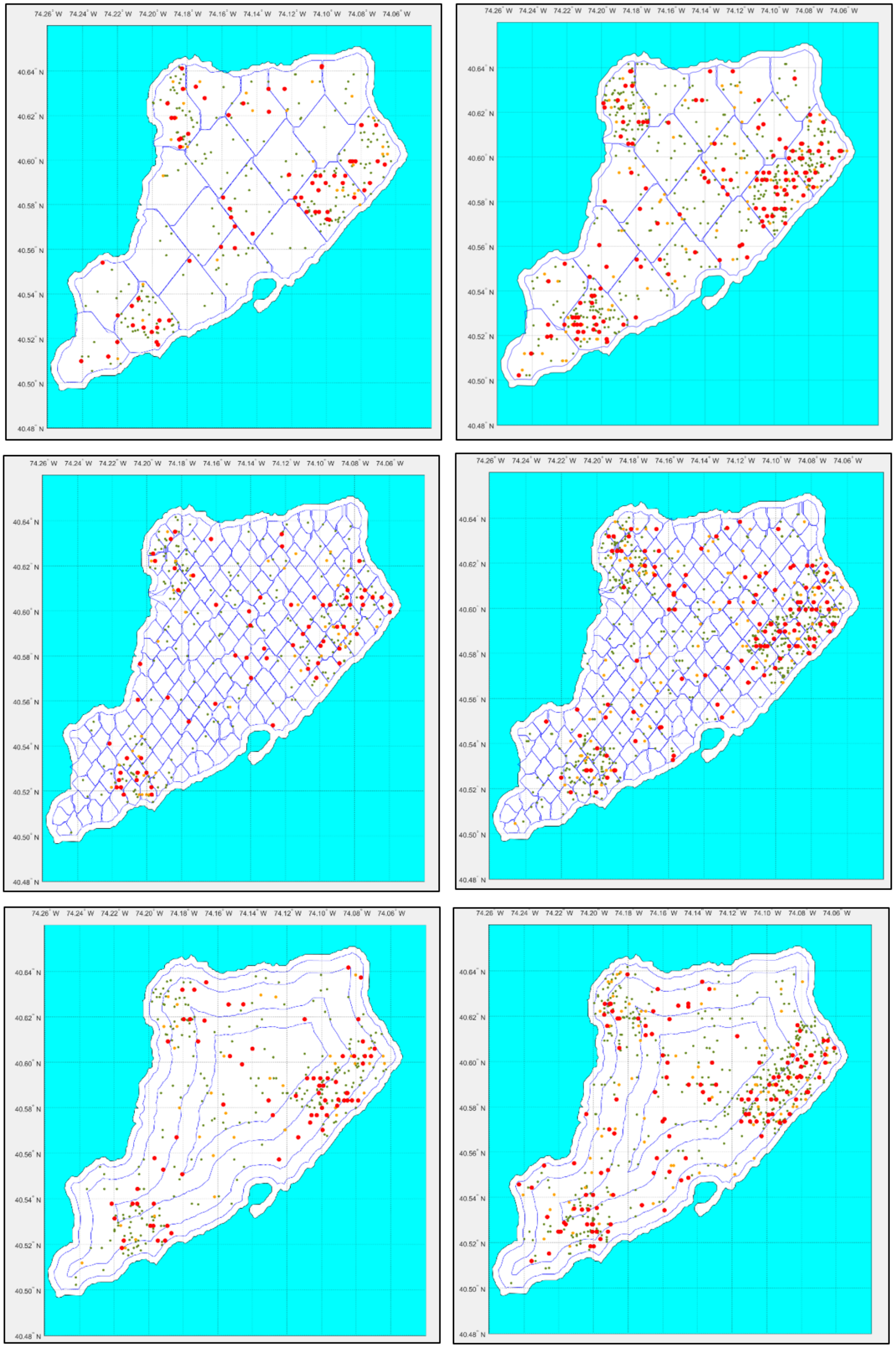
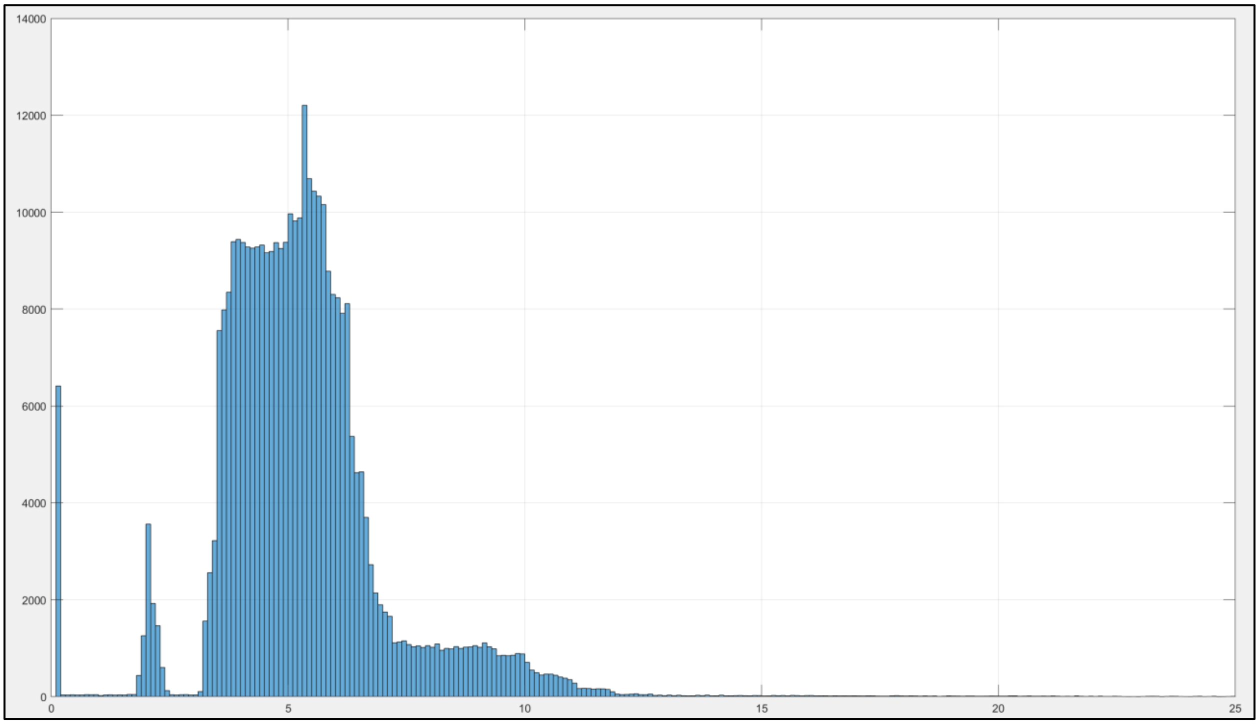
