Corrosion Analysis of Duckbill, Manta Ray, and Stingray Earth Anchors

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Introduction

This document presents an analytical method to predict the residual strength of Manta Ray, Stingray and Duckbill anchors after exposure to underground corrosion. The analytical method developed broadly and conservatively categorizes soils as Moderate or Aggressive depending upon resistivity, pH, Chlorides, Sulfates and Aeration. Calculations for various exposure times are made for the following anchors:

- Galvanized ductile iron Manta Ray anchors
- Stainless steel Manta Ray anchors
- Galvanized ductile iron Stingray anchors
- Duckbill anchors with galvanized steel cable
- Duckbill anchors with stainless steel cable

Brief General Summary

Galvanized Ductile iron Stingray anchors retain 94 percent of the original strength after 50 year exposure to Moderate soils.

Galvanized Ductile iron Manta Ray MK-B, MR-SR, MR-1, MR-2 anchors retain 89 percent of the original strength after 50 year exposure to Moderate soils.

Stainless Steel Manta Ray anchors retain 100 percent of their original strength after 100 year exposure to Moderate soils.

Stainless Steel Manta Ray anchors retain 99 percent of their original strength after 100 year exposure to Aggressive soils.

Duckbill 68,88,138 anchors equipped with galvanized steel cable retain 55,66, and 70 percent respectively of their original strength after 2 year exposure to Moderate soils.

Duckbill 68,88,138 anchors equipped with AISI 304 stainless steel cable retain 91, 94, and 95 percent respectively of their original strength after 5 year exposure to Aggressive soils.

Duckbill 68,88,138 anchors equipped with AISI 316 stainless steel cable retain 91, 95, 97 percent respectively of their original strength after 10 year exposure to Aggressive soils.

Analysis Introduction

Underground corrosion of structural members is a significant phenomenon and must be accounted for in any responsible civil engineering design. This document presents an analytical method for the prediction of the residual strength of Manta Ray, Stingray and Duckbill anchors due to material loss from underground corrosion. Use of this analytical method will allow a designer to reasonably estimate and evaluate the residual strength at the end of the design life of the structure. This in turn will allow the designer to select and specify the proper anchors, materials, and installation methods.

Basic analytical concept

The method presented predicts material loss and pit depth as a function of exposure time for different materials and 2 conservative and broad categories of soils. The residual strength is calculated by stress analysis of the remaining material at the end of the selected exposure time.

References and development of analytical method:

Primary References used:

1) Underground Corrosion, Melvin Romanoff, National Bureau of Standards, Circular 579, Washington DC, 1957.
2) Durability of Reinforced Earth Structures using Galvanized Steel Reinforcing Strips, Reinforced Earth Corporation Publication.

Reference 1 presents the results of a comprehensive long term experiment involving burial of test specimens in numerous soils followed by excavation, and examination. The specimens were weighed before and after the experiment to measure their loss of material and maximum pitting depth was measured. Numerous materials including bare ferrous materials, galvanized ferrous materials, chrome-nickel (stainless) steels, aluminum and copper were tested among many others. An analytical prediction method is presented which calculates both the weight loss and pit depth as a constant multiplied by the exposure time in years (T) raised to an exponent (n). Or, in general P =K(T)^n.

Reference 2 slightly modifies this method to calculate the loss of thickness due to general corrosion per side of a strip in microns (millionths of a meter) by the same analytical method This reference further suggests a K value of 25 microns and an exponent n of .65 for galvanized steel and most soils. For "submerged" projects they suggest K= 50 and n = 0.6. For pitting corrosion, this reference broadly suggests that pit depth of 5 times the loss in thickness due to general corrosion at a constant rate of growth is a reasonable estimate. These suggestions are based upon their experience with construction of earth retention structures using galvanized steel strips.

Material loss (ML) and pit depth (PD)

The method proposed herein predicts the dimensional change of anchor components due to material loss (ML) from general corrosion using the method of reference 2 with the constants K and n derived from the experimental results of reference 1. It uses the same analytical method with different constants (also derived from reference 1) to predict the depth of pitting corrosion.

Residual strength ratio (RSR)

The method predicts the residual strength of a member by stress analysis of the residual material at the end of the exposure period by assuming that the residual material retains its original intrinsic strength characteristics. It calculates the residual strength ratio (RSR) as the ratio of net residual to original cross sectional area. The method assumes that basic component cross sections remain unchanged as they loose material equally around their perimeters, and assumes the existence of a pit of width equal to its depth further reducing the net area. Thus residual strengths of components are calculated by multiplying the original strength by the calculated RSR for the desired design life.

