EZ PLACE CABLE RAIL
STRENGTH ANALYSIS - REV 1
(Includes Test Results)

INTRODUCTION:

This report is an update to SEP's previous report of 3-20-24 and is issue for the following purposes:

1. Summarize the results of the work done to date and provide design values for the EZ Place Rail assembly.

2. Provide test results of recent testing at WGF's Ft Lauderdale facility the week of 7/02/24.

SUMMARY OF RESULTS:

SEP accomplished stress analyses on the railing system as installed and directed testing of three samples of the rail assembly installed into an 18 x 18" column. Test results showed failure at lower values than were predicted by the analysis… (29.6 kips test vs 32.5 kips analysis). For design purposes, SEP recommends using the test results as shown below. The Ultimate Strength of the WGF rail assembly pre-placed into an 18" x 18" cast in place column with 4 each #8 vertical rebar in the corners, and #3 stirrups 4" o.c. , and concrete of fc' = 5500 psi is:

$$F_{ult} = \phi * 117.4 \text{ Kips} = .75\,(117.4) = \mathbf{88.1\ Kips}$$

This value is for **three** inserts, thus: ⇨ $\boxed{\textbf{29.4 Kips / Insert.}}$

<u>For other fc'</u>: $F_{ult} = (f'c / 5500)^{.5} * 29.4$ Kips / Insert

<u>ANALYSIS RESULTS: Three Failure Modes:</u>

The ultimate design strength of the system is assumed to be based on the minimum failure value for the lessor of three different failure modes:

A. Failure of the PT cable. (**MULTS = 41.31 Kips**)
B. Failure of the steel components or welds of the Rail Assembly. (**43.6 Kips**)
C. Failure of the **concrete** around the Rail Assembly … by *breakout*. An analysis of the shear failure indicates an 18" X 18" column would fail at **32.5 Kips**

Summaries of analysis for these failure modes are shown below:

MODE A: BARRIER CABLE FAILURE

Barrier Cables have MULTS (Min Ult Strength) = 41.31 Kips. (Note they are designed to 90% of this (37.2 Kips). There are additional pedestrian static tension loads on the system, roughly 1500 lbs each, which would total 8 x 1.5 Kips = 12 kips. *For the purposes of this analysis, we are ignoring those loads*, *assuming a pedestrian is not hitting the cables at the same time a vehicle does*. Ignoring the additional loads on the rail system. Since 41.31 Kips > 29.6 Kips, the PT cables are not the limiting failure mode.

MODE B: RAIL STRENGTH

There actually has not been a test of the *rail assembly* to failure. Furthermore, the following analyses from the previous report were accomplished using linear elastic modeling, thus not taking into account the plastic behavior that would provide further strength than shown here. The structural analysis is presented as a strength analysis of the re-designed EZ Place Cable Rail assembly to be produced by WG Fabricators. The following assumptions are made for this work:

1. The Design Loading is that as described in FBC 2014, 5th Ed., Sec 1618.5.3: a 5000 lb vehicle at 5.0 mph and impacting three barrier cables (1 SFT area) at a center height of 22 inches.

2. An Elastic analysis as outlined in PTI Tech Note 14, Eqn (3) was utilized to determine a max cable tension load of 15,446 lbs and a max ***vehicular*** impact Force of 7983 lbs.

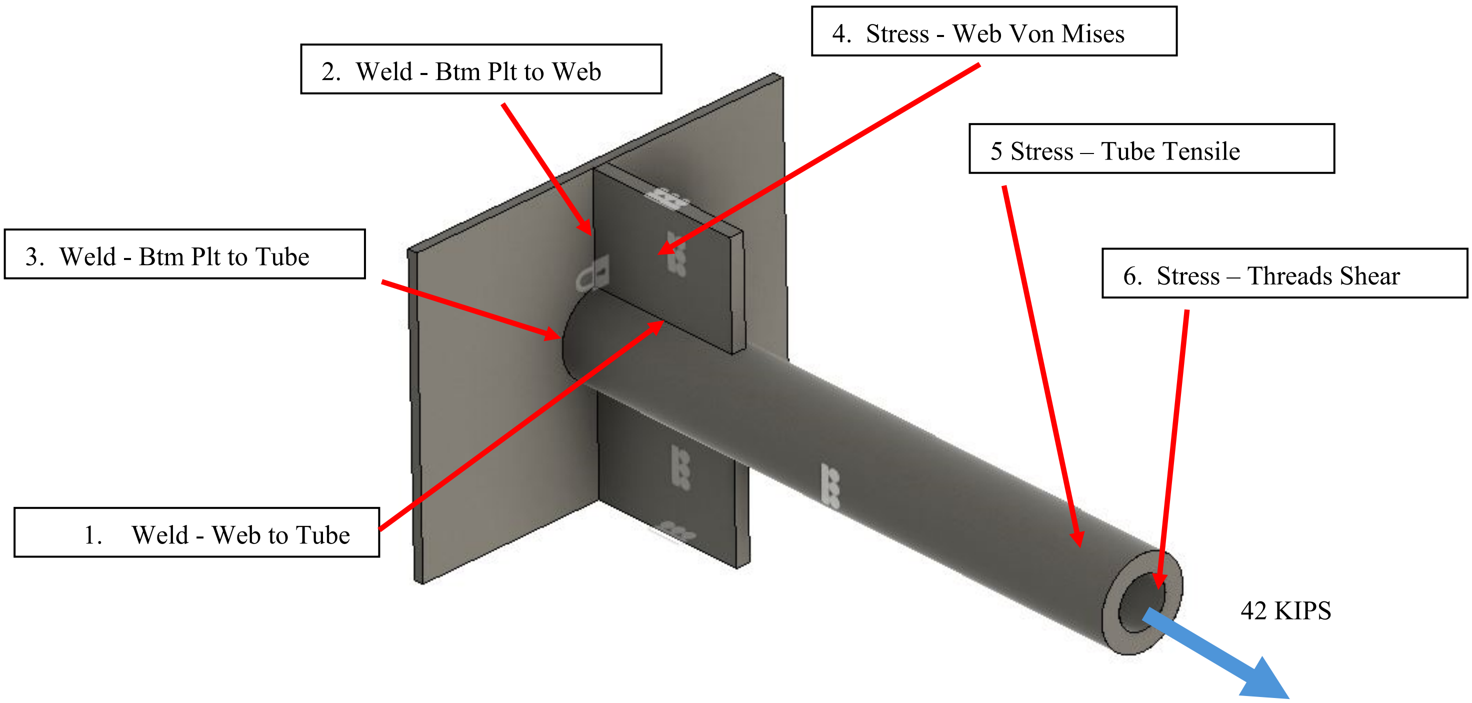
3. This rail assembly is installed into a reinforced concrete column of minimum 24" x 24" cross section, Min f'c = 4000 psi.

