Jon Guerry Taylor & Associates, Inc.
ENGINEERS - PLANNERS - ENVIRONMENTAL CONSULTANTS
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June 17, 2021

Ms. Laurie Schueler
Property Management Services
1340-G Ben Sawyer Blvd.
Mt. Pleasant, SC 29464

RE: Morgan Creek Bulkhead Corrosion Study; Structural Corrosion Analysis

Ms. Schueler,
Jon Guerry Taylor & Associates,Inc. (JGT) and Southern Cathodic Protection (SCP) were commissioned to perform a corrosion analysis of the existing approximately 6,090 linear feet steel bulkhead along the Morgan Creek Harbor. JGT undertook the structural analysis of the existing steel bulkhead based on the results of the non-destructive and destructive testing that was performed on the existing steel bulkhead.

The bulkhead was installed between 1997 and 1998 and based on plans provided by Parker Marine Contracting, Inc., the sheets were AZ13 and AZ18 A572 Grade 50 and Grade 60. There is approximately 465 linear feet of AZ13 sheet piling and approximately 5,625 linear feet of AZ18 sheet piling. The lengths of the sheet piling vary throughout the length of the bulkhead. The lengths vary from 27 feet to 33 feet for the AZ13 sheets and between 31 feet to 42 feet long for the AZ18 sheets. ***Figure 1*** is the original design plan provided by Parker Marine Contractors, Inc. A 11"x17 copy of the design plan can be seen in **Appendix A**

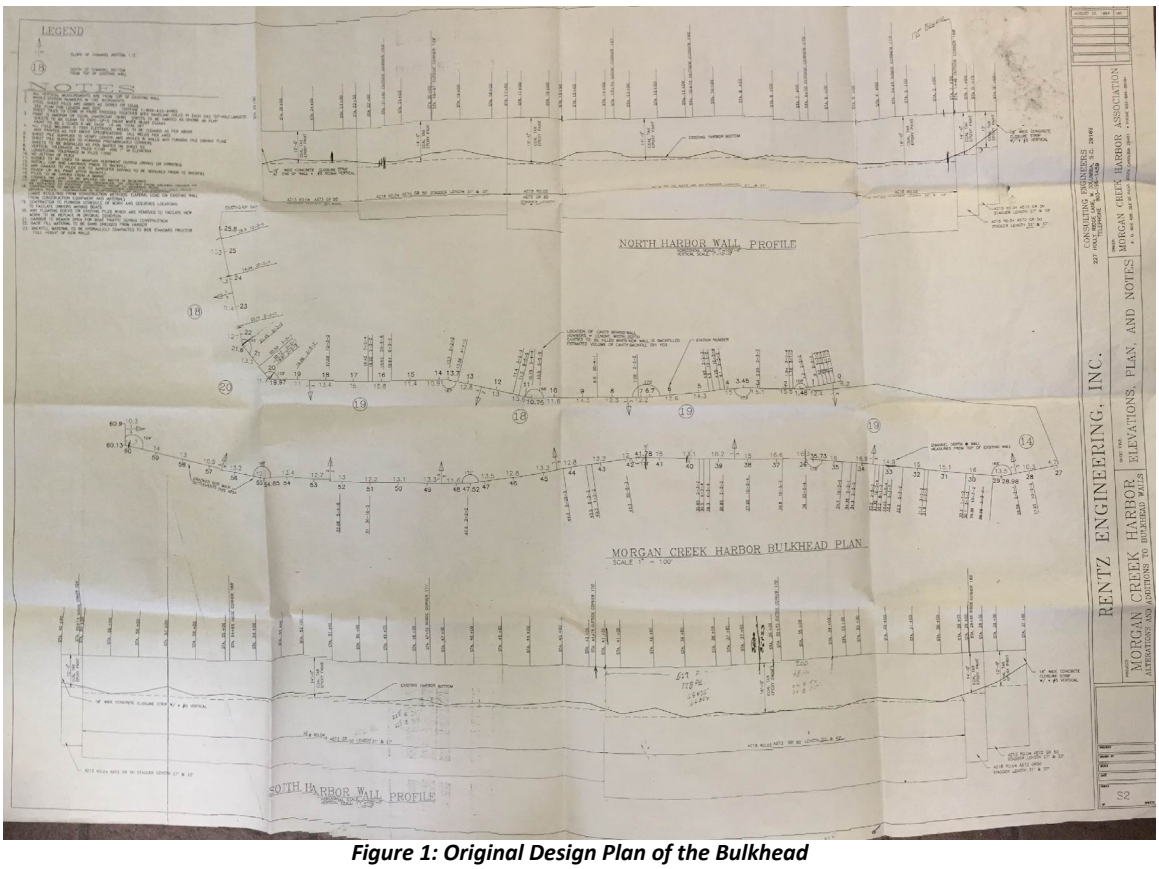


Figure 1: Original Design Plan of the Bulkhead

The AZ18 and AZ13 sheet pile properties are as follows (**Table A**):