Residual strength calculation methods

The RSR for Manta Ray and Stingray anchor rods the is equal to the residual area after general corrosion less the cross sectional area of the pit divided by the original area.

The critical portion of Manta Ray and Stingray anchors is the section through the hinge pin hole of the shackle which is stressed in tension. Thus the RSR is the ratio of the residual cross sectional area less the pit area divided by the original area.

The hinge pin of Manta Ray and Stingray anchors is a shear element and thus its RSR is calculated in the same manner as that of the anchor rods.

Duckbill anchors equipped with wire rope historically have failed by corrosion of the wire rope tendon. The RSR for the wire rope is developed identically to the circular anchor rod. It is assumed that each individual strand in the wire rope corrodes at the same rate of material loss. Because the cable used on Duckbill anchors is composed of very small diameter strands (.14 - .48mm), the effect of pitting corrosion in the residual strength analysis is not included. This is because the samples used for the experiments of reference 1 (from which the pit sized calculations are derived) are dimensionally much larger than the cable strands. The buried samples in some cases had surface areas in excess of 6000 times that of a single strand of the cable used for Duckbill anchors. It has been the policy of Foresight Products to consider Duckbill anchors with galvanized steel cable to be acceptable for temporary duty only. For longer term applications or if aggressive soils are expected, Foresight has always recommended the use of stainless steel cable or Manta ray anchors equipped with solid steel rods.

The RSR of the eye of the aluminum Duckbill anchor head is calculated in the same manner as the Manta Ray and Stingray shackle.

Soil categories and parameters

The soil in which the anchors perform is probably the most important variable. The experiments of Reference 1 were performed in over 100 different types of soils of different classifications, hydrogen potentials (pH), resistivity and drainage. The resultant material loss rates vary significantly. The analytical method developed here attempts to simplify this by broadly and conservatively categorizing soils as Moderate and Aggressive and assigning different values of K and n for them based upon the results of the tests in reference 1 for the materials appropriate to Manta Ray, Stingray and Duckbill anchors. The constants for Moderate soil are calculated to predict the average material loss and pit depth reported in reference 1 and the Aggressive soil constants are calculated to predict the maximum material loss and pit depth reported in reference 1. Based upon a review of the soil parameters used for the experiments in reference 1 the following soil categories are suggested:

Moderate soils:

Resistivity greater than 3000 ohm-cm
PH between 5 and 9
Chlorides less than 100ppm
Sulfates less than 500 ppm
Fairly aerated

Aggressive soils:

Resistivity less than 3000 ohm-cm
PH less than5
Chlorides greater than 100ppm
Sulfates greater than 500 ppm
Very poorly aerated

Material parameters

Galvanized Ferrous Materials (general corrosion)
Manta Ray and Stingray anchor components and anchor rods and the wire rope used for tendons on Duckbill anchors are galvanized ferrous material. Table 65 in reference 1 is the most appropriate for these. Manta Ray and Stingray anchors are hot dip galvanized per ASTM A-123 and A-153 which specifies a minimum coating weight of 1.0 ounce per square foot (ozsf) (305 gram per sq. m.) which matches the coating weight of the sample labeled A3 in table 65 of reference 1. The weight loss for these samples ranged from a low of 0.11 ozsf to a high of 4.62 ozsf with an average of approximately 2.0 ozsf over an average time of 10 years.
Using T=10 years and n=0.65 as suggested by reference 2 in the P= K(T)^n formula, K can calculated. Performing these calculations, converting to thickness measurements and SI units results in a range of K from a low of 1.8 microns to a high of 44.6 microns with an average of 19.3 microns. This lends credibility to the suggestion of Reference 2 of a K value of 25 microns for most soils.
Based upon the above, it is conservative to suggest K=25 and n=0.65 for Moderate soils because this will predict more corrosion than the average level found in the study which was in a silt loam soil of poor drainage, low resistivity (1215ohm-cm) and neutral pH (7).

Reference 2 suggests K=50 and n=0.6 for submerged projects. Based upon the calculations above it is a bit more conservative to suggest K = 50 microns and n=0.75 for Aggressive soils as this will predict more corrosion than even the worst level in the tests of Reference 1, Table 65.