4. # 3 stirrups to be placed to form a cage around the rail assembly…
   4" vertical spacing adjacent to all barrier cables

5. 2.0" Thread Engagement. (Tube Will Exceed Thread Rod Strength)

6. Localized yielding may occur within the rail assembly to redistribute loads greater than 42 Kips.

The system was analyzed for a 42 Kip load and then scaled upward slightly. The weakest component is the weld at location 2. (Btm Plt to Web) F.S. 1.04. Scaling upward based on this result, Failure Load = 42 kips x 1.04 = **43.6 Kips** Per Anchor**.** As has been stated previously, this is a conservative value because the weld limit includes a F.S. of 2.0 and the model was elastic; so the rail system will likely show an ultimate strength significantly greater than this.


2. Weld - Btm Plt to Web
4. Stress - Web Von Mises
5 Stress – Tube Tensile
3. Weld - Btm Plt to Tube
6. Stress – Threads Shear
1. Weld - Web to Tube
42 KIPS

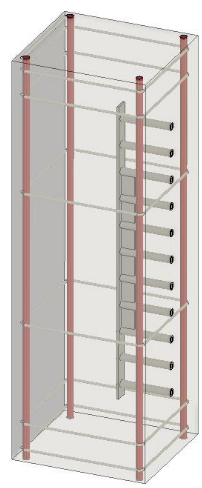
ANALYSIS RESULTS

LOCATION	ENTITY	VALUE	ALLOWABLE	F.S.
1	Fillet Weld Tube to Web	1.72 K/in	3.71 k/in	2.15
2	Fillet Weld BTM PLT to Web	3.56 K/in	3.71 K/in	1.04
3	Fillet Weld LWR PLT to Tube	0	3.71	> 10
4	Shear Web Shear Stress	13.9 KSI	51 KSI	1.12
5	Tube Tensile Stress	62.6 KSI	70 KSI	1.12
6	Tube Inner Threads Shear Stress	42 KIPS	79.2 KIPS	1.89

NOTE: Item 6 assumes 2" thread engagement

MODE C: CONCRETE FAILURE

Looking at the figure below, the stress state around the installed WGF rail system is influenced by 1) the column cross sectional size, 2) the stress state (compression + bending) of column itself, 3) the size & location of adjacent vertical steel 4) the length of the insert tubes (depth of rail), and 5) the size and spacing of the stirrups. Intuitively, the failure mode is most likely associated with either shear failure or concrete breakout in front of the rail assembly. However, even for a relatively simple case of *failure of a beam in shear*, the ACI freely admits that the exact nature of shear stress is not completely understood. The Code approach for design is therefore to apply empirical safety factors to their equations rather than attempt to analytically predict the exact state of the material stresses in similar circumstances.



Based on our current understanding, the limiting failure mode for the WGF Rail system is most associated with the column size and *the size and spacing of shear stirrups installed with the rail assembly.*

The minimum concrete column the system is assumed to be installed into is a **18” x 18”** column, with 4 corner # 8 vertical rebars, # 3 stirrups at 4” o.c., and fc’= 5500 psi. SEP analyzed the above situation utilizing ClearCalcs™ software and ACI 318-19, CI 22.5 (See the attached). Based on this analysis, the shear allowable is found as follows:

For an 85% utilization,

$$85\ \%\ \phi\, V_n = 82.8 \text{ Kips}$$
$$\phi\, V_n = 97.4 \text{ Kips}$$

The allowable for a single insert would be 97.4/ 3 = **32.5 Kips**

WGF BREAK TEST:

SEP in coordination with WGF accomplished break tests of three column samples containing the WGF rail design the week of July 2, 2024. The actual testing was accomplished by QC Metallurgical, LLC at the WGF facility in Ft Lauderdale. The test configuration for the samples is as described in the QC Metallurgical report attached herein and the attached drawing.

The concrete tested had an estimated fc'= 5500 psi (6 days after placement). The test load was increased to such point that cracking of the concrete was noted on the face of the "column" and stopped at that point. The break results for the three tests were very close at 132.48, 130.27, and 130.27 kips respectively, giving an average of **131.0 kips**.

OBSERVATIONS:

The exact classification (shear / bending / pull out) of the beam failures is difficult to determine from the cracking patterns. In one case, there was a transverse crack across the center of the beam (mid-span). This would indicate the beam acting like a "long beam" and failing as a classic bending failure as opposed to a beam failing in shear. However, there was only a single instance of this.

The nature of the failure – was **not sudden** as if by *shear failure*. This would support the conclusion that this was a complex failure involving yielding of the steel rather of the concrete.

The rail assembly itself was bent (See pictures). This is because the rail assembly was being held down on its ends by the test fixture.

Looking at the analytical results for the beam, an 18 x 18 column with stirrups at 3" spacing would fail at Vn= 97.4/.85 = 114.5 kips, considerably less than these test results. Since the stirrups in this test were actually further apart, this implies that a concrete shear failure should have occurred well before the results of this test.

Unfortunately, these results do not compare easily to a direct analysis, such as a short beam shear failure or a beam bending failure. It is thus difficult to separate out the separate analytical aspects of test and completely understand what actually failed.

ADJUSTING FOR RAIL OVER CONSTRAINT:

It was also noted that the rail assembly was bent just outboard of the three center inserts when the testing was done. The raw test results indicate that the rail assembly sustained a test load of 131.0 Kips before failure. However, this load also included some "overage" due to the fact that we were holding the rail assembly down at it's ends at the same time. We therefore attempted to adjust for this "overload" by estimating how much load it took to bend the rail assembly as was observed in the test results. By removing this "overage", the reasoning is that we would come closer to estimating the net strength without beam assembly being overly constrained.

An additional test was completed at the WGF facility in Vero Beach 10/4/24. A rig as shown was set up to pull upward on the rail assembly and measure it's stiffness when held similarly to how it was restrained in the break test. The approach was to determine the stiffness then use this value to estimate how much movement would result in the concrete cracking and thus to determine an estimate of the "overage" load.