Table A:

Section	Width (in)	Height (in)	Flange thickness (in)	Web Thickness (in)	Section area (in^2/ft)	Elastic Modulus (in^3/ft)	Moment of Inertia (in^4/ft)
AZ13	26.38	11.93	0.375	0.375	6.47	24.2	144.3
AZ18	24.80	14.96	0.375	0.375	7.11	33.5	250.4

As shown on the plans, the AZ13 sheets were A572 Grade 50 KSI steel and the AZ18 sheets were A572 Grade 50 KSI and 60 KSI steel (KSI is Kips per square inch, 1 kip equals 1000 lbs; therefore, a grade or yield strength of 50 KSI equals 50,000 PSI steel).

The destructive testing involved removing a 4-inch diameter sample of the steel bulkhead sheet at six (6) locations proposed by SPC. These samples were removed and sent to a lab for testing. The locations were as follows (**Table B**):

Table B:

Station along wall	Sta 0+60	Sta 17+30	Sta 21+18	Sta 34+00	Sta 35+89	Sta 44+44
Sample location below the cap.	33 inches	41 inches	36 inches	41 inches	57 inches	12 inches
Sheet	AZ13	AZ18	AZ18	AZ18	AZ18	AZ18

The destructive tested analyzed the structural (tensile) and chemical make-up of the samples removed from the existing sheets. The test results can be found in **Appendix B** of this report.

STRUCTUAL ANALYSIS

JGT used the information from the tensile test report (found in **Appendix B**) to approximate the existing structural capacity of the bulkhead. JGT used the section profile of the AZ18 sheet as a basis for the analysis of the AZ18 sheets. A digital version of the AZ13 sheet section could not be found so an analysis of the AZ13 sheet was not completed. Outlined below is a summary of the Tensile Test Results of the steel coupons (**Table C**)

Table C:

Location	Thickness (in)	Area (in^2)	Ultimate Load (lbs)	Yield Strength (PSI)
Original	0.375	-	-	50,000 or 60,000
0+60	0.1990	0.05	3,940	58,000
17+30	0.1151	0.0289	2,484	64,000
21+18	0.2554	0.0641	5,250	60,500
34+00	0.1951	0.0488	4,241	65,000
35+89	0.1241	0.031	2,329	47,300
44+44	0.2447	0.0615	4,891	62,000

The AZ18 section was used to determine the existing properties of the sheets based on the testing data and thickness determination of the coupons. Assumptions were made to complete the analysis. Based on the thickness as determined from the testing, it was assumed that the entire sheet section and

length was this measured thickness from the test results. The longer lengths of the sheets, as shown on the design plan, was used in the structural evaluation.

Based on this information, the original AZ18 section was digitally modified to represent the existing thickness as determined from the testing. This resulted in an approximate new section area, Section Modulus and Moment of Inertia for the sheets at each of the test locations. This information was used to determine the maximum bending moment of the existing steel sheets for the test locations. This was compared to the original AZ18 maximum bending moment. The comparison of section loss, Section Area, Elastic Modulus and Moment of Inertia are summarized in **Table D** below:

Table D:

Location	Thickness (in)	% Section Loss	Section Area (in^2)	Elastic Modulus (in^3/ft)	Moment of Inertia (in^4/ft)
AZ18	0.375	0	14.655	33.5	250.4
0+60	0.1991	47%	-*	-*	-*
17+30	0.1151	69%	7.1676	19.73	134.8
21+18	0.2554	32%	11.06	26.71	193.48
34+00	0.1951	48%	9.373	23.66	168.02
35+89	0.1241	67%	7.4138	20.16	138.55
44+44	0.2447	35%	10.7591	26.16	188.93

**This information could not be determined for the AZ13 sheet*

Using information from **Table D, Table E** outlines the Maximum Bending Moments of the existing sheets at the test locations compared to the original sheet section properties and steel grade. The maximum bending moment is a value based on the section properties of the sheet (elastic modulus and/or moment of inertia) and the steel yield strength or grade of steel of the sheet. The maximum bending moment represents the maximum bending force that can be applied to the sheet without it yielding or failing.