Galvanized Ferrous Materials (pitting corrosion)
Reference 1 discusses pitting corrosion in great detail, and suggests that aeration and drainage are significant factors that affect the initial formation and growth of pits. It suggests that poorly aerated soils caused faster pit growth. Conversely, well aerated soils caused slower pit growth. Table 19 in reference 1 suggests the use of n=0.35 for soils of fair aeration (moderate soils) and n=0.68 for very poorly aerated (aggressive) soils.

Table 65 in reference 1 lists pit depths from 0 to 57 mils with an average of 13 mils over the 10 year test. Using the same analytical procedure as for general corrosion material loss results in the following K values for pitting. For Moderate soils: K= 147 microns and n=0.35. For Aggressive soils: K=300 microns and n=.68

Stainless Steels (general corrosion)

Some Manta Ray anchors are produced of AISI type 316 stainless steel and some Duckbill anchors use type 304 stainless steel tendons. For stainless steels the data of Reference 1 Table 25 are used. Results for AISI type 304 stainless steels were in the range of 0.0 ozsf to 0.20 ozsf with an average of approximately 0.02 ozsf. Results for AISI type 316 stainless steel were in the range of 0.0 ozsf to 0.02 ozsf with an average of approximately .0047 ozsf. This test was performed over 13 years.

Using the same analytical method as for the ferrous materials the results for AISI type 304 stainless steel are: Moderate soils: K=0.25 microns and n=0.65. Aggressive soils: K=2.0 microns and n=0.75. For AISI type 316 Stainless Steels the results are: Moderate soils: K=0.04 microns and n=0.65. Aggressive soils: K=0.15 microns and n=0.75.

Stainless Steels (pitting corrosion)

For AISI type 304 stainless steels Table 25 in reference 1 lists pit depths from 0 to 32 mils with an average of 9 mils over the 10 year test. Using the same analytical procedure as for general corrosion material loss results in the following K values for pitting. For AISI 304 stainless steels for Moderate soils: K= 91 microns and n=0.35. For Aggressive soils: K=135 microns and n=0.68.

For AISI type 316 stainless steels Table 25 in reference 1 lists no definite pitting over the 10 year test. For conservatism, this analytical method will assume that pitting does occur in the 316 stainless steels at the level of 1/5 of the pit depth of the type 304. This results in the following K values for pitting: For AISI 316 stainless steels for Moderate soils: K= 18 microns and n=0.35. For Aggressive soils: K=27 microns and n=0.68.

Aluminum (general corrosion)

Duckbill anchor heads and wire rope swage sleeves are aluminum. Table 56 of reference 1 lists weight loss data for aluminum. The data for aluminum alloyed with manganese is used because it exhibited greater average weight loss than that for pure aluminum. Results were in the range of 0.20 ozsf to 0.97 ozsf with an average of approximately 0.41 ozsf. This test was performed over 10 years. Using the same analytical method as for the ferrous materials, the results are: Moderate soils: K=5 microns and n=0.65. Aggressive soils: K=10.0 microns and n=0.75.

Aluminum (pitting corrosion)

Table 56 in reference 1 lists pit depths from 13 to 62 mils with an average of 31 mils over the 10 year test. Using the same analytical procedure as for general corrosion material loss results in the following K values for pitting. For Moderate soils: K= 329 microns and n= 0.35. For Aggressive soils: K=356 microns and n=0.68

Copper (general corrosion)
Some Duckbill anchor assemblies utilize stainless wire rope and copper swage sleeves. Table 48 of reference 1 lists weight loss data for copper. Results were in the range of 0.0078 ozsf to 0.095 ozsf with an average of approximately 0.026 ozsf. This test was performed over 13 years. Using the same analytical method as for the ferrous materials, the results are: Moderate soils: K=0.25 microns and n=0.65. Aggressive soils: K=0.65 microns and n=0.75.

Copper (pitting corrosion)
Table 48 in reference 1 lists pit depths from 0 to 6 mils with an average of 4 mils over the 13 year test. Using the same analytical procedure as for general corrosion material loss results in the following K values for pitting. For Moderate soils: K= 41 microns and n=0.35. For Aggressive soils: K=25 microns and n=0.68.