We chose to use 1/32" as the crack width on the concrete surface that would define "failure". From basic geometry, it was estimated that an upward deflection of .016" would be a reasonable limiting value. We therefore determined the associated overload as follows:

Test Pull load = 6.283 Kips
Delta Z = .0074"
K = 6.283 / .0074 = 849 kips / inch

Overload = .016" * 849 = **13.58 Kips**

Adjusting the test result downward by the overage… Vult = 131.00 – 13.58 = **117.4 kips**

On a per insert basis, and after applying an ultimate knockdown ϕ of .75,

Fult = .75 * 117.4 / 3 = 29.4 Kips / Insert

CONCLUSIONS:

- When tested in a similar manner to others, the WGF rail assembly exceeds previous tested rail designs in strength by **13.4 %** (29.4 vs 26.0 kips / insert). This is even after adjusting the results downward for the effects of the rail being overly constrained during the break testing.

- The rail assembly itself likely has sufficient strength to exceed even these values if tested in such a manner that it is not constrained as it was in the test. (This is not to suggest that we should re-test the assembly, but rather to point out that more needs to be learned about previous tests and the implications of how components were constrained).

- Defining the exact stress field adjacent to these types of rail assemblies installed in a column filled with vertical steel and other structural features is beyond the capability of myself and probably that of several others. We may not always completely understand the results we get when field tested until further research and development of the process takes place. However, that is not to say we can't or shouldn't design such components. We shall continue to use the current ACI Code ϕ's, knock down factors, design procedures, etc. to get conservative results.

Should you have any questions regarding the above, please contact our office.

Respectfully,

DAVID T. COLSTON
LICENSE
No 55501
STATE OF
FLORIDA
PROFESSIONAL ENGINEER

Digitally signed by David T Colston
DN: CN=David T Colston,
dnQualifier=A01410C00000187A49A405D00012FEF,
O=Florida, C=US
Date: 2024.12.09 12:15:37-05'00'

David T Colston, PE, SI
FL Reg 55501

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GENERAL NOTES

ALL STEEL FABRICATIONS SHALL BE ZINC PLATED.

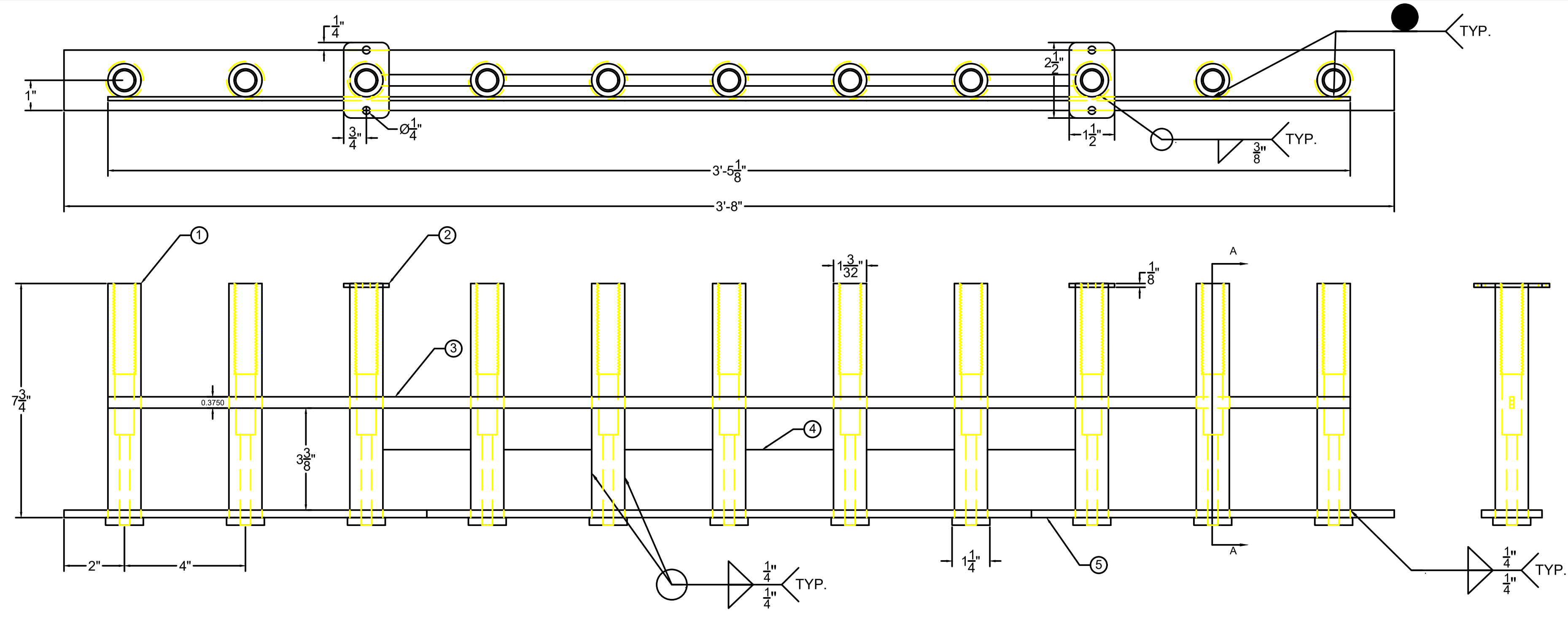
ALL WELDS SHALL BE E70 ELCTRODE UNLESS STATED OTHERWISE.

PLATE STEEL: ASTM A36.

TUBE STEEL: COLD ROLLED 1018 GRADE 108.

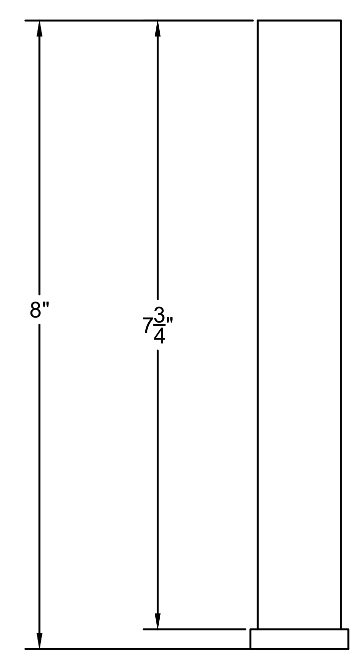
$\frac{3}{8}$" TACK WELDS WILL BE REPRESENTED WITH ●.