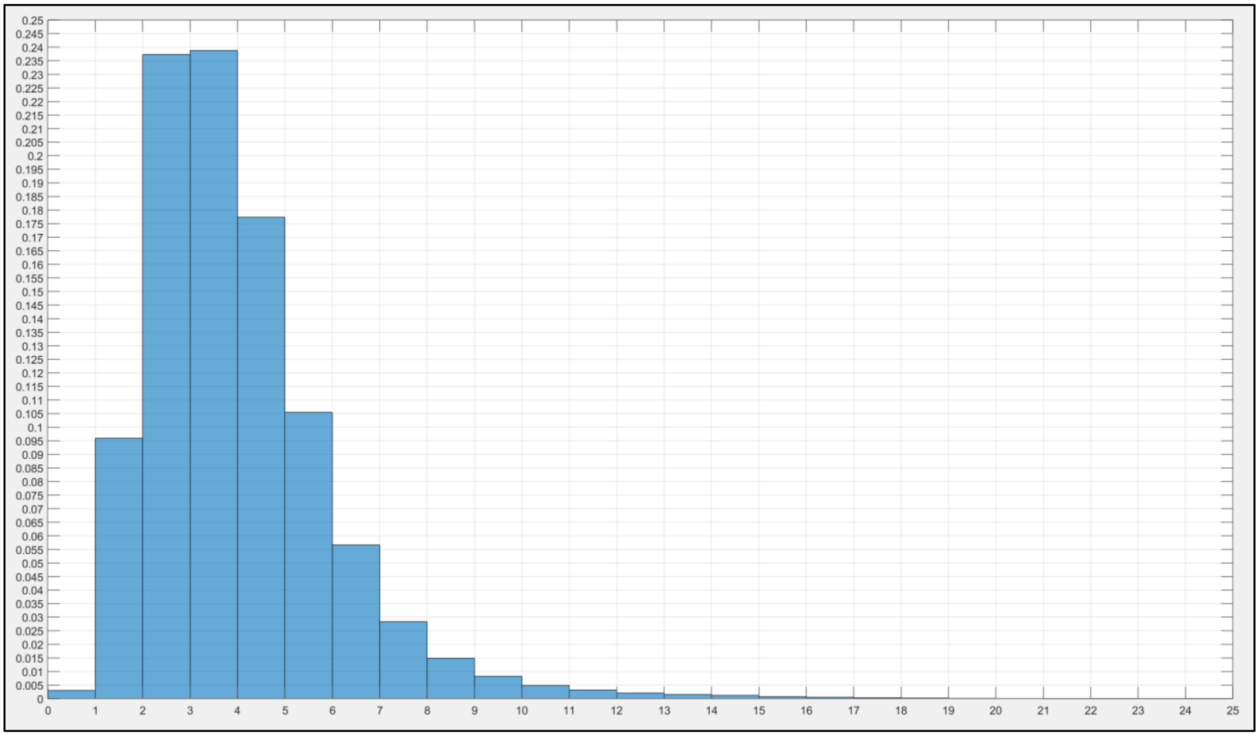