Table E:

Station along wall	Original	Sta 0+60	Sta 17+30	Sta 21+18	Sta 34+00	Sta 35+89	Sta 44+44
Maximum Bending Moment (ft-lbs/ft)	90,729.2	-*	53,435.4	72,312.5	64,079.2	54,600.0	70,850.0
Sheet	AZ18	AZ13	AZ18	AZ18	AZ18	AZ18	AZ18

**This information could not be determined for the AZ13 sheet*

Typically, steel sheet piling is designed using the allowable stress design method (ASD). This method reduces the allowable stress in the steel sheet pile from the yield stress (steel grade) as a safety factor for the design. The value for static loads on a permanent structure is generally a 0.65 reduction or 65% of the yield strength of the steel. This value was used in the analysis of the existing bulkhead.

Through analysis of the existing bulkhead, its exposed height, soil properties, sheet length, sheet section properties, and approximate anchor location throughout the bulkhead, the approximate actual bending moment for the worse sheet section (Sta 17+30) was determined to be less than the maximum bending moment calculated. There were several assumptions made during this analysis as to the anchor height along the bulkhead and that the soil properties remaining constant throughout the length of the bulkhead or are the same at all the test locations.

The shear strength of the steel at these test locations could not be determined accurately given some of the unknowns at the anchor locations and anchors not necessarily located at the test locations. The shear strength of the steel would represent the force needed to pull through the steel sheet.

SUMMARY

While the steel sheets have experienced significant section loss due to corrosion of the steel, the steel sheets remain structurally stable based on the assumptions made, the estimated steel section properties and the completed analysis. Much of this structural stability could be due to the grades of steel used for the steel piling. The higher (50KSI and 60KSI) grades of steel are stronger than lower grades of steel. However, these test samples only represent six locations along the bulkhead at the specific heights from the cap outlined. There may be other areas along the 6,090 linear feet of bulkhead where the steel is thinner and the section properties are less. Penetrations in the steel sheets of the bulkhead have been found in small localized locations. In these areas the steel thickness would be much less than determined in the test samples.

The worse test area was at Sta 17+30 where the sample thickness was 0.1151 inches and represented a section loss in that area of approximately 69% compared to the original thickness. Further corrosion of the sheets will continue to lessen the structural strength of the steel sheets and the bulkhead in general. While the section loss does vary between 32% and 69%, there is no visible pattern to the amount of section loss that has occurred since the bulkhead was installed.

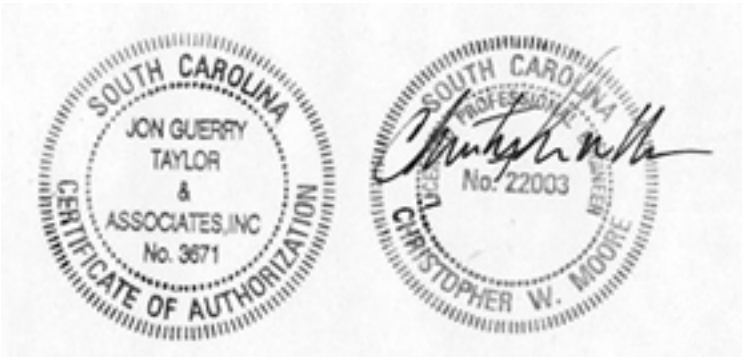
In reviewing the recommendations from the corrosion analysis report by SCP, JGT would also recommend a cathodic protection system to eliminate any further corrosion of the steel sheets. By eliminating further corrosion, the structural stability of the steel sheets and the bulkhead would remain stable and would not continue to decrease due to continued corrosion of the steel.

The other recommendation option consider would be the full replacement of the steel sheet pile bulkhead with a properly designed and properly coated (on both the front and back of the sheets) bulkhead. This option would be much more expensive that the installation of a cathodic protection system.

Should you have any questions or comments concerning this report, please feel free to let us know.

Sincerely,
JON GUERRY TAYLOR & ASSOCIATES, INC.