BILL OF MATERIAL			
I.D.	TITLE	DESCRIPTION	QNTY
1	RAIL INSERT	$7\frac{3}{4}$" TALL ROD $1\frac{3}{32}$"Ø W/ A $\frac{1}{4}$" TALL $1\frac{1}{4}$"Ø END WITH A 5" INCH DEEP .657"Ø HOLE THREADED W/ $\frac{3}{4}$"Ø THREADS 3" DEEP ON ONE SIDE AND A 3" DEEP .343"Ø HOLE ON THE OTHER SIDE.	11
2	NAIL TAB	$1\frac{1}{2}$"X$2\frac{1}{2}$"X$\frac{1}{8}$" STEEL PLATE WITH 2X $\frac{1}{4}$"Ø HOLES.	2
3	SPACER BAR	$\frac{1}{8}$"X$\frac{1}{2}$"X41-$\frac{1}{8}$" STEEL PLATE.	1
4	GUSSETS	2.9"X2"X$\frac{1}{4}$" STEEL PLATE.	6
5	BOTTOM PLATE	44"X2"X$\frac{1}{4}$" PLATE.	1



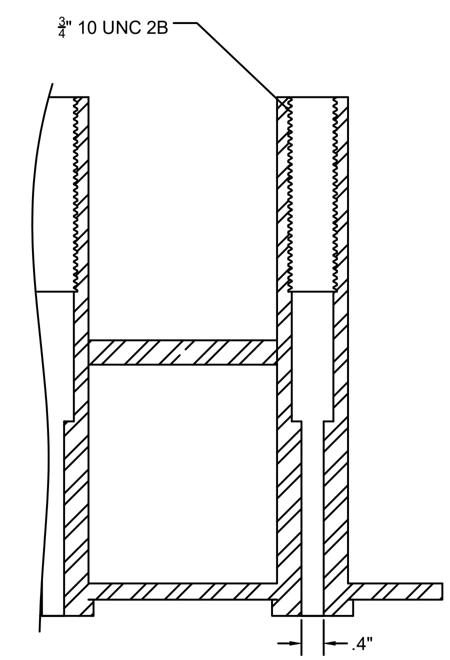
TYPICAL RAIL SECTION

NTS



TYPICAL INSERT

NTS



SECTION A-A

NTS

REVESION		
A	TOOK OUT REBAR AND REPLACED IT WITH $\frac{1}{8}$" STEEL PLATES AND MADE THE DIAMETER OF THE INSERT $1\frac{3}{32}$".	2/27/2024
B	CHANGED INSERT WELD TO $\frac{1}{4}$" FILLET WELD AND MADE THE BOTTOM PLATE 2" WIDE THROUGHOUT THE PLATE	4/1/2024

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SEAL

APPROVED BY:

DAVID T. COLSTON LICENSE No 55501 STATE OF FLORIDA PROFESSIONAL ENGINEER

CRVH-001

EZPLACE CABLE RAIL - HIGH IMPACT 90 DEGREE

WG FABRICATORS LLC.

9140 CR 229 N, SANDERSON, FL, 32087

DRAWN	GLL
CHECKED	FG
SCALE	NTS
DATE	04/01/24

SK-1

SHEET 1 OF 1

QC Metallurgical, Inc.

WG Fabricators LLC
QCM Job No. 24GM-404

August 7, 2024

RE: WFG Rail Pull Test P/N AC1318-19.
Test Performed 07/02/24

This summary is for load testing to failure of WFG Rail P/N AC1318-19. Three concrete enclosures were fabricated to encase WFG Rail Assembly, 24" x 24" x 60" with 6,500 PSI cement mix and cured for six days prior to testing. See Figures 1-3. A fabricated steel I-Beam for a cross-head was used; connecting eight threaded ¾"-B7 rods to ½" steel plate with three Grade 8, ¾" bolts torqued to 104 ft/lbs. inserted to WFG Rail Assembly. See Figures 4-10. Two hydraulic 30 ton jacks were used under cross-head to produce a tension load on the WFG rail assembly. Power was applied to Enerpac Pump/Gauge and Jacks to give an indicated 1,000 PSI on pressure gauge producing a PSI stress load of approximately 22,000 on all samples. See Figures 11-16.

Power was applied to an estimated rate of.5 in/min C/H speed until maximum value achieved on pressure gauge when pressure drops indicating failure load. Procedure was performed on all three samples showing failure mode. See Figures 17-22.

RESULTS:

Cross sectional area of RAM is 11.04" x 2 Rams = cross sectional area of 22.08".
Failure Load of test #1-3 6000 lbs. = 132.480 ~~PSI.~~ LBS
Failure load #2-2 = 5,900 lbs. = 130,272 ~~PSI.~~ LBS
Failure load #3-1 = 5,900 lbs. = 130,272 ~~PSI.~~ LBS

Jerry Iaciofano
QC Metallurgical, Inc.