Figure 12. Histogram of ave. flaw stress in [ksi] per segment (all segments)



X-axis flaw stress in ksi; y axis segment count

Figure 13. Histogram of safety factor for ave. flaw stress.



X- axis SF; Y - axis probability density

Figure 14. Histogram of lines with safety factor < 1.4

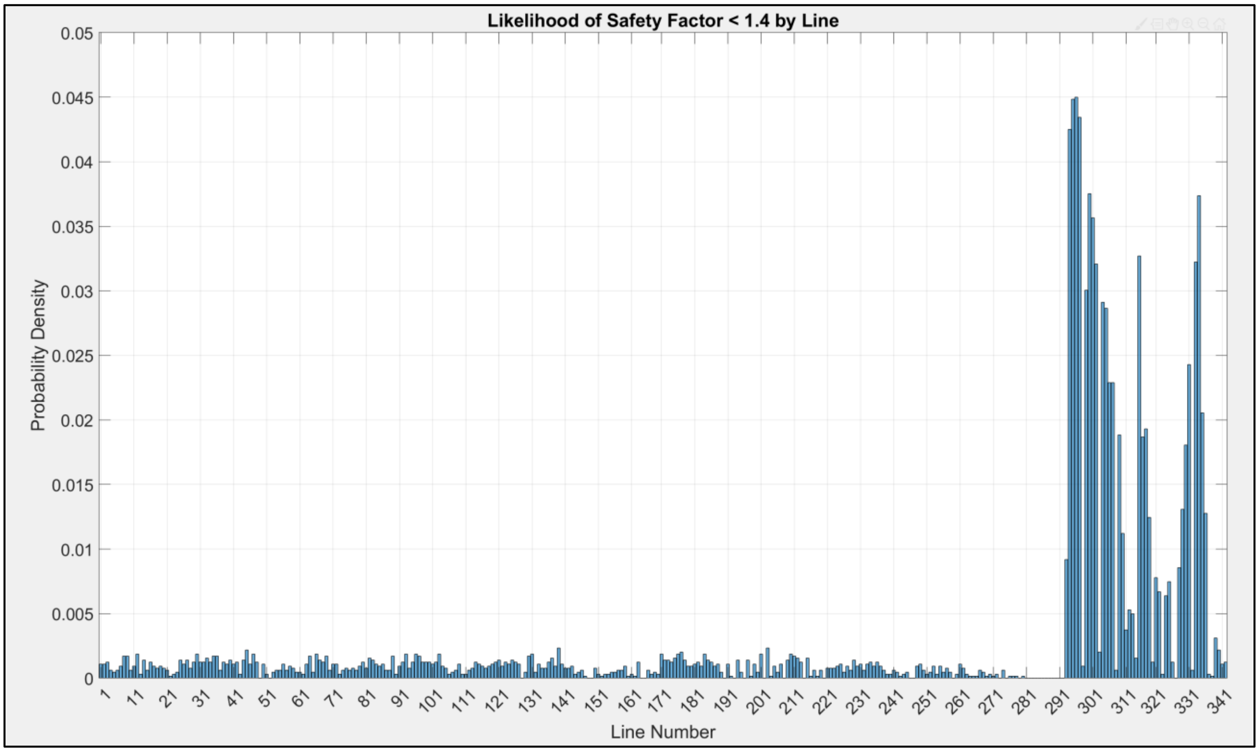


Figure 15. Histogram of strength class with safety factor < 1.4