Summary Chart of K , n for soils and materials in material loss calculation of ML= K(T)^n

	Moderate Soils R>3000 ohm-cm So4<500ppm 5<pH<9 CL<100 ppm	Aggressive Soils R<3000 ohm- cm So4>500 ppm PH,<5 CL>100 ppm
Galvanized ferrous Materials – Ductile Iron, Steel, Galvanized wire rope	K= 25 microns n=.65	K=50 microns n=.75
AISI type 304 Stainless Steel	K=0.25 microns n=.65	K=2.0 microns n=.75
AISI type 316 Stainless Steel	K=0.04 microns n=0.65	K=0.15 microns n=.75
Aluminum	K=5.0 microns n=.65	K=10.0 microns n=.75
Copper	K=0.25microns n=0.65	K=0.65 microns n=0.75

Summary Chart of K , n for soils and materials in pit depth calculation of PD= K(T)^n

	Moderate Soils R>3000 ohm-cm So4<500ppm 5<pH<9 CL<100 ppm	Aggressive Soils R<3000 ohm- cm So4>500 ppm PH,<5 CL>100 ppm
Galvanized ferrous Materials – Ductile Iron, Steel, Galvanized wire rope	K= 147 microns n=.35	K=300 microns n=.68
AISI type 304 Stainless Steel	K=91 microns n=.35	K=135 microns n=.68
AISI type 316 Stainless Steel	K=18 microns n=0.65	K=27 microns n=.68
Aluminum	K=329 microns n=.35	K=356 microns n=.68
Copper	K=41 microns n=0.35	K= 25 microns n=0.68

Material loss calculations

Life expectancies of 1, 2, 5, 10, 50 and 100 years are arbitrarily selected for material loss calculations. The resulting dimensional loss for different materials and soil categories are presented in the charts below.

Material loss from corrosion (mm per side) for moderate soils

# of Years Material	1	2	5	10	50	100
Galvanized Ferrous	.00249	.0391	.0711	.1118	.318	.4989
304 Stainless	.0003	.0005	.0008	.0010	.0033	.0051
316 Stainless	.00000	.00000	.00001	.0003	.0005	.0008
Aluminum	.0051	.0079	.0142	.0224	.0635	.0998
Copper	.0003	.0005	.0008	.0010	.0033	.0051

(Divide mm per side by 25.4 to give inches per side)

Material loss from corrosion (mm per side) for aggressive soils

# of Years Material	1	2	5	10	50	100
Galvanized Ferrous	.0500	.0841	.1671	.2812	.9401	1.5812
304 Stainless	.0020	.0033	.0066	.0112	.0376	.0632
316 Stainless	.0002	.0003	.0005	.0008	.0028	.0048
Aluminum	.0099	.0168	.0335	.0561	.1880	.3162
Copper	.0008	.0010	.0023	.0036	.0122	.0206

(Divide mm per side by 25.4 to give inches per side)

Pit depth calculations

Life expectancies of 1, 2, 5, 10, 50 and 100 years are arbitrarily selected for pit depth calculations. The resulting pit depths for different materials and soil categories are presented in the charts below.

Pit depth from corrosion (mm) for moderate soils

# of Years Material	1	2	5	10	50	100
Galvanized Ferrous	.1470	.1875	.2583	.3292	.5781	.7369
304 Stainless	.0909	.1161	.1598	.2037	.3579	.4562
316 Stainless	.0180	.0229	.0315	.0404	.0709	.0902
Aluminum	.3289	.4194	.5779	.7366	1.2936	1.6490
Copper	.0409	.0523	.0721	.0917	.1613	.2055

(Divide mm by 25.4 to give inches)

Pit depth from corrosion (mm) for aggressive soils

# of Years Material	1	2	5	10	50	100
Galvanized Ferrous	.3000	.4806	.8961	1.4359	4.2875	6.8725
304 Stainless	.1349	.2164	.4034	.6462	1.9304	3.0927
316 Stainless	.0269	.0432	.0808	.1293	.3861	.6185
Aluminum	.6561	.5705	1.0635	1.7038	5.0904	8.1554
Copper	.0249	.0401	.0747	.1196	.3574	.5728

(Divide mm by 25.4 to give inches)

Sample calculation

Galvanized Manta Ray (MK-B, MR-SR, MR-1, or MR-2) Anchor in Moderate soil for 50 years.