Fig 1

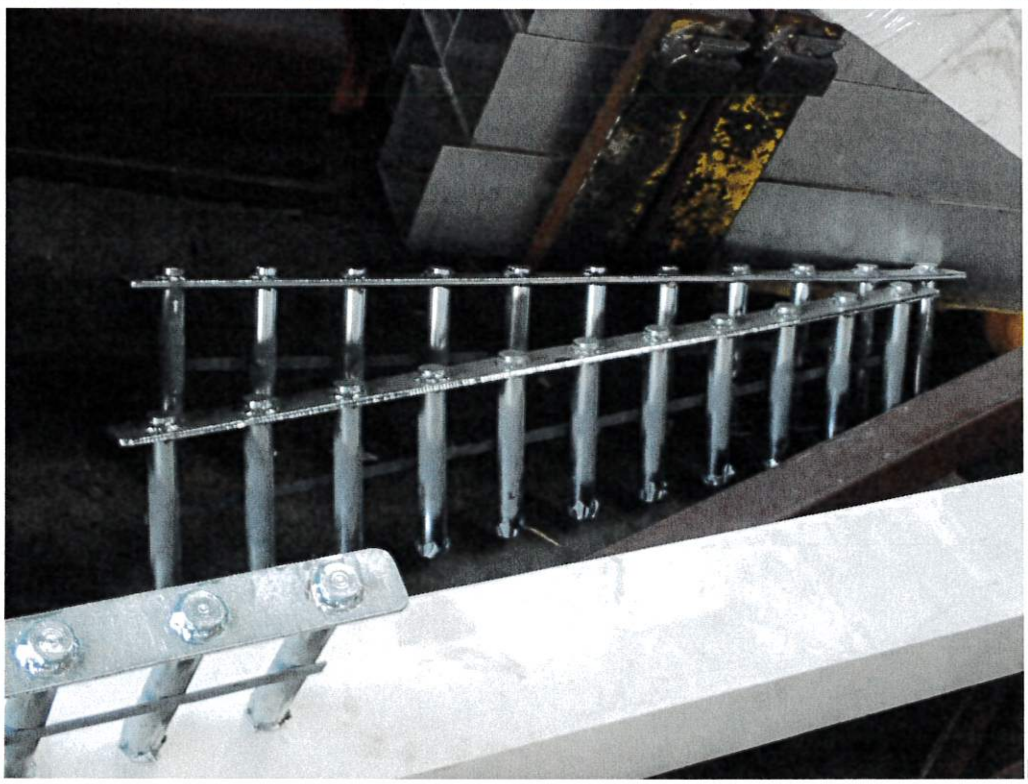


Fig2

Fig3


Fig4

Fig5

Fig6

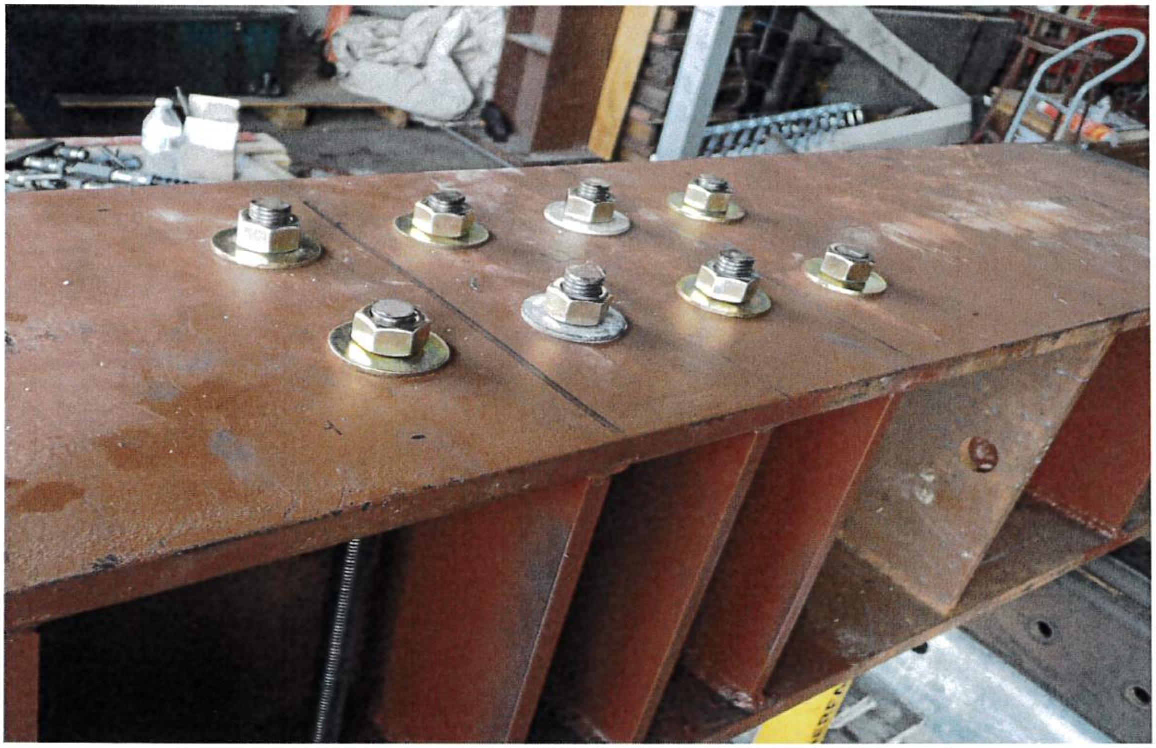


Fig7

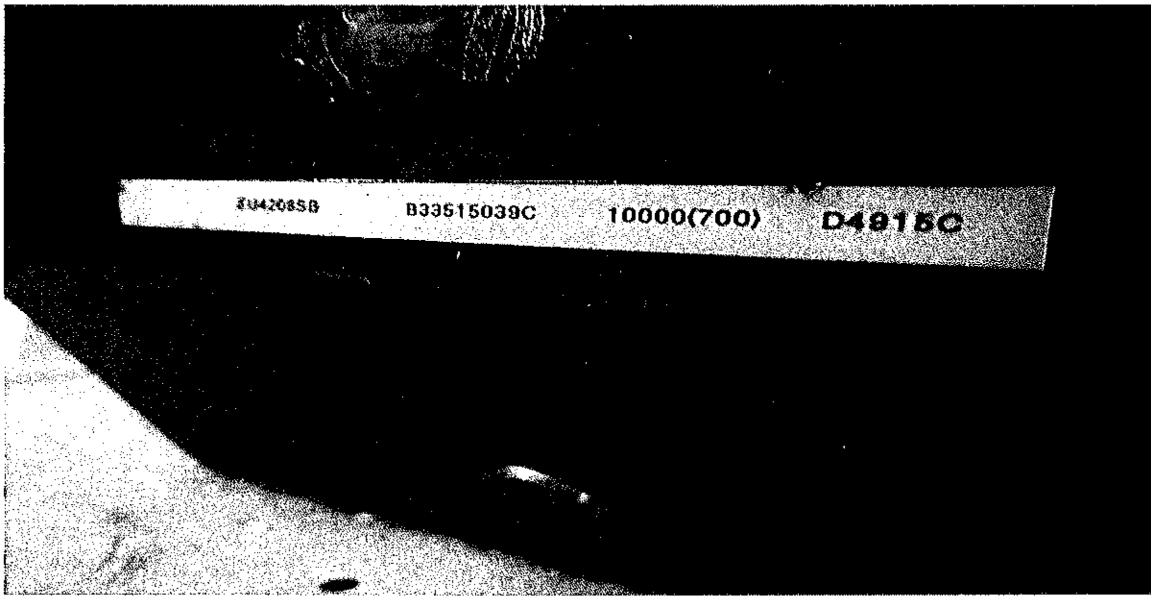
Fig8

Fig9

Fig10


11185271
ENERPAC
SUNBELT
RENTALS
INDUSTRIAL
SERVICES
Fig11


11185274
ENERPAC
RC-TRIO — 50 TON
SUNBELT
RENTALS
INDUSTRIAL
SERVICES
50 TON
MADE IN CHINA
Fig12


ZU4208SB
B33515039C
10000(700)
D4915C
Fig13


ZU4208SB
B33515039C
10000(700)
D4915C
Fig14