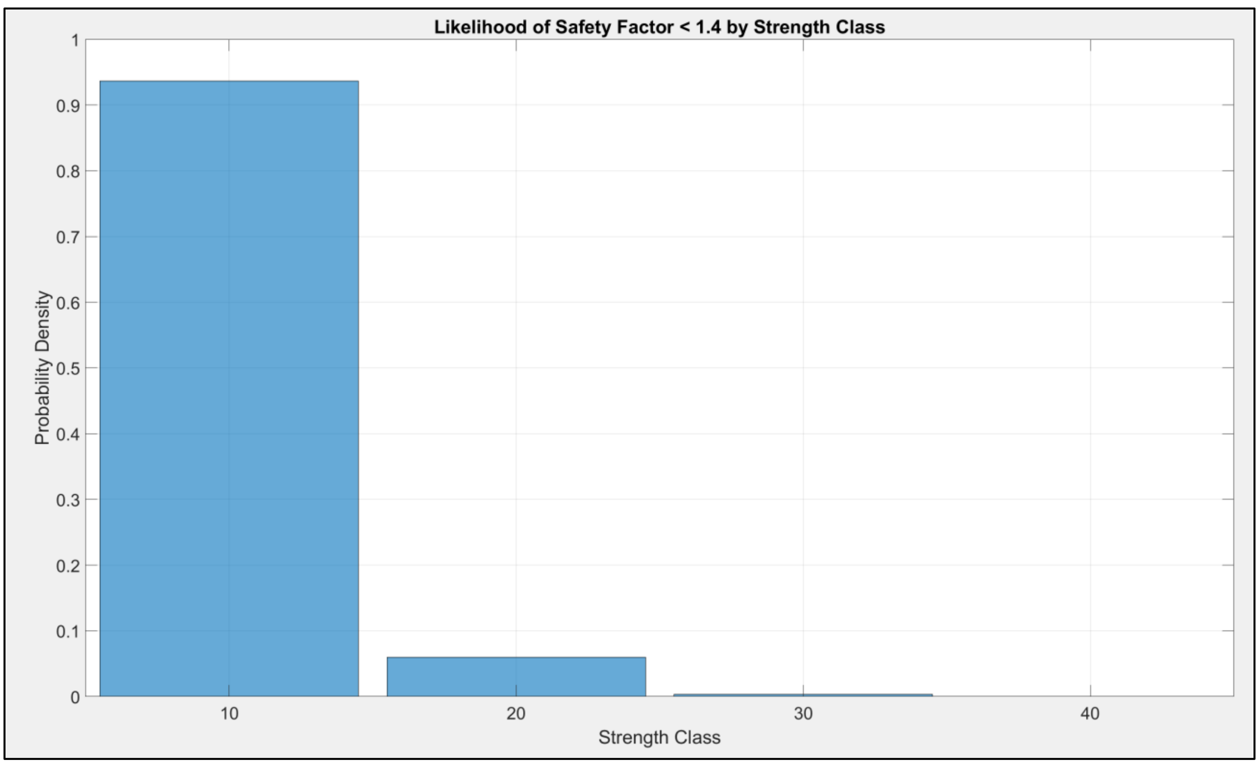


Figure 16. Histogram of vintage with safety factor < 1.4

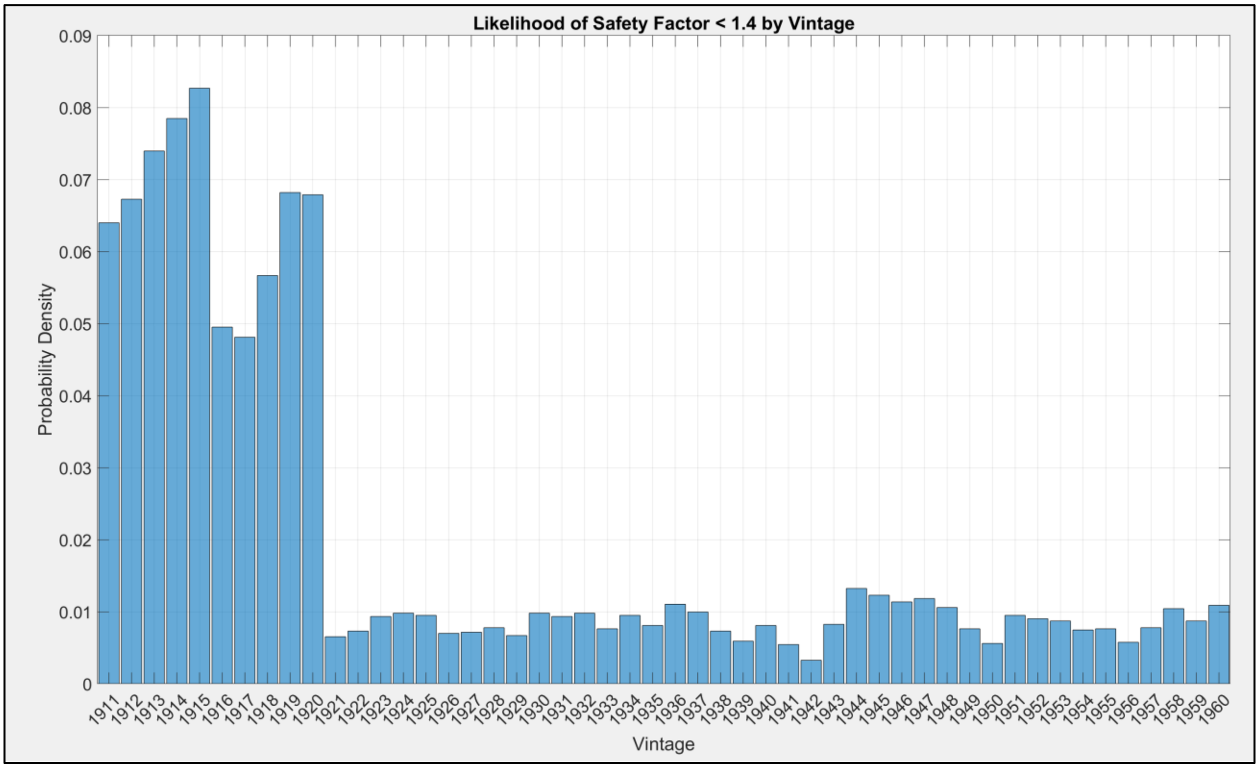


Figure 17. Histogram of sub-region