Christopher W. Moore, PE
President/Principle Engineer



Appendix A

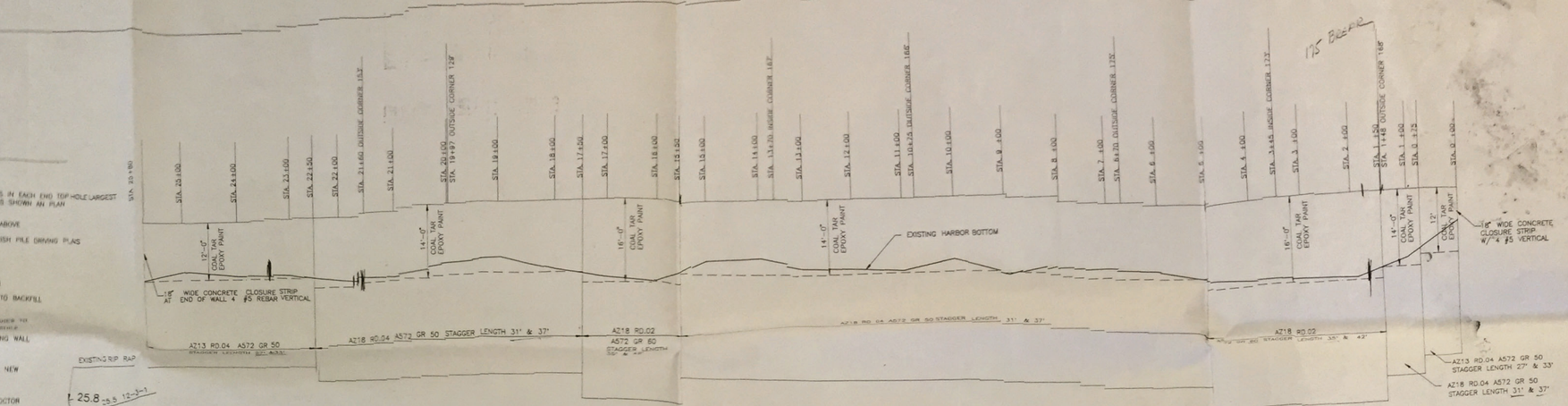
LEGEND

SLOPE OF CHANNEL BOTTOM 1/3

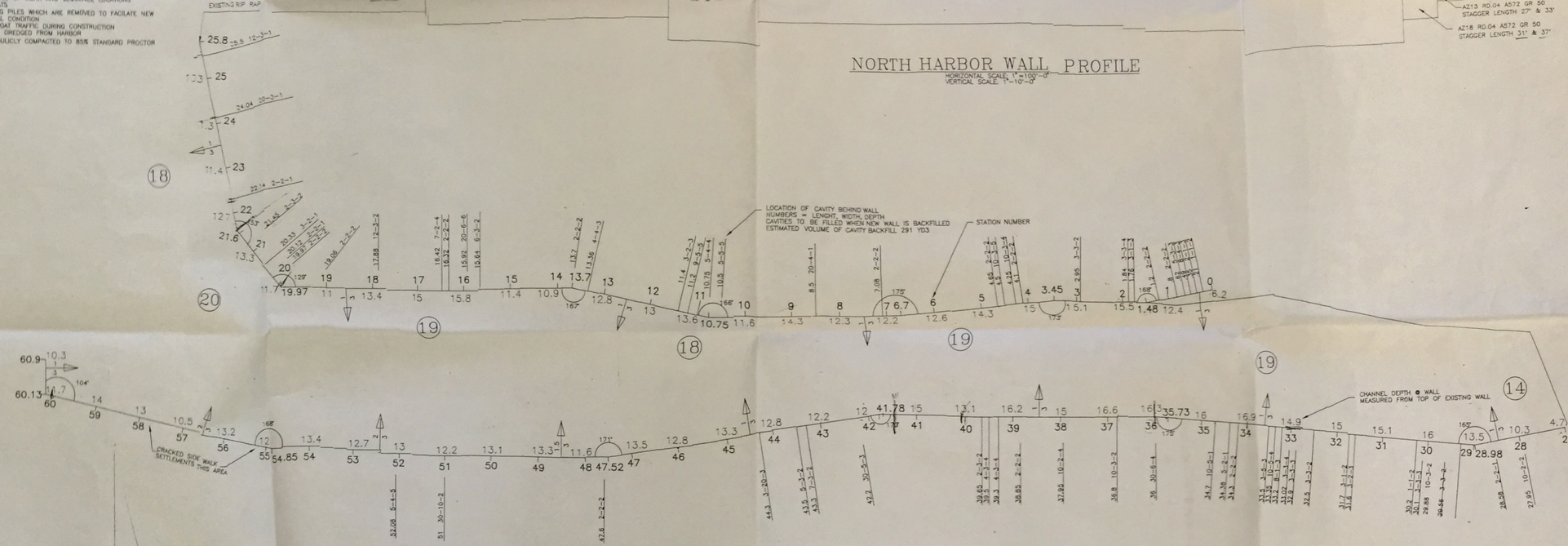
(18) DEPTH OF CHANNEL BOTTOM FROM TOP OF EXISTING WALL