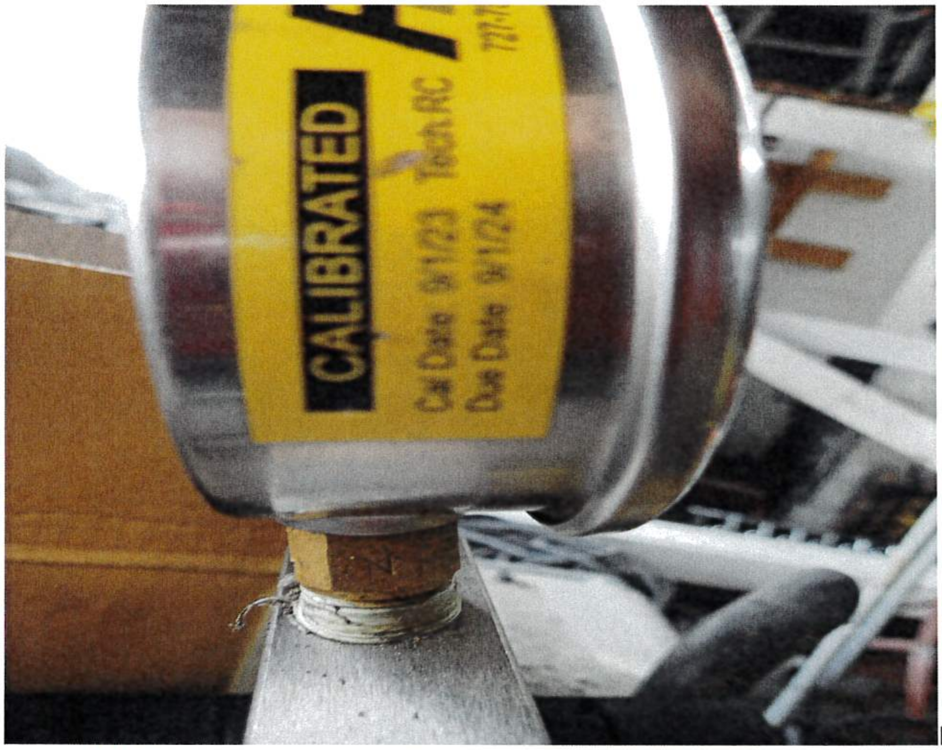


Fig15

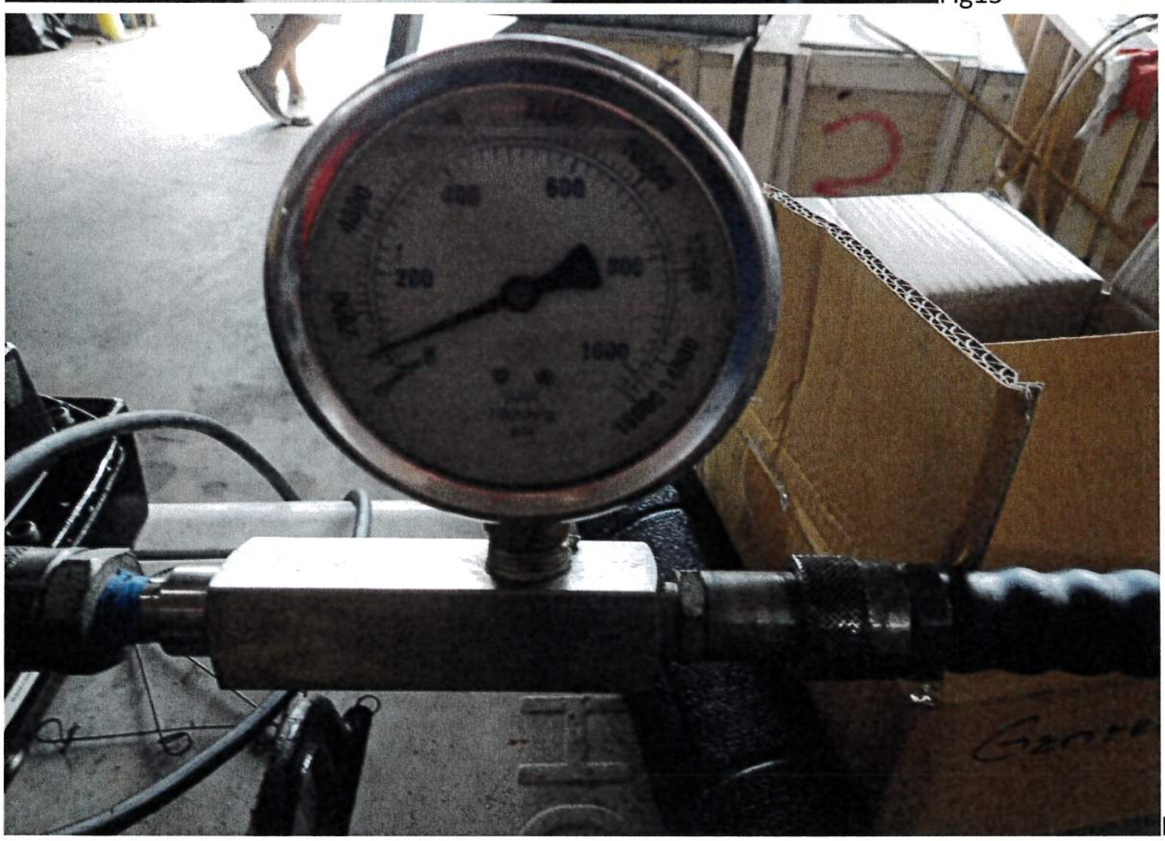


Fig16


Fig17

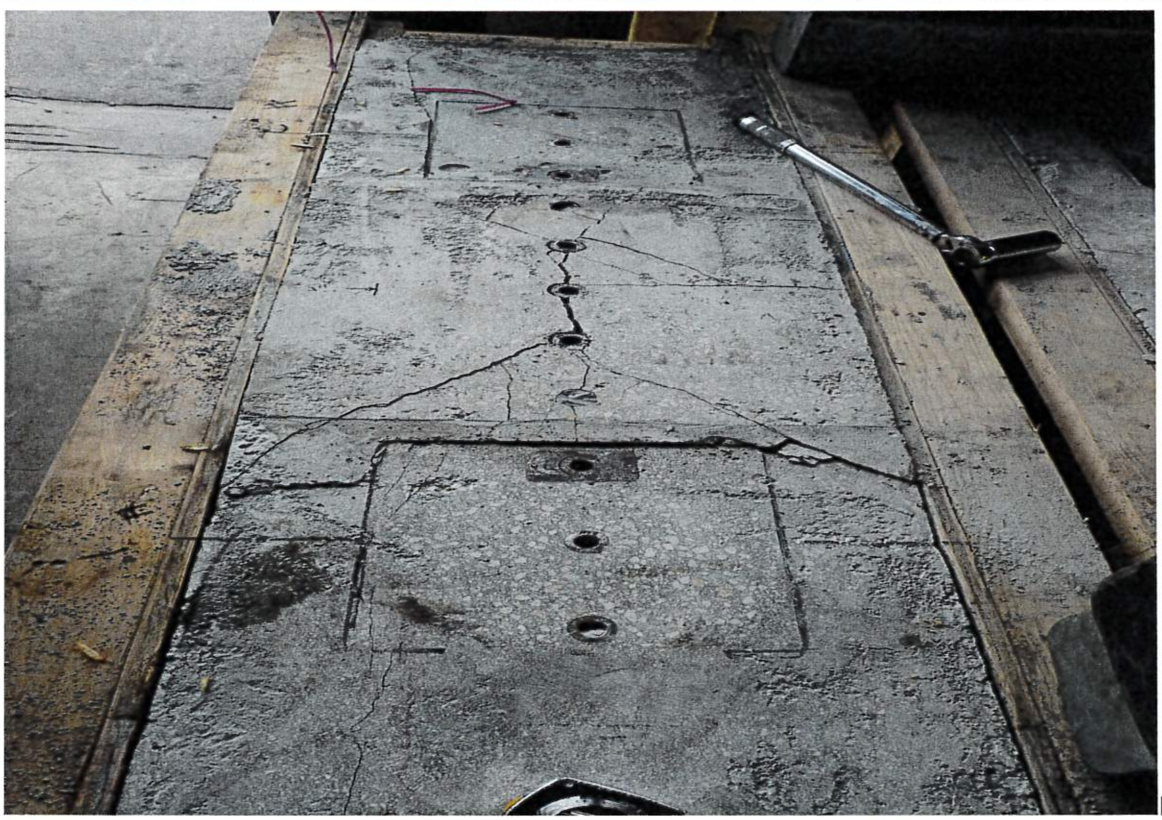


Fig18


Fig19


Fig20

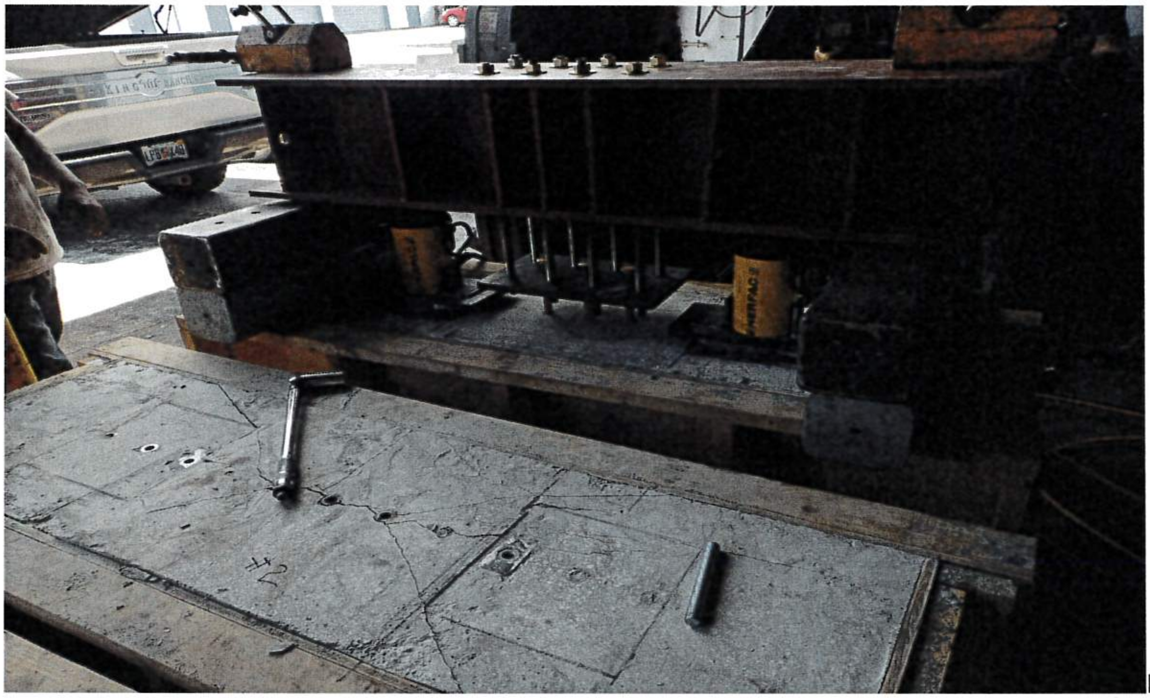


Fig21


Fig22

QC Metallurgical, Inc.
Testing & Consulting Services

Barrier Cable Constructors
P.O. No.Verbal

August 2, 2024
QCM Job No. 24GM-404

CALIBRATION CERTIFICATE

Pittsburgh- Torque Wrench
Range 10-150 Ft. Lbs. Accuracy ±4 % @ Set Scale
Serial No. 1213A0254

Standard In Ft. Lbs.	Instrument Reads in Ft. Lbs.
30	29.0
90	92.1
150	147.1

Acceptable

Calibrated With: Snap-On Torque Calibrator TTD1000A S/N 1044
Calibration Date :2/29/2024 Due: 2/28/2025.
Calibration IAW Mil-Std-45662-A and ANSI/NCSL Z-540-1-94

The accuracy and calibration of this instrument are traceable to the National Institute of Standards & Technology and are guaranteed to meet published specifications.