with safety factor < 1.4

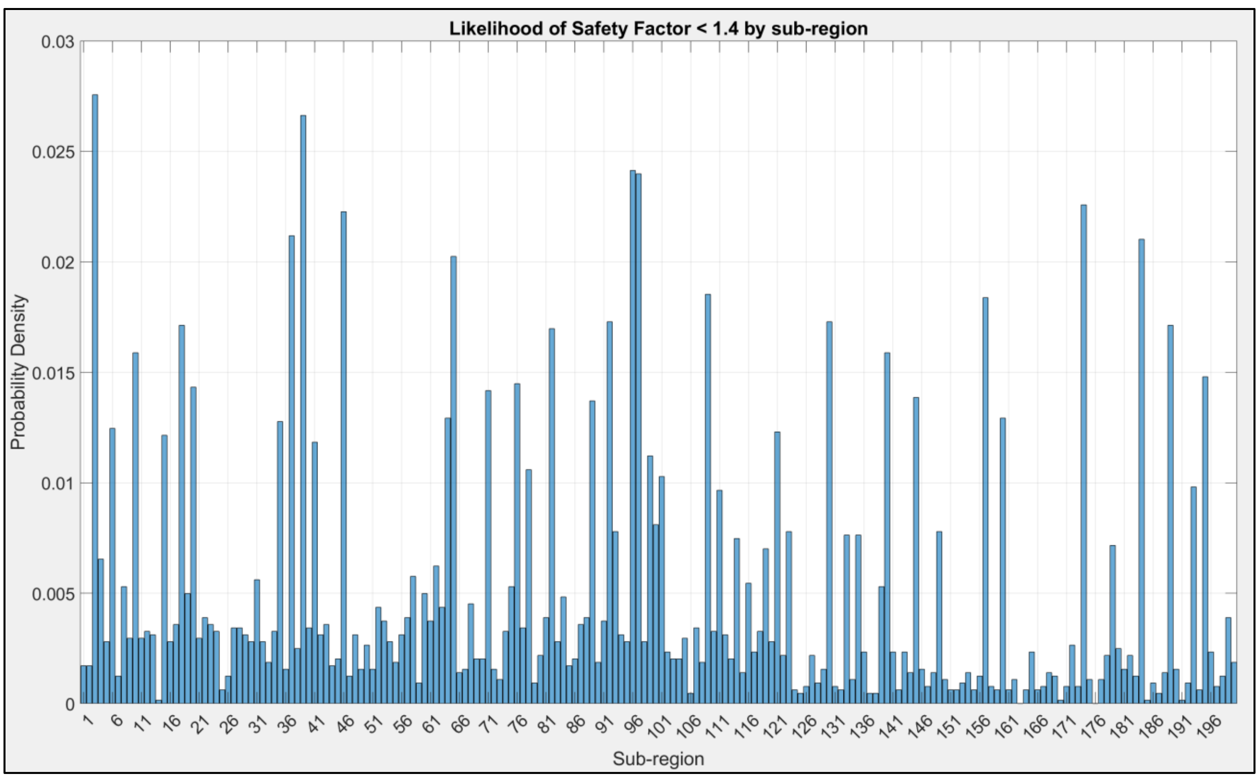


Figure 18. Histogram of region with safety factor < 1.4

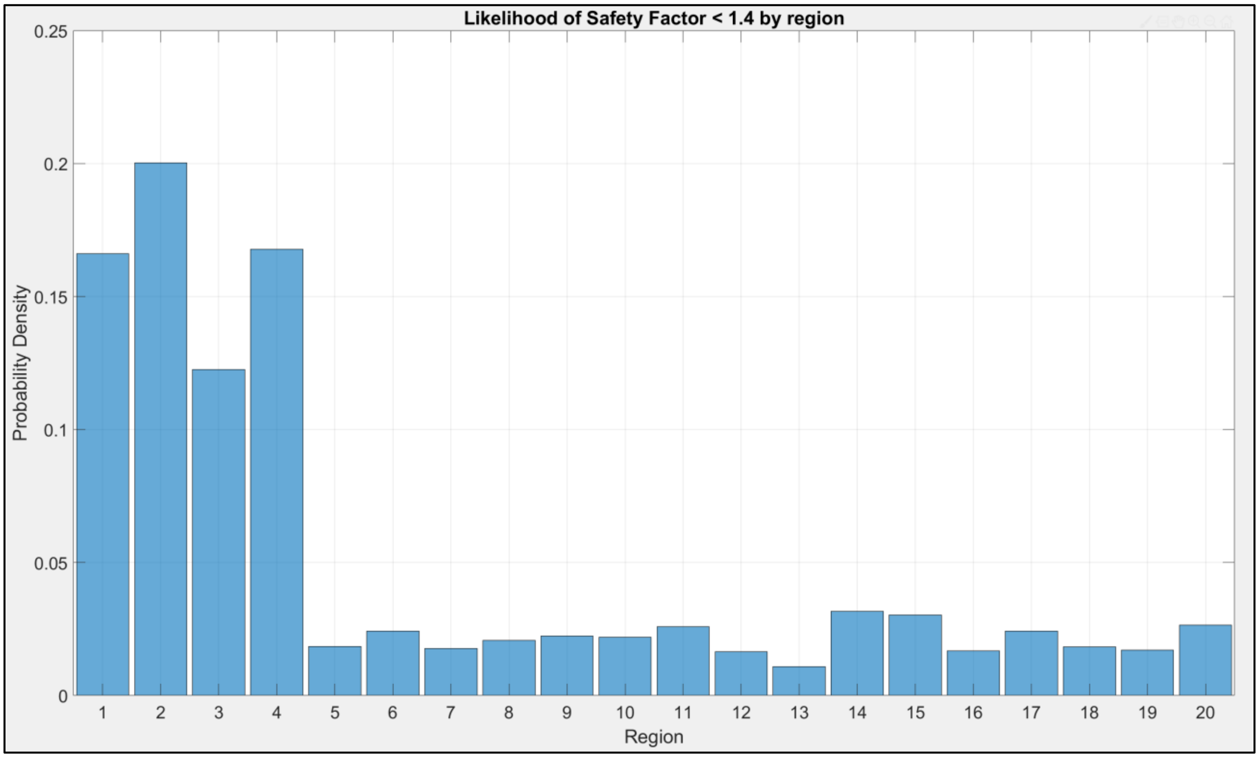