Material Loss
K=25 microns, n= .65
ML=25(50)^.65
ML=318 microns (.0125 inches) per side

Pit Depth
K=147 microns, n= .35
PD=147 (50)^.35
PD=578 microns (.0228 inches)

Continuous Thread Bar (CTB) anchor rod
Minimum minor diameter = 17.094mm (.673")
Original Area = (3.14*17.094^2/4)= 229.381 sq. mm
Original Yield Strength = 147kn (33 kips)
Original Ultimate Strength = 196kN (44 kips)
Residual Diameter = 17.094-2*(.318)= 16.458mm
Residual Area = (3.14*16.458^2/4 -.578^2 = 212.296 sq. mm
RSR = 212.296/229.381 = .925 (93%)
Residual Yield Strength = .925 (147) = 136kN (30.5 kips)
Residual Ultimate Strength = .925(196) = 181kN (40.7 kips)

Manta Ray Hinge Pin
Minimum minor diameter = 15.62mm (.615")
Original Area = (3.14*15.62^2/4)= 191.53 sq. mm
Original Yield Strength = 133kN (30 kips)
Original Ultimate Strength = 178kN (40 kips)
Residual Diameter = 15.62-2*(.318)= 14.984mm (.590")
Residual Area = (3.14*14.984^2/4 -.578^2 = 175.91 sq. mm
RSR = 175.91/191.53= .92 (92%)
Residual Yield Strength = .92 (133) = 122 kN (27.6 kips)
Residual Ultimate Strength = .92 (178) = 164kN (36.8 kips)

Sample calculation – continued

Galvanized Manta Ray (MK-B, MR-SR, MR-1, or MR-2) Anchor in Moderate soil for 50 years.

Manta Ray Shackle
Minimum section : 11.43mm x 12.57mm = 143.71 sq. mm (.2228 sq. inches)
Original Yield Strength = 133kN (30 kips)
Original Ultimate Strength = 178kN (40 kips)
Residual section = 11.43-2*(.318) x 12.57-2*(.0125) -.578^2
= 10.794 x 11.93" -.578^2 = 128.481 sq mm (.1991 sq. inches)
RSR = (128.481/143.71) = .894 (89%)
Residual Yield Strength = .894 (133) = 119kN (26.8 kips)
Residual Ultimate Strength = .894 (178) = 159 kN (35.8) kips

Summary of sample calculation:
Galvanized Manta Ray (MK-B, MR-SR, MR-1, or MR-2) Anchor in Moderate soil for 50 years.

Component	Residual Strength Ratio (%)	Residual Strength kN	Residual Strength Kips
CTB Anchor Rod	93	181	40.7
Hinge Pin	92	164	36.8
Shackle	89	159	35.8

Summary Chart for galvanized Manta Ray and Stingray anchors

The following Chart lists the Residual Strength Ratio (RSR) and the calculated residual strength of the weakest component of Galvanized Ductile Iron Manta Ray and Stingray anchors after 50 year exposure to Moderate and Aggressive soils.

	Moderate Soil 50 years	Aggressive Soil 50 years
Stingray SR-1, SR-2, SR-3 SCR Anchor rod	94% (Shackle) 316kN (71 kips) Yield 418kN (94 kips) Ultimate	80% (Shackle) 267kN (60 kips) Yield 356kN (80 kips) Ultimate
Manta Ray MK-B, MR-SR, MR-1, MR-2, SAR-10, Sar-34, CTB Anchor rod	89% (Shackle) 120kN (27 kips) Yield 160kN (36 kips) Ultimate	58% (Shackle) 76kN (17 kips) Yield 102kN (23 kips) Ultimate
Manta Ray MR-3, MR-4 SAR-58, CTB Anchor rod	86% (Shackle) 14 kips Yield 17 kips Ultimate	39% (Shackle) 28kN (6.28 kips) Yield 35kN (7.8 kips) Ultimate
Manta Ray MR-88 ½ UNC Anchor rod	81% (Shackle) 6 kips Yield 8 kips Ultimate	8% (Shackle) 2.7kN (.6 kips) Yield 3.6kN (.8 kips) Ultimate
Manta Ray MR-68 3/8 UNC Anchor rod	72% (Shackle) 2.6 kips Yield 3.7 kips Ultimate	0% (Shackle) 0.0 Yield 0.0 Ultimate

Summary Chart for 316 stainless steel Manta Ray anchors

The following Chart lists the Residual Strength Ratio (RSR) and the calculated residual strength of the weakest component of 316 stainless steel Manta Ray anchors after 100 year exposure to Moderate and Aggressive soils.