Date Calibrated 8/2/2024
Date Due 8/2/2025

Jerry Iaciofano

Q. C. Metallurgical, Inc.

2870 Stirling Road * Hollywood, Fl. 33020-1199 * **(954) 889-0089** * Fax (954) 362-5742
E-mail: fgrate@qcmet.com

Capacity tons (maximum)	(in)	Number	Effective Area (in²)	Capacity (in³)	Height (in)
5 (4.9)	0.63	**RC50**	0.99	0.62	1.63
	1.00	**RC51**	0.99	0.99	4.34
	3.00	**RC53**	0.99	2.97	6.50
	5.00	**RC55***	0.99	4.95	8.50
	7.00	**RC57**	0.99	6.93	10.75
	9.13	**RC59**	0.99	9.04	12.75
10 (11.2)	1.00	**RC101**	2.24	2.24	3.53
	2.13	**RC102***	2.24	4.76	4.78
	4.13	**RC104**	2.24	9.23	6.75
	6.13	**RC106***	2.24	13.70	9.75
	8.00	**RC108**	2.24	17.88	11.75
	10.13	**RC1010***	2.24	22.64	13.75
	12.00	**RC1012**	2.24	26.82	15.75
	14.00	**RC1014**	2.24	31.29	17.75
15 (15.7)	1.00	**RC151**	3.14	3.14	4.88
	2.00	**RC152**	3.14	6.28	5.88
	4.00	**RC154***	3.14	12.57	7.88
	6.00	**RC156***	3.14	18.85	10.69
	8.00	**RC158**	3.14	25.13	12.69
	10.00	**RC1510**	3.14	31.42	14.69
	12.00	**RC1512**	3.14	37.70	16.69
	14.00	**RC1514**	3.14	43.98	18.69
25 (25.8)	1.00	**RC251**	5.16	5.16	5.50
	2.00	**RC252***	5.16	10.32	6.50
	4.00	**RC254***	5.16	20.64	8.50
	6.25	**RC256***	5.16	32.25	10.75
	8.25	**RC258**	5.16	42.56	12.75
	10.25	**RC2510**	5.16	52.88	14.75
	12.25	**RC2512**	5.16	63.20	16.75
	14.25	**RC2514***	5.16	73.52	18.75
30 (32.4)	8.25	**RC308**	6.49	53.56	15.25
50 (55.2)	2.00	**RC502**	11.04	22.09	6.94
	4.00	**RC504**	11.04	44.18	8.94
	6.25	**RC506***	11.04	69.03	11.13
	10.25	**RC5010**	11.04	113.21	15.13
	13.25	**RC5013**	11.04	146.34	18.13
75 (79.5)	6.13	**RC756**	15.90	97.49	11.25
	13.13	**RC7513**	[illegible]	[illegible]	[illegible]

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Nutting Engineers of Florida, Inc. - Boynton Beach
1310 Neptune Drive
Boynton Beach, FL 33426
Phone: (561) 736-4900
Fax: (561) 737-9975

Report No: CTR:24-12644-C01

Concrete Test Report

Client: WG Fabricators, LLC.
P.O. Box 208
Sanderson, FL 32087

Project: EZ Placeable Rail Test - 6718 NW 20th Avenue
Project No: P244663
Location: 6718 NW 20th Avenue, Fort Lauderdale, FL

PO/Legal:

Mix Data

Supplier: Cemex
Plant: 1071
Mix Identification: 1177769 PRPM
Specified Design Strength (psi): 6500 at age 28 days

Sample Details

Date Sampled: 06/26/24 **Date Received:** 06/28/24
General Location: TEST COLUMNS
Sample Location: N/A
Curing Method: Two day Field/Laboratory Cure
Field Cure Temp (°F) High: N/A
Low: N/A

Ticket no.: 40015595
Truck No.: 71715
Sampled By: Jose Rodriguez
Submitted By: Anthony Range
Weather: N/A

		Measured	Specified
Slump (in):	ASTM C 143		4.00 - 6.00
Air Temp (°F):		N/A	
Concrete Temp (°F):	ASTM C 1064	N/A	
Air Content (%)	ASTM C 231	N/A	
Unit Weight (pcf):	ASTM C 138	N/A	
Volume of Density Measure (ft³):		N/A	

Batch Size (yd³): 3.0 **Time Batched:** 11:03
Yd³ Placed: 3.0 **Time Sampled:** 11:46
Water Added (gal) Before: N/A **Time Placed:** N/A
After: N/A **Time in Truck (mins):** N/A

Compressive Strength of Concrete Cylinders — ASTM C 39

Specimen ID	Date Tested	Age (Days)	Diameter (in)	Length (in)	Area (in²)	Type of Cap	Maximum Load (lbf)	Type of Fracture	Compressive Strength (psi)	Remarks	Tested By
24-12644-C01A	06/29/24	3	4.01	8.00	12.63	U	62810	2	4970	G	RB
24-12644-C01B	07/01/24	5	4.01	7.96	12.63	U	69210	2	5480	G	RB
24-12644-C01C	07/02/24	6	4.02	7.98	12.69	U	73770	2	5810	G	RB
24-12644-C01D	07/24/24	28	N/A	N/A	N/A	U	N/A	N/A	N/A	G	N/A
24-12644-C01E	07/24/24	28	N/A	N/A	N/A	U	N/A	N/A	N/A	G	N/A
24-12644-C01F	07/24/24	28	N/A	N/A	N/A	U	N/A	N/A	N/A	G	N/A

Average 28 Day Compressive Strength (psi)
Required Strength (psi) 6500

Notes

1. Sampling to ASTM C 172
2. Specimen(s) prepared to ASTM C 31
3. Capping: B = Bonded ASTM C 617,U = Unbonded ASTM C 1231
Cylinders were cast by others

Remarks

RB - Ryan Brammer
Marks: G = Good
Fracture Type: 2 = Cone & Shear, 2 = Cone/Split

FPT Industrial Solutions
727-734-8589
21933 US 19 N
Clearwater, FL
United States 33759

Calibration Certificate

Certification Number: 12804

Customer: Sunbelt Rentals
Contact: Dani Gardner
Address: 1865 Massaro Blvd
Tampa, Florida 33619 US
Phone:
Purchase Order:

Calibration Date: September 1, 2023
Due Date: September 1, 2024
Recall Interval: 12 Months
Temperature: 86F
Humidity: 23%
New / Recal: Recal

Tool Name: Hytorc 10K
Equipment: N/A
Model: 10K
Manufacturer: Hytorc
Capacity: 10000 FTLB
Accuracy: +/-1% OFS

Type / Class: 10000 PSI Pressure Gauge
Serial Number: 0041180820
Lot / ID: 3118
Testing Procedure: PSG-CP01
Units: PSI

	Nominal	As Found		Nominal	As Left		Nominal	+ Tolerance	-
	2000	Pass	Pass	2000	Pass	Pass	2000	100	100
PSI	4000	Pass	Pass	4000	Pass	Pass	4000	100	100
	6000	Pass	Pass	6000	Pass	Pass	6000	100	100
	8000	Pass	Pass	8000	Pass	Pass	8000	100	100
	10000	Pass	Pass	10000	Pass	Pass	10000	100	100

Manufacturer	Item	Model	Serial Number	Due Date	NIST Traceability
Fluke	10,000 PSI Gauge	2700G	5824035	1/20/2024	3000293427

We certify that this equipment has been compared to standards traceable to N.I.S.T. and/or NPL and has been calibrated to the stated accuracy.
The issuer of this certificate bears sole responsibility for calibration and documentation thereof.

Comments:

Technician: Rees Cralley
Date: September 1, 2023

This certificate shall not be repoduced except in full, without the written approval of the laboratory.

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