Figure 19. Histogram of diameter with safety factor < 1.4

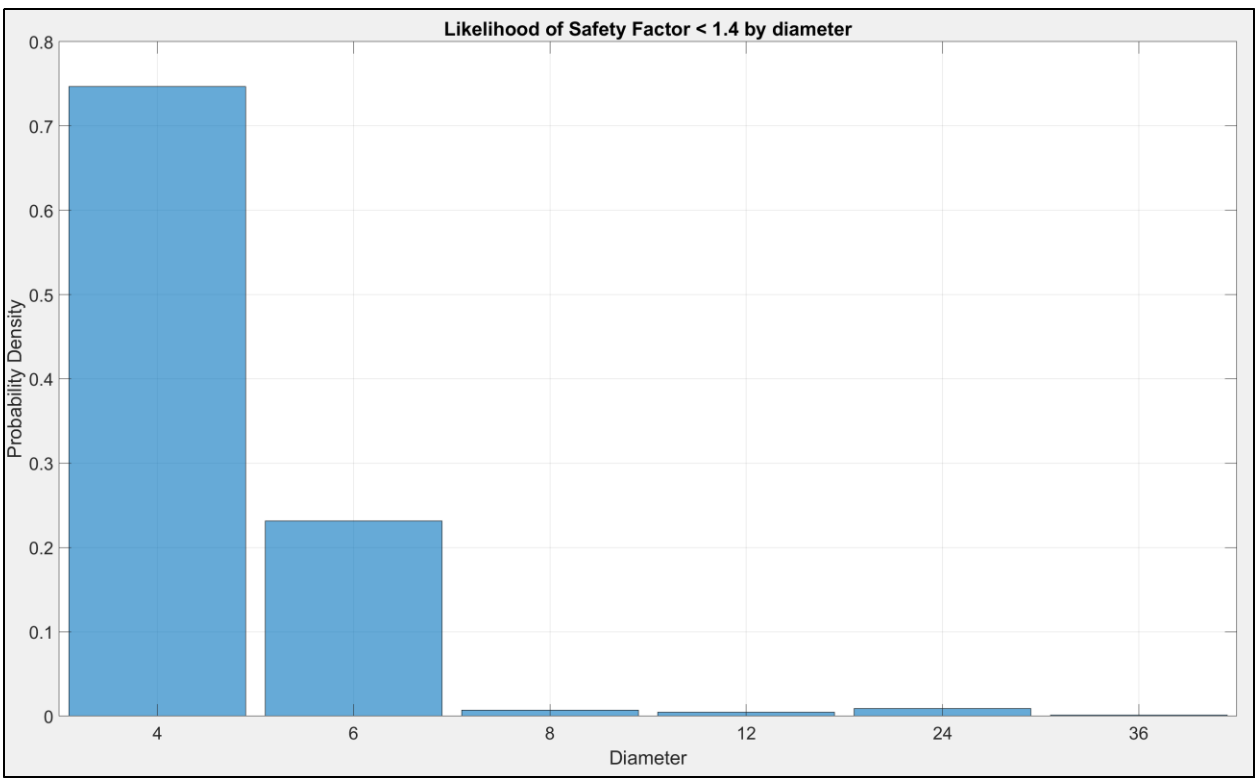
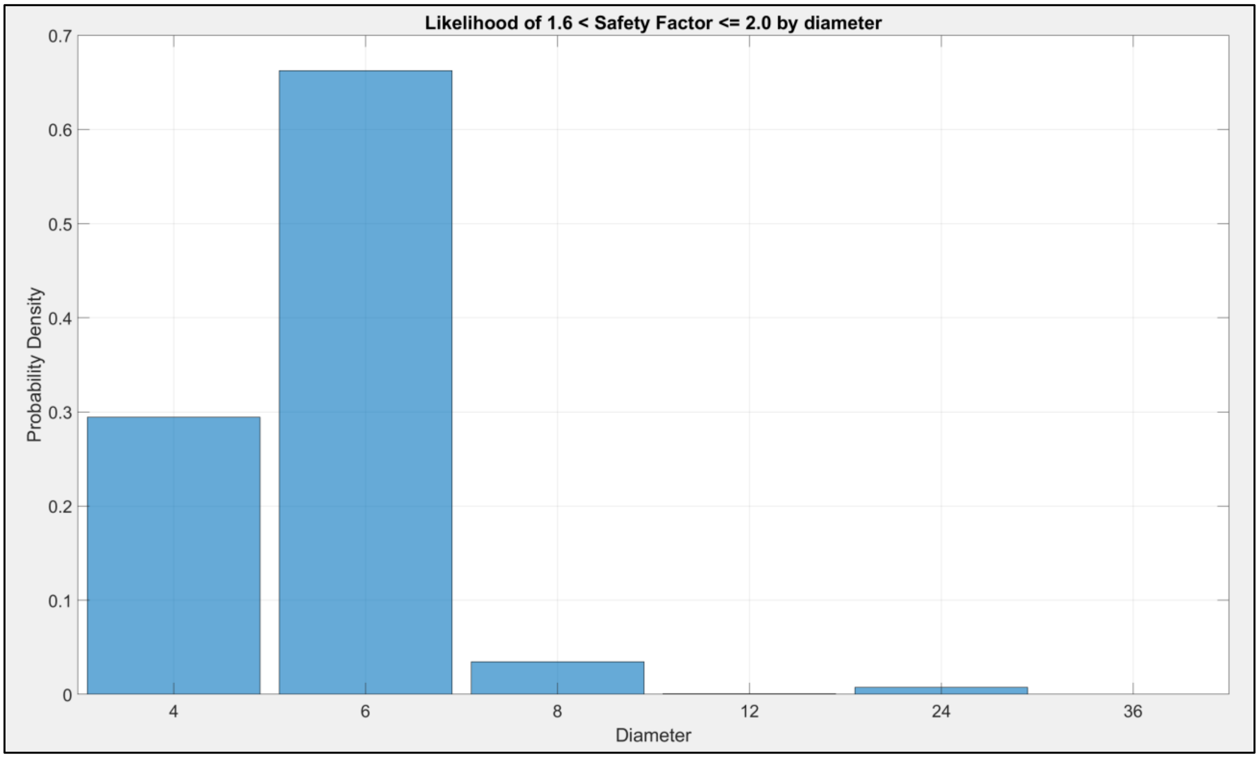


Figure 20. Histogram of diameter with 1.6 < safety factor ≤ 2.0



References

1. Wessel, P. and W.H.J.J.o.G.R.S.E. Smith, *A global, self-consistent, hierarchical, high-resolution shoreline database.* 1996. **101**(B4): p. 8741-8743.

End of Addendum Report