	Moderate Soil 100 years	Aggressive Soil 100 years
Manta Ray MR-1, MR-2, SAR-10, CTB Anchor rod	100% (Shackle) 133kN (30 kips) Yield 178kN (40 kips) Ultimate	99% (Shackle) 132kN (29.7 kips) Yield 176kN (39.6 kips) Ultimate
Manta Ray MK-3, CTB Anchor rod	100% (Shackle) 71kN (16 kips) Yield 89kN (20 kips) Ultimate	99% (Shackle) 70kN (15.8 kips) Yield 88kN (19.8 kips) Ultimate

2 year Residual Strength Ratio (RSR) in Percent
For Moderate and Aggressive soils For Duckbill anchors
With Galvanized steel cable and Aluminum Sleeves

	Aluminum Anchor Head		Ductile Iron Anchor Head		Galvanized Steel Cable		Aluminum Swage Sleeves	
Anchor Model	Mod Soil	Aggr Soil	Mod Soil	Aggr Soil	Mod Soil	Aggr Soil	Mod Soil	Aggr Soil
40	>93	>88	N/A	N/A	19	4	>99	99
68	>97	>96	>93	>89	55	20	>99	99
88	>98	>97	>95	>93	66	36	>99	99
138	>99	>98	>96	>94	70	42	>99	99

5 year Residual Strength Ratio (RSR) in Percent
For Moderate and Aggressive soils For Duckbill anchors
With 304 Stainless steel cable and Copper Sleeves

	Aluminum Anchor Head		Ductile Iron Anchor Head		304 Stainless Steel Cable		Copper Swage Sleeves	
Anchor Model	Mod Soil	Aggr Soil	Mod Soil	Aggr Soil	Mod Soil	Aggr Soil	Mod Soil	Aggr Soil
40	>88	88	N/A	N/A	98	81	>99	99
68	>96	96	>89	89	99	91	>99	99
88	>97	97	>93	93	99	94	>99	99
138	>98	98	>94	94	99	95	>99	99

10 year Residual Strength Ratio (RSR) in Percent
For Moderate and Aggressive soils For Duckbill anchors
With 316 Stainless Steel cable and Copper Sleeves

	Aluminum Anchor Head		Ductile Iron Anchor Head		316 Stainless Steel Cable		Copper Swage Sleeves	
Anchor Model	Mod Soil	Aggr Soil	Mod Soil	Aggr Soil	Mod Soil	Aggr Soil	Mod Soil	Aggr Soil
40	94	73	N/A	N/A	100	98	100	99
68	98	91	94	81	100	99	100	100
88	99	95	95	87	100	99	100	100
138	99	97	96	90	100	99	100	100

Reference Data:Manta Ray & Stingray shackle minimum section dimensions
These dimensions are for the tensile section through one " leg" of the shackle through the hinge pin hole.

Shackle	Drawing Number	Length (mm)	Width (mm)
Stingray SR-1S	X20066	23.75	20.07
Manta Ray MR-1S	X20041	12.57	11.43
Manta Ray MR-3S	X20047	.9.72	8.13
Manta Ray MR-88S	X20111	7.18	5.70
Manta Ray MR-68S	X20265	4.09	4.83

Reference Data:Duckbill eye minimum section dimensions
These dimensions are for the tensile section through one "half" of the eye.

Anchor	Drawing Number	Width (mm)	Height (mm)
40-DB	X20244	.5.08	2.79
68-DB	X10004	8.38	6.22
88-DB	X10002	15.24	7.87
138-DB	X20363	19.05	9.14

Reference Data:Duckbill Cable sizes

Anchor	Cable size (in.)	Cable size (mm)	Strand size (mm)
40-DB1	1/16 7x7	1.6	0.14
68-DB1	1/8 7x7	3.2	0.30
88-DB1	¼ 7x19	6.35	0.42
138-DB1	5/16 7x19	7.94	0.48

Reference Data:Duckbill sleeve sizes
Per drawings X20360, X20370

Anchor	Sleeve size (in)	Sleeve thickness (mm)
40-DB1	1/16	1.14
68-DB1	1/8	2.22
88-DB1	¼	1.65
138-DB1	5/16	2.22

Reference Data:Actual Calculations: Actual calculations are done in an MS Excell spreadsheet @ 3C:\xfr…\analyses\corrosion calcs\Corrosion Material Loss & Pitting.