CITY OF NOVI CITY COUNCIL
MARCH 6, 2023

SUBJECT: Consideration of approval to award the construction contract to LGC Global Inc., the sole bidder, for the Novi Road/13 Mile Road PCCP Water Main Repair project in the amount of $1,236,231.00.

SUBMITTING DEPARTMENT: Department of Public Works, Engineering Division

EXPENDITURE REQUIRED	**$ 1,236,231.00**
AMOUNT BUDGETED	**$ 1,351,460.00**
APPROPRIATION REQUIRED	**$ 0**
LINE ITEM NUMBER	**592-592.00-976.112**

BACKGROUND INFORMATION:

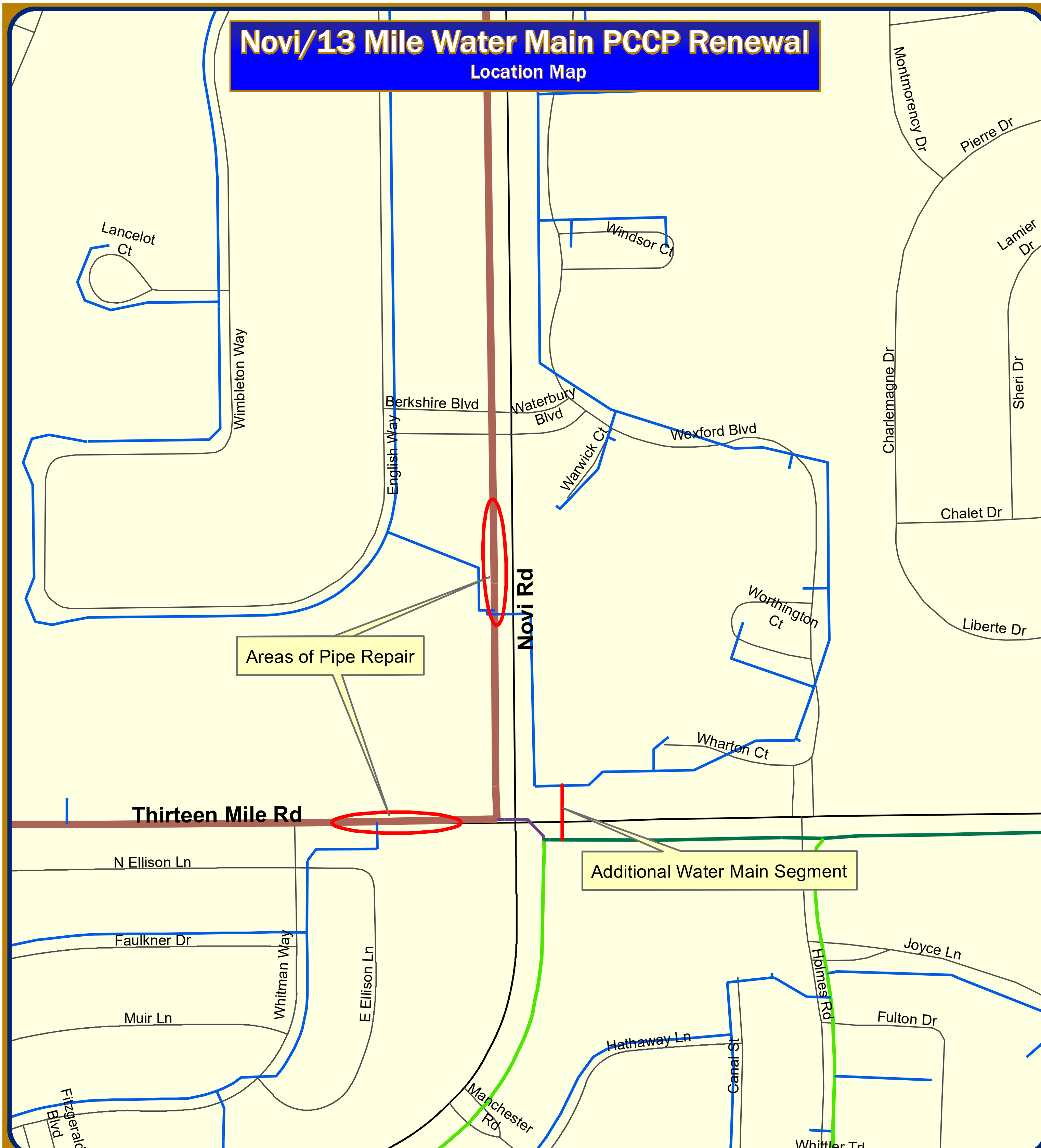
In 2019, staff inspected a portion of the City's 36-inch prestressed concrete cylinder pipe (PCCP) water transmission main using the Pipe Diver inspection tool. The Pipe Diver (a robotic data collection device inserted into the water main) identified and ranked structural deficiencies in four pipe segments. The PCCP pipe material fails catastrophically, like the 2017 Great Lakes Water Authority (GLWA) pipe failure on 14 Mile Road, and would significantly affect the water supply to the majority of the City.

Several options were considered to address the defects, including lining options, concrete encasement, and removal and replacement. Ultimately, it was determined Carbon Fiber Reinforced Polymer (CFRP) lining would be the best option given the success GLWA has recently had on their critical mains on 14 Mile Road. CFRP is a carbon fiber wrap, installed by hand inside the pipe and requires less excavation and surface disruption. The pipe can be accessed by existing manholes, eliminating the need to expose the pipe, however, excavation will still be required to install temporary line stop valves to perform the lining.

Staff worked with consulting engineer AECOM to develop the plans for this project. The project was advertised for public bids on December 28, 2022. One (1) bid was received and opened on January 17, 2023, following the solicitation period. Based on the specialized nature of the work, staff is not surprised one bid was received. LGC Global's subcontractor, Structural Technologies, is the primary company in the region performing the CFRP and has successfully completed similar projects for the GLWA. LGC Global's bid is recommended in the best interest of the City, as it is responsive and complies with all requirements of the bidding instructions.

There are several variables impacting the construction schedule. Since this project involves the 36-inch transmission main, which is the primary source of water for a large portion of the City, the work cannot be done during the high-demand irrigation summer season. Furthermore, the contractor requires the pressure in the water main to be lowered to ~58 PSI (from the typical 90-100 PSI) to provide safe operating conditions for the water main work. Currently, this pressure reduction is not possible, resulting in a total service shutdown. Therefore, to avoid a loss of water service, an additional connection can be installed across 13 Mile Road to provide redundancy. Staff is working with AECOM to design, permit, and install this water main segment, which will allow the lining project to commence in fall 2023.

RECOMMENDED ACTION: Approval to award the construction contract to LGC Global Inc., the sole bidder, for the Novi Road/13 Mile Road PCCP Water Main Repair project in the amount of $1,236,231.00.



Map Author: Croy
Date: 1/20/23
Project: PCCP Renewal
Version #: v1.0

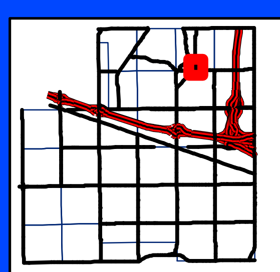
MAP INTERPRETATION NOTICE

Map information depicted is not intended to replace or substitute for any official or primary source. This map was intended to meet National Map Accuracy Standards and use the most recent, accurate sources available to the people of the City of Novi. Boundary measurements and area calculations are approximate and should not be construed as survey measurements performed by a licensed Michigan Surveyor as defined in Michigan Public Act 132 of 1970 as amended. Please contact the City GIS Manager to confirm source and accuracy information related to this map.

Map Legend

Diameter

- 8" Water Main
- 12" Water Main
- 16" Water Main
- 24" Water Main
- 36" Water Main



City of Novi
Engineering Division
Department of Public Works
26300 Lee BeGole Drive
Novi, MI 48375
cityofnovi.org

Feet
0 50 100 200 300
1 inch = 250 feet

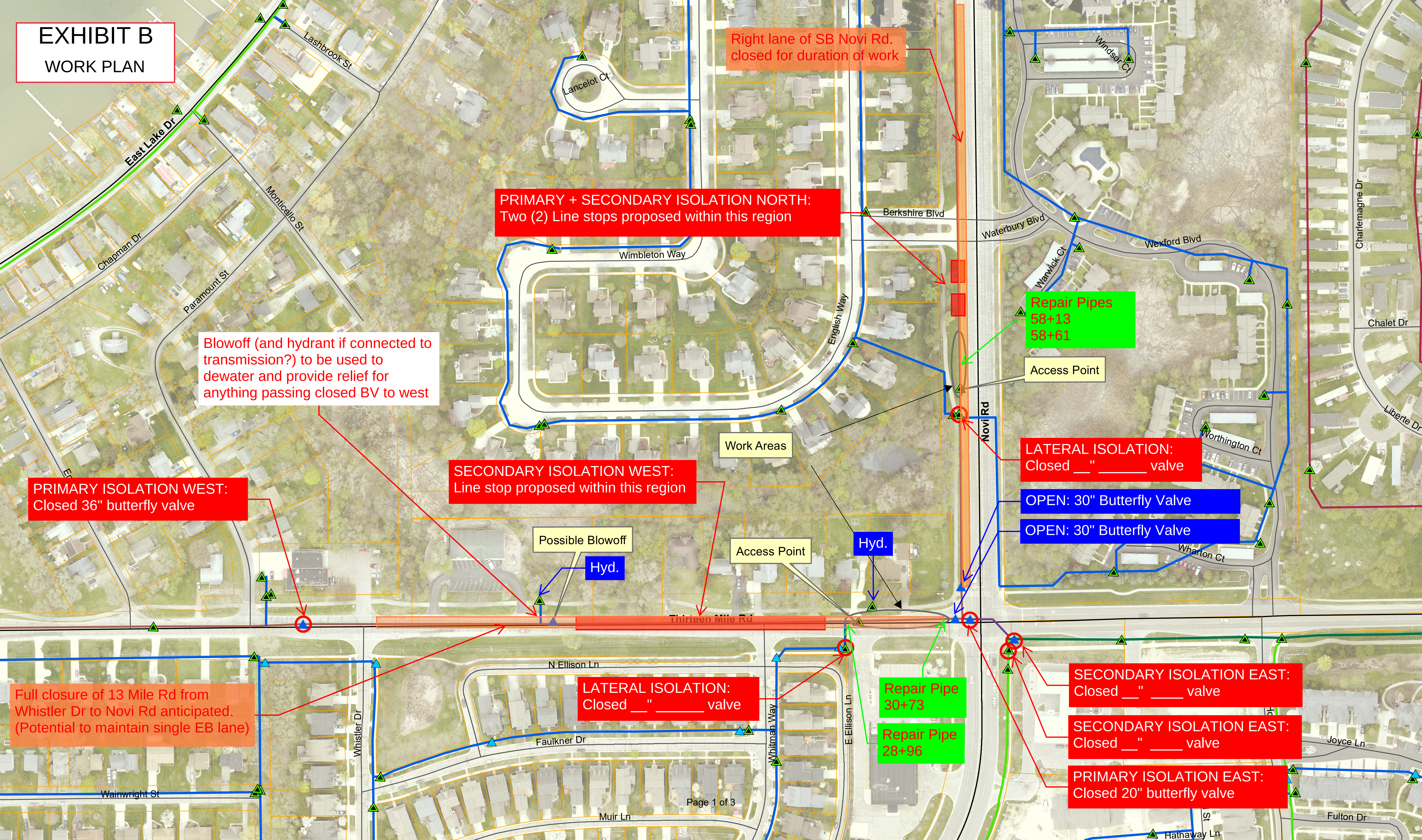
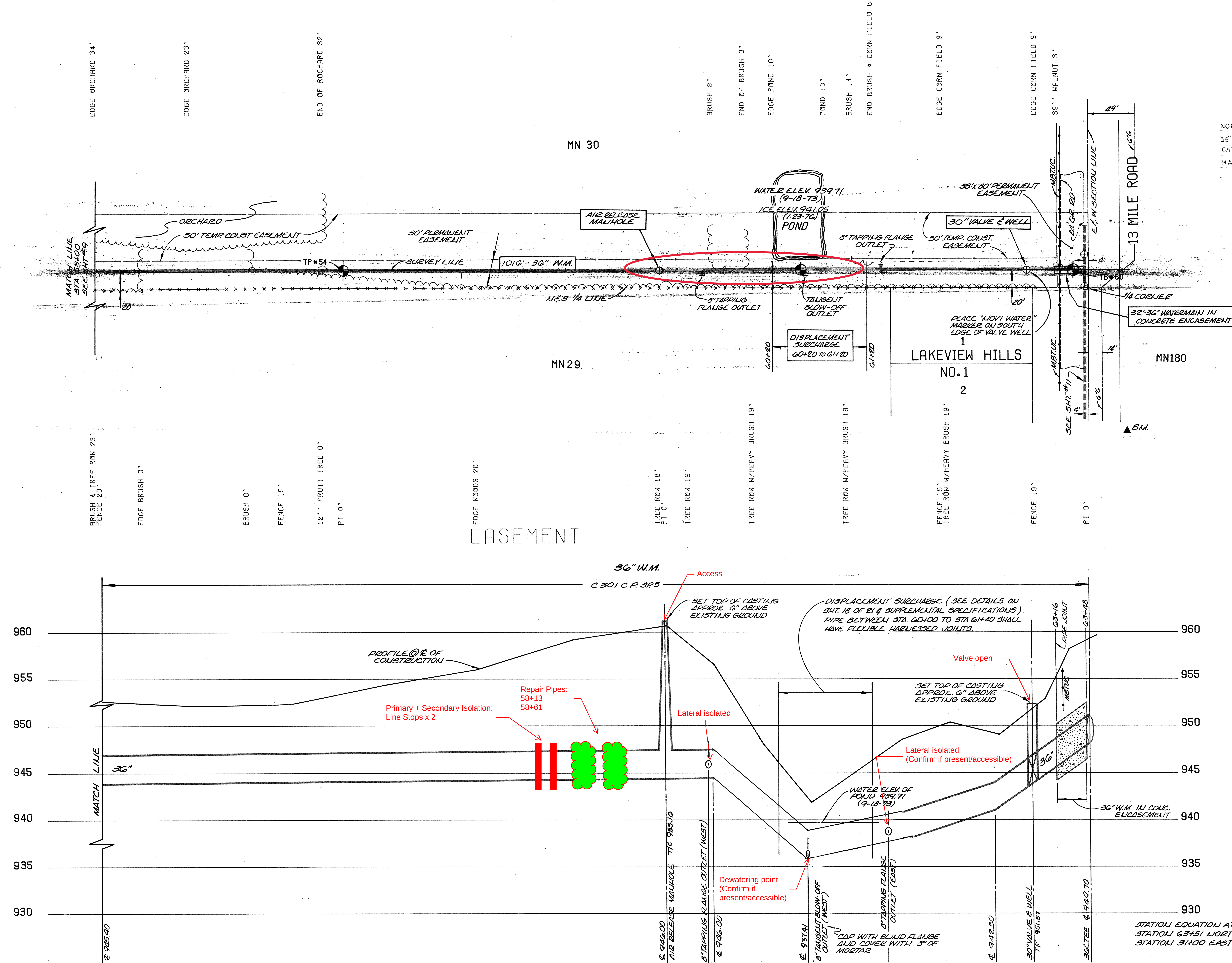


EXHIBIT B
WORK PLAN
Right lane of SB Novi Rd. closed for duration of work
PRIMARY + SECONDARY ISOLATION NORTH: Two (2) Line stops proposed within this region
Repair Pipes 58+13 58+61
Access Point
Blowoff (and hydrant if connected to transmission?) to be used to dewater and provide relief for anything passing closed BV to west
Work Areas
LATERAL ISOLATION: Closed __" ______ valve
OPEN: 30" Butterfly Valve
OPEN: 30" Butterfly Valve
SECONDARY ISOLATION WEST: Line stop proposed within this region
PRIMARY ISOLATION WEST: Closed 36" butterfly valve
Possible Blowoff
Hyd.
Access Point
Hyd.
Full closure of 13 Mile Rd from Whistler Dr to Novi Rd anticipated. (Potential to maintain single EB lane)
LATERAL ISOLATION: Closed __" ______ valve
Repair Pipe 30+73
Repair Pipe 28+96
SECONDARY ISOLATION EAST: Closed __" _____ valve
SECONDARY ISOLATION EAST: Closed __" _____ valve
PRIMARY ISOLATION EAST: Closed 20" butterfly valve
Lashbrook St
Lancelot Ct
East Lake Dr
Monticello St
Chapman Dr
Paramount St
Wimbleton Way
English Way
Berkshire Blvd
Waterbury Blvd
Windsor Ct
Warwick Ct
Wexford Blvd
Charlemagne Dr
Chalet Dr
Liberte Dr
Worthington Ct
Novi Rd
Wharton Ct
Thirteen Mile Rd
N Ellison Ln
Whistler Dr
Faulkner Dr
Whitman Way
E Ellison Ln
Wainwright St
Muir Ln
Joyce Ln
Fulton Dr
Hathaway Ln
Page 1 of 3

B.M. 16 PENNYNAIL N. SIDE P. POLE 150'± WEST ELEV. 962.05
OF FARM HSE., S. SIDE 13 MILE RD.
200'± W. OF 1/4 COR.



NOTE
36" WATERMAIN INTERPACE LOCKJOINT SP-5
GATE VALVE BUTTERFLY VALVES - PRATT
MANHOLE STRUCTURES PRECAST

QUANTITIES THIS SHEET		
ITEM	QUAN.	AS BUILT
36" WATERMAIN	1016 L.F.	1016 L.F.
36" W.M. IN CONC. ENCASEM'T	32 L.F.	32 L.F.
30" VALVE & WELL	1 EA.	1 E.A.
AIR RELEASE MANHOLE	1 EA.	1 E.A.
DISPLACEMENT SURCHARGE 60+20 TO 61+20	LUMP SUM	

WARNING

UTILITY LOCATIONS ARE NOT CONFIRMED. THOSE SHOWN WERE OBTAINED FROM UTILITY OWNERS.
48 HOURS PRIOR TO BEGINNING WORK, THE CONTRACTOR SHALL NOTIFY UTILITY OWNERS TO HAVE WORK AREA STAKED, AND HE SHALL PROTECT, OR HAVE RELOCATED, AS NOTED IN THE SPECIFICATIONS, ALL UTILITIES THAT MIGHT INTERFERE WITH CONSTRUCTION

NOTES:
TOPO REFERENCED OFF SURVEY LINE, SURVEY LINE IS ℄ OF CONSTRUCTION

CENTERLINE OF CONSTRUCTION STATIONING IS SAME AS SURVEY STATIONING.

DRAWN: JK MORTIMORE
DESIGN: J.K.M., M.G.K.
CHECKED:
DATE COMPLETED:
FINAL:
PRELIMINARY:

SCALE: VERT. 1" = 5' HORIZ. 1" = 50'

REVISIONS

MARK	BULLETIN	DATE
DGL	REVISED	2-76
JLK	AS-BUILT	3-79

JOHNSON & ANDERSON, INC.
CONSULTING ENGINEERS
PONTIAC, MICHIGAN

SECTION 2 OF CONTRACT
36" WATER MAIN EASEMENT
N. & S. 1/4 LINE SEC. 2

CITY OF NOVI
WATER TRANSMISSION SYSTEM

JOB NO. 4455-01
DATE ISSUED 6-19-76
SHEET NO. 10 OF 21

NWB 1320 250 7-73 56048

FN #13 53+00-END EASEMENT

QUANTITIES THIS SHEET

ITEM	QUAN.	AS BUILT
36" WATERMAIN	1394 L.F.	1394 LF
24" WATERMAIN	20 L.F.	20 LF
8" WATERMAIN	80 L.F.	101 LF
30" VALVE & WELL	1 EA.	1 EA
20" VALVE & WELL	1 EA	1 EA
8" VALVE & WELL	1 EA.	1 EA
HYDRANT VALVE & BOX	1 EA.	1 EA
AIR RELEASE MANHOLE	1 EA.	1 EA
BLOW-OFF MANHOLE	1 EA.	1 EA
36" WATERMAIN IN CONC. ENCASEMENT	12 L.F.	12 LF
24" W.M. IN CONC. ENCASE.	20 L.F.	20 LF
HYDRANT VALVE & BOX TYPE TMH	1 EA	1 EA

DRAWN: JK MORTIMORE
DESIGN: J.K.M., M.R.K.
CHECKED:
DATE COMPLETED:
FINAL:
PRELIMINARY:

MARK	BULLETIN	DATE
DGL	REVISED	2-76
JLK	AS-BUILT	3-79

VERT. 1" = 5'
HORIZ. 1" = 50'

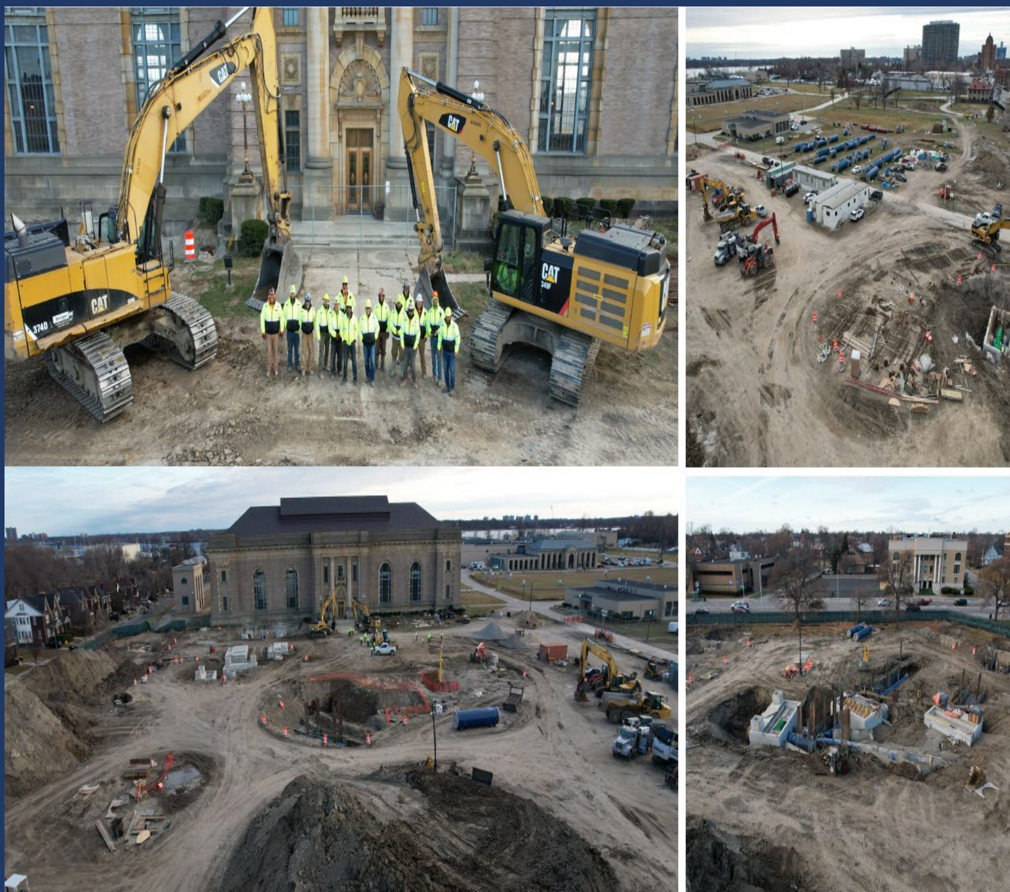
JOHNSON & ANDERSON, INC.
CONSULTING ENGINEERS
PONTIAC, MICHIGAN

SECTION 2 OF CONTRACT
36" WATER MAIN 13 MILE ROAD
SOUTH LINE SEC. 2

CITY OF NOVI
WATER TRANSMISSION SYSTEM

JOB NO. 4455-01
DATE ISSUED 6-19-76
SHEET NO. 11 OF 21

04455-00 FN#1 17+00-END 13 MILE RD.



Date of Submittal:

January 16, 2023

City of Novi
Novi Road / 13 Mile Road PCCP Water Main Renewal – RFP
Cover Letter

Submitted To:

City of Novi, Attn: Finance Department
45175 Ten Mile Road, Novi, MI 48375

Submitted By:

LGC Global Inc.
7310 Woodward Ave
Ste 500
Detroit, MI 48202

NMSDC
MBE Certified

Cover Letter

Table of Contents

1. Cover Letter

January 16, 2023

City of Novi
45175 Ten Mile Road,
Novi, MI 48375

SUBJECT: NOVI RD/13 MILE RD PCCP WATER MAIN RENEWAL
Reference No.: 122922

Dear Sir/Madam,

LGC Global, Inc. appreciates the opportunity to submit a proposal in response to the "Novi/13 Mile Rd PCCP Water Main Renewal" solicited project and expresses gratitude for the opportunity to serve and meet City of Novi's needs for this important pipeline concern. LGC is a successful and qualified general contractor with 28 years of experience executing similar projects for GLWA/DWSD in the city of Detroit. LGC's body of work includes many successful water main renewal projects such as GLWA's CS-181 Water Transmission Main Assessment/Repair, GLWA's CON-2003730 Water Transmission Main, Valve and Other Emergency Repair, GLWA's CON-105 30" Transmission main under Jefferson St. River Rouge, and GLWA-CON-158 Specialized Services Contract.

LGC plans to add value and perform this solicited project by utilizing our in-house team of key personnel who have executed similar projects together for over 10 years. To add further value, we plan to leverage our wide network of subcontractors and suppliers in the metro-Detroit area to reduce mobilization costs and decrease delays to the project schedule. We have mentioned specific subcontractors throughout the proposal that we will be utilizing on this project. These subcontractors are thoroughly vetted and have all worked with LGC on similar projects in the past.

Additionally, LGC has an open line of credit with our subcontractors and suppliers, which will shorten procurement and lead times and significantly increase overall efficiencies. As further demonstrated within our subsequent proposal and technical plan, LGC has the knowledge, experience, and resources to successfully deliver this project on budget and on time.