NOTES

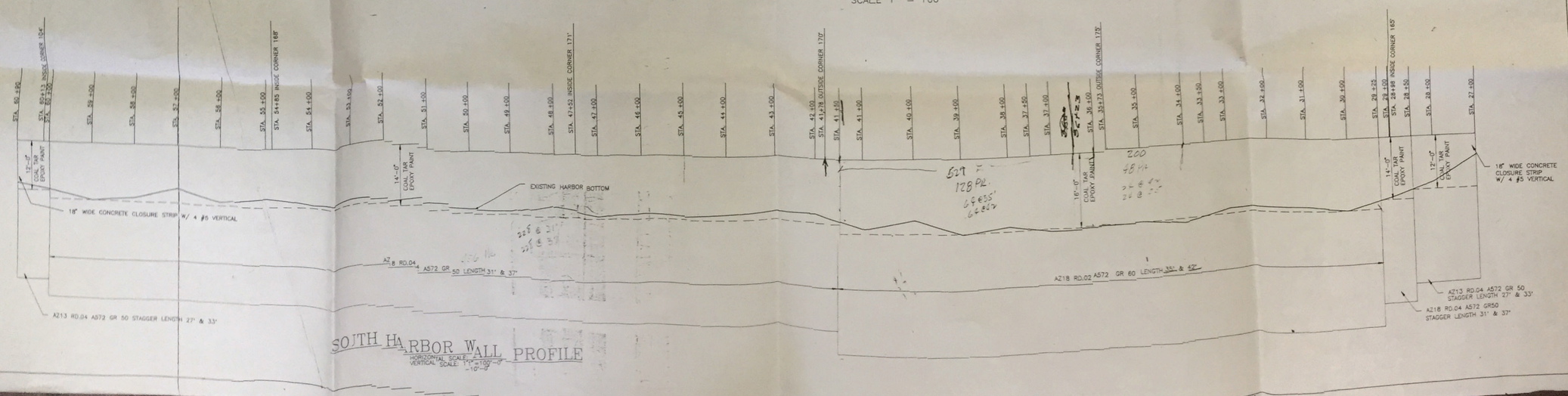
1. ALL VERTICAL MEASUREMENTS ARE FROM TOP OF EXISTING WALL
2. WHOLE STATION NUMBERS IN 100' INCREMENTS
3. STEEL SHEET PILES ARE ARBED AZ SIZES OR EQUAL SEE PLAN FOR LENGTH AND SIZE (SKYLINE 1-800-433-6460)
4. SHEET PILES TO COME IN PAIRS PRESSED TOGETHER WITH HANDLING HOLES IN EACH END TOP HOLE LARGEST
5. SHEETS TO BE CLEAN TO SSPC-SP10 (NEAR WHITE BLAST CLEAN) SHEETS TO BE PAINTED AS SHOWN AN PLAN PAINT TO BE 2 COATS 8 MIL EACH 16 MIL TOTAL DFT
6. ALL FIELD WELDING IS 70XX ELECTRODS WELDS TO BE CLEANED AS PER ABOVE AND PAINTED AS PER ABOVE SPECIFICATIONS (ALL WELDS PER AWS)
7. SHEET PILE SUPPLIER TO VERIFY LENGTH AND ANGLES IN WALLS AND FURNISH PILE DRIVING PLAS
8. SHEETS TO BE INSPALLED AS PER BATTER ON SHEET S3
9. VERTICAL TOLERANCE IN PILES 1:100 AND 1" IN ELEVATION
10. LONGITUDINAL TOLERANCE IN PILES 1:500
11. NO JETTING OF PILES
12. GUIDES TO BE USED TO MAINTAIN ALIGNMENT DURING DRIVING OR VIBRATING
13. INSTALL CAP AND LANDINGS PRIOR TO BACKFILL
14. ANY DAMAGE TO PILES DUE TO IMPROPER DRIVING TO BE REPAIRED PRIOR TO BACKFILL
15. TOUCH UP ALL PAINT AFTER BACKFILL
16. PILES TO BE DRIVEN FROM A BARGE
17. CRANES ON LAND TO BE WALKED ON MATTS IN REQUIRED
18. ANY DAMAGED TO LANDSCAPING, SIDEWALKS, OR UTILITIES FROM WALKING CRANES TO BE REPAIRED TO CONDITIONS PRIOR TO BEGINNING WORK. CONTRACTOR TO MONITOR EXISTING CONDITIONS PRIOR TO BEGINNING PILE DRIVING PILES. CONTRACTOR IS RESPONSIBLE FOR ALL REPAIRS OF DAMAGED AREAS.
19. CONTRACTOR TO FURNISH SCHEDULE OF WORK AND SEQUENCE LOCATIONS TO FACILATE OWNERS MOVING BOATS
20. ANY FLOATING DOCKS OR EXISTING PILES WHICH ARE REMOVED TO FACILATE NEW WORK TO BE REPLACE IN ORIGINAL CONDITION
21. HARBOR TO REMAIN OPEN FOR BOAT TRAFFIC DURING CONSTRUCTION
22. BACK FILL MATERIAL TO BE SAND DREDGED FROM HARBOR
23. BACKFILL MATERIAL TO BE HYDRAULICLY COMPACTED TO 85% STANDARD PROCTOR FULL HEIGHT OF NEW WALLS