LGC acknowledges the receipt of Addendum # 1 issued on 01/12/2023.

We have enclosed following, in response to your request for RFP NOVI RD/13 MILE RD PCCP WATER MAIN RENEWAL to be submitted with the bid.

- Bid Bond
- Fee Proposal Form
- Appendix A - Technical Work Plan
- Appendix B – Experience and Qualifications
- Appendix C – Resumes
- Appendix D – Project Schedule (Preliminary)
- Hourly Rates by discipline (2023)
- Product Data

7310 Woodward Avenue, Ste. 500A
Detroit, MI 48202
www.lgccorp.com
Office (313) 989-4141
Fax (313) 875-2732

LGC GLOBAL

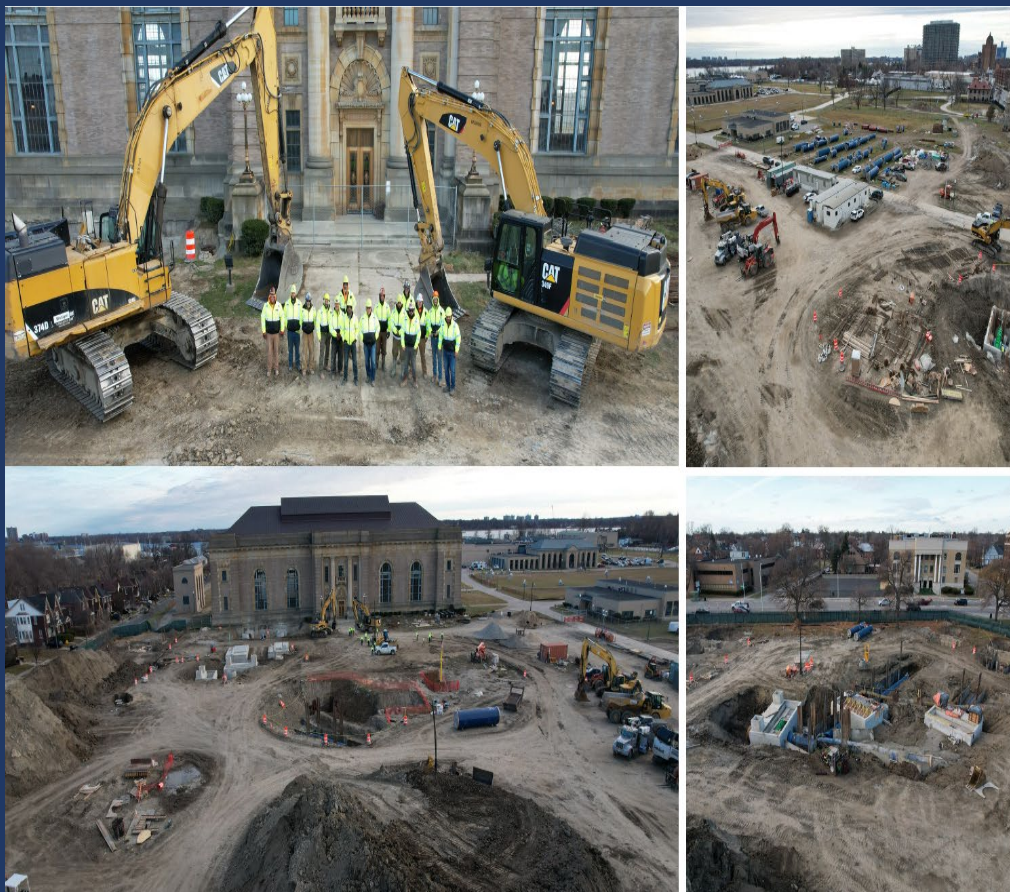
The LGC Team believes that the various components of our technical approach will provide "Best Value" for City of Novi under this contract. The following individual possesses decision-making and signatory authority to execute this proposal and any subsequent contract documentation on the Offeror's behalf. Please let us know if we can further assist with the evaluation of our proposal.

Avinash Rachmale, Chairman/CEO
LGC Global, Inc.
M: (313) 215-1669
F: (313) 420-0339
E: avinash.rachmale@lgccorp.com

Regards,

A. N. Rachmale

Avinash Rachmale, CEO



Date of Submittal:

January 16, 2023

LGC GLOBAL

City of Novi
Novi Road / 13 Mile Road PCCP Water Main Renewal – RFP

NMSDC
MBE Certified

Submitted To:

City of Novi, Attn: Finance Department
45175 Ten Mile Road, Novi, MI 48375

Submitted By:

LGC Global Inc.
7310 Woodward Ave
Ste 500
Detroit, MI 48202

Bid Bond

BID BOND (PENAL SUM FORM)

Bidder	**Surety**
Name: LGC Global Inc Address *(principal place of business)*: 7310 Woodward Ave, Suite 500A Detroit, MI 48202	Name: Swiss Re Corporate Solutions America Insurance Corporation Address *(principal place of business)*: 1200 Main St, Suite 800 Kansas City, MO 64105-2478
Telephone Number: (313) 329-5802	Telephone Number: (248) 828-3377
Owner	**Bid**
Name: City of Novi Address *(principal place of business)*: 45175 W. Ten Mile Road Novi, MI 48375	Project *(name and location)*: Novi Rd / 13 Mile Rd. PCCP Water Main Renewal Bid Due Date: 01/16/2023

Bond

Penal Sum: Five Percent of Amount of Bid (5%)

Date of Bond: 01/16/2023

Surety and Bidder, intending to be legally bound hereby, subject to the terms set forth in this Bid Bond, do each cause this Bid Bond to be duly executed by an authorized officer, agent, or representative.

Bidder	Surety
LGC Global Inc *(Full formal name of Bidder)*	Swiss Re Corporate Solutions America Insurance Corporation *(Full formal name of Surety) (corporate seal)*
By: [signature] *(Signature)*	By: [signature] *(Signature) (Attach Power of Attorney)*
Name: Avinash Rachmale *(Printed or typed)*	Name: Susan L. Small *(Printed or typed)*
Title: Chairman / CEO	Title: Attorney-in-Fact
Attest: [illegible] *(Signature)*	Attest: [signature] *(Signature)*
Name: [illegible] *(Printed or typed)*	Name: Krista L. Pocket *(Printed or typed)*
Title: Admin Proposal	Title: Surety Administrator

Notes: (1) Note: Addresses are to be used for giving any required notice. (2) Provide execution by any additional parties, such as joint venturers, if necessary.

1. Bidder and Surety, jointly and severally, bind themselves, their heirs, executors, administrators, successors, and assigns to pay to Owner upon default of Bidder the penal sum set forth on the face of this Bond. Payment of the penal sum is the extent of Bidder's and Surety's liability. Recovery of such penal sum under the terms of this Bond will be Owner's sole and exclusive remedy upon default of Bidder.

2. Default of Bidder occurs upon the failure of Bidder to deliver within the time required by the Bidding Documents (or any extension thereof agreed to in writing by Owner) the executed Agreement required by the Bidding Documents and any performance and payment bonds required by the Bidding Documents.

3. This obligation will be null and void if:

   3.1. Owner accepts Bidder's Bid and Bidder delivers within the time required by the Bidding Documents (or any extension thereof agreed to in writing by Owner) the executed Agreement required by the Bidding Documents and any performance and payment bonds required by the Bidding Documents, or

   3.2. All Bids are rejected by Owner, or

   3.3. Owner fails to issue a Notice of Award to Bidder within the time specified in the Bidding Documents (or any extension thereof agreed to in writing by Bidder and, if applicable, consented to by Surety when required by Paragraph 5 hereof).

4. Payment under this Bond will be due and payable upon default of Bidder and within thirty (30) calendar days after receipt by Bidder and Surety of written notice of default from Owner, which notice will be given with reasonable promptness, identifying this Bond and the Project and including a statement of the amount due.

5. Surety waives notice of any and all defenses based on or arising out of any time extension to issue Notice of Award agreed to in writing by Owner and Bidder, provided that the total time for issuing Notice of Award including extensions does not in the aggregate exceed one hundred eighty (180) days from the Bid due date without Surety's written consent.

6. No suit or action will be commenced under this Bond prior to thirty (30) calendar days after the notice of default required in Paragraph 4 above is received by Bidder and Surety, and in no case later than one year after the Bid due date.

7. Any suit or action under this Bond will be commenced only in a court of competent jurisdiction located in the state in which the Project is located.

8. Notices required hereunder must be in writing and sent to Bidder and Surety at their respective addresses shown on the face of this Bond. Such notices may be sent by personal delivery, commercial courier, or by United States Postal Service registered or certified mail, return receipt requested, postage pre-paid, and will be deemed to be effective upon receipt by the party concerned.

9. Surety shall cause to be attached to this Bond a current and effective Power of Attorney evidencing the authority of the officer, agent, or representative who executed this Bond on behalf of Surety to execute, seal, and deliver such Bond and bind the Surety thereby.

10. This Bond is intended to conform to all applicable statutory requirements. Any applicable requirement of any applicable statute that has been omitted from this Bond will be deemed to be included herein as if set forth at length. If any provision of this Bond conflicts with any applicable statute, then the provision of said statute governs and the remainder of this Bond that is not in conflict therewith continues in full force and effect.

11. The term "Bid" as used herein includes a Bid, offer, or proposal as applicable.

SWISS RE CORPORATE SOLUTIONS

SWISS RE CORPORATE SOLUTIONS AMERICA INSURANCE CORPORATION ("SRCSAIC")
SWISS RE CORPORATE SOLUTIONS PREMIER INSURANCE CORPORATION ("SRCSPIC")
WESTPORT INSURANCE CORPORATION ("WIC")

GENERAL POWER OF ATTORNEY

KNOW ALL MEN BY THESE PRESENTS, THAT SRCSAIC, a corporation duly organized and existing under laws of the State of Missouri, and having its principal office in the City of Kansas City, Missouri, and SRCSPIC, a corporation organized and existing under the laws of the State of Missouri and having its principal office in the City of Kansas City, Missouri, and WIC, organized under the laws of the State of Missouri, and having its principal office in the City of Kansas City, Missouri, each does hereby make, constitute and appoint:

ROBERT TROBEC, KATHLEEN M. IRELAN, IAN J. DONALD, JEFFREY A. CHANDLER, ALAN P. CHANDLER, SUSAN L. SMALL, T.J. GRIFFIN, JOHN L. BUDDE,
STEVEN K. BRANDON, TERENCE J. GRIFFIN, TERRI L. YOUNG, PATRICK E. WILLIAMS, WENDY LEE HINGSON, and BRYAN FORMSA

JOINTLY OR SEVERALLY

Its true and lawful Attorney(s)-in-Fact, to make, execute, seal and deliver, for and on its behalf and as its act and deed, bonds or other writings obligatory in the nature of a bond on behalf of each of said Companies, as surety, on contracts of suretyship as are or may be required or permitted by law, regulation, contract or otherwise, provided that no bond or undertaking or contract or suretyship executed under this authority shall exceed the amount of:

TWO HUNDRED MILLION ($200,000,000.00) DOLLARS

This Power of Attorney is granted and is signed by facsimile under and by the authority of the following Resolutions adopted by the Boards of Directors of both SRCSAIC and SRCSPIC at meetings duly called and held on the 18th of November 2021 and WIC by written consent of its Executive Committee dated July 18, 2011.

"RESOLVED, that any two of the President, any Managing Director, any Senior Vice President, any Vice President, the Secretary or any Assistant Secretary be, and each or any of them hereby is, authorized to execute a Power of Attorney qualifying the attorney named in the given Power of Attorney to execute on behalf of the Corporation bonds, undertakings and all contracts of surety, and that each or any of them hereby is authorized to attest to the execution of any such Power of Attorney and to attach therein the seal of the Corporation; and it is

FURTHER RESOLVED, that the signature of such officers and the seal of the Corporation may be affixed to any such Power of Attorney or to any certificate relating thereto by facsimile, and any such Power of Attorney or certificate bearing such facsimile signatures or facsimile seal shall be binding upon the Corporation when so affixed and in the future with regard to any bond, undertaking or contract of surety to which it is attached."

SEAL SEAL

By____________________
Erik Janssens, Senior Vice President of SRCSAIC & Senior Vice President of SRCSPIC & Senior Vice President of WIC

By____________________
Gerald Jagrowski, Vice President of SRCSAIC & Vice President of SRCSPIC & Vice President of WIC

IN WITNESS WHEREOF, SRCSAIC, SRCSPIC, and WIC have caused their official seals to be hereunto affixed, and these presents to be signed by their authorized officers

this 10 day of NOVEMBER, 20 22

Swiss Re Corporate Solutions America Insurance Corporation
Swiss Re Corporate Solutions Premier Insurance Corporation
Westport Insurance Corporation

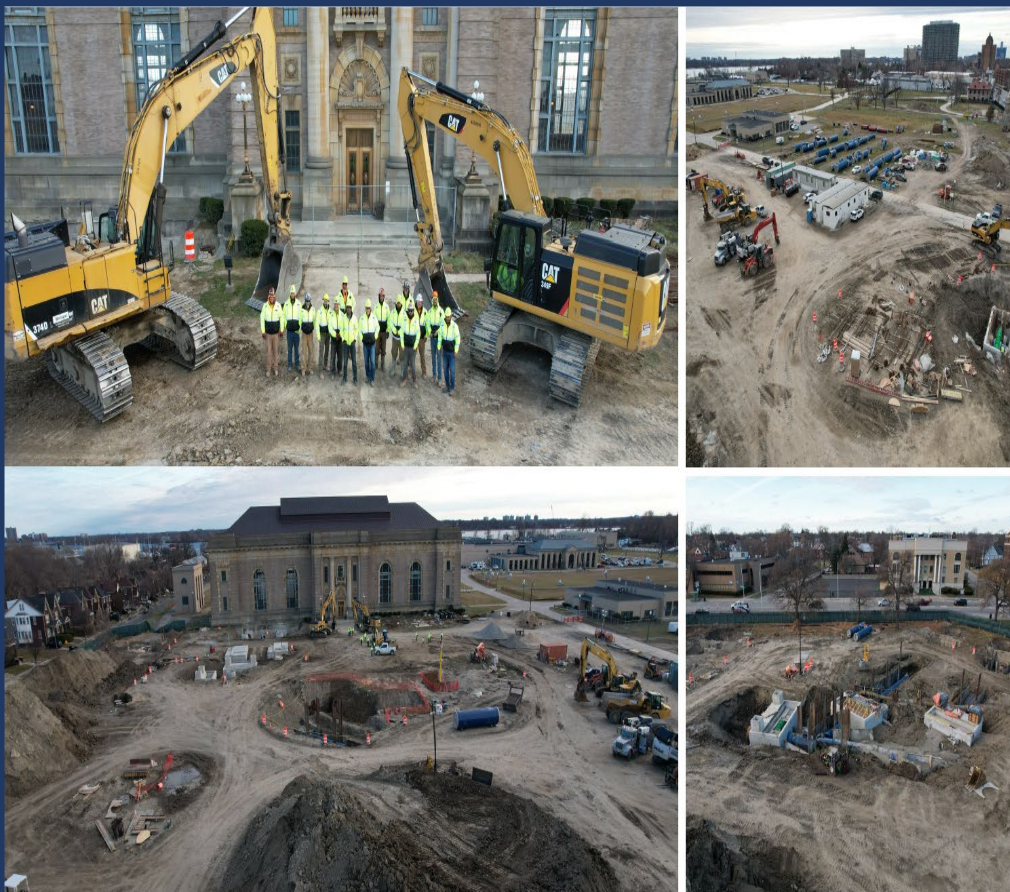
State of Illinois
County of Cook ss

On this 10 day of NOVEMBER, 20 22, before me, a Notary Public personally appeared Erik Janssens, Senior Vice President of SRCSAIC and Senior Vice President of SRCSPIC and Senior Vice President of WIC and Gerald Jagrowski, Vice President of SRCSAIC and Vice President of SPCSPIC and Vice President of WIC, personally known to me, who being by me duly sworn, acknowledged that they signed the above Power of Attorney as officers of and acknowledged said instrument to be the voluntary act and deed of their respective companies.

OFFICIAL SEAL
CHRISTINA MANISCO
NOTARY PUBLIC, STATE OF ILLINOIS
My Commission Expires March 28, 2026

I, Jeffrey Goldberg, the duly elected Senior Vice President and Assistant Secretary of SRCSAIC and SRCSPIC and WIC, do hereby certify that the above and foregoing is a true and correct copy of a Power of Attorney given by said SRCSAIC and SRCSPIC and WIC, which is still in full force and effect.
IN WITNESS WHEREOF, I have set my hand and affixed the seals of the Companies this 16th day of January, 2023.

____
Jeffrey Goldberg, Senior Vice President & Assistant Secretary of SRCSAIC and SRCSPIC and WIC



Date of Submittal:

January 16, 2023

City of Novi
Novi Road / 13 Mile Road PCCP Water Main Renewal – RFP
Fee Proposal Form and Reference List

Submitted To:

City of Novi, Attn: Finance Department
45175 Ten Mile Road, Novi, MI 48375

Submitted By:

LGC Global Inc.
7310 Woodward Ave
Ste 500
Detroit, MI 48202

NMSDC MBE Certified

Reference List

CITY OF NOVI

NOVI RD/13 MILE RD PCCP WATER MAIN RENEWAL

FEE PROPOSAL FORM

We the undersigned as proposer, propose to furnish to the City of Novi, according to the specifications, terms, conditions and instructions attached hereto and made a part thereof:

Item Description	Unit	Extended Cost
Provide and install a stand-alone CFRP structural upgrade for the four identified pipe segments.	LS	872,744.00
Installation of three (3) Line Stops	LS	201,952.00
Line Stop Extended Duration (if required beyond anticipated duration of 21 days due to unforeseen circumstances)	Day	1,250.00
Pavement Restoration – temporary and permanent	LS	160,285.00
Total Cost		1,236,231.00

We acknowledge receipt of the following Addenda: 1 Addendum1 01/12/2023
(please indicate numbers)

EXCEPTIONS TO SPECIFICATIONS (all exceptions must be noted here):

Included in Appendix A - Technical Proposal , General Notes and Assumptions

COMMENTS: None

REFERENCES: Please provide at least three client (3) references for projects of similar scope done in the last 3 years.

Company Great Lakes Water Authority- 2003730 Water Transmission Main Valve & Other Priority Repair

Address 735 Randolph St Ste 1900, Detroit, Michigan 48226

Phone 313-999-4494 Contact name Todd King

Company Great Lakes Water Authority- 181 Water Transmission Main Repair

Address 735 Randolph St Ste 1900, Detroit, Michigan 48226

Phone 313-999-4494 Contact name Todd King

Company Great Lakes Water Authority-2004889 Specialized Contract

Address 735 Randolph St Ste 1900, Detroit, Michigan 48226

Phone 313-999-1455 Contact name Tom Hall

THIS PROPOSAL SUBMITTED BY:

Company (Legal Registration) LGC Global, Inc.

Address 7310 Woodward Ave., Ste 500,

City Detroit State Michigan Zip 48202

Telephone 313-215-1669 Fax 313-875-2732

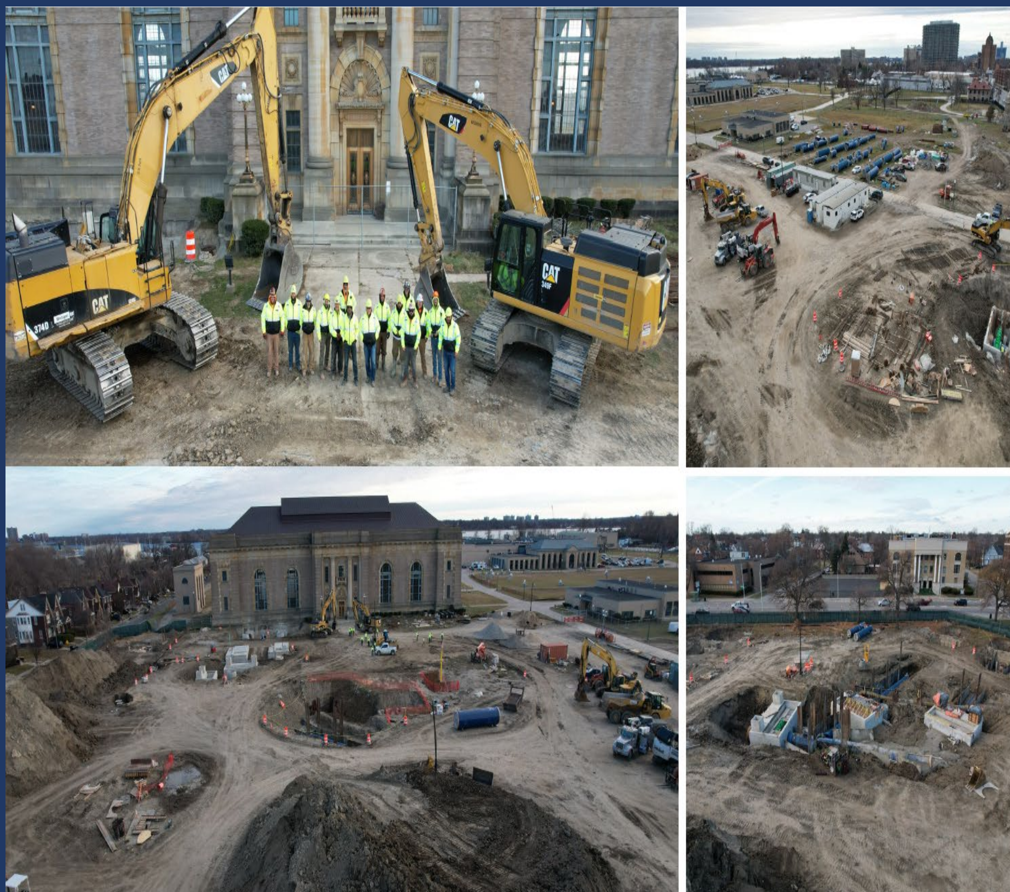
Representative's Name Avinash Rachmale

Representative's Title Chairman/CEO

Authorized Signature A. N. Rachmale

E-mail avinash.rachmale@lgccorp.com

Date 01/12/2023



Date of Submittal:

January 16, 2023

LGC GLOBAL

City of Novi
Novi Road / 13 Mile Road PCCP Water Main Renewal – RFP
Appendix A - Technical Proposal

Submitted To:

City of Novi, Attn: Finance Department
45175 Ten Mile Road, Novi, MI 48375

Submitted By:

LGC Global Inc.
7310 Woodward Ave
Ste 500
Detroit, MI 48202

NMSDC
MBE Certified

Appendix A

Table of Contents

1. Appendix A – Technical Work Plan

1.1Understanding of Project

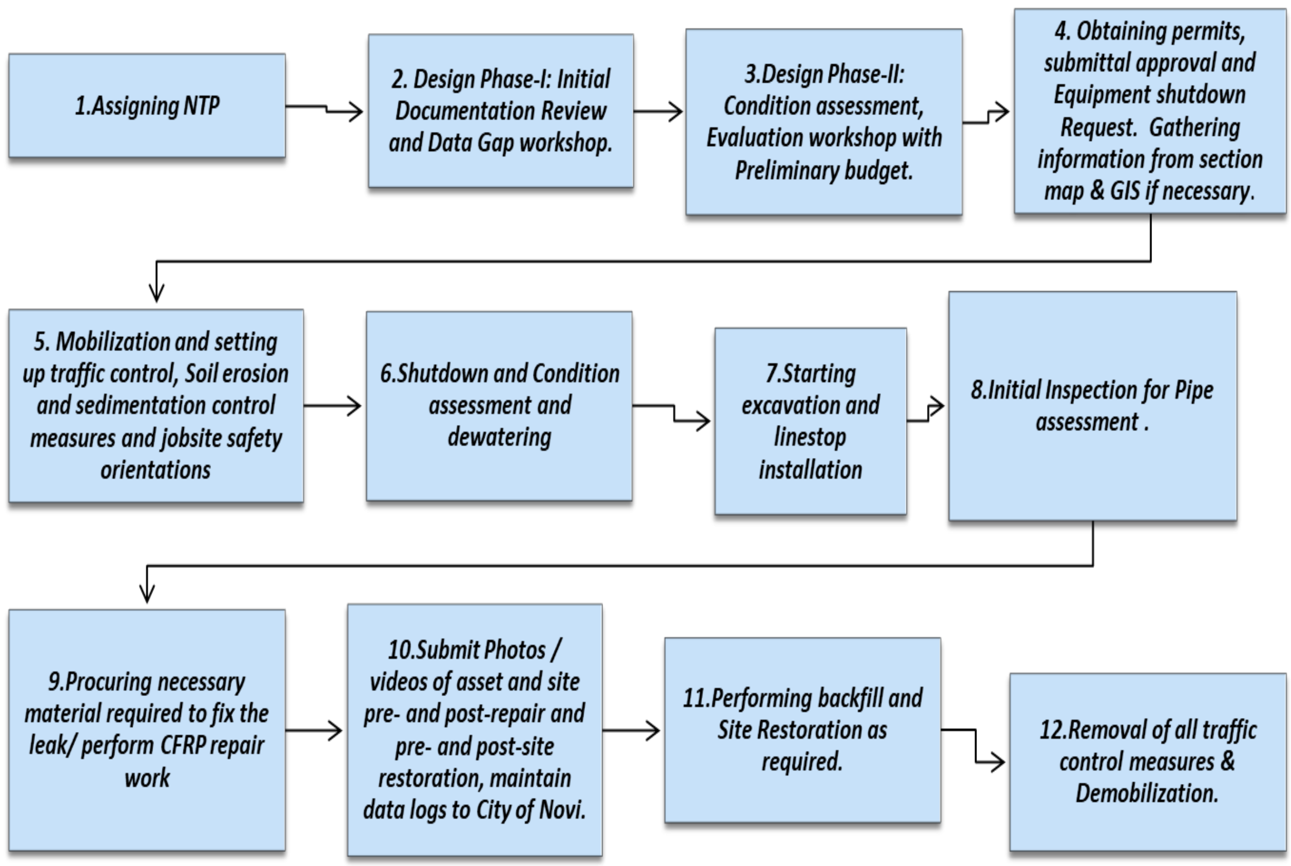
LGC Global, Inc (LGC/ LGC Global) is pleased to submit a proposal for City of Novi to perform work that includes rehabilitation of the four pipe segments (64 Lineal Feet) of 36-inch diameter PCCP Water Transmission Main at Sta 58+13 and 58+16 on Novi Rd and at Sta 30+73 and 28+96 on 13 Mile Rd as directed by City of Novi under contract ***"RFP Novi Rd/13 Mile Rd PCCP Water Main Renewal"***.