NORTH HARBOR WALL PROFILE
HORIZONTAL SCALE 1"=100'-0"
VERTICAL SCALE 1"=10'-0"



MORGAN CREEK HARBOR BULKHEAD PLAN
SCALE 1" = 100'



SOUTH HARBOR WALL PROFILE
HORIZONTAL SCALE 1"=100'-0"
VERTICAL SCALE 1"=10'-0"

AUGUST 22, 1994	MR

RENTZ ENGINEERING, INC.
CONSULTING ENGINEERS
227 HOLLY RIDGE LANE, W. COLUMBIA, S.C. 29169
TELEPHONE 803-796-1489

OWNER
MORGAN CREEK HARBOR ASSOCIATION
P. O. BOX 406, ISLE OF PALMS, SOUTH CAROLINA 29451 • PHONE 803-886-8646

PROJECT:
MORGAN CREEK HARBOR
ALTERATIONS AND ADDITIONS TO BULKHEAD WALLS

SHEET TITLE:
ELEVATIONS, PLAN, AND NOTES

PROJECT
DRAWN BY
SCALE
DATE
SHEET S2
OF SHEETS

Appendix B

APPLIED TECHNICAL SERVICES

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TENSILE TEST REPORT

Ref. 353667 **Date** April 20, 2021 **Page** 1 **of** 3

Customer: Southern Cathodic Protection, 780 Johnson Ferry Road NE, Suite 225, Atlanta, GA 30342

Attention: Chris McKinley

Purchase Order #: 1824-CRM Part #/Name: Sheet Pile Samples, See Below

Material Designation: Steel Specimen Type: Flat Reduced Section

Tensile Test Equipment: Tinius Olsen ATS #: 6266 Cal. Due: 10/28/21

Extensometer: Tinius Olsen ATS #: 2320 Cal. Due: 12/28/21

Lab Comment: Tested per ASTM A370-20.

Test Results

Specimen Identification	Thickness, in.	Diameter or Width in.	Area, $in.^2$	Ultimate Load, lbs.	0.2% Offset Load, lbs.	Tensile Strength, psi	Yield Strength, psi	Elong. % in 1 in.	Red. in Area, %
00+60, 33", 2:05pm, 3-8-21	0.1990	0.251	0.0500	3,940	2,895	79,000	58,000	32	—
21+18, 36", 12:10pm, 3-8-21	0.2554	0.251	0.0641	5,250	3,869	82,000	60,500	32	—
35+89, 57", 1:27pm, 3-8-21	0.1241	0.250	0.0310	2,329	1,469	75,000	47,300	32	—
34+00, 41", 7:45pm, 3-9-21	0.1951	0.250	0.0488	4,241	3,166	87,000	65,000	30	—
17+30, 41", 12:45pm, 3-8-21	0.1151	0.251	0.0289	2,484	1,843	86,000	64,000	25	—
44+44, 12", 8:24am, 39-21	0.2447	0.251	0.0615	4,891	3,825	79,500	62,000	32	—