LGC has a high-level understanding and experience of working on infrastructure that consists of similar scope of work required under this RFP. Our Team is 100% local and highly qualified to perform specialty repairs to aging infrastructure on planned and emergency projects.
With the quantity and scopes of work that our team has performed in the past, LGC Team has a thorough understanding of the requirements under this RFP and outlined the scope of work below keeping safety as topmost priority:

1. Documentation review and engineering 2. Permitting and submittals 3. Geo-tech engineering 4. Traffic control and SESC measures 5. Shutdown requirements, dewatering, excavation and shoring needs 6. Linestop installations	7. Preliminary inspection and condition assessment of pipe 8. Design and install CFRP repairs 9. Quality Control, Closeout documentation and Photo Logs 10. Disinfection and Chlorination 11. Site Restoration and Demobilization

An uninterrupted supply of clean drinking water is of significant importance for the City of Novi and LGC understands the severity of issues caused by water main breaks. LGC also acknowledges that this work must be performed in a timely manner to cause minimum disruption to City of Novi residents and businesses.

1.1.1 Flow Chart of Sequence of Work



LGC has necessary equipment such as excavators (with reaches to the required depth), sheeting, shoring, trench-boxes, by-pass pumping equipment, saw cutting equipment, cranes, boom-trucks, vactor trucks, CCTV inspection truck, grouting equipment, jack & bore equipment, trucks, and loaders.

Figure 1: LGC Project Site

1.1.2 Capabilities and Expertise

- LGC was established on and is strategically located in City of Detroit to serve the Tri-County region comprising of Oakland, Macomb and Wayne.

LGC has a long history in the City of Detroit and is considered one of the most experienced infrastructure repair and replacement contractor in the region.

- LGC houses 25 acres yard on Hamilton Ave. in Highland Park, 5 acres yard on Midland St. in Highland Park and 30000 square feet headquarters on Woodward Ave. in Detroit.
- LGC shares nearly 3 decades of history in structural improvements of watermains, sewers, facilities, and structures specializing in trenchless repairs and rehabilitation solutions for water, storm, and other underground piping systems.
- LGC provides GLWA, DWSD, Wayne County, Federal Government, and other municipality clients throughout the United States with innovative solutions which include a robust 24/7 Emergency Response capability.
- LGC carries a large inventory of most widely used materials for watermain and sewer repairs at its service yards in Highland Park facilities.
- LGC currently holds two emergency watermain repair contracts with GLWA and DWSD. These contracts were awarded after careful evaluations of capabilities, experience, technical knowledge, project understanding, equipment availability, and aptitude to meet scheduling deadlines. Our team members have been part of heavy construction and underground rehabilitation for the last 27 years.
- LGC Team is completely familiar and understands the coordination/procedures needed between City of Novi, EGLE, GLWA, jurisdictional authority, and other permitting agencies. LGC has worked on various regulatory issues ranging from obtaining permits to installation of various water system products.
- LGC Team experience and qualifications are included in **Appendix B**

Figure 2: 48-inch WM and GV Installation

Listed below are some of our projects similar in nature to the RFP.

- GLWA’s CS-181 Water Transmission Main Assessment/Repair
- GLWA’s CON-2003730 Water Transmission Main, Valve and Other Emergency Repair
- GLWA’s CON-105 30” Transmission main under Jefferson St. River Rouge
- GLWA-CON-158 Specialized Services Contract

LGC Team is best suited to perform this work as intended by City of Novi because of following.

- Available Manpower and Equipment: As the ideal contractor, LGC is able to draw from pools of in-house (Team) manpower, equipment, facilities, and support assets to provide immediate and timely response to City of Novi requirements as outlined in the RFP. LGC Team has redundant capacity to ensure that work can continue on all fronts simultaneously.

- Responsiveness: The LGC Management team is trained and equipped to accomplish each of the scope/sequence as identified above. Over last three decades of providing this service to DWSD, and the last 6 years to GLWA, LGC has established and maintains a flexible and responsive program office hat is physically 25 miles away from City of Novi. LGC has successfully responded to DWSD needs on the day of flooding June 26th, 2021 as part of emergency flood relief efforts, successfully responded to 14 Mile water main break for GLWA and continues to do so on daily basis consistently.
- Proximity: LGC Team, as the ideal contractor, has two facilities just 25 miles southeast of City of Novi which houses wide range of equipment necessary to successfully perform the work identified in the RFP. LGC Team stands out from competition due to our multiple office locations near City of Novi and our manpower, equipment, and materials, are already in place due to current support of these emergency contracts with DWSWD and GLWA. Likewise, redundancy built into the LGC Team cannot be duplicated.
- Financial Ability to Support Work: The correct solution to this issue requires the ideal contractor to have sufficient size and financial strength to accommodate demands on its resources as well as ability to fund the additional equipment, personnel, and material required to support the project in all respect. Our team is positioned perfectly in this regards, with all team members in extremely strong financial positions.

LGC has assembled a team of subcontractors recognized for their abilities to effectively support the rehabilitation of water transmission repair. LGC Team will collectively facilitate the expeditious performance of the work, the first time around, without sacrificing the standard of quality and responsiveness expected by the City of Novi.

1.1.3 Subcontractor Team

LGC has assembled a highly experienced, team comprising of national and local premium subcontractors to address the full scope of work for the proposed City of Novi project, enabling prompt execution of the work with no delays or impacts to the project schedule. The team will provide management, technical, and specialized services that will ensure cost-effective and timely completion of assigned tasks. Proposed team members have previously worked with each other on similar assignments or for the GLWA/DWSD and other projects.

LGC Team is intimately aware of the project area, specifications, schedule, and applicable City of Novi, policies, and procedures. LGC will continually and proactively manage the performance and deliverables of our subcontractors to ensure conformance to the requirements of the Contract.

Structural Group is listed in the Engineering News Record ranking as one of the Top Specialty Contractors and is recognized as the largest structural repair and strengthening contractor in the US. Since its founding in 1976, STRUCTURAL has successfully completed more than 18,000 repair and remediation projects and has been recognized with more than 50 industry awards.

This unmatched level of experience and recognition has set Structural Group apart in the market as the go-to company for some of the most difficult projects completed in the repair industry, including buried pipelines which we repair and strengthen for power plants, municipalities, industrial facilities, and nuclear power generation plants throughout the United States.

FK Engineering Associates was founded in 2012 and is a full service geotechnical and underground engineering firm, specializing in innovative solutions for complex infrastructure engineering challenges. FKE specializes in heavy infrastructure engineering, particularly tunnel and shaft design, geotechnical instrumentation, groundwater dewatering analysis, infrastructure rehabilitation, and cost/risk analysis, as well as all aspects of field engineering and construction oversight related to such services. They have designed over one hundred tunnel linings (up to 25 feet diameter), and hundreds of shafts (up to 75-foot diameter and up to 250 feet deep). The FKE team has a proven record in southeast Michigan and works locally out of their Madison Heights office. FKE's wide range of design, analysis, and field engineering services are summarized:

- ✓ Geotechnical Engineering
- ✓ Tunnel and Shaft Design
- ✓ Groundwater Dewatering
- ✓ PACP/MACP Inspections
- ✓ Vibration Monitoring and Analysis
- ✓ Geotechnical Instrumentation
- ✓ Temporary Earth Retention Systems
- ✓ Construction Contract Administration
- ✓ Plan and Shop Drawing Review
- ✓ Construction Inspection and Sequencing

With more than 20 years of doing business in Michigan and across the country, Watertap Inc. has the knowledge and the experience to help its customers tackle the most complicated watermain issues when they arise. Watertap Inc. provides line stops ranging from 1-1/2" to 42" with multiple stop and bypass capabilities, with a huge inventory on-hand.

Pipe types include:

- Concrete
- Ductile/Cast Iron
- High-density polyethylene (HDPE)
- Carbon Steel
- C900

LGC's past experience working with our proposed team members is depicted in the chart below:

	TEAM MEMBER			
PROJECT	LGC	STRUCTURAL	WATERTAP	FKE
SCOPE OF SERVICE	General Contractor	CFRP LINING	LINESTOP	GEO-TECHNICAL SERVICES
CON-3730- Water Transmission Main,Valve and Other Emergency Repair	x	x	x	x
CON-181- Water Transmission Main Repair	x		x	x
CON-158- Support Systems Control for Water/Wastewater systems	x			x
PC-793- Asset Maintenance of Water Systems	x			x

1.2Proposed Work Plan

LGC Global and Team, possess experience as well as capabilities to provide services for work involving priority repairs, as well as essential restoration work necessary in City of Novi and get the water main in operation by May 5, 2023, prior entering the high demand season.

LGC Global will follow below steps to meet City of Novi's requirements:

- The LGC team will obtain necessary information from City of Novi records including but not limited to record drawings, field books, layout schedule, gate books, section maps, and available GIS data.

- This portion of the pipeline can be isolated using a combination of closing in-line butterfly valves and the emplacement of two line stops as per the referenced isolation plan. Entry ports into the main are available at: STA 28+98 and STA 59+00.

Figure 3: Initial Pipe Inspection

- Our team will prepare a report & schedule meeting with City of Novi to discuss means & method to repair.

- Our project management team will prepare traffic control plans including lane closure details and detour routes per the MDOT requirements, Michigan manual on Uniform Traffic Control Devices, local municipality requirements, county, and state standards when applicable.

- LGC team will obtain ***necessary permits*** for traffic control and Soil Erosion and Sedimentation Control (SESC) and work within the local municipality, county, and MDOT right of way.

- All operation of valves will be performed as required for Isolation Plan. LGC will proceed with excavation and co-ordination with Watertap to implement Linestops with appropriate line pressures. Sheet piling will be installed if required on T&M basis.

Figure 4: Project Layout

Figure 5: Line Stop Installation

1.2.1 CFRP Design

The design options are based on calculating the strains and stress in the Structural Technologies product systems and checking structural demands and capabilities following the load and resistance factor design (LFRD) approach for hoop and longitudinal limit states as demanded by the AWWA C305 Standard. STRUCTURAL has utilized the following design criteria:

Pipe Type:	PCCP
Pipe Diameter:	36"
Design Type:	Stand Alone
Design Code:	AWWA C305
Working pressure, Pw:	92 psi (Specified)
Transient Pressure, Pt:	29psi = 40% of Pw (Specified)
Vacuum pressure, Pv:	0 psi (Assumed)
Soil Height, H:	12 ft (Specified)
Water Table Height, Hw:	0 (Specified)
Temperature Differential:	+/- 40° F (Assumed)
Hydraulic thrust:	PA (Some pipes are in vicinity of valves and bends)
Vehicular load:	HL-93 (Assumed)
Soil modulus, Ms:	1,000 psi (Assumed)

LGC Team believes STRUCTURAL's V-WrapTM Carbon Fiber System is an excellent candidate for the rehabilitation of the 36-inch Novi Road PCCP Water Transmission Main due to the following features:

1. Speed of installation.

The anticipated base scope designated repairs will be implemented within 2.5 weeks in-pipe duration.

2. Ability to tolerate pressures and loads including traffic (HL-93) loads.

The V-Wrap™ Carbon Fiber System can accommodate the working and transient pressures and the corresponding live loads that the pipeline will be subject to.

3. Minimizes diameter loss / hydraulic impacts.

The final thickness of the V-Wrap™ Carbon Fiber System is anticipated to be ½" to ¾", with a diameter reduction of 1 to 1.5 in. Hydraulic impacts are anticipated to be negligible, however, as CFRP has a Manning's coefficient similar to PVC.

4. The repair system must be NSF 61 and NSF 61 Annex G approved.

The V-Wrap™ CFRP lining system is NSF 61 and NSF 61 Annex G approved.

5. Product used in the repair must have a 50-year design life.

The V-Wrap™ CFRP lining system has a 50-year design life.

6. Strengthening System qualifications.

STRUCTURAL's V-Wrap™ Carbon Fiber System has undergone rigorous testing, audits, and/or approvals by various independent bodies including International Code Council (ICC), National Sanitation Foundation (NSF) and the US Nuclear Regulatory Commission (NRC). STRUCTURAL's V-Wrap™ Carbon Fiber System is the only CFRP system in the world that has been approved by the US NRC for use in strengthening safety-related piping – the piping that is necessary to safely cool the reactor core at a nuclear power plant.

7. History of Performance.

STRUCTURAL has utilized its V-Wrap™ Carbon Fiber System to restore the structural integrity of client pipelines in over 100 projects throughout the United States.

Figure 6: CFRP Partial Install

STRUCTURAL is the certified applicator of this systems. STRUCTURAL will provide turnkey completion of the project including:

1. Signed stamped and sealed drawings provided by a professional engineer registered in the state of Michigan (SGH).
2. Health & Safety including Job Safety Analysis (JSA), daily pre-job briefing, compliance with Site Health, Safety & Environmental Programs.
3. Quality Assurance (QA) & Control Activities.
4. All confined space requirements including equipment (lighting, gas meters, etc.). Confined space rescue team.
5. Environmental control equipment for temperature and humidity control.

Figure 7: GFRP Install with cable for curing

6. If infiltration exists through cracks in the concrete core or at the joints, STRUCTURAL will take measures to eliminate the infiltration on a T&M basis.
7. Surface preparation as required. Dust controls inside the pipeline.
8. On-site storage, mixing and saturation facilities.
9. Materials for V-WrapTM System.
10. All equipment associated with installation of FRP system (saturator, etc.).
11. Installation of the V-WrapTM System.
12. Testing:
    i. STRUCTURAL will prepare and perform ASTM D4541 pull-off tests. To be witnessed and documented by GC/Owner, etc.
    ii. STRUCTURAL will prepare test panels of the FRP system for ASTM D3039 tensile testing. Shipment and payment of testing is assumed to be by STRUCTURAL to an Owner approved laboratory.
13. Clean pipeline of debris, equipment, and leftover material.
    - Removal of the linestop and site restoration will be performed.
    - LGC will follow general procedure for chlorination, first to flush all dirty or discolored water from the lines and then introduce chlorine in approved dosages through a tap at one end, while water is being withdrawn at the other end of the line.
    - The chlorine solution will remain in the pipeline for 24 hours. LGC will perform disinfection per reference standards ***AWWA C651, AWWA C652 & C653, ANSI/NSF 61*** *standards* for drinking water system compounds. LGC will provide reports for each test, chain-of-custody documentation for bacteriological and odor tests per City of Novi requirements.

1.2.2 Key Project Personnel:

The name and titles of the individuals we consider to be key to the successful completion of the project are presented in the following table along with the LGC organizational chart for the work outlined in RFP.

Included in Appendix C are resumes of key project personnel to be assigned for this project's successful execution.

Table 1: Staff Experience

No.	Staff Name	Employer Name	Yrs. Of Related Experience	Related Projects	Project Role
1	Ken Anderson	LGC Global	45	GLWA-181 Water Transmission Main Repair	Project Director
2	Parth Dixit	LGC Global	3	GLWA-2003730 Water Transmission Main, Valve and Other Emergency Repairs	Project Manager
3	Tom Tersigni	LGC Global	38	GLWA-181 Water Transmission Main Repair	Project Superintendent
4	Edward Deanzer	LGC Global	32	GLWA-2003730 Water Transmission Main, Valve and Other Emergency Repairs	Project Site Safety
5	Rasko Ojdrovic, PE	Structural Technologies	15	GLWA-2003730 WTM, Valve and Other Emergency Repair (CFRP Repair on 14 Mile Rd, Farmington Hills)	Sr. Engr CFRP Design
6	Aldolfo Cepeda	Structural Technologies	15	GLWA-2003730 WTM, Valve and Other Emergency Repair (CFRP Repair on 14 Mile Rd, Farmington Hills)	Operations Manager
7	Anthony Carpini	Water Tap		GLWA-2003730 WTM, Valve and Other Emergency Repair (14 Mile and Drake WM Break)	Operations Manager
8	Joseph Albert	FKE	28	GLWA-2003730 WTM, Valve and Other Emergency Repair (14 Mile and Drake WM Break)	Geotech Engineer

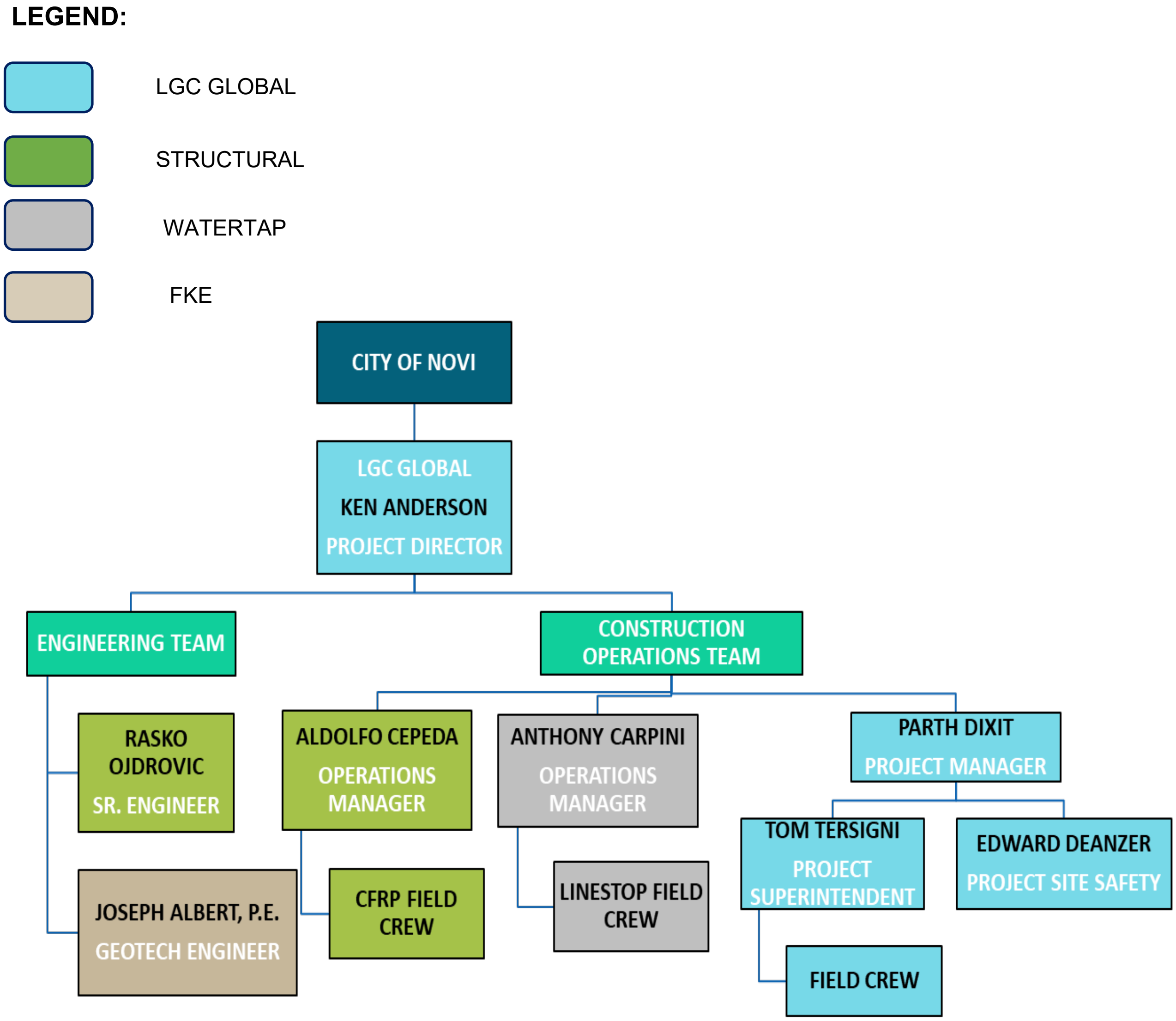


Figure 8: Organization Chart- for Novi Road/13 Mile Rd PCCP Water Main Renewal

1.3Project Schedule

- LGC considered the start date to be January 25, 2023 and provided a draft schedule in ***Primavera P6*** that projects run parallel to show the complexity and how the duration of around 3 months would be utilized in a timely manner. Please refer to **Appendix D** for a detailed schedule.

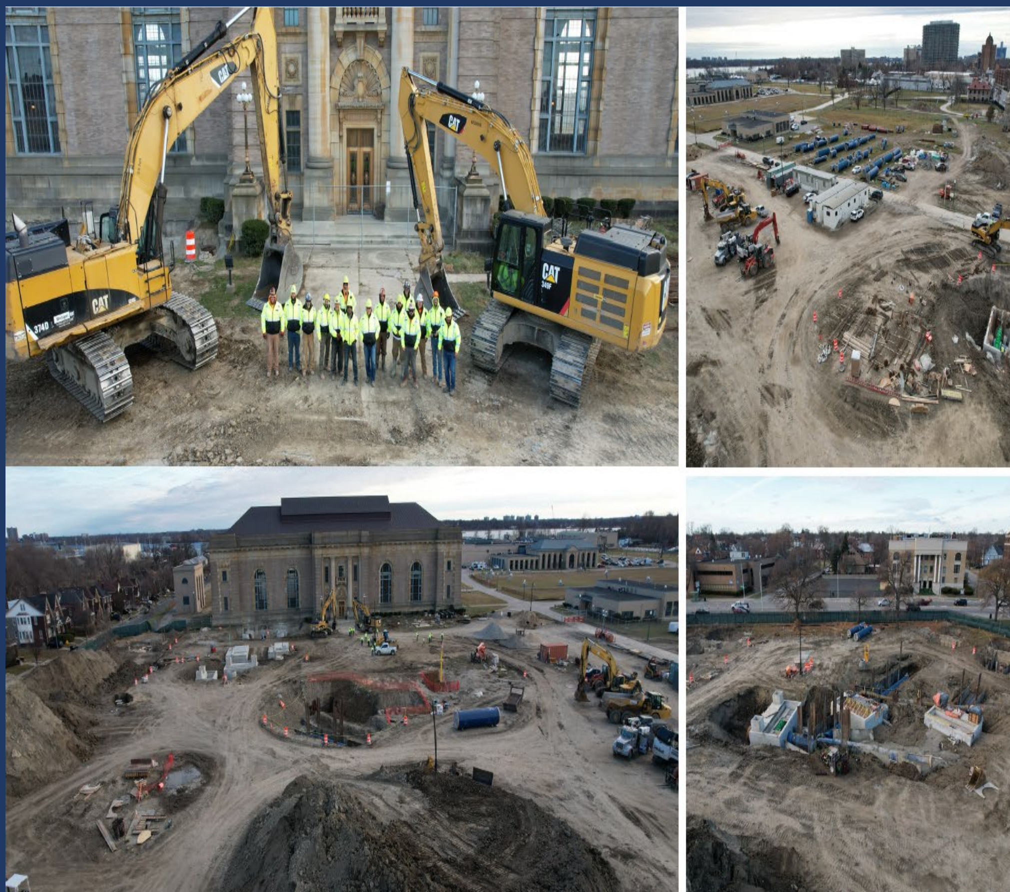
1.4City of Novi's Role

- LGC acknowledges all the work to be done under this contract will be performed as directed by the City of Novi.

- In an event where critical decisions and evaluations are to be made, LGC will communicate and schedule a meeting with the City of Novi to pursue the best practical methods for performing the work.
- As such, LGC would like to thank the City of Novi for providing us with an opportunity in considering our proposal for the contract "RFP Novi Rd/13-Mile Rd PCCP Watermain Renewal".

1.5General Notes and Assumptions:

1. Proposal based upon single mobilization. Proposal assumes access to pipe as detailed in the project overview.
2. Pricing is based upon Non-Union, non-prevailing wages. LGC and it's team is a specialty work force.
3. Proposal assumes LGC Team can perform the work 12 hours / day, 7 days/week.
4. Proposal assumes that the LGC Team has 24/7 access to the pipeline and equipment operations.
5. Proposal assumes that no leaking valves. If a leak occurs, it will be assessed and may be subjected to delay costs and schedule impacts.
6. No noise, lighting, odor restrictions.
7. Proposal includes warranty as per section 3.09 of the specification.
8. Proposal assume Class-II sand for backfill and MDOT EMH Superpave mixed to be used.
9. Proposal assume installation of sheeting will be performed if required, on T&M basis provided by Hourly Rates by discipline.
10. SAFETY: When line stopping or tapping PCCP there are pressure rating charts for when psi is a safe working pressure to performing cutting of prestressed wires. Once gland is on and bolted to body of line stop fitting or tap fitting pressure can be put back to normal operating pressure. The safe working pressure for a 36" line stop on LCP PCCP is 58psi.