ISO 9001

Prepared by: A. Anderson
Materials Testing

Reviewed by: W. R. Allen
Materials Testing

APPLIED TECHNICAL SERVICES

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CHEMICAL TEST REPORT

Ref. 353667 **Date** April 20, 2021 **Page** 2 **of** 3

Customer: Southern Cathodic Protection, 780 Johnson Ferry Road, Suite 225, Atlanta, GA 30342

Attention: Christopher McKinley

Purchase Order #: 1824-CRM Part #/Name: See below

Material Designation: 5L Carbon Steel Pipe, PSL 1, Steel Grade B

Special Requirement: N/A

Lab Comment: Analyzed using ASTM E415-17 as a guide.

Test Results

Composition: Weight %

Identification	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V
Alloy or Spec. Req. (1)	0.28 max	1.20 max	0.030 max	0.030 max	—	—	—	—	—	—
00+60, 33", 2:05pm, 3-8-21	0.18	0.82	0.023	0.011	0.06	0.09	0.06	0.05	0.01	<0.01
21+18, 36", 12:10pm, 3-8-21	0.14	0.97	0.026	0.015	0.05	0.09	0.07	0.08	0.01	<0.01
35+89, 57", 1:27pm, 3-8-21	0.22	0.68	0.019	0.025	0.08	0.10	0.08	0.05	0.01	<0.01
34+00, 41", 7:45pm, 3-9-21	0.18	1.18	0.030	0.013	0.05	0.08	0.06	0.07	0.01	<0.01
17+30, 41", 12:45pm, 3-8-21	0.17	1.23[2]	0.021	0.017	0.04	0.07	0.05	0.04	0.01	<0.01
44+44, 12", 8:24am, 39-21	0.16	0.91	0.022	0.020	0.06	0.10	0.05	0.05	0.01	<0.01

Sample meets chemical requirements.

Sample will also meet other Steel Grade chemical requirements.

(1) API Specification 5L/ISO 3183, 44th edition, Oct. 1, 2007, PSL 1 pipe, Steel Grade B

(2) For each reduction of 0,01 % below the specified maximum concentration for carbon, an increase of 0,05 % above the specified maximum concentration for manganese is permissible, up to a maximum of 1,65 %.

ISO 9001

Prepared by: K. Banyas
Chemist

Approved by: D. M. McKay
Supervisor

APPLIED TECHNICAL SERVICES

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non-standard test method, ATS does not assume responsibility for validation of the method. Measurement uncertainty available upon request where applicable.

CHEMICAL TEST REPORT

Ref. 353667 **Date** April 20, 2021 **Page** 3 **of** 3

Customer: Southern Cathodic Protection, 780 Johnson Ferry Road, Suite 225, Atlanta, GA 30342

Attention: Christopher McKinley

Purchase Order #: 1824-CRM Part #/Name: See below

Material Designation: 5L Carbon Steel Pipe, PSL 1, Steel Grade B

Special Requirement: N/A

Lab Comment: Analyzed using ASTM E415-17 as a guide.

Test Results

Composition: Weight %

Identification	Nb	Ti	(2)	(3)						
Alloy or Spec. Req. (1)	—	—	0.06 max	0.15 max	—					
00+60, 33", 2:05pm, 3-8-21	0.03	<0.01	<0.06	<0.15						
21+18, 36", 12:10pm, 3-8-21	0.02	<0.01	<0.06	<0.15						
35+89, 57", 1:27pm, 3-8-21	<0.01	<0.01	<0.06	<0.15						
34+00, 41", 7:45pm, 3-9-21	0.04	<0.01	<0.06	<0.15						
17+30, 41", 12:45pm, 3-8-21	0.04	<0.01	<0.06	<0.15						
44+44, 12", 8:24am, 39-21	0.02	<0.01	<0.06	<0.15						

Sample meets chemical requirements.

Sample will also meet other Steel Grade chemical requirements.

(1) API Specification 5L/ISO 3183, 44th edition, Oct. 1, 2007, PSL 1 pipe, Steel Grade B

(2) Nb + V

(3) Nb + V + Ti

ISO 9001

Prepared by: K. Banyas
Chemist

Approved by: D. M. McKay
Supervisor