City of Novi
Novi Road / 13 Mile Road PCCP Water Main Renewal – RFP
Appendix B - Experience & Qualifications

Submitted To:

City of Novi, Attn: Finance Department
45175 Ten Mile Road, Novi, MI 48375

Submitted By:

LGC Global Inc.
7310 Woodward Ave
Ste 500
Detroit, MI 48202

Date of Submittal:

January 16, 2023

LGC GLOBAL

NMSDC
MBE Certified

Appendix B

Manufacturer & Installer Project Reference List - Internal Standalone V-Wrap™ CFRP Projects

No.	Year	Industry	Owner	City, State	Contact Name	Contact Info	Diameter (in)	Repair Length (LF)	Max Internal Pressure (psi)
1	2020	Municipal	City of Dallas	Rolling Oaks, TX	Luis Bodington	214-670-8107	84	260	100
2	2020	Municipal	Pittsburgh Water & Sewer Authority	Pittsburgh, PA	Sara Bolenbaugh	412-255-8800 etx. 5519	60	61	175
3	2020	Municipal	City of Tucson Water Department	Tucson, AZ	Paul Acosta	520-837-2409	96	168	210
4	2020	Municipal	North Texas Municipal Water District	Garland, TX	Sam Marston	316-772-8937	96	64	210
5	2021	Municipal	City of Ottawa	Ottawa, Canada	Bruce Kenny	613-324-1833	48	61	100
6	2021	Municipal	Santa Clara Valley Water District	Santa Clara, CA	Ethan Brand	707-753-3162	78	120	158
7	2021	Municipal	Middlesex Water Company	Iselin, NJ	Jan Chwiedosiuk	732-218-1109	54	16	55
8	2021	Municipal	Baltimore City Department of Public Works	Baltimore, MD	Majid Afshar	410.545.3301	36, 54	388	152
9	2021	Municipal	Great Lakes Water Authority	Farmington, MI	Todd King	313-799-0289	48	320	175
10	2021	Municipal	Baltimore City Department of Public Works	Baltimore, MD	Majid Afshar	410-545-3301	48	140	140
11	2021	Municipal	North Shore Water Reclamation District	Waukegan, IL	Bill Stoltz	847-623-6060	54	60	210
12	2021	Municipal	City of Sacramento	Sacramento, CA	Ashley Smith	530-200-6309	30, 36	34	55
13	2021	Municipal	Canadian River Municipal Water Authority	Sanford, TX	Chad Pernell	806-865-3257	78	44	200
14	2022	Municipal	New Jersey American Water	South Plainfield, NJ	Rich Conklin	908-323-5422	60	460	175
15	2022	Municipal	City of Tucson Water Department	Tucson, AZ	Paul Acosta	520-837-2409	54		210

No.	Year	Industry	Owner	City, State	Contact Name	Contact Info	Diameter (in)	Repair Length (LF)	Max Internal Pressure (psi)
16	2022	Municipal	City of Baltimore Gwynn Falls	Baltimore, MD	Majid Afshar	410-545-3301	66	58	89
17	2022	Municipal	City of Wichita	Wichita, KS	Braden Lysen	316-351-9830	42	18	180
18	2022	Municipal	Middlesex County Utilities Authority	Holmden, NJ	Joe Salgado	201-954-2469	102	56	175
19	2022	Municipal	Tucson	Tucson, AZ	Paul Acosta	520-837-2409	96	48	200
20	2022	Municipal	GLWA	Farmington, MI	Gino D'agostini	810-459-0505	42	160	210
21	2022	Municipal	Dallas Water Utilities	Addison, TX	Jeff Hadaway	214-670-8005	54	100	150
22	2022	Power	Brandon Shores	Curtis Bay, MD	Harry Brocato	410-787-5088	102	20	65
23	2022	Municipal	City of Baltimore	Baltimore, MD	Michael Johnson	202-330-9003	36	16	149
24	2022	Municipal	Region of York	Vaughan, ON, CA	Matt Hickey	647-283-9144	66	1202	250
25	2022	Municipal	Dallas Water Utilities	Dallas, TX	Jeff Hadaway	214-670-8005	84	124	140

Designer Project Reference List

Year	Project Description	Client	Owner	City, State	Contact Name	Contact Info	Diameter (in.)	Design Maximum Pressure (psi)
2022	CFRP Repair Design of one 42 in. Diameter PCCP, NE Transmission Line at I-135 & 18th St, City of Wichita KS	STRUCTURAL	City of Wichita	Wichita, KS	Alexander, Jason	jalexander@structural.net	42	180
2022	Design of CFRP Repair of 66 in. and 72 in. Diameter PCCP, N Street Watermain, DC Water and Sewer Authority, Washington, DC	STRUCTURAL	DC Water	Washington, DC	Alexander, Jason	jalexander@structural.net	66 and 72	95
2022	CFRP Repair Design of the 108 in. Diameter PCCP and the Adjacent Transition Piece, Unit 4 Circulating Water Line, Martins Creek Power Plant, Bangor, PA	STRUCTURAL	Martins Creek Power Plant	Bangor, PA	Alexander, Jason	jalexander@structural.net	108	88
2022	Design of Internal CFRP Repair for 42 in. Diameter PCCP, 14-Mile Road Transmission Main, Great Lakes Water Authority, Detroit, MI	STRUCTURAL	Great Lakes Water Authority	Detroit, MI	Alexander, Jason	jalexander@structural.net	42	210
2021	Design of Internal CFRP Repair for 48in Diameter PCCP, 14-Mile Road Transmission Main, Great Lakes Water Authority, Detroit, MI	HDR Inc.	Great Lakes Water Authority	Detroit, MI	Higgins, Michael	mike.higgins@hdrinc.com	48	210
2021	DTE Fermi CW Pipe Failure risk evaluation, CFRP repair design, and field engineering support, Newport, MI 48116	STRUCTURAL	DTE Fermi Power Plant	Newport, MI	Alexander, Jason	jalexander@structural.net	144	75
2021	CFRP Renewal Design Rarita Millstone Transmission Main, New Jersey American Water, Middlesex County NJ	STRUCTURAL	New Jersey American Water	Middlesex County, NJ	Alexander, Jason	jalexander@structural.net	60	175
2021	Design of Internal CFRP Repair for 48 in. Diameter PCCP, Towson East Transmission Main, Baltimore, MD	STRUCTURAL	City of Baltimore	Baltimore, MD	Alexander, Jason	jalexander@structural.net	48	140

Year	Project Description	Client	Owner	City, State	Contact Name	Contact Info	Diameter (in.)	Design Maximum Pressure (psi)
2021	Design of External CFRP Repair for 42 in. Diameter PCCP, Northern Valley Force Main, Bergen County, NJ	STRUCTURAL	Bergen County Utilities Authority	Bergen County, NJ	Alexander, Jason	jalexander@structural.net	42	82.5
2021	Carbon-Fiber-Reinforced Polymer (CFRP) Pipe renewal Design for Eight Pipes In 54 in. Diameter Prestressed Concrete Cylinder Pipe (PCCP) Transmission Main, Tucson Water, Tucson, AZ	STRUCTURAL	Tucson Water	Tucson, AZ	Alexander, Jason	jalexander@structural.net	54	210
2021	Design of Internal CFRP Repairs of one 120 in. Diameter PCCP in the Unit 1 Cooling Water Pipeline, Intermountain Power Service Corporation, Delta, UT	STRUCTURAL	Intermountain Power Service Corporation	Delta, UT	Alexander, Jason	jalexander@structural.net	120	72
2021	CFRP Repair Design, 48 in. Diameter Woodroffe Ave Water Main, City of Ottawa, Canada	STRUCTURAL	City of Ottawa	Ottawa, ON, Canada	Alexander, Jason	jalexander@structural.net	48	115
2022	2022 Scope, CFRP Repairs, Southwest Transmission Main, Baltimore, MD	STRUCTURAL	City of Baltimore	Baltimore, MD	Alexander, Jason	jalexander@structural.net	36	209
2021	CFRP Repair of 36 in. and 54 in. Diameter PCCP, Southwest Transmission Main, Baltimore, MD	STRUCTURAL	City of Baltimore	Baltimore, MD	Alexander, Jason	jalexander@structural.net	54; 36; 36	209
2021	PCCP Condition Assessment and CFRP Repair Monitoring, Craig Generating Station Unit 3 Circulating Water Pipe Condition Assessment, Spring 2021 Outage, Craig, CO	Tri-State Generation and Transmission Association, Inc.	Tri-State Generation and Transmission Association, Inc.	Craig, CO	Calegan-Solano, Karen	kcalegan-solano@tristategt.org	60	55
2021	CFRP Repair Design and Construction Engineering Support of 54 in. Diameter PCCP F 3 Waukegan Effluent Force Main, North Shore Water Reclamation District, Waukegan, IL	North Shore Water Reclamation District	North Shore Water Reclamation District	Waukegan, IL	Stoltz, William	BiStoltz@northshorewrd.org	54	210

Year	Project Description	Client	Owner	City, State	Contact Name	Contact Info	Diameter (in.)	Design Maximum Pressure (psi)
2020	Failure Risk Analysis and Carbon-Fiber-Reinforced Polymer Repair (CFRP) Design for Four 54 in. Diameter Prestressed Concrete Cylinder Pipe (PCCP), Interior “C” Zone Transmission Main, Tucson Water, Tucson, AZ	STRUCTURAL	Tucson Water	Tucson, AZ	Alexander, Jason	jalexander@structural.net	54	213
2020	Design of CFRP Repair for Pipe 2-301 in 54 in. Diameter PCCP Raw Water Main, Middlesex Water Company, NJ	STRUCTURAL	Middlesex Water Company	Edison, NJ	Alexander, Jason	jalexander@structural.net	54	83
2020	Design and Quality Assurance Inspection of Unit 2 Safety Related CFRP, Surry Power Station, Surry County, VA	Dominion Energy Surry Power Station	Dominion Energy	Surry, VA	Jones, Jeffrey	jeffrey.k.jones@dominionenergy.com	96	61
2020	Pre-stressed Concrete Cylinder Pipe (PCCP) Finite Element Analysis and Carbon Fiber Reinforced Polymer Repair (CFRP) Design, CAP Water Transmission Main 177-1987 and 074-1988, 96-inch PCCP Pipeline, RFP No. 001-2020, Tucson Water, Tucson, AZ	STRUCTURAL	Tucson Water	Tucson, AZ	Alexander, Jason	jalexander@structural.net	96	201
2020	CFRP Repair of 84 in. Diameter PCCP, Tawakoni Transmission Main, Dallas Water Utilities, Dallas, TX	STRUCTURAL	Dallas Water Utility	Dallas, TX	Alexander, Jason	jalexander@structural.net	84	100
2020	Brandon Shores Unit 2 CFRP Design and Monitoring Fall 2020, Baltimore, MD	Talen Energy	Talen Energy, Brandon Shores Power Plant	Curtis, MD	Bowie, Russell	Russell.Bowie@talenenergy.com	120; 102	65
2020	CFRP termination modification of 60” diameter PCCP, Pittsburgh Water and Sewer Authority, Pittsburgh, PA	STRUCTURAL	Pittsburgh Water and Sewer Authority	Pittsburgh, PA	Alexander, Jason	jalexander@structural.net	60	175

Year	Project Description	Client	Owner	City, State	Contact Name	Contact Info	Diameter (in.)	Design Maximum Pressure (psi)
2020	Design of Internal CFRP Repair of 48 in. Diameter PCCP Transmission Water Main, Olsen Water Treatment Plant, Middlesex Water Company, Edison, NJ	STRUCTURAL	Middlesex Water Company	Edison, NJ	Chwiedosiuk, Jan	jchwiedosiuk@middlesexwater.com	48	225
2020	Engineering Support for CFRP Repair of Distressed PCCP in 60 in. Diameter North Garland Pipeline No. 1, Section 3, North Texas Municipal Water District, TX	STRUCTURAL	North Texas Municipal Water District	Garland, TX	Alexander, Jason	jalexander@structural.net	60	210
2022	CFRP Repairs in 138 in. CW Lines at STP Unit 2 for Fall 2022 Outage, South Texas Project, Wadsworth, TX	STRUCTURAL	South Texas Project Nuclear Operating Company	Wadsworth, TX	Boshart, Stan	sboshart@structuraltec.com	138	55
2021	CFRP repair of 138 in. diameter PCCP, Unit 2 2RE21 Outage, South Texas Project, Wadsworth, TX	STRUCTURAL	South Texas Project Nuclear Operating Company	Wadsworth, TX	Boshart, Stan	sboshart@structuraltec.com	138	55
2020	Design and Construction Monitoring of Pipe CFRP and Post-Tensioning Repairs, 36 in. and 48 in. Diameter PCCP, Louisville Water Company, Louisville, KY	STRUCTURAL	Louisville Water Company	Louisville, KY	Alexander, Jason	jalexander@structural.net	48	210
2021	Fall 2022 CFRP Repairs, Internal Inspection, Failure Risk Analysis and Reporting of 120 in. Diameter PCCP Circulating Water Pipelines, Unit 1, Shearon Harris Plant, New Hill, NC	STRUCTURAL	Duke Energy Shearon Harris Nuclear Plant	New Hill, NC	Alexander, Jason	jalexander@structural.net	120	65
2021	CFRP Repair Design for 138 in. Diameter PCCP in the Unit 1 Circulating Water Line, South Texas Project Electric Generating Station, Wadsworth, TX	STRUCTURAL	South Texas Project Nuclear Operating Company	Wadsworth, TX	Alexander, Jason	714-869-8119	138	55

Year	Project Description	Client	Owner	City, State	Contact Name	Contact Info	Diameter (in.)	Design Maximum Pressure (psi)
2020	CFRP Repair Design for Three 138 in. Diameter PCCP Pipes, Circulating Water System, Unit 1, South Texas Project Electric Generating Station, Wadsworth, TX	STRUCTURAL	South Texas Project Nuclear Operating Company	Wadsworth, TX	Alexander, Jason	714-869-8119	138	55
2022	Internal CFRP Repairs of 48 in. Diam. PCCP, Circulating Water Blowdown Pipeline, Braidwood Nuclear Generating Station, Braceville, IL	STRUCTURAL	Exelon Generation Braidwood Station	Braceville, IL	Alexander, Jason	714-869-8119	48	110
2021	Design of Internal CFRP Repairs of Two 48 in. Diameter PCCPs in the Circulating Water Blowdown Pipeline, Braidwood Nuclear Generating Station, Braceville, IL	STRUCTURAL	Exelon Generation Braidwood Station	Braceville, IL	Alexander, Jason	714-869-8119	48	80

DEPARTMENT OF LICENSING AND REGULATORY AFFAIRS
BUREAU OF PROFESSIONAL LICENSING
P.O. BOX 30670
LANSING, MI 48909

STATE OF MICHIGAN - DEPARTMENT OF LICENSING AND REGULATORY AFFAIRS

BUREAU OF PROFESSIONAL LICENSING
PROFESSIONAL ENGINEER LICENSE

RASKO OJDROVIC

LICENSE NO.	EXPIRATION DATE	
6201069686	11/27/2024	22318091150

RASKO OJDROVIC
480 TOTTEN POND ROAD
SIMPSON GUMPERTZ & HEGER INC.
WALTHAM, MA 02451

COMPLAINT INFORMATION:
THE ISSUANCE OF THIS LICENSE SHOULD NOT BE CONSTRUED AS A WAIVER, DISMISSAL OR ACQUIESCENCE TO ANY COMPLAINTS OR VIOLATIONS PENDING AGAINST THE LICENSEE, ITS AGENTS OR EMPLOYEES.

FUTURE CONTACTS:
YOU SHOULD DIRECT INQUIRIES REGARDING THIS LICENSE OR ADDRESS CHANGES TO THE DEPARTMENT OF LICENSING AND REGULATORY AFFAIRS BY EMAILING BPLHELP@MICHIGAN.GOV OR CALL (517) 241-0199

GRETCHEN WHITMER
GOVERNOR

STATE OF MICHIGAN
DEPARTMENT OF LICENSING AND REGULATORY AFFAIRS
BUREAU OF PROFESSIONAL LICENSING
PROFESSIONAL ENGINEER LICENSE

RASKO OJDROVIC

LICENSE NO.	EXPIRATION DATE		
6201069686	11/27/2024	22318091150	THIS DOCUMENT IS DULY ISSUED UNDER THE LAWS OF THE STATE OF MICHIGAN

SIMPGUM-01 LGHIGLIAZZA

CERTIFICATE OF LIABILITY INSURANCE

DATE (MM/DD/YYYY): 1/6/2023

THIS CERTIFICATE IS ISSUED AS A MATTER OF INFORMATION ONLY AND CONFERS NO RIGHTS UPON THE CERTIFICATE HOLDER. THIS CERTIFICATE DOES NOT AFFIRMATIVELY OR NEGATIVELY AMEND, EXTEND OR ALTER THE COVERAGE AFFORDED BY THE POLICIES BELOW. THIS CERTIFICATE OF INSURANCE DOES NOT CONSTITUTE A CONTRACT BETWEEN THE ISSUING INSURER(S), AUTHORIZED REPRESENTATIVE OR PRODUCER, AND THE CERTIFICATE HOLDER.

IMPORTANT: If the certificate holder is an ADDITIONAL INSURED, the policy(ies) must have ADDITIONAL INSURED provisions or be endorsed. If SUBROGATION IS WAIVED, subject to the terms and conditions of the policy, certain policies may require an endorsement. A statement on this certificate does not confer rights to the certificate holder in lieu of such endorsement(s).

PRODUCER
Ames & Gough
859 Willard Street
Suite 320
Quincy, MA 02169

CONTACT NAME:
PHONE (A/C, No, Ext): (617) 328-6555 FAX (A/C, No): (617) 328-6888
E-MAIL ADDRESS: boston@amesgough.com

INSURED
Simpson Gumpertz & Heger Inc.
480 Totten Pond Road
Waltham, MA 02451

INSURER(S) AFFORDING COVERAGE	NAIC #
INSURER A : Phoenix Insurance Company A++, XV	25623
INSURER B : Travelers Property Casualty Company of America	25674
INSURER C : Lexington Insurance Company A, XV	19437
INSURER D :	
INSURER E :	
INSURER F :	

COVERAGES CERTIFICATE NUMBER: REVISION NUMBER:

THIS IS TO CERTIFY THAT THE POLICIES OF INSURANCE LISTED BELOW HAVE BEEN ISSUED TO THE INSURED NAMED ABOVE FOR THE POLICY PERIOD INDICATED. NOTWITHSTANDING ANY REQUIREMENT, TERM OR CONDITION OF ANY CONTRACT OR OTHER DOCUMENT WITH RESPECT TO WHICH THIS CERTIFICATE MAY BE ISSUED OR MAY PERTAIN, THE INSURANCE AFFORDED BY THE POLICIES DESCRIBED HEREIN IS SUBJECT TO ALL THE TERMS, EXCLUSIONS AND CONDITIONS OF SUCH POLICIES. LIMITS SHOWN MAY HAVE BEEN REDUCED BY PAID CLAIMS.

INSR LTR	TYPE OF INSURANCE	ADDL INSD	SUBR WVD	POLICY NUMBER	POLICY EFF (MM/DD/YYYY)	POLICY EXP (MM/DD/YYYY)	LIMITS	
A	X COMMERCIAL GENERAL LIABILITY CLAIMS-MADE [X] OCCUR GEN'L AGGREGATE LIMIT APPLIES PER: POLICY [X] PRO-JECT [X] LOC OTHER:			6303646P601PHX23	1/1/2023	1/1/2024	EACH OCCURRENCE	$ 1,000,000
							DAMAGE TO RENTED PREMISES (Ea occurrence)	$ 1,000,000
							MED EXP (Any one person)	$ 15,000
							PERSONAL & ADV INJURY	$ 1,000,000
							GENERAL AGGREGATE	$ 2,000,000
							PRODUCTS - COMP/OP AGG	$ 2,000,000
								$
B	AUTOMOBILE LIABILITY X ANY AUTO OWNED AUTOS ONLY / SCHEDULED AUTOS HIRED AUTOS ONLY / NON-OWNED AUTOS ONLY			BA2L5447902343G	1/1/2023	1/1/2024	COMBINED SINGLE LIMIT (Ea accident)	$ 1,000,000
							BODILY INJURY (Per person)	$
							BODILY INJURY (Per accident)	$
							PROPERTY DAMAGE (Per accident)	$
								$
B	X UMBRELLA LIAB [X] OCCUR EXCESS LIAB CLAIMS-MADE DED [X] RETENTION $ 10,000			CUP3W1976622343	1/1/2023	1/1/2024	EACH OCCURRENCE	$ 1,000,000
							AGGREGATE	$ 1,000,000
								$
B	WORKERS COMPENSATION AND EMPLOYERS' LIABILITY Y/N ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? (Mandatory in NH) N If yes, describe under DESCRIPTION OF OPERATIONS below	N / A		UB3W1929922343E	1/1/2023	1/1/2024	X PER STATUTE / OTH-ER	
							E.L. EACH ACCIDENT	$ 1,000,000
							E.L. DISEASE - EA EMPLOYEE	$ 1,000,000
							E.L. DISEASE - POLICY LIMIT	$ 1,000,000
C	Prof & Poll. Liab			023462679	7/2/2022	7/2/2023	Per Claim	5,000,000
C				023462679	7/2/2022	7/2/2023	Aggregate	5,000,000

DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES (ACORD 101, Additional Remarks Schedule, may be attached if more space is required)
All Coverages are in accordance with the policy terms and conditions.

For Proposal Only

CERTIFICATE HOLDER

For Proposal Only

CANCELLATION

SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, NOTICE WILL BE DELIVERED IN ACCORDANCE WITH THE POLICY PROVISIONS.

AUTHORIZED REPRESENTATIVE
Jared maxwell

structural

January 12, 2023

Re: City of Novi – Novi Rd / 13 Mile Rd PCCP Water Main Renewal

Subject: Certified Applicator Letter

To Whom It May Concern:

This letter is to confirm that Structural Preservation Systems, LLC (STRUCTURAL) is a certified applicator of Structural Technologies' V-Wrap™ Carbon Fiber (CFRP) Systems. As required by the CFRP Specification Exhibit A Section 1.03.C.2, Structural Technologies, LLC, manufacturer and supplier of the V-Wrap™ system, certifies STRUCTURAL as an applicator and has a training program to instruct its applicators in the installation of the products. One clear benefit of selecting our products and installation team is the synergy created between top-of-the-line products and quality craftsmanship in the field. The selected project team has extensive history installing V-Wrap™ CFRP in pipeline structures.

We are eager to work with you and your group to support your pipeline's upgrades need on this project.
If you should have any questions regarding this correspondence, or need any additional information, please contact me at apridmore@structural.net or by phone at 714.869.8824.

Sincerely,

Anna Pridmore, PhD
Vice-President, Pipeline Solutions

January 12, 2023

Re: City of Novi – Novi Rd / 13 Mile Rd PCCP Water Main Renewal

Subject: Team Experience Letter

To whom it may concern,

Structural Preservation Systems, LLC (STRUCTURAL) has over 150,000 man-hours worked on pipeline projects in the past three (3) years, and our crews have extensive experience working in pipeline structures. STRUCTURAL certifies that the superintendent, foreman, and ten (10) lead technicians able to perform the work each have a minimum of three (3) years of experience with a minimum of twenty (20) separate projects in large diameter (36-inch or greater) internal pipeline repair projects utilizing CFRP liner. STRUCTURAL's crew exceeds the experience requirement specified in the technical specification. Staffing for the project will include the following:

Superintendent – Aldolfo Cepeda
Foreman – Salvador Lechuga
Lead Technician –John Ely
Lead Technician – Sergio Lechuga
Lead Technician – Jose Cervantes
Lead Technician – Keith Beckford
Lead Technician – Jose Lopez
Lead Technician – John Mounga
Lead Technician – Jose Gallardo
Lead Technician – Lionel Francis
Lead Technician –Marcelo Hermisilla
Lead Technician – Jose Miranda

We are eager to work with you and your group to support the important pipeline's upgrades needs on this project. If you should have any questions regarding this correspondence, or need any additional information, please contact me at mfrye@structural.net or by phone at 443-561-3612.

Sincerely,

Matt Frye
Branch Director

structural TECHNOLOGIES

Crew Reference List - CFRP Project Experience

Total projects per team member			46	27	32	22	30	31	36	31	32	36	29	29	34	21
			Name:	**Name:**	**Name:**	**Name:**	**Name:**	**Name:**	**Name:**	**Name:**	**Name:**	**Name:**	**Name:**	**Name:**	**Name:**	**Name:**
			Adolfo Cepeda	Salvador Lechuga	Sergio Lechuga	Jose Cervantes	John Ely	Andrew Davidson	Keith Beckford	Jose Lopez	Nelson McDonald	John Mounga	Jose Gallardo	Lionel Francis	Marcelo Hermisillo	Jose Miranda
No.	**Year**	**Owner / Job Name**	**Title:**	**Title:**	**Title:**	**Title:**	**Title:**	**Title:**	**Title:**	**Title:**	**Title:**	**Title:**	**Title:**	**Title:**	**Title:**	**Title:**
			Superintendent	Foreman	Leadman	Leadman	Leadman	Leadman	Leadman	Leadman	Technician	Leadman	Leadman	Leadman	Leadman	Leadman
			15+ Years	20+ Years	20+ Years	10+ years	7+ years	6+ years	7+ years	8+ years	8+ years	8+ years	5+ years	10+ years	10+ years	10+ years
1	2018	City of Phoenix			X		X				X	X		X	X	
2	2018	South Coast Water										X				
3	2018	City of Phoenix					X					X		X		
4	2018	Davis Besse Nuclear Station	X						X	X						
5	2018	Missouri American Water					X					X				
6	2018	North Shore Water Reclamation District	X						X	X						
7	2018	Metro Government of Nashville and Davidson County						X	X							
8	2018	City of Springfield Utilities					X					X			X	
9	2018	Brandon Shores	X					X	X	X						
10	2018	Baltimore Department of Public works	X							X						
11	2018	Dallas Water				X	X					X		X		
12	2018	Dallas County Park Cities Municipal Utilities District			X		X					X		X		
13	2018	Louisville Water	X		X									X	X	
14	2018	Brandon Shores	X					X	X	X						
15	2018	Talen Energy			X	X	X					X				

16	2018	Santa Clara Valley Water District	X	X		X			X	X	X			X	X	
17	2018	Miami Fort Station						X	X	X						
18	2018	Duke Mayo	X							X						
19	2018	Westar Jeffery Station	X				X			X	X	X				
20	2018	City of Ottawa	X					X	X							
21	2018	MCUA	X	X			X			X				X		
22	2019	Homestake Water Project			X				X					X	X	X
23	2019	Santa Clara Valley Water District	X			X		X	X	X	X	X				
24	2019	Brandon Shores	X							X						
25	2019	WSSC Mid-County	X	X						X						
26	2019	MCUA	X					X	X	X					X	
27	2019	City of Baltimore								X						
28	2019	WSSC Byrd Road	X				X				X					
29	2019	Louisville Water	X	X	X						X			X		
30	2019	City of Baltimore						X	X	X						
31	2019	WSSC Penn Ave					X		X	X				X		
32	2019	Intermountain Power		X	X		X	X	X			X		X	X	
33	2019	Oak Ridge National Laboratory (ORNL)	X					X			X					X
34	2019	Los Angles Department of Water & Power (Haiwee Power Plant)		X	X		X					X	X		X	
35	2019	City of Baltimore				X		X	X		X					
36	2019	New Castle County				X	X			X						
37	2019	New Jersey American Water	X	X			X	X	X		X	X	X	X	X	
38	2019	Duke Harris Circ Water	X				X	X	X							

39	2019	Public Service New Mexico - San Juan	X	X	X					X	X		X		X	
40	2019	Dallas Water Utilities		X			X	X	X			X	X			
41	2019	Entergy Arkansas						X	X			X				
42	2020	Davis Besse Nuclear Station			X	X										
43	2020	Pittsburgh Water & Sewer Authority (PWSA)		X	X					X					X	
44	2020	Santa Clara Valley Water District			X		X					X				X
45	2020	City of Baltimore	X							X	X					
46	2020	Navajo Agricultural Products Industry		X	X								X	X		
47	2020	Washington Suburban Sanitary Commission			X					X						
48	2020	Louisville Water Company (March)	X								X		X			
49	2020	North Texas MWD		X			X					X				X
50	2020	Talen Colstrip MT		X			X	X	X			X			X	
51	2020	City of Tucson	X							X	X		X			
52	2020	Dallas Water Utilities			X	X		X	X				X		X	
53	2020	City of Fort Lauderdale G.T. Lohmeyer WWTP		X				X	X							
54	2020	North Texas Municipal Water District			X											
55	2020	DWU Lake Tawakoni					X				X	X	X	X	X	
56	2020	APS Palo Verde	X		X	X	X	X	X		X	X				X
57	2020	New Castle Christina River	X							X	X					
58	2020	Washington Aquaduct	X							X						
59	2020	Middlesex Water	X	X						X						
60	2020	Tucson Water					X				X	X				

61	2020	Duke Asheville	X					X	X							
62	2020	Brandon Shores	X							X						
63	2020	Surry Low Level	X			X					X	X				X
64	2021	Tri-State Craig Generating Station		X			X	X	X	X			X	X		
65	2021	Navajo Agricultural Products Industry		X	X						X		X		X	
66	2021	Canadian River Municipal Water Authority		X									X			
67	2021	Surry Low Level	X								X	X			X	
68	2021	Surry Safety Related	X		X	X	X	X			X	X			X	X
69	2021	STP Nuclear (Fall)			X	X	X				X	X		X	X	X
70	2021	GLWA 14 Mile	X					X	X	X		X	X	X	X	X
71	2021	City of Beaumont		X					X					X		
72	2021	North Shore Sanitation District			X	X	X		X			X		X	X	X
73	2021	Constellation Energy Braidwood SCL CWBD	X	X	X			X	X		X		X			
74	2021	City of Sacramento							X		X			X		
75	2021	STP Nuclear (Spring)			X	X	X	X	X		X	X			X	X
76	2021	Duke Shearon Harris	X								X					X
77	2021	Kentucky Utilities Ghent (Spring)	X	X		X							X		X	
78	2021	Kentucky Utilities Ghent (Fall)	X										X		X	
79	2021	Talen			X								X			
80	2021	APS Palo Verde			X	X	X				X	X				X
81	2021	City of Ottawa							X							
82	2021	MCUA	X						X			X	X	X		
83	2021	Santa Clara Valley Water District		X		X							X		X	

85	2021	Tucson Electric Power Company											X			
88	2022	DTE Fermi II	X		X	X		X				X		X	X	X
89	2022	Duke Energy Brunswick	X					X			X					X
90	2022	Surry Power Station	X			X		X				X	X	X	X	X
91	2022	New Jersey American Water	X	X	X			X	X	X	X	X	X	X	X	X
93	2022	City of Tucson Water Department		X	X			X				X	X	X	X	
94	2022	Arizona Public Service				X							X			
95	2022	Kentucky Utilities		X									X		X	
96	2022	Talen Energy			X	X					X			X		X
97	2022	City of Winnipeg		X									X	X	X	
101	2022	Bergen County Utilities Authority			X						X			X	X	X
103	2022	Metro Government of Nashville and Davidson County			X											
104	2022	DC Water											X		X	
105	2022	Middlesex County Utilities Authority	X									X				
106	2022	Constellation Energy Braidwood SCL CWBD			X		X		X	X	X	X		X	X	X
107	2022	Dallas Water Utilities - Cadiz				X							X		X	
108	2022	Bergen County Utilities Authority	X													
109	2022	Duke Roxboro Circ Water		X									X			
110	2022	Duke Harris Circ Water	X					X	X							X

structural

January 12, 2023

Re: City of Novi – Novi Rd / 13 Mile Rd PCCP Water Main Renewal

Subject: V-Wrap™ CFRP Installation – Self Perform Letter & Equipment Provision Confirmation

To whom it may concern,

Structural Preservation Systems, LLC (STRUCTURAL) and Structural Technologies, LLC acknowledge that if awarded the work, the entities will be self-performing all aspects of the CFRP installation project for the City of Novi, Novi Rd / 13 Mile Rd PCCP Water Main Renewal Project.

SELF-PERFORM CERTIFICATION

Per sub-section 1.03.C.4 of Exhibit A of the project's technical specifications, this letter is to serve as confirmation that we will self-perform the CFRP installation and all associated work tasks with our own workforce. This includes, but is not limited to, all surface preparation, water mitigation, confined space attendant, confined space safety program, maintenance of environmental control equipment, mixing of epoxies, saturation of reinforcing fabrics, installation of the CFRP system, supply of QA/QC representative from the CFRP Manufacturer to be onsite for the duration of the project, and installation of end joint details.

PROVISION OF EQUIPMENT CONFIRMATION

We will also provide all necessary ancillary equipment for the project including surface preparation equipment, ventilation, environmental controls units and generators. Below is a preliminary list of the specific equipment to be provided:

Description	Quantity	Power/Fuel Req'ts	Eq. Size
375 CFM Air Compressor	TBD	Diesel	10' L x 6' W x 6'H
HC 5000 Desiccant Dehumidifier	TBD	460 volt, 138 full load amps	14'L x 4'W x 6' H
18,000 CFM Dust Collector	TBD	Diesel	16'L x 9'Wx10'2"H
60KW In-line Heater	TBD	460 volt, 72 full load amps	3'L x 3'W x 3' H
Material Storage Trailer	TBD	Diesel	50'L x 8'W x 9'H
FRP Saturator Machine	TBD	110 v	4' L x 2' W x 5'H
Light Tower	TBD	Diesel	TBD
Abrasive Blast Pot	TBD	Pneumatic	2'L x 2'W x 4'H
Tool Trailer	TBD	110v	50'L x 8'W x 9'H

We are eager to work with you and your group to support the important pipeline's upgrades needs on this project. If you should have any questions regarding this correspondence, or need any additional information, please contact me at mfrye@structural.net or by phone at 443-561-3612.

Sincerely,

Matt Frye
Branch Director

S.NO	EQUIPMENT CODE	EQUIPMENT DESCRIPTION	EQUIPMENT CATOGERY	MAKE	MODEL
1	EQ000439	HITACHI WHEEL LOADER	LOADER	HITACHI	ZW180-6
2	EQ000298	CAT 325 EXCAVATOR	EXCAVATOR	CATERPILLAR	325C
3	EQ000297	CAT 305 MINI EXCAVATOR	MINI EXCAVATOR	CATERPILLAR	305CCR
4	EQ000305	JOHN DEERE BACKHOE LOADER	BACKHOE LOADER	JOHN DEERE	310SL
5	T-201	2008 STERLING VACTOR 2000 SEWER CLEANER	VAC TRUCK	STERLING	VACTOR 2000
6	EQ000309	KAWASAKI 65 TMV WHEEL LOADER	WHEEL LOADER	KAWASAKI	65TMV
7	EQ000417	BROCE BROOM RJT350 TRUCK	SWEEPER	BOOM TRUCK	RJT350
8	EQ000306	JOHN DHEERE 310SL BACKHOE LOADER	BACKHOE LOADER	JOHN DEERE	310SL
9	EQ000529	LINK BELT 145X4	EXCAVATOR	LINK BELT	145X4
10	EQ000530	JOHN DHEERE MINI EXCAVATOR 135G	MINI EXCAVATOR	JOHN DHEERE	135 G
11	EQ000296	LINK BELT QUANTUM 2700	EXCAVATOR	LINK BELT	QUANTUM 2700
12	E-105	LINK BELT 130X3	EXCAVATOR	LINK BELT	130X3
13	EQ000416	KOMATSU 41P DOZER	DOZER	KOMATSU	41P
14	EQ000397	KOMATSU PC650 LC HYDRALIC EXCAVATOR	HYDRALIC EXCAVATOR	KOMATSU	PC650 LC
15	EQ000396	LINK BELT 160X4	EXCAVATOR	LINK BELT	160X4
16	C-125	AMERICAN 5300 CRANE	CRANE	AMERICAN	5300
17	EQ000532	KOMATSU WA500-3 WHEEL LOADER	WHEEL LOADER	KOMATSU	WA500-3
18	EQ000435	CATERPILLAR 262D SKIDSTEER	SKIDSTEER	CATERPILLAR	262D
19	EQ000314	BOBCAT 753 SKIDSTEER	SKIDSTEER	BOBCAT	753
20		CATERPILLAR 247 SKID STEER	SKIDSTEER	CATERPILLAR	247
21	EQ000304	JOHN DEERE 310J BACKHOE LOADER	BACKHOE LOADER	JOHN DEERE	310J
22	EQ000535	CATERPILLAR 374D EXCAVATOR	EXCAVATOR	CATERPILLAR	374D
23	EQ000536	LINK BELT 290LX EXCAVATOR	EXCAVATOR	LINK BELT	290LX
24	EQ000537	HITACHI LOADER ZW180-6	LOADER	HITACHI	LOADER ZW180-6
25	EQ000538	HITACHI LOADER Z220-6	LOADER	HITACHI	LOADER Z220-6
26	EQ000539	CATERPILLAR SKID STEER 239 D	SKIDSTEER	CATERPILLAR	239D
27	EQ000395	KOMATSU D31E DOZER D31E-18	DOZER	KOMATSU	D31E-18
28	EQ000540	LINK BELT 300X4 EX EXCAVATOR	EXCAVATOR	LINK BELT	300X4 EX
29	EQ000544	BROCE BROOM RJT350 TRUCK	SWEEPER	BROCE BROOM	RJT350
30	EQ000545	JOHN DEERE 333E	SKIDSTEER	JOHN DEERE	333E
31	EQ000546	KUBOTA M680 TRACTOR	TRACTOR	KUBOTA	M680

ZURICH

January 10, 2023

City of Novi
45175 W 10 Mile Rd.
Novi, MI 48375

Re: City of Novi 36in PCCP

Zurich American Insurance Company and/or its subsidiary, Fidelity and Deposit Company of Maryland, have provided surety credit to Structural Preservation Systems, LLC for single projects of $60 Million and an aggregate uncompleted backlog of $600 Million, with an estimated unused capacity of $250 Million. Zurich/F&D is rated "A+" (Excellent) with a financial size category of XV ($2 billion +) by AM Best and has a US Treasury Limit exceeding $650 million.

If Structural Preservation Systems, LLC is awarded a contract for the referenced project and requests that we provide the necessary Performance and/or Payment Bonds, we will be prepared to execute the bonds, including the 5 year warranty period subject to our acceptable review of the contract terms and conditions, bond forms, appropriate contract funding and any other underwriting considerations at the time of the request.

We trust that this information meets with your satisfaction. If there are further questions, please feel free to contact me.

Sincerely
Zurich American Insurance Company
Fidelity and Deposit Company of Maryland

Catherine Thompson, Attorney-in-Fact

ZURICH AMERICAN INSURANCE COMPANY
COLONIAL AMERICAN CASUALTY AND SURETY COMPANY
FIDELITY AND DEPOSIT COMPANY OF MARYLAND
POWER OF ATTORNEY

KNOW ALL MEN BY THESE PRESENTS: That the ZURICH AMERICAN INSURANCE COMPANY, a corporation of the State of New York, the COLONIAL AMERICAN CASUALTY AND SURETY COMPANY, a corporation of the State of Illinois, and the FIDELITY AND DEPOSIT COMPANY OF MARYLAND a corporation of the State of Illinois (herein collectively called the "Companies"), by **ROBERT D. MURRAY, Vice President,** in pursuance of authority granted by Article V, Section 8, of the By-Laws of said Companies, which are set forth on the reverse side hereof and are hereby certified to be in full force and effect on the date hereof, do hereby nominate, constitute, and appoint **John F. THOMAS, Jynell Marie WHITEHEAD, Jennifer B. GULLETT, Catherine THOMPSON, Amy R. WAUGH, Noah William PIERCE and Andrew M. BENNETT, all of Charlotte, North Carolina, EACH** its true and lawful agent and Attorney-in-Fact, to make, execute, seal and deliver, for, and on its behalf as surety, and as its act and deed: **any and all bonds and undertakings,** and the execution of such bonds or undertakings in pursuance of these presents, shall be as binding upon said Companies, as fully and amply, to all intents and purposes, as if they had been duly executed and acknowledged by the regularly elected officers of the ZURICH AMERICAN INSURANCE COMPANY at its office in New York, New York., the regularly elected officers of the COLONIAL AMERICAN CASUALTY AND SURETY COMPANY at its office in Owings Mills, Maryland., and the regularly elected officers of the FIDELITY AND DEPOSIT COMPANY OF MARYLAND at its office in Owings Mills, Maryland., in their own proper persons.

The said Vice President does hereby certify that the extract set forth on the reverse side hereof is a true copy of Article V, Section 8, of the By-Laws of said Companies, and is now in force.

IN WITNESS WHEREOF, the said Vice-President has hereunto subscribed his/her names and affixed the Corporate Seals of the said **ZURICH AMERICAN INSURANCE COMPANY, COLONIAL AMERICAN CASUALTY AND SURETY COMPANY, and FIDELITY AND DEPOSIT COMPANY OF MARYLAND,** this 16th day of August, A.D. 2019.

ATTEST:

ZURICH AMERICAN INSURANCE COMPANY
COLONIAL AMERICAN CASUALTY AND SURETY COMPANY
FIDELITY AND DEPOSIT COMPANY OF MARYLAND

By: ______________________
Assistant Secretary
Dawn E. Brown

____
Vice President
Robert D. Murray

State of Maryland
County of Baltimore

On this 16th day of August, A.D. 2019, before the subscriber, a Notary Public of the State of Maryland, duly commissioned and qualified, **ROBERT D. MURRAY, Vice President, and DAWN E. BROWN, Assistant Secretary,** of the Companies, to me personally known to be the individuals and officers described in and who executed the preceding instrument, and acknowledged the execution of same, and being by me duly sworn, deposeth and saith, that he/she is the said officer of the Company aforesaid, and that the seals affixed to the preceding instrument are the Corporate Seals of said Companies, and that the said Corporate Seals and the signature as such officer were duly affixed and subscribed to the said instrument by the authority and direction of the said Corporations.

IN TESTIMONY WHEREOF, I have hereunto set my hand and affixed my Official Seal the day and year first above written.

____
Constance A. Dunn, Notary Public
My Commission Expires: July 9, 2023

POA-F 177-0035B

EXTRACT FROM BY-LAWS OF THE COMPANIES

"Article V, Section 8, Attorneys-in-Fact. The Chief Executive Officer, the President, or any Executive Vice President or Vice President may, by written instrument under the attested corporate seal, appoint attorneys-in-fact with authority to execute bonds, policies, recognizances, stipulations, undertakings, or other like instruments on behalf of the Company, and may authorize any officer or any such attorney-in-fact to affix the corporate seal thereto; and may with or without cause modify of revoke any such appointment or authority at any time."

CERTIFICATE

I, the undersigned, Vice President of the ZURICH AMERICAN INSURANCE COMPANY, the COLONIAL AMERICAN CASUALTY AND SURETY COMPANY, and the FIDELITY AND DEPOSIT COMPANY OF MARYLAND, do hereby certify that the foregoing Power of Attorney is still in full force and effect on the date of this certificate; and I do further certify that Article V, Section 8, of the By-Laws of the Companies is still in force.

This Power of Attorney and Certificate may be signed by facsimile under and by authority of the following resolution of the Board of Directors of the ZURICH AMERICAN INSURANCE COMPANY at a meeting duly called and held on the 15th day of December 1998.

RESOLVED: "That the signature of the President or a Vice President and the attesting signature of a Secretary or an Assistant Secretary and the Seal of the Company may be affixed by facsimile on any Power of Attorney...Any such Power or any certificate thereof bearing such facsimile signature and seal shall be valid and binding on the Company."

This Power of Attorney and Certificate may be signed by facsimile under and by authority of the following resolution of the Board of Directors of the COLONIAL AMERICAN CASUALTY AND SURETY COMPANY at a meeting duly called and held on the 5th day of May, 1994, and the following resolution of the Board of Directors of the FIDELITY AND DEPOSIT COMPANY OF MARYLAND at a meeting duly called and held on the 10th day of May, 1990.

RESOLVED: "That the facsimile or mechanically reproduced seal of the company and facsimile or mechanically reproduced signature of any Vice-President, Secretary, or Assistant Secretary of the Company, whether made heretofore or hereafter, wherever appearing upon a certified copy of any power of attorney issued by the Company, shall be valid and binding upon the Company with the same force and effect as though manually affixed.

IN TESTIMONY WHEREOF, I have hereunto subscribed my name and affixed the corporate seals of the said Companies, this 10 day of January, 2023

FIDELITY AND DEPOSIT COMPANY OF MARYLAND INCORPORATED 1890

ZURICH AMERICAN INSURANCE COMPANY INCORPORATED 1998

COLONIAL AMERICAN CASUALTY AND SURETY COMPANY SEAL

Brian M Hodges

Brian M. Hodges, Vice President

TO REPORT A CLAIM WITH REGARD TO A SURETY BOND, PLEASE SUBMIT ALL REQUIRED INFORMATION TO:

Zurich American Insurance Co.
Attn: Surety Claims
1299 Zurich Way
Schaumburg, IL 60196-1056

January 12, 2023

Re: City of Novi – Novi Rd / 13 Mile Rd PCCP Water Main Renewal

Subject: V-Wrap™ CFRP System Performance

To whom it may concern,

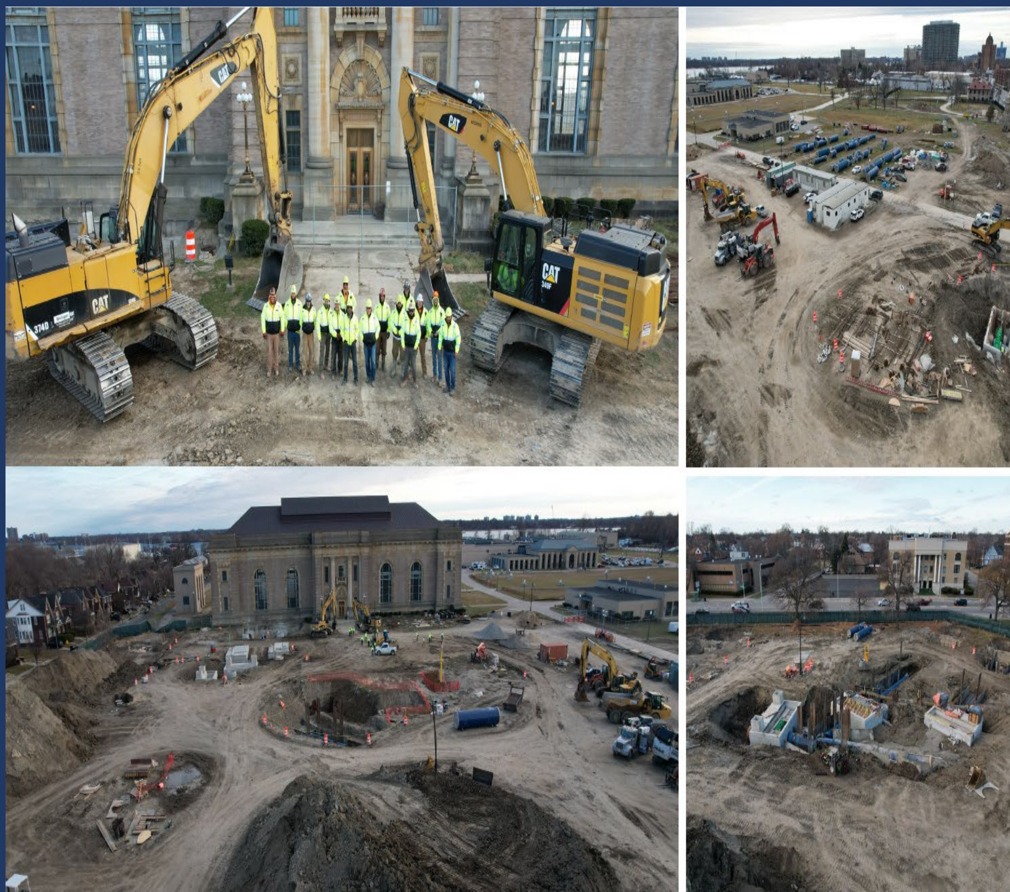
Structural Preservation Systems, LLC (STRUCTURAL) acknowledges, per the RFP requirements of sub-section 1.03.C.7 of Specifications Exhibit A, that STRUCTURAL (including all Structural Group entities) has not had any projects where the installed Structural Technologies V-Wrap™ CFRP system failed, did not perform as intended or where work was halted or abandoned prior to completion of the originally contracted scope of work.

If you should have any questions regarding this correspondence, or need any additional information, please contact me at apridmore@structuraltec.com or by phone at 714.869.8824.

Sincerely,

Anna Pridmore, PE, PhD
Vice-President, Pipeline Solutions
Structural Technologies, LLC

cc: Jason Alexander
Mark Geraghty
Dave Caughlin



City of Novi
Novi Road / 13 Mile Road PCCP Water Main Renewal – RFP
Appendix C - Resumes of Key Personnel

Submitted To:

City of Novi, Attn: Finance Department
45175 Ten Mile Road, Novi, MI 48375

Submitted By:

LGC Global Inc.
7310 Woodward Ave
Ste 500
Detroit, MI 48202

Date of Submittal:

January 16, 2023

Appendix C

JOSEPH B. ALBERTS, P.E.
PRINCIPAL ENGINEER

EXPERIENCE
Mr. Alberts has practiced geotechnical engineering for over 23 years including vibration monitoring, geotechnical investigations, and design of earth retention systems. Relevant project experience is presented below:

EDUCATION:

B.S.C.E.	Michigan State University 1988
M.S.C.E	Michigan State University 1990

VIBRATION MONITORING AND ANALYSIS

Macomb Meter Vaults: Performed vibration monitoring and analysis for large steel sheetpile structure adjacent to residential structures and existing large diameter sewers in Macomb County, Michigan. Analysis included velocity versus distance evaluation and evaluation of damage potential based on USBM standards.

Black River Bridge: Performed long term vibration monitoring in urban area for blasting effects for construction of new drawbridge in downtown Port Huron, Michigan. Efforts included monitoring building cracks during activities and evaluation of potential vibration damage.

South Haven Marina Park: Performed vibration monitoring for installation of steel sheetpile immediately adjacent to residential structures in South Haven, Michigan. Work included evaluationg and addressing damage claim attributed to sheetpile driving vibration damage.

Kennedy Square Garage Demolition: Performed long term vibration monitoring of downtown Detroit office buildings during demolition of Kennedy Square. Evaluated effects of vibrations and potential damage based on published criteria.

Macomb Sewer Repair: Monitored vibrations for pile driving and drilled pier installations on residential and commercial structures based on published criteria. Work included discussing and negotiating solutions to vibration nuisances with third parties.

Downriver Regional Storage and Transport System: Monitored vibrations caused by pile driving and rock blasting activities on residential and commercial structures as well as large adjacent utility lines. Included initial evaluation of potential damage based on driving hammers and evaluation after readings were taken.

GEOTECHNCIAL INVESTIGATIONS:

Project Engineer/Project Manager for over 100 geotechnical investigations for various shoreline designs construction shafts, tunnels, and other heavy civil projects. Duties included preparing investigation plans, coordinating drilling operations and access permits, direct oversight and troubleshooting of field issues, assigning appropriate laboratory testing, performing all aspects of analysis; and preparing geotechnical reports. Specific examples include:

Project Manager for Detroit River International Crossing U.S Geotechnical Investigation: Managed all aspects for the DRIC Bridge project U.S. side in coordination with MDOT including soft ground sampling, vane shear testing, groundwater monitoring, utility clearances, rock coring, foundation recommendations, etc. Investigation includes over 100 test borings.

Project Manager for Detroit/Wayne County Port Authority Offshore Dock, Detroit, Michigan: Directed the project geotechnical investigation offshore of the Renaissance Center including coordination with the US Coast Guard, Homeland Security, and Detroit Police. Work including barge drilling, sampling and testing. Prepared project geotechnical report including consideration of ice forces, dredging, shipping effects, etc.

EARTH RETENTION SYSTEMS DESIGN

Mr. Alberts has designed numerous permanent and temporary earth retention systems in Michigan, Ohio, Illinois, and other states. The systems varied from steel sheetpile both cantilevered and anchored, to steel rib and wood lagging, so sinking caissons, and others. Specific experience is described below:

Project Manager for Jennmar Corporation National Design Contract – Designed earth retention systems including circular, rectangular, rib and board, steel sheetpile, and rock anchor with wire mesh systems, along with primary tunnel liner design for projects throughout United States.

Project Manager for River Side Drive Temporary Earth Retention System – Design retention system for tunneling contractor on MDOT tunnel project under I-94. Retention system was designed to MDOT standards and MDOT review process.

Project Engineer for Design of Detroit Marine Terminal Seawall: Prepared all designs, specifications, and allowable surcharge charts for the replacement of the Detroit Marine Terminal Seawall. The design included a tied back wall, anchors, walers, etc. Participated in construction engineering making changes requested by the contractor along with field visits to confirm construction operations were in accordance with the design.

Project Manager Big Walnut Tunnel Augmentation Relief Tunnel Shafts, Columbus, Ohio: Prepared shaft designs for tunnel contractor including steel sheetpile and slurry shafts with dewatering well, pump testing, etc.

TUNNEL ENGINEERING

Detroit River Outfall No. 2 Tunnel, Detroit, Michigan. Consulted on tunneling methods for this 22-foot diameter pre-cast concrete segmental liner tunnel in Detroit. Observed liner construction and placement including difficulties grouting behind segmental units.

Kaneohe/Kailua Sewer Tunnel Project, Oahu, Hawaii. Performed primary tunnel liner design through Basalt for Jennmar Corporation including steel rib and wood lagging tunnel through various rock quality. Horseshoe type sets were also required.

Upper Rouge Tunnel, Detroit, Michigan: Project engineer assisting in identification of rock properties and tunneling methods during feasibility investigation. Rock conditions varied from shale to dolomitic limestone.

Downriver Regional Storage and Transport Tunnel Contracts 1 through 9: Performed primary and secondary tunnel liner design for this 17 mile long tunnel through clay soils in southeastern, Michigan. Efforts included serving as geotechnical field engineer observing construction.

SEMINARS/OTHER

Earth Pressure Balanced Tunneling Conference – ASCE Seattle Section - 2011
Author – Pipe Jacking Through Hardpan –North American Tunneling Conference – 2010
Author – An Encounter with Boulders – Rapid Excavation and Tunneling Conference - 1999
North American Tunneling, 2008, 2010
Rapid Excavation and Tunneling Conferences, 2001-2013
Registered Professional Engineer – Michigan and Ohio
ASCE Michigan Section Engineer of the Year 2011
ASCE Southeastern Michigan Branch Geotechnical Chair

LGC GLOBAL	**EDWARD DAENZER**
	KEY PERSONNEL RESUME

Project Assignment	Site Safety and Health Officer (SSHO)
Name of Firm:	LGC Global, Inc.
Years of Experience:	32

EDUCATION

Education:

- ASSOCIATE OF SCIENCE OCCUPATIONAL SAFETY AND HEALTH, COLUMBIA SOUTHERN UNIVERSITY, ORANGE BEACH, AL
- ANTICIPATED COMPLETION 02/22 OF A BACHELOR OF SCIENCE OCCUPATIONAL SAFETY AND HEALTH, COLUMBIA SOUTHERN UNIVERSITY, ORANGE BEACH, AL
- OCCUPATIONAL ERGONOMICS, MI (2019)
- LEAD PROFESSIONAL ABATEMENT SPECIALIST, DEPARMENT OF HEALTH AND HUMAN SERVICES, LANSING, MI (2018)
- FEMA FIRE PREVENTION, US DEPARTMENT OF HOMELAND SECURITY (2017)
- MIAT TECH COLLEGE

LICENSES. CERTIFICATIONS. TRAINING

- OSHA 30 HOUR OUTREACH PROGRAM, AUSTIN, TX (2017)
- OSHA 510/500 TRAINER COURSE IN OS&H STANDARDS FOR CONSTRUTION INDUSTRY, EASTERN MICHIGAN UNIVERSITY (2017)
- OSHA 7115 LOCKOUT/TAGOUT, CONTROLLING HAZARDOUS ENERGY TO PREVENT WORKPLACE INJURY, EASTERN MICHIGAN UNIVERSITY (2017)
- 40 Hr EM 3851-1

PROJECT EXPERIENCE

Safety Manager – LGC Global Inc. (August 2021-Present)

- Manage/supervise field personal to ensure compliance with EHS/OSHA policies, programs, procedures, and legislative standards. Communicate and contribute to site specific EHS programs. Conduct onsite EHS audits and inspections to ensure corrective action is taken.
- Ensure medical preparedness and welfare facilities are available for all employees and that records are properly managed.
- Ensure all projects are adhering to safety standards and protocols as per OSHA guidelines and contract specifications.

Site Safety Specialist, Fieldcore General Electric (2016 – present)

- Manage/supervise field personal to ensure compliance with EHS/OSHA policies, programs, procedures, and legislative standards. Communicate and contribute to site specific EHS programs. Conduct onsite EHS audits and inspections to ensure corrective action is taken.
- Compile and maintain necessary documentation and records.
- Ensure medical preparedness and welfare facilities are available for all employees and that records are properly managed.

- Develop and assist personnel in STA, JSA , safety risk assessment implementation, Success factor and LMS .
- Ensure all hot work permits and safety procedures are followed.
- Ensure the chemical management program is strictly adhered to.
- Ensure LOTO and all potential energy is isolated and locked out.
- Ensure all confined space procedures are followed, and atmospheric testing equipment is calibrated and properly utilized.
- Communicate all company & customer site specific updates through posting of safety stand-downs and pre & post job briefings.
- Hazardous materials management, exposure, TWA limits, PPE, and mitigation experience.
- Establish a good rapport with site personal, contractors, and customers.
- Assist regional manager with injury and illness investigations, incident reporting and documentation.

  Instructing and coaching OSHA company principals, toolbox talks, JSA & SWAT's.

SAFETY Turbine TECNICIAN, GRANITE, MI (2015 – 2016)

- Steam/Gas Turbine - design, operation, manufacturing, maintenance, and overhaul.

SSI/NAUI Scuba Diving / Mixed Gas /Tech Diving Instructor, MI (1989 – PRESENT)

- Instructing hundreds of students in diving safety fundamentals and practice along with specialized dive courses, equipment, rescue, and diver evaluations.
- Technical equipment, variable gas mixtures, decompression tables.
- Minimizing diving risks by maximizing continued education.

University of Cincinnati

Continuing Education
Great Lakes OSHA Education Center

This is to certify that

Edward Daenzer

has successfully completed

OSHA #502 - Update for Construction Industry Outreach Trainers

502-7
Certificate Number

1.8
Continuing Education Units

05/31/22 - 06/03/22
Course Dates

Timothy R. Roberts CSMP, COSM, CHST
Tim Roberts

Brandon Workman
Course Director

GREAT LAKES
OSHA EDUCATION CENTER

OSHA Training Institute Education Centers®
Great Lakes OSHA Education Center

Department of Environmental and Public Health Sciences Continuing Education Programs, 160 Panzeca Way, Kettering Lab Room 129, ML 0056, Cincinnati, OH 45221-0056, (800) 207-9399

Certificate of Achievement

This certificate of achievement is awarded to:

Edward Daenzer

in recognition of the completion of 60 minutes of training for detecting the signs of substance abuse and 60 minutes of training for detecting alcohol misuse in the workplace in accordance with 49 CFR Part 40 § 382.603 presented by Compliance Educators.

DOT
COMPLIANCE EDUCATORS

Compliance Educators LLC.

Issuing Authority

100 Decker Court Ste. 250 Irving, TX 75062 • 855.368.7233

April 7, 2022

University of Cincinnati

Department of Environmental and Public Health Sciences

Occupational Health & Safety,
Continuing Education

Certifies that

Introduction to Trenches & Excavations
www.TrenchingSafety.com
(800) 207-9399

Edward Daenzer

GREAT LAKES
OSHA EDUCATION CENTER

has successfully completed

Advanced Topics in Trenches and Excavations, 4 Hour Course Online

#SH-05166-SH9-7
Certificate Number

0.4
Continuing Education Units

12/06/21
Course Date

Daryl Daniels

Course Director

This material was produced under grant number SH-05166-SH9 from the Occupational Safety and Health Administration, U.S. Department of Labor. It does not necessarily reflect the views or policies of the U.S. Department of Labor, nor does mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government.

Department of Environmental and Public Health Sciences Continuing Education Programs, 160 Panzeca Way, Kettering Lab Room 129, Cincinnati, OH 45221-0056 - (800) 207-9399

Certificate Of Completion

American Safety Council

EDWARD DAENZER

Has diligently and with merit completed the

40-Hour EM 385-1-1 on 10/27/2021

Director: Jeff Pairan

LGC GLOBAL	Ken Anderson, MACP
	KEY PERSONNEL RESUME

Project Assignment:	Project Director
Years of Experience:	45
Contact:	Cell: 313-218-7496; Email: Ken.Anderson@lgccorp.com

EDUCATION

Education:	▪ Cumberland College – Williamsburg, KY

LICENSES, CERTIFICATIONS, TRAINING

- OSHA 10-hr Construction Safety Training
- OSHA Confined Space Entry Certification – Supervisor / Attendant / Entrant
- OSHA Trenching & Excavation Safety Training
- American Red Cross First Aid / CPR Training
- Competent Person Training for Excavation
- National Association of Sewer Service Companies (NASSCO), PACP, MACP, and LACP certifications

PROJECT EXPERIENCE

LGC Global Inc. (2011 – Present)

GLWA-CON-181: Water Transmission Main Assessment & Repair (10/2017 – Present)
Value: $15M
Mr. Anderson works as the Project Manager, overseeing the assessment, replacement, and repair of large water transmission mains 24" and greater. The project consisted of replacement of defective distribution and 24" valves along with the replacement of 48" actuators. Specifically, this project included 48" butterfly valve actuator replacement and replacement of a 24" gate valve at Elmwood and Canfield. A portion of the scope of work under this contract includes assistance with operating and diagnosing valve-related problems and repairing and replacing valves.

GLWA-CON-158: Specialized Services Contract
Value: $10M
Mr. Anderson serves as Project Manager for this project to perform emergency and planned work on an on-call basis. Work performed under this contract includes replacing two (2) 42" gate valves at the NE Water Treatment Plant and repairing 24" gate valves at the Lake Huron Water Treatment Plant.

PC-798A: Facilities Maintenance Requirement Contract
Value: $10.7
Mr. Anderson served as QAQC for job including furnished skilled labor, working foremen, and over-all supervision to complete major and minor skilled trades maintenance projects as well as specialized sub contractual maintenance services on an as-required basis at Wastewater Treatment Plant Operations, Group Facilities, CSO Facilities, Wastewater Treatment Plant, Industrial Waste Control Facilities, and all other GLWA facilities related directly or indirectly to the Jefferson Wastewater Treatment Plant.

MCWDD Sewerage Metering Facility Rehabilitation/Repair Project
Value: $6.8M
Mr. Anderson served as Project manager for the construction of (3) sewerage metering facilities, including replacing 48" to 54" influent and effluent sewers, associated structures, access and safety improvements, and adding new electrical systems and components and the rehabilitation of (15) sewerage metering facilities including an applied surface concrete membrane system, internal piping system repairs, access and safety improvements, and adding new electrical systems.

Detroit Water and Sewerage Department WS-704: Water System Improvements Various Streets Throughout the City of Detroit
Value: $5.5M

Working as Project Manager, Mr. Anderson was involved in the overseeing of the connecting of existing services and fire hydrants, replacing or installing the Gate Valves and Gate Boxes, Constructing/furnishing and installing the new Gate Wells, repairing the existing Gate Wells, replacing fire hydrants and all the appurtenances, conducting hydrostatic test, chlorinating and flushing new water mains, repairing the stop boxes, road boxes, and gate boxes, replacing existing lead services (either as applies, in the ROW and from the curb box to the customer water meter), flushing the existing services

Detroit Water and Sewerage Department WS-891 – Pressure Regulating Valve (PRV) Vault Improvements
Value: $2.6M
Serving as Project Manager in charge of all field operations under this contract, Mr. Anderson was involved in overseeing the demolition and reconstruction of five (5) PRV vaults in the city of Detroit. The project consisted of $2M worth of meter replacement as well as the addition of pressure reducing valves (PRVs) measuring 8", 16", and 24".

PC-793: Specialized Process Equipment Installation and Maintenance at Water and Wastewater Facilities
Value: $27,799,000
Mr. Anderson Project Manager designated to inspecting outfalls, chambers, and responding to emergencies such as manholes, sewer system and sink holes in the wastewater treatment plants and other facilities. A $5.3M task order under this contract vehicle involves the installation of retail automatic reading equipment including removal of old meters, re-piping within the meter pit chamber, meter replacement, gate valve replacement/repair, and sump discharge repair. This project included repair and replacement of valves measuring up to 48", including 30" butterfly valves and 32" meter replacement.

GLWA-CON-105: 30" Transmission Main under Jefferson Street, Rouge River Bridge – Detroit, MI
Value: $2.3M
Mr. Anderson served as Project Manager for this critical GLWA project to install (using trenchless methods) a new 30" diameter water transmission main 50' below the bed of the Rouge River. High Definition Single Slot (HDSS) joints were installed via directional bore. The transmission main included 30" valves.

Sewer Separation East of Telegraph, North of Cherry Hill, CSO #004, Phase II
Value: $13.2M
Mr. Anderson served as Project Manager for sewer separation in the area of Telegraph Rd, Wilson St, Cherry Hill Rd, and Martha St. This project consisted of sewer separation in the area of Telegraph Rd, Wilson St, Cherry Hill Rd, and Martha St. The work included inspection and assessment, excavation, cleaning, disposal, grading, compacted backfill, trench bracing, concrete paving, reinforcing steel, miscellaneous iron, cold milling of asphalt surface, asphalt resurfacing, removal and/or replacement of bituminous & concrete pavement, sidewalks, sidewalk ramps, curbs, aprons, conduit, under drains, sanitary sewer, manholes, storm sewer and water main construction, testing and disinfection of water main, television inspection of sewers, installation of drainage structures, gate valve structures & restoration.

Great Lakes Water Authority Contract #3591: Valve and Transmission Main Study, Assessment, and Repairs
Value: $491,706
Mr. Anderson served as Project Manager for the investigation of low water pressure, including a valve and transmission main study, assessment, and repairs at various locations inside the valve vaults and transmission system in GLWA's intermediate pressure zone (IPZ).

Detroit Water and Sewerage Department DWS-685 – Water System Improvements
Value: $6.4M
Mr. Anderson worked as Project Manager, overseeing of all field operations for this project for DWSD, repairing 42,000' of 8" water main.

LGC GLOBAL	Parth Dixit **KEY PERSONNEL RESUME**
Project Assignment:	Assistant Project Manager
Years of Experience:	3

EDUCATION

Education:	• Bachelor of Science in Mechanical Engineering, Indus University - Ahmedabad, India (June 2017) • Master of Science in Mechanical Engineering, Wayne State University – Detroit, MI (May 2020)

LICENSES, CERTIFICATIONS, TRAINING

- ✓ OSHA 30-hr Construction Safety Training
- ✓ National Association of Sewer Service Companies (NASSCO), PACP, MACP, LACP certifications
- ✓ Six Sigma Black Belt

PROJECT EXPERIENCE

LGC Global, Inc. (2019 – present)

GLWA Contract -1804129: Schoolcraft Road 48-inch Water Transmission Main
Contract Value: $ 14.5M

- Responsible for overseeing installation of 12,000 linear feet of 48-inch diameter steel pipe transmission main, associated gate valves, blow offs, entrance manholes air release valves, cathodic protection system and pavement restoration along the restoration route. Approximately 425 linear feet of 48inch transmission main was to be installed using Jack & Bore method.
- Responsible for all aspects of welder qualification on-site testing. Responsible for issuance, control, and coordination of Post Weld Heat Treatment (PWHT) and Non-Destructive Examination (NDE) contacts.
- Prepare and establish Inspection and Test plans and track inspections/actions identified, manage non-conformance and deficiency processes. Participate in cross functional development teams within the company to develop and communicate program deliverables, priorities, and timeline targets based on customer derived expectations and external stakeholder requirements.

GLWA Contract-2003730: Water Transmission Main, Valve and Other Priority Repair
Contract Value – $ 15M

- Responsible for managing assigned budget, schedule, quality requirement and develop streamline method for project planning and execution. The project consists of emergency repair or replacement of water transmission main, valve and vaults that involves shutdown/startup planning, dewatering, filling, disinfection, pipeline access and data verification.
- A portion of the scope of work under this contract included CFRP repair on 17 sections of the 48-inch diameter pipe on 14 Mile in Farmington Hills, MI.

GLWA CS-277 Fourteen Mile Road PCCP Water Main Condition Assessment Responsibilities:
Mr. Dixit performed as the assistant project manager with the following responsibilities.

- Develop and update CPM schedule using primavera P6 to meet project timeline requirements.
- Review, prepare and submit all the material safety data sheets and shop drawings as per specifications and drawings of the project.
- Controlled site engineering activities to maintain work standards and meet quality assurance targets.
- Completed daily construction tasks while ensuring safe working conditions, staying on budget, and meeting project deadlines.

LGC GLOBAL	Thomas Tersigni KEY PERSONNEL RESUME
Project Assignment:	Site Superintendent
Years of Experience:	24

EDUCATION

Education:

- Detroit Training Center
- East Detroit High School

LICENSES, CERTIFICATIONS, TRAINING

- OSHA 40 Hour Hazpower
- CPR certification

PROJECT EXPERIENCE

LGC Global, Inc.

DWSD Contract WS-707: Water System Improvements Various Streets Throughout the City of Detroit
Detroit, MI

Served as site superintendent responsible for oversight of crews and set up for project scope which consisted of the replacement of existing six-inch through sixteen-inch water main with approximately 18,671 linear feet of 8 inch, 937 linear feet of 12-inch, and 30 linear feet of 16-inch Ductile Iron Water Main with an 8-mil Polyethylene Wrap.

GLWA-CON-181: Water Transmission Main, Valve and Other Priority Repair
Value: $15M

Tom worked as the Project site superintendent responsible for overseeing crews performing the assessment, replacement and repair of large water transmission mains 24" and greater. The project consisted of replacement of defective distribution and 24" valves along with the replacement of 48" actuators. Specifically, this project included 48" butterfly valve actuator replacement and replacement of a 24" gate valve at Elmwood and Canfield. A portion of the scope of work under this contract includes assistance with operating and diagnosing valve-related problems and repairing and replacing valves.

CITY OF HIGHLAND PARK - Hydrant & System Valve Replacement Program
Detroit, MI

Performed as project engineer in reference to work related to assembly and installing of fire hydrants connected to water mains including excavating, backfilling, concrete, asphalt as well as lawn restoration work. Performed the removal and installation of existing gate valve boxes.

Great Lakes Water Authority GLWA-CON-105: New Water Main Construction – Detroit, MI

Serving as Project Coordinator on the construction of a new 30" water main at West Jefferson Bascule Bridge below the Rouge River for the City of Detroit, using the Horizontal Directional Drilling / Directional Boring trenchless method.

All State Directional Drilling

Tom served as a pump operator and pipelayer for all projects along with managing site crews to ensure all work was executed as per the defined scope of work which included red box changes, fusing pipelines, curb rehabilitation and replacement.

Magnet Construction

Tom performed scope of work for all projects that entailed pipelaying, grading & earthwork, manhole and catch basin rehabilitation as well as choke pipe clearing.

Adolfo Cepeda

STRUCTURAL
Superintendent

TRAINING:

- Confined Space: Certification
- Abrasive Blasting Operator: Certifications
- Hazard Communication/GHS (HAZCOM): Awareness
- FRP Installer Certification: Modules 1-7
- FRP Carbon fiber Reinforcement Technician (SME Verified)
- OSHA 10 Construction Safety & Health
- OSHA 30 Certification
- Nuclear Safety Culture and SCWE

YEARS OF EXPERIENCE:

- 17 years

YEARS WITH THE FIRM:

- 17 years

Background Experience:

Adolfo Cepeda has 17 years of experience in the construction rehabilitation industry. He has performed numerous repair projects for commercial, public and nuclear infrastructure. He is responsible for overseeing daily operations at worksite to ensure the completion of projects in a safe and efficient manner.

Areas of Expertise:

- Concrete Repairs
- FRP Strengthening
- Post-Tension Repairs
- Waterproofing
- Epoxy Injection
- Coatings
- Fireproofing
- Sandblasting
- Hydroblasting

Past Positions:

- STRUCTURAL - Superintendent – August 2005 - Present
    - Manage/lead large project crews throughout all phases of work scope (dewatering, surface preparation and CFRP installation)

Project Experience:

- **DTE Fermi Nuclear, Spring 2022**, Monroe, MI – Pipe Strengthening of (13) 144” PCCP segments with CFRP
- **Braidwood CWBD SLC Spring 2021**, Braceville, IL - Pipe Strengthening of 48" PCCP with SCL and CFRP (540 Total LF)
- **GLWA 7 Mile Winter 2021,** Detroit, MI – Emergency pipe strengthening of (11) 42” PCCP segments with CFRP
- **Surry Power Station Safety Related Pipe Repairs** *(Various Outages from 2018 – 2021),* Surry, VA – Safety Related Pipe Strengthening of Steel Inlet and Outlet Pipes
- **APS Palo Verde Pipe Strengthening** (*Various Outages from 2019 – 2022)*, Tonopah, AZ – CFRP Repairs to 96” – 144” PCCP Segments in Circ Water Inlet and Outlet Pipes
- **Almaden Valley Pipeline 78-inch Diameter PCCP Anderson Valley Pipeline Spring 2018,** Santa Clara Valley Water District – 80 PCCP Pipe Segment Rehabilitation with V-Wrap CFRP System

Rasko P. Ojdrovic

Ph.D., P.E.

Senior Principal

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REGISTRATIONS

Professional Engineer

AR	CO	DC
DE	FL	GA
IN	KS	KY
MA	MD	MI
MO	NC	NE
NJ	NM	NY
OH	PA	RI
SC	TN	TX
UT	VA	WI

Civil Engineer

AZ

OTHER

NCEES

CERTIFICATIONS

SECB Certification

EDUCATION

Duke University, Durham, NC
Ph.D. in Civil Engineering, 1988
M.S. in Civil Engineering, 1986

Belgrade University, Serbia
B.S. in Civil Engineering, 1984

Dr. Ojdrovic has more than thirty years of experience in structural engineering, engineering mechanics, and infrastructure engineering. His experience includes pipeline condition assessment, failure risk analysis, failure investigation, repair design, CFRP, concrete fracture, fracture mechanics, seismic analysis, and others. He has published more than fifty papers on these subjects.

Experience

Simpson Gumpertz & Heger Inc. (SGH). From 1990 to present.

Duke University. From 1988 to 1990.

Pipe and tanks

- Pipeline condition assessment, failure investigation, failure risk analysis, internal inspection, external inspection, testing, failure risk analysis, seismic and blast analysis of prestressed concrete cylinder pipe (PCCP), concrete, metallic, HDPE, asbestos cement, fiberglass, and other pipe, in more than 100 projects.
- Design of pipe repairs using carbon fiber reinforced polymer (CFRP), post-tensioning, encasement, and other methods, and design of new pipe in more than 100 projects.
- Projects throughout the US, Canada, and Mexico on water, sewer, cooling water, and other pipelines at municipalities, nuclear and conventional power plants, and other facilities including:
- **Massachusetts Water Resources Authority, Boston, MA.** Investigation of HDPE slip-lined pipeline and repair design.
- **Washington Suburban Sanitary Commission, Laurel, MD.** On-call project for PCCP condition assessment, inspection, forensic and failure risk analysis.
- **Louisville Water Company, Louisville, KY.** Pipeline condition assessment and repair design, construction, and blast load analysis.
- **Surry Nuclear Power Plant.** CFRP repair design of safety and non-safety 96 to 24 in. dia. steel pipelines; development of NRC-approved alternative request.
- **South Texas Nuclear Power Plant, TX.** CFRP repair design of 138 in. dia. PCCP pipelines and 36 in. dia. failed pipe; development of NRC-approved alternative request for CFRP repair of aluminum bronze pipeline.
- **Arkansas Nuclear One Power Plant, AR.** Development of alternative request for CFRP repair of steel pipelines.
- **Middlesex Water Company, NJ.** PCCP pipeline condition assessment and design of CFRP repairs.
- **Newcastle, DE.** Investigation and repair design of 84 in. dia. nearly collapsed sewer force main.
- **North Texas Municipal Water District, TX.** Failure investigation of PCCP, condition assessment and CFRP repair design.
- **Tri-State Power Generation, Craig, CO.** Failure risk analysis, field inspection, repair design and construction services, 102 and 96 in. dia. PCCP.
- **Palo Alto, CA.** Development of a PCCP section for EPRI: *Recommendations for an Effective Program to Control the Degradation of Buried Pipe*.

- **Tlahuac, Mexico.** Failure risk analysis of PCCP line.
- **Dofasco Steel Mill, Canada.** Failure risk analysis of PCCP line.
- **Peel, Canada.** Evaluation of internal inspection results, 42 in. PCCP line.
- **Palo Verde Nuclear Generating Station, Tonopah, AZ.** Evaluation of cooling water pipe material options.
- **Palo Verde Nuclear Generating Station, Tonopah, AZ.** Cooling water pipeline installation engineering construction support.
- **Ottawa, Canada.** Failure risk analysis of PCCP lines, CFRP repair design, evaluation of live loads due to highway widening.
- **Forest Park Water, NJ.** CFRP repair design of PCCP.
- **Colstrip Power Plant, MT.** Failure risk analysis and CFRP repair design.
- **Muskegon, MI.** Investigation of steel piping movement and Depend-o-lock couplings in pumping station.
- **Tucson, AZ.** Development of program for asbestos cement pipeline condition assessment.
- **Providence, RI.** Review of pump corrosion issues.
- **Boston, MA.** Investigation of 16 in. dia. ductile iron pipe (DIP) water main failure.
- **Boston, MA.** Investigation of 12 in. dia. ductile iron pipe (DIP) water main failure.
- **Fort Worth, TX.** Condition assessment of 54 in. dia. PCCP.
- **Denver, CO.** CFRP repair design of 72 in. dia. steel pipe.
- **Tucson, AZ.** Failure risk analysis and repair of 96 to 66 in. dia. PCCP.
- **Brandon Shores, MD.** Condition assessment and repair options, 102 in. dia. PCCP.
- **Mexico City, Mexico.** Failure risk analysis of 99 in. dia. PCCP.
- **Guadalajara, Mexico.** Condition assessment and failure risk analysis of 72 in. dia. prestressed-concrete non-cylinder pipe.
- **Tijuana, Mexico.** Post-tensioning repair design of PCCP.
- **Cambridge, MA.** Investigation of DIP water main break.
- **Flushing Bay CSO, New York, NY.** Investigation of temporary bulkhead failure.
- **San Felipe, CA.** Failure risk analysis and repair prioritization of 120 in. dia. PCCP.
- **Sandow Powerplant, Sandow, TX.** Failure risk analysis and repair prioritization of 66 in., 84 in., and 108 in. dia. PCCP.
- **Limestone Powerplant, Jewett, TX.** Failure risk analysis and repair prioritization of 30 in. dia. PCCP.
- **Lubbock, TX.** Structural Evaluation of 42 in. and 45 in. dia. bar wrapped pipe.
- **Howard County, MD.** Failure risk analysis and repair prioritization of 36 in. and 54 in. dia. PCCP.
- **Springfield, MA.** Failure risk analysis of 60 in. dia. PCCP.
- **DuPont, Fayetteville, NC.** Failure risk analysis of 42 in. dia. PCCP.
- **Chicago, IL.** Failure risk analysis and field inspection of 36 in. dia. PCCP.
- **Elgin, IL.** Design of PCCP under high soil cover.
- **Greybull, WY.** Condition assessment of asbestos cement pipeline.
- **Los Angeles, CA.** Evaluation of RCP with elliptical cage installed off-center.
- **PVNGS, Tonopah, AZ.** Analysis of and design of repairs for highway crossing over PCCP.
- **Puerto Nuevo, PR.** Design of 90 in. sewer under new canal including live tapping and flow stoppage.
- **Palo Verde Nuclear Generating Station, AZ.** Stress analysis of 12 in. dia. FRP-flanged connections of fire protection line.
- **Highland-Trebisky Line, Cleveland, OH.** CFRP repair of distressed prestressed concrete pipe with broken wires.
- **Palo Verde Nuclear Generating Station, AZ.** Design of six sumps for collection of the under-drain water from holding reservoirs.
- **MWRA, Boston, MA.** Investigation in tank wall cracking, concrete deterioration, and repair options for ozonation tanks.
- **Muskegon, MI.** Failure investigation of 60 in. dia. PCCP, condition assessment of 11-mile-long pipeline, and design of new 60 in. DIP line and thrust restraint at live line stop.
- **PVNGS, Tonopah, AZ.** Evaluation of pipeline replacement options near high voltage transmission tower.

- **Plum Point Power Plant, Osceola, AR.** Condition assessment of floated 102 in. dia. pipeline.
- **Central Pipeline, Santa Clara Valley Water District, San Jose, CA.** Failure risk analysis and repair priorities of prestressed concrete cylinder pipe with broken wires.
- **Libya.** Structural evaluation of prestressed concrete cylinder pipe with non-uniform wall.
- **O'Hare Airport Project, Chicago, IL.** Investigation of pipe floatation damage.
- **Highland-Trebiesky Pipeline, Cleveland, OH.** Failure risk analysis and CFRP and post-tensioning repair design of prestressed-concrete cylinder pipe.
- **Halifax, Nova Scotia, Canada.** Failure risk analysis and repair priority of prestressed concrete pipe.
- **Bay Division Pipeline 4 – Section A, San Francisco Public of Utilities Commission, CA.** Failure risk analysis, condition assessment, and repair.
- **Walnut Hill, MWRA, MA.** Failure investigation of restraint joint in 144 in. dia. PCCP line.
- Research and development on a new thrust restraint design procedure for concrete pressure pipe.
- Research and development of failure risk analysis and repair priorities of PCCP with broken wires for PCCP Users Group.
- **Waltham, MA.** Condition assessment and safety analysis of 60 in. dia riveted steel WASM 3 pipeline.
- **Providence, RI.** Failure risk analysis and repair design of 102 and 78 in. dia. PCCP.
- **Springfield, MA.** Failure risk analysis of 54 in. dia. PCCP.
- **Metropolitan Water District, Los Angeles, CA.** Risk analysis of 54 in. to 201 in. dia. PCCP.
- **South Africa.** Preliminary design of internal CFRP lining repairs and evaluation of inner joint seals.
- **San Diego County Water Authority, CA.** Evaluation of 96 in. dia. PCCP under deep cover.
- **Miami-Dade Water and Sewer Authority, FL.** Analysis of blast effects on 96 in. PCCP.
- **North Shore Sanitary District, IL.** Condition assessment of four 24 in. to 36 in. dia. LCP force mains.
- **Tucson, AZ.** Analysis of risk of failure and repair priorities for 66 in. and 78 in. PCCP, and repair design.
- **Palo Verde Nuclear Generating Station, Tonopah, AZ.** Evaluation of PCCP under deep cover and repair design.
- **Phoenix, AZ.** Analysis of T-Lock failure in 54 in. and 78 in. dia. PCCP and pipeline condition assessment.
- **San Francisco, CA.** Determination of failure risk and repair priorities for 96 in. dia. PCCP.
- **Constellation Power, MD.** Evaluation of internal repair options and preliminary design of CFRP lining.
- **Navajo Indian Irrigation Project, USBR, Farmington, NM.** Analysis of risk of failure and repair priorities for 210 in. dia. prestressed concrete non-cylinder pipe.
- **Houston, TX.** Risk analysis and structural evaluation of 60 in. PCCP.
- **Tarrant County, TX.** Consulting on PCCP damaged by hydrogen embrittlement.
- **Cleveland, OH.** Structural Evaluation and design check for a new 108 in. dia. outfall.
- **WASM, Waltham, MA.** Structural evaluation of increased soil cover effects on 60 in. lock-bar steel pipe.
- **Intermountain Power Service Corporation, Delta, UT.** Determination of failure risk and repair priority of 120 in. circulating water PCCP.
- **Bushard Trunk Sewer Line, Orange County, CA.** Investigation of 108 in. RCP joint leakage.
- **Detroit Metropolitan Airport, Detroit, MI.** Condition assessment of 84 in. Glycol force main and joint leakage in jack and bore section.
- **Cheyenne, WY.** Condition assessment of four PCCP pipelines 16 in. to 30 in. dia.
- **Dallas, TX.** Evaluation of blast effects on 72 in. and 84 in. dia. pipelines.
- **Austin, TX.** Failure investigation and design of repairs for 72 in. and 66 in. dia. PCCP pipelines.
- **ExxonMobil Refinery, Joliet, IL.** Failure investigation and condition assessment of 30 to 48 in. dia. cooling water PCCP pipelines.
- **Springfield, MA.** Failure investigation of 12 in. dia. cast iron pipe.
- **Holyoke, MA.** Failure investigation of 10 ft dia. masonry combined sewer overflow pipe.

- **Richmond, VA.** Investigation of code compliance of decommissioned above-ground steel oil tanks.
- **Alafia River Intake and Pumping Station, Alafia River, FL.** Design of 24 in. to 54 in. dia. steel pipe.
- **Eastside Water Treatment Plant, High Point, NC.** Design of 6 in. to 36 in. dia. steel pipe.
- **Austin, TX.** Design of steel pipe to PCCP joint for 72 in. dia. pipeline.
- **Central Arizona Project, AZ.** Risk analysis and repair design for 252 in. PCCP with broken wires.
- **Tonopah, AZ.** Design of installation for HDPE crossing under a drainage wash.
- **Tonopah, AZ.** Design of HDPE manhole chambers.
- **Waukegan, IL.** Risk analysis for 24 in. to 54 in. PCCP with broken wires.
- **Dallas, TX.** Failure investigation of 84 in. dia. PCCP.
- **Windy Gap Pipeline, CO.** Risk analysis and design of repairs for 108 in. dia. PCCP.
- **Central Arizona Project, AZ.** Risk analysis and design of repairs for 72 in. dia. PCCP.
- **North Coast Superaqueduct, Puerto Rico.** Failure investigation, condition assessment, and repair design of the 50 mi. long, 72 in. dia. PCCP.
- Investigation of prestress loss effect on PCCP behavior and risk assessment of PCCP with broken wires.
- **Hartford, CT.** Failure investigation of 6 in. DIP dia. water line.
- **Northeast Aqueduct, Puerto Rico.** Design of reinforced concrete pipe under deep cover of a dam.
- **Arizona Public Service, Palo Verde Nuclear Generating Facility, AZ.** Investigation, repair design, and long-term rehabilitation of 36-mile 66 in. to 144 in. PCCP lines.
- **Cranston, RI.** Failure investigation of 102 in. dia. PCCP, internal inspection, and condition assessment of portion of the pipeline.
- **Arizona Public Service Company, Palo Verde Nuclear Generating Facility, AZ.** Design of installation for 36 in. high-density polyethylene (HDPE) pipe.
- **Massachusetts Water Resources Authority, Boston, MA.** Leak investigation and emergency repairs of 48 in. PCCP pipe through Spot Pond Dam.
- **C.T. Perry Water Treatment Plant, Montgomery, AL.** Investigation of concrete tank shrinkage and temperature cracking and leakage.
- **Burlington, VT.** Failure investigation of floated steel outfall pipeline.
- **Richland Creek Pipeline, Tarrant County, TX.** Investigation of thrust restraint failure and thrust restraint design.
- **Hultman Aqueduct, Massachusetts Water Resources Authority, Boston, MA.** Analysis and design of joint repair.
- Analysis and design of RCCP pipe tunnel liners.
- FRP pipe joint analysis (research for Owens-Corning Fiberglas Corp.).
- **Black Butte Hydroelectric Power Plant.** Seismic analysis of penstock.
- Investigation of post failure safety for human entry of pipeline under Houston Ship Channel.
- **Benbrook and Plano-McKinney pipelines, TX.** Design of thrust restraint.
- **Philippines and Puerto Rico.** Seismic design of pipelines.
- **West Coast Regional Water Supply Authority, FL.** Investigations of prestressed concrete cylinder pipe.
- **Santa Margarita, CA.** Investigation of mortar-coated steel pipe.
- Analysis of pipe burst, post-failure pipe behavior, effect of loss of prestress, and harnessed joint.
- Development of AWWA C304-92 Standard for Design of Prestressed-Concrete Cylinder Pipe and computer program UDP.
- Development of 3EB program for calculation of loads on rigid pipe.
- Research on shrinkage cracking and coating delamination by radial tension.
- Research on prediction of concrete creep and shrinkage.
- **Yarmouth Treatment Facility, Yarmouth, MA.** Investigation of concrete tank leakage.

Seismic

- Triaxiality failure analysis of steel-moment frames, development of triaxiality fracture theory, and application to several buildings in Los Angeles that experience fracture of moment frames in Northridge earthquake.
- **Glass Building and Triangle Building, Warner Bros. Studios, Burbank, CA.** Repair of steel-moment-frame buildings damaged during Northridge Earthquake, including investigation, analysis, design, and construction supervision.
- **Computer Building, Warner Bros. Studios, Burbank, CA.** Investigation, analysis, design, and repairs of a steel-braced-frame building damaged during Northridge Earthquake.
- **Boston, MA.** Seismic analysis and design of electrical ductwork supports.
- **Dallas, TX.** Analysis of blast effects on 84 and 72 in. dia. pipelines.
- **Hultman Aqueduct, Boston, MA.** Analysis of blast effects.
- **Trident Center, Los Angeles, CA.** Analysis and assessment of risk of structural collapse of the complex of three steel-moment-frame buildings damaged during the Northridge Earthquake.
- **Boston, MA.** Seismic analysis of piping connected to egg-shaped digesters.
- **Mullins Arena, University of Massachusetts, Amherst, MA.** Seismic analysis.
- **Lawrence Livermore National Laboratory, CA.** Seismic analysis of a liquid nitrogen tank.
- Seismic analysis of pipelines.

Precision structures

- Evaluation of foundation design for dynamic response of Have Stare Antenna.
- Preliminary design of a 6 m dia. offset antenna.
- **Superconducting Super Collider, Dallas, TX.** Design and optimization of the muon subsystem structure.
- **Superconducting Super Collider, Dallas, TX.** Analysis of muon cathode strip chambers, layout, alignment, and error.
- **Onsala, Sweden.** Analysis and performance evaluation of surface deformations and adjustments, and upgrade of 66 ft dia. antenna.
- Analysis and performance evaluation of the quadrupod structure of a 60-ft-dia. antenna.
- **Mount Hopkins, AZ.** Design of a torispherical vacuum chamber head for in situ re-aluminizing of the 6.5 m primary mirror on the Smithsonian Institution Multiple Mirror Telescope conversion.

Building structures

- **Dallas, TX.** Failure investigation of the collapse of Dallas Cowboys indoor practice facility.
- **New York, NY.** Investigation of collapse of suspended scaffold.
- **South Tower, Milwaukee City Hall, Milwaukee, WI.** Investigation, condition assessment, and repair design.
- **Wachusett Dam, Clinton, MA.** Design of replacement topping slab and investigation of distress in Bastion structure.
- **Cosgrove Intake Building, Clinton, MA.** Construction load capacity, building sealants, and floor painting.
- **Turning Stone Tower, Verona, NY.** Investigation of curtain wall support system.
- **Westin, Long Beach, CA.** Condition assessment and repair of parking deck.
- **NIST, New York, NY.** Evaluation of material properties used in non-linear analysis of the World Trade Center Collapse.
- **Nantucket, MA.** Design of house pile foundation for wave and flood loads.
- **Holyoke, MA.** Assessment of water damage on two warehouse buildings.
- **Suffolk County Courthouse, Boston, MA.** Design of roof deck replacement.
- **Boston Public Library, Boston, MA.** Design of underground areaway, roof safety line, and miscellaneous structural details for roof repairs.
- **Govalle Tunnel, Austin, TX.** Design of miscellaneous steel structures to assist in tunnel inspection.
- **Boston Public Library, Boston, MA.** Design of safety platform.
- **Meadow Elementary School, Needham, MA.** Investigation of drywall cracking.
- **Denver, CO.** Evaluation and remedial design of curtain wall.
- **One Prudential Plaza, Chicago, IL.** Design of alternative cladding repairs and consulting on recladding.

- **Baltimore, MD.** Masonry wall FEM analysis.
- **Mayo Clinic, Rochester, MN.** Investigation of cracking of reinforced limestone panels.
- **Marriott Hotel, Atlanta, GA.** Wind pressure on cladding.
- **Yale University Law School, Stiles and Morse Colleges, Sterling Memorial Library, New Haven, CT.** Consulting on structural issues during building envelope and roof repairs, including roof replacement, investigation and repairs of masonry cracking, and retaining wall repairs.
- **Yale University Law School, New Haven, CT.** Masonry consolidation and cleaning.
- **Portland High School, Portland, ME.** Peer review.
- **One Constitution Plaza and 100 Constitution Plaza, Hartford, CT.** Evaluation and remedial design of glass curtain wall support structure.
- **Somerset Chambers, Somerville, MA.** Building envelope assessment.
- **Metro-Dade Center, Miami, FL.** Analysis of limestone cladding anchorage.
- **Highland Superstore, Dallas, TX.** Analysis of water flow and roof ponding.
- **Northwest Arkansas Mall, Fayette, AR, and College Square Mall, Cedar Falls, IA.** Structural repairs.
- **Schodack, NY.** Analysis of corrosion of roof deck.
- **One Meridian Plaza, Philadelphia, PA.** Stress analysis of window glass panes.
- **Massachusetts State House, Boston, MA.** Experimental analysis of epoxy-marble bond strength.

Other projects

- **Provincetown, MA.** Failure investigation of concrete floating dock.
- **Onion Creek Tunnel, Austin, TX.** Design of 42 ft-high steel bulkhead and steel platforms.
- **PVNGS, Tonopah, AZ.** Design of support structure for safety tripods over shafts.
- **Yale University, New Haven, CT.** Design of repairs for a historic flagpole.
- **East Office Tower at World Trade Center, Boston, MA.** Wind tunnel test in the SGH wind tunnel to determine wind pressure contours and zones.
- **Holyoke Center, Cambridge, MA.** Investigation of balanced doors problems.
- **Liberty Place II, Philadelphia, PA.** Wind tunnel test of air flow around the roof.
- **Hawthorne Place, Boston, MA.** Wind tunnel tests of pedestrian level wind effects.
- Evaluation of wind effects on roof pavers (research for Hanover).
- **Arlington, MA.** Design of repairs of historic flagpole.
- **Chalmette, LA.** Investigation of emergency discharge of contaminated water from oil refinery.
- **Boston Public Library, Boston, MA, and Palo Verde, AZ.** Design of horizontal cable structure safety line.
- Creep of FRP laminates exposed to oxygenated fuels (research for Fluid Containment, Inc.).
- Creep buckling analysis FRP fuel tanks (research for Owens-Corning Fiberglas Corp.).
- **One Prudential Plaza, Chicago, IL.** Freeze-thaw tests and durability assessment of granite for cladding.
- **Lead, SD.** Failure analysis of reinforced earth and precast concrete arch overpass.
- **Entropy Limited, Lincoln, MA.** Evaluation of program for statistical detection of tank leakage.
- **Deep Water, NJ.** Analysis of wind effects on membrane tank cover.
- **Boston, MA.** Analysis of premature failure of prestressed concrete railroad ties.
- **Boston, MA.** Statistical analysis of MBTA lines railroad tie deterioration.
- **Riverside Rest Home, Dover, NH.** Investigation of fracture of petroleum pipe.

Research

- Research on NDT inspection and monitoring technologies for PCCP, Water Research Foundation, Denver, CO.

- Development of ASME Code Case N-781 for Internal and External Repair of Class 2 and 3 Piping using Carbon Fiber Reinforced Polymer Composites.
- Development of a PCCP section for EPRI Recommendations for an Effective Program to Control the Degradation of Buried Pipe, Palo Alto, CA.
- Research and development on a new thrust restraint design procedure for concrete pressure pipe for AWWA M9 Manual.
- Research and development of failure risk analysis and repair priorities of PCCP with broken wires.
- Development of AWWA C304-92 Standard for Design of Prestressed Concrete Cylinder Pipe and computer program UDP.
- Prediction of concrete creep and shrinkage from short-term tests.
- Shrinkage cracking and coating delamination by radial tension.
- Visiting Assistant Professor, Duke University from September 1988 to Aug 1990. Research in fracture mechanics and failure analysis.
- Ph.D. Dissertation: "Process Zone Growth and Crack Propagation in Softening Materials," 1988.
- M.S. Thesis: "The Notched Cylinder for Fracture Toughness Testing of Concrete," 1986.
- B.S. Thesis: "Analysis and Design of a Prestressed Concrete Pier," 1984.

Honors and awards

- **Nuclear Energy Institute, 2019 Best-of-the-Best Top Innovative Practice Award,** Dominion Energy, Surry Power Station, First-of-a-kind CFRP repairs of safety-related pipeline.
- **Chi Epsilon,** Civil Engineering Honor Society.
- **Sigma Xi,** The Scientific Research Society.

Professional activities

- **AWWA.** Member, Chair of committees C301 and C304 for design of PCCP.
- **ASME.** Code Case N-871 for CFRP Repair of Metallic Pipe.
- **American Society of Civil Engineers.** Member.
- **Boston Society of Civil Engineers.** Member.
- **New England Water Works Association.** Member.
- Organized the Second Annual Robert J. Melosh Competition for the Best Student Paper on Finite-Element Analysis and assisted in editing of the special issue of the journal *Finite Elements in Analysis and Design*, Vol. 7, No. 2, Nov. 1990.

Teaching experience

- **Duke University, Durham, NC.** Visiting Assistant Professor. Taught courses in computer programming and numerical analysis, dynamics, and steel design; research in fracture mechanics and failure analysis, (1988 to 1990).
- **Duke University, Durham, NC.** Research and Teaching Assistant. Theoretical and experimental investigation of cracking in concrete; assisted in a number of graduate and undergraduate level courses, (1984 to 1988).
- **Belgrade University, Yugoslavia.** Research Assistant. Testing of 20 m prestressed-concrete girders with exterior cables, (1984).

Publications and presentations

- **Acosta, P., P.D. Nardini, R.P. Ojdrovic, and A. Pridmore,** "Not Failing on My Watch: Tucson Water's Proactive Approach to Pipeline Reliability," *Pipelines 2019: Condition Assessment, Construction, and Rehabilitation*, ASCE, July 2019, 257-264.
- **Williams, A.F., K.A. Peterson, P.D. Nardini, and R.P. Ojdrovic,** "Condition Assessment and Repair Prioritization of a Large Diameter Pipeline System," *Pipelines 2019: Condition Assessment, Construction, and Rehabilitation,* ASCE, July 2019, 95-104.
- **Gipsov, M.P., M. Engindeniz, and R.P. Ojdrovic,** "Performance of CFRP-Lined PCCP with Continuing Wire Breakage," *Pipelines 2019: Multidisciplinary Topics,* Utility Engineering, and Surveying, ASCE, July 2019, 555-564.
- **Ojdrovic, R.P.,** "Prestressed Concrete Cylinder Pipe (PCCP) Analysis, Design and Failure Risk Analysis of Distressed Pipe," *EPRI Buried Pipe Integrity Group Summer Meeting,* 31 July 2019, Norfolk, VA.

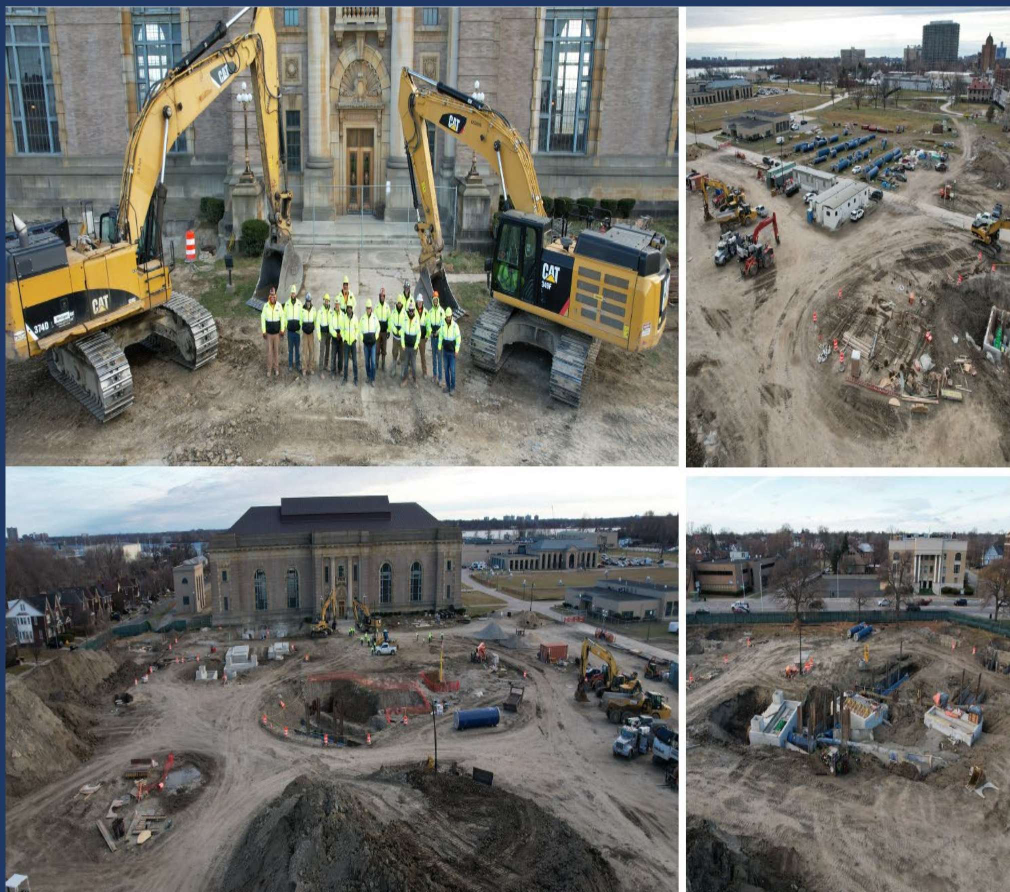
- **Cilluffo, G., and R.P. Ojdrovic,** "Prestressed Concrete Cylinder Pipe (PCCP) Liner Corrosion Model," *EPRI Buried Pipe Integrity Group Summer Meeting,* 31 July 2019, Norfolk, VA.
- **Pridmore, A., and R.P. Ojdrovic,** "Safety Related Application of Carbon Fiber for Steel Pipeline Upgrades," *EPRI 2019 Nuclear Plant Performance Program Combined Users Groups Meeting (HXPUG, P2EP, SWAP),* 30 Jan. 2019, Jacksonville, FL.
- **Livingston, B., R.P. Ojdrovic, and B. Powell,** "Forensic Evaluation of PCCP Failures: Green Bay Water Utilities Case Study," *ASCE Pipelines 2018: Condition Assessment, Construction, and Rehabilitation,* Toronto, ON, Canada, 13 – 18 July 2018,
p. 362-370.
- **Chwiedosiuk, J., D.J. Tanzi, A.B. Pridmore, and R.P. Ojdrovic,** "Middlesex Water Company 30-Inch Pipeline Upgrade under U.S. Route 1," *ASCE Pipelines 2018: Condition Assessment, Construction, and Rehabilitation,* Toronto, ON, Canada, 13 – 18 July 2018, p. 753-760.
- **Pridmore, A.B., M. Larsen, M. Engindeniz, M, R.P. Ojdrovic, and M. Katta,** "Enid Water Treatment Plant Addresses Challenging Repair of 30-Inch Pipeline," *ASCE Pipelines 2018: Condition Assessment, Construction, and Rehabilitation,* Toronto, ON, Canada, 13 – 18 July 2018, p. 761-775.
- **Marohl, M. and R.P. Ojdrovic,** "Determination of Safety Factors for Repair of Buried Nuclear Safety Related Metallic Pipe Using Carbon Fiber Reinforced Polymer," *Proceedings of the ASME 2018 Pressure Vessels and Piping Conference,* PVP2018-84788, July 15-20, 2018, Prague, Czech Republic.
- **Sealey, J., A. Pridmore, and R.P. Ojdrovic,** "Use of CFRP for Safety Related Circulating and Service Water Inlet Pipe Repair," *EPRI BPIG 2018 Summer Meeting,* July 9-11, Charlotte, NC.
- **Pridmore, A. and R.P. Ojdrovic,** "Exelon Braidwood In-Service Mitigation of Buried Condensate Pipelines," *EPRI BPIG 2018 Winter Meeting,* February 12-16, Lake Buena Vista, FL.
- **Darr, S., R.P. Ojdrovic, and A. Pridmore,** "Davis-Besse Nuclear Power Station Ice Shield Project*," EPRI BPIG 2018 Winter Meeting,* Feb. 12-16, Lake Buena Vista, FL.
- **Gipsov, M., S.F. Arnold, and R.P. Ojdrovic,** "Shooting at a Moving Target: Forensic Analysis of CFRP Strengthened PCCP Confirms the Evolution of Joint Detailing and Design," *Pipelines 2017: Condition Assessment, Surveying, and Geomatics,* ASCE, Phoenix, AZ, 6 – 9 Aug. 2017, 363-372.
- **Nielsen, G., A. Shane, P.D. Nardini, and R.P. Ojdrovic,** "Developing and Implementing a PCCP Condition Assessment Program," *Pipelines 2017: Condition Assessment, Surveying, and Geomatics,* ASCE, Phoenix, AZ, 6 – 9 Aug. 2017, 486-495.
- **Patel, M., R.P. Ojdrovic, and J. Marciszewski,** "Analysis and Verification of PCCP Stiffness Testing Using Non-Invasive Acoustics," *Pipelines 2017: Condition Assessment, Surveying, and Geomatics,* ASCE, Phoenix, AZ, 6 – 9 Aug. 2017, 527-538.
- **Nardini, P.D., R.P. Ojdrovic, and P. Pasko,** "Criticality Ranking and Condition Assessment of PCCP," *Pipelines 2017: Condition Assessment, Surveying, and Geomatics,* ASCE, Phoenix, AZ, 6 – 9 Aug. 2017, 539-550.
- **Engindeniz, M., R.P. Ojdrovic, and M. Gipsov,** "WSSC Breaks Its Record in CFRP Lining of PCCP in One Outage," *Pipelines 2017: Condition Assessment, Surveying, and Geomatics,* ASCE, Phoenix, AZ, 6 – 9 Aug. 2017, 522-531.
- **Ojdrovic R., and A. Pridmore,** "Internal Repair of Buried Pipe with CFRP Composites," *Proceedings of the ASME 2017 Pressure Vessels and Piping Conference PVP2017,* July 16-20, 2017, Waikoloa, Hawaii, PVP2017-66076.
- **Sealey, J., L. Gordon, R.P. Ojdrovic, and A. Pridmore,** "Application of CFRP for Steel Pipeline Upgrades at Surry Power Station," *Proceedings of the ASME 2017 Pressure Vessels and Piping Conference PVP2017,* July 16-20, 2017, Waikoloa, Hawaii, PVP2017-66129.
- **Patel, M., R.P. Ojdrovic, and J. Marciszewski,** "Analysis and Verification of PCCP Stiffness Testing Using Non-Invasive Acoustics," North American Society for Trenchless Technology (NASTT), *2017 No-Dig Show,* Washington, DC., Apr. 9-12, 2017.
- **Gipsov, M., R.P. Ojdrovic, and A. Pridmore,** "Raising the Bar: Rapid Implementation of CFRP Repair of Large Diameter Pipelines," North American Society for Trenchless Technology (NASTT), *2017 No-Dig Show,* Washington, DC., Apr. 9-12, 2017.
- **Bian, S., R.P. Ojdrovic, M. Engindeniz, and A. Pridmore,** "DC Water Emergency Repair - 22-Feet Brick Sewer," *Weftec 2016,* New Orleans, LA.
- **Steves, L., R.P. Ojdrovic, and J. Marciszewski,** "Using Condition Assessment to More Efficiently Manage Your Pipelines," *NJ AWWA Annual Conference,* Mar. 23, 2017.
- **Ojdrovic, R.P.,** "Condition Assessment, Failure Risk Analysis, and Rehabilitation of Circulating Water Piping with CFRP in a Single Shutdown at DTE Fermi," *EPRI Buried Pipe Integrity Group and Cathodic Protection User Group Winter 2017 Meeting.*

- **Melchionna, J., R.P. Ojdrovic, and M. Higgins,** “Cooling Water Piping Asset Management Within Hope Creek,” *EPRI Swap and BPIG Meeting,* July 24, Skokie, IL.
- **Nardini, P.D., R.P. Ojdrovic, and A. Pridmore,** “Silicon Valley Mid-Summer Emergency: Santa Clara Addresses the Peak-Demand Repair of a 96-inch Pipeline,” *Pipelines 2016: Out of Sight, Out of Mind, Not out of Risk,* ASCE, Kansas City, MS, 17-20 July 2016.
- **Nardini, P.D., R.P. Ojdrovic, and S.J. DelloRusso,** “Evaluation of Unintended Live Load Effects on Buried Pipelines,” *Pipelines 2016: Out of Sight, Out of Mind, Not out of Risk,* ASCE, Kansas City, MS, 17-20 July 2016.
- **Ojdrovic, R.P., M. Engindeniz, N. Meyer, and S. Arnold,** “Evaluation of the Impact of typical Imperfections in Hand-Applied CFRP Liners in Pressure Pipelines by Hydrostatic Testing,” *Pipelines 2016: Out of Sight, Out of Mind, Not out of Risk,* ASCE, Kansas City, MS, 17-20 July 2016.
- **Bian, S., A. Pridmore, M. Engindeniz, B. Deaton, and R.P. Ojdrovic,** “DC Water 22-Foot Brick Sewer Emergency Repair,” *Pipelines 2016: Out of Sight, Out of Mind, Not out of Risk,* ASCE, Kansas City, MS, 17-20 July 2016.
- **Long, S., T. Markham, M. Larsen, A. Pridmore, R.P. Ojdrovic, and M. Engindeniz,** “Discovery to Solution Implementation: NTMWD Addresses Degraded Piping under a Major Highway,” *Pipelines 2016: Out of Sight, Out of Mind, Not out of Risk,* ASCE, Kansas City, MS, 17-20 July 2016.
- **Pridmore, A., and R.P. Ojdrovic,** “From Reactive to Proactive: A Pipeline Owner’s Change in Philosophy,” *Pipelines 2016: Out of Sight, Out of Mind, Not out of Risk,* ASCE, Kansas City, MS, 17-20 July 2016.
- **Trautner, C., and R.P. Ojdrovic,** “Forensic Analysis of Large Diameter Knife Gate Valve Performance,” *Pipelines 2016: Out of Sight, Out of Mind, Not out of Risk,* ASCE, Kansas City, MS, 17-20 July 2016.
- **Ojdrovic, R.P., and P.D. Nardini,** “Evaluation of Live Load Effects on Buried Pipelines,” *EPRI Buried Pipe Integrity Group (BPIG) Meeting,* Tampa, FL, 16-17 Feb. 2016.
- **Sealey, J., L. Gordon, A. Pridmore, and R.P. Ojdrovic,** “Dominion Surry Power Station Fall 2015 Outage: Application of Carbon Fiber for Steel Pipeline Upgrades,” *EPRI Buried Pipe Integrity Group (BPIG) Meeting,* Tampa, FL, 16-17 Feb. 2016.
- **Ojdrovic, R.P., P.D. Nardini, M. Bracken, and J. Marciszewski,** “Analysis and Verification of Acoustic Wave Based PCCP Stiffness Testing Results,” *ASCE Pipelines 2015 Conference,* Baltimore, MD, 23-26 Aug. 2015, 1150-1159.
- **Ojdrovic, R.P., M. Gipsov, and A. Pridmore,** “Composite versus Stand-Alone Design Methodologies for Carbon Fiber Lining Systems,” *Pipelines 2015: Recent Advances in Underground Pipeline Engineering and Construction,* ASCE, Baltimore, MD, 23-26 Aug. 2015.
- **Ojdrovic, R.P., P.D. Nardini, M. Bracken, and J. Marciszewski,** “Evaluation of Acoustic Wave Based PCCP Stiffness Testing Results,” *Pipelines 2015: Recent Advances in Underground Pipeline Engineering and Construction,* ASCE, Baltimore, MD, 23-26 Aug. 2015.
- **Wise, J., S.J. Newton, R.P. Ojdrovic, and D. Caughlin,** “Rehabilitating a Buckled Penstock Using CFRP,” *Hydro Review*, Vol. 34, Issue 2, 2015.
- **Engindeniz, M., R.P. Ojdrovic, S. Arnold, and T. Jimenez,** “Cure Behavior of Epoxies used for CFRP Repair of Pipelines,” *2014 ASCE Pipelines Conference,* Portland, OR, pp. 908-919.
- **Bass, B.J., R.P. Ojdrovic, and B.M. Haemmerle,** “Repair of a Punctured 48 in. Diameter Prestressed Concrete Cylinder Pipe on a Sixty Degree Slope,” *ASCE Pipelines 2012 Conference,* Miami, FL, 19-22 Aug. 2012, 816-826.
- **Engindeniz, M., P.D. Nardini, R.P. Ojdrovic, and M.S. Zarghamee,** “CFRP Repair and Strengthening of PCCP for Thrust Restraint,” *ASCE Pipelines 2012 Conference,* Miami, FL, 19-22 Aug. 2012, 1368-1376.
- **Trautner, C.A., and R.P. Ojdrovic,** “Comparison of the Directional and Envelope Wind Load Provisions of ASCE 7," *ASCE Journal of Structural Engineering,* Vol. 140, Issue 4, Apr. 2014.
- **Engindeniz, M., R.P. Ojdrovic, and M.S. Zarghamee,** “Quality Assurance Procedures for Repair of Concrete Pressure Pipes with CFRP Composites,” *ASCE Pipelines 2011 Conference,* Seattle, WA, 23-27 July 2011.
- **Ojdrovic, R.P., M.S. Zarghamee, and P.D. Nardini,** “Verification of PCCP Failure Margin and Risk Curves,” *ASCE Pipelines 2011 Conference,* Seattle, WA, 23-27 July 2011.
- **Zarghamee, M.S., R.P. Ojdrovic, and P.D. Nardini,** “Prestressed Concrete Cylinder Pipe Condition Assessment – What Works, What Doesn’t, What’s Next,” *ASCE Pipelines 2011 Conference,* Seattle, WA, 23-27 July 2011.
- **Ojdrovic, R.P.,** “Design and Quality Assurance of CFRP Repair of Concrete Pressure Pipes,” *ICRI 2011 Fall Convention,* Cincinnati, OH, 12-14 Oct. 2011.
- **Ojdrovic, R.P.,** “Excavating, Shoring and Re-burial,” *BP 101: Training for the Buried Pipe Program Owner,* EPRI, Charlotte, NC, 23-25 Aug. 2011.
- **Ojdrovic, R.P.,** “Condition Assessment and Repair of Concrete Pipe,” *BP 101: Training for the Buried Pipe Program Owner,* EPRI, Charlotte, NC, 23-25 Aug. 2011.

- **Ojdrovic, R.P., F.W. Kan, O.O. Erbay, and M.S. Zarghamee,** "Seismic Analysis and Evaluation of Buried Pipes in Power Plants," *Buried Pipe Integrity Group Open Door Meeting,* St. Louis, MO, 11- 12 July 2011.
- **Ojdrovic, R.P., M. Engindeniz, and M.S. Zarghamee,** "Quality Assurance Procedures for Repair of Buried Pipes with CFRP Composites," *Buried Pipe Integrity Group Open Door Meeting,* St. Louis, MO, 11- 12 July 2011.
- **Engindeniz, M., O.O. Erbay, R.P. Ojdrovic, and M. Zarghamee,** "Repair of Concrete Pressure Pipes with CFRP Composites," *ASCE Structural Congress,* 2010.
- **Zarghamee, M.S., R.P. Ojdrovic, and P.D. Nardini,** "Progress Report – Prestressed Concrete Cylinder Pipe Condition Assessment – What Works, What Doesn't, What's Next," *ASCE Pipeline Conference,* 2010.
- **Ojdrovic, R.P., I. Mead, and P. Gadoury,** "Condition Assessment and Repair of a 40-Year-Old Aqueduct," *ASCE Pipeline Conference,* San Diego, CA, Aug. 2009.
- **Ojdrovic, R.P.,** "Prestressed-Concrete Cylinder Pipe (PCCP) Condition Assessment and Repair," *EPRI Buried Pipe Integrity Group Meeting,* Golden, CO, July 2009.
- **Ojdrovic, R.P., and G. LaBonté,** "Inspection, Failure Risk Analysis, and Repair of Cooling-Water Lines in One Outage," *ASCE Pipeline Conference,* Atlanta, GA, 22-27 July 2008.
- **Ojdrovic, R.P.,** "Review of Prestressed-Concrete Cylinder Pipe, Asbestos Cement Pipe, and MAOP Prediction Models in Steel, Ductile Iron, and Cast Iron Pipes," *ASCE Pipeline Conference Workshop,* Pipeline Risk Management: A Compendium for Pipeline Systems Managers, Mayors, City Managers, Utility Managers and Design Engineers, Atlanta, GA, 22-27 July 2008.
- **Ojdrovic, R.P., and M.S. Zarghamee,** "Restoring the Pipeline – CFRP Repair of Large-Diameter Pressure Pipes," C*onstruction Specifier*, Dec. 2007, pp. 86-92.
- **Ojdrovic, R.P., C. Moody, M.T. Schroeder, M.S. Zarghamee, and M. Scali,** "Condition Assessment of Asbestos Cement Pipeline," *ASCE Pipeline Conference,* Boston, MA, 8-11 July 2007.
- **Erbay O.O., M.S. Zarghamee, and R.P. Ojdrovic,** "Failure Risk Analysis of Lined Cylinder Pipes with Broken Wires and Corroded Cylinder," *ASCE Pipeline Conference,* Boston, MA, 8-11 July 2007.
- **Zarghamee, M.S., and R.P. Ojdrovic,** "Some Lessons Learned from Failure of Pipeline," *ASCE Pipelines Conference,* 30 July to 2 Aug. 2006.
- **Ojdrovic, R.P., and M.S. Zarghamee,** "Prestressed-Concrete Tank Roof Failure Investigation," *ACI Spring Convention,* Charlotte, NC, Mar. 2006.
- **Zarghamee, M.S., D.W. Eggers, R.P. Ojdrovic, and D. Valentine,** "Closure to Thrust Restraint Design of Concrete Pressure Pipe," *Journal of Structural Engineering,* ASCE, Sept. 2005, Vol. 131, No. 9, pp. 1473-1482.
- **Ojdrovic, R.P.,** "Pipeline Asset Management Workshops," Boston, MA; Atlanta, GA; Baltimore, MD; Chicago, IL; St. Louis, MO; Kansas City, KS; Dallas, TX; San Antonio, TX; Salt Lake City, UT; New Orleans, LA; and other locations 2005, Middlesex County, NJ, 2004.
- **Zarghamee, M.S., D.W. Eggers, R.P. Ojdrovic, D. Valentine,** "Thrust Restraint Design of Concrete Pressure Pipe," *Journal of Structural Engineering,* ASCE, Jan. 2004, Vol. 130, No. 1, pp. 95-107.
- **Scali, M., P. Scheiner, W. Aquino, R.P. Ojdrovic, and M.S. Zarghamee,** "Analysis and Performance of PCCP Mortar Coating," *Proceedings of ASCE Specialty Conference Pipelines 2003, ASCE Specialty Conference,* Baltimore, MD, pp. 972-982.
- **Ojdrovic, R.P., B. Rose, and M.S. Zarghamee,** "Analysis of Blast Effects on PCCP Pipelines," *Proceedings of ASCE Specialty Conference Pipelines 2003, ASCE Specialty Conference,* Baltimore, MD, pp. 1201-1209.
- **Ojdrovic, R.P., M.S. Zarghamee, M.T. Schroeder, and B. Brooks,** "Condition Assessment and Performance of 50-Year-Old LCP," *Proceedings of ASCE Specialty Conference Pipelines 2003, ASCE Specialty Conference,* Baltimore, MD, pp. 82-92.
- **Zarghamee, M.S., D.W. Eggers, R.P. Ojdrovic, and B. Rose,** "Risk Analysis of Prestressed-Concrete Cylinder Pipe with Broken Wires," *Proceedings of ASCE Specialty Conference Pipelines 2003, ASCE Specialty Conference,* Baltimore, MD, pp. 599-609.
- **Zarghamee, M.S., D.W. Eggers, and R.P. Ojdrovic,** "Finite-Element Modeling of Failure of PCCP with Broken Wires Subjected to Combined Loads," *Proceedings of ASCE Specialty Conference Pipelines 2002, ASCE Specialty Conference,* Cleveland, OH, 4-7 Aug. 2002.
- **Hegarty, J.R., R.P. Ojdrovic, M.S. Zarghamee, and T. Westman,** "Replacement of Forcemain without Service Interruption," *Proceedings of ASCE Specialty Conference Pipelines 2002,* Cleveland, OH, 4-7 Aug. 2002.
- **Zarghamee, M.S., D.W. Eggers, and R.P. Ojdrovic,** "Finite-Element Modeling of Failure of PCCP with Broken Wires Subjected to Combined Loads," *Proceedings of ASCE Specialty Conference Pipelines 2002,* Cleveland, OH, 4-7 Aug. 2002.

- **Shama, A.A., R.P. Ojdrovic, B.W. Schafer, and M.S. Zarghamee,** "Role of Stress Triaxiality on the Seismic Damage of Steel-Moment Frames," *Seventh U.S. National Conference on Earthquake Engineering,* EERI, Boston, MA, 21-25 July 2002.
- **Ojdrovic, R.P., M.S. Zarghamee, J.R. Hegarty, and T. Westman,** "Condition Assessment of PCCP Line that is Accessible from Outside Only," *Proceedings of 2001 Pipelines, ASCE Specialty Conference,* San Diego, CA, 15-18 July 2001.
- **Zarghamee, M.S., and R.P. Ojdrovic,** "Risk Assessment and Repair Priority of PCCP with Broken Wires," *Proceedings of 2001 Pipelines, ASCE Specialty Conference,* San Diego, CA, 15-18 July 2001.
- **Parks, R.R., J. Drager, and R.P. Ojdrovic,** "Condition Assessment and Rehabilitation of the Windy Gap Pipeline – An Owner's Perspective," *Proceedings of 2001 Pipelines, ASCE Specialty Conference,* San Diego, CA, 15-18 July 2001.
- **Schafer, B.W., R.P. Ojdrovic, and M.S. Zarghamee,** "Triaxiality and Fracture of Steel-Moment Connections," *Journal of Structural Engineering,* ASCE, Oct. 2000, pp. 1131-1139.
- **Ojdrovic, R.P., B.W. Schafer, and M.S. Zarghamee,** "Fracture and the Role of Triaxiality for Steel Structures," *Proceedings of 2000 Structures Congress,* Philadelphia, PA, 6-9 May 2000.
- **Zarghamee, M.S., R.P. Ojdrovic, and R. Fongemie,** "Condition Assessment and Repair of Prestressed Concrete Pipeline," *Pipelines in the Constructed Environment,* ASCE, Aug. 1998, pp.702-711.
- **Ojdrovic, R.P.,** "Pipe Repair with External Post-tensioning," invited presentation for the International Concrete Repair Institute, Boston, MA, 1997.
- **Ojdrovic, R.P., and M.S. Zarghamee,** "Fracture of Steel-Moment Connections in Northridge Earthquake," *Structures and Buildings Journal,* Institution of Civil Engineers, May 1997, pp. 209-217.
- **Ojdrovic, R.P., and M.S. Zarghamee,** "A Repair Approach for Fractured Steel-Moment Connections," *Proceedings of 1997 ASCE Structures Congress XV,* Building to Last, Portland, OR, pp. 596-701.
- **Zarghamee, M.S., R.P. Ojdrovic, P.A. Sharff, and D. Valentine,** "Structural Evaluation of Hultman Aqueduct," *Proceedings of ASCE Infrastructure Condition Assessment Conference,* 1997.
- **Zarghamee, M.S., and R.P. Ojdrovic,** "Large Deformation of Curtain Walls in Earthquakes," *The Construction Specifier,* Sept. 1996, pp. 74-78.
- **Ojdrovic, R.P., M.S. Zarghamee,** "Concrete Creep and Shrinkage Prediction from Short-Term Tests," *ACI Materials Journal,* 93, Mar./Apr. 1996, pp. 1-10.
- **Zarghamee, M.S., J. Antebi, and R.P. Ojdrovic,** "Optimization of Large Scientific Structures," *Proceedings of Structures Congress XIII,* ASCE, Boston, MA, 1995, pp. 130-140.
- **Zarghamee, M.S., and R.P. Ojdrovic,** "Lessons from Northridge Earthquake: Steel Connections," *Civil Engineering,* Apr. 1995, pp. 68-71.
- **Ojdrovic, R.P., and M.S. Zarghamee,** "Dynamic Sagitta Error of Muon Subsystem Structure," GEM-TN-520, 9 Feb. 1994.
- **Zarghamee, M.S., J. Antebi, R.P. Ojdrovic, D.O. Dusenberry, and F.W. Kan,** "Monolithic Integrated Concerns for Muon Subsystem Structure," GEM-TN-519, 9 Feb. 1994.
- **Zarghamee, M.S., R.P. Ojdrovic, and W. Dana,** "Preventing Coating Delamination in Prestressed Concrete Pipe," *Pipeline Infrastructure II: Proceedings of the International Conference,* San Antonio, TX, 16-17 Aug. 1993, pp. 574-594.
- **Zarghamee, M.S., R.P. Ojdrovic, and W. Dana,** "Coating Delamination by Radial Tension in Prestressed-Concrete Pipe: Part I – Experiments," *Journal of Structural Engineering 119*, 1993, pp. 2701-2719.
- **Zarghamee, M.S., R.P. Ojdrovic, and W. Dana,** "Coating Delamination by Radial Tension in Prestressed Concrete Pipe. Part II – Analysis," *Journal of Structural Engineering 119,* 1993, pp. 2720-2732.
- **Ojdrovic, R.P., and H. Petroski,** "Weight Functions from Multiple Reference States and Crack Profile Derivatives," *Engineering Fracture Mechanics 39,* 1991, pp. 105-111.
- **Ojdrovic, R.P., and H. Petroski,** "Process Zone Analysis for the Single-Edge Notched Specimen: Part I – Process Zone Size and Crack Profile," *International Journal of Fracture 49,* 1991, pp. 1-16.
- **Ojdrovic, R.P.,and H. Petroski,** "Process Zone Analysis for the Single-Edge Notched Specimen: Part II – Process Zone Growth and Crack Propagation," *International Journal of Fracture 49,* 1991, pp. 17-28.
- **Ojdrovic, R.P., and H. Petroski,** "Reference Response Curves: A Novel Representation of Load Displacement Data to Failure," *Twenty-Second National Symposium on Fracture Mechanics,* Atlanta, GA, 1990.
- **Ojdrovic, R.P.,** "Theoretical and Experimental Load vs. CMOD Curves Through Softening to Failure," *Journal of Engineering Mechanics 116,* 1990, pp. 1317-1331.
- **Ojdrovic, R.P.,** "A New Concept of Similarity at Failure," *Proceedings of AIAA 31st SDM Conference,* Long Beach, CA, 1990, pp. 961-965.

- **Ojdrovic, R.P., and H. Petroski,** “Fracture Behavior of the Notched Concrete Cylinder,” *Journal of Engineering Mechanics 113,* 1987, pp. 1551-1564.
- **Petroski H.J., R.P. Ojdrovic,** "The Concrete Cylinder: Stress Analysis and Failure Modes," *International Journal of Fracture 34,* 1987, pp. 263-279.
- **Moseley, M.D., R.P. Ojdrovic, and H. Petroski,** “Influence of Aggregate Size on Fracture Toughness of Concrete,” *Theoretical and Applied Fracture Mechanics 7,* 1987, pp. 207-210.
- **Ojdrovic, R.P., A.L. Stojimirovic, and H. Petroski,** “Effect of Age on Splitting Tensile Strength and Fracture Resistance of Concrete,” *Cement and Concrete Research 17,* 1987, pp. 70-76.
- **Ojdrovic, R.P., and H. Petroski,** “Effect of Notch Length on Specimen Behavior and Fracture Toughness of Concrete,” *ASCE Structures Congress,* New Orleans, LA, 1986.
- **Ojdrovic, R.P., H.J. Petroski,** “The Cracked Brazilian Specimen for Fracture Toughness Testing of Concrete,” *International Journal of Fracture 27,* 1985, pp. R75-R 0.
- **Ojdrovic, R.P., and H. Petroski,** “The Cracked Brazilian Specimen for Fracture Toughness Testing of Concrete,” *Society of Engineering Science, Twenty-Second Annual Meeting,* Pennsylvania State University, 1985.



Date of Submittal:

January 16, 2023

City of Novi
Novi Road / 13 Mile Road PCCP Water Main Renewal – RFP
Appendix D - Project Schedule

Submitted To:

City of Novi, Attn: Finance Department
45175 Ten Mile Road, Novi, MI 48375

Submitted By:

LGC Global Inc.
7310 Woodward Ave
Ste 500
Detroit, MI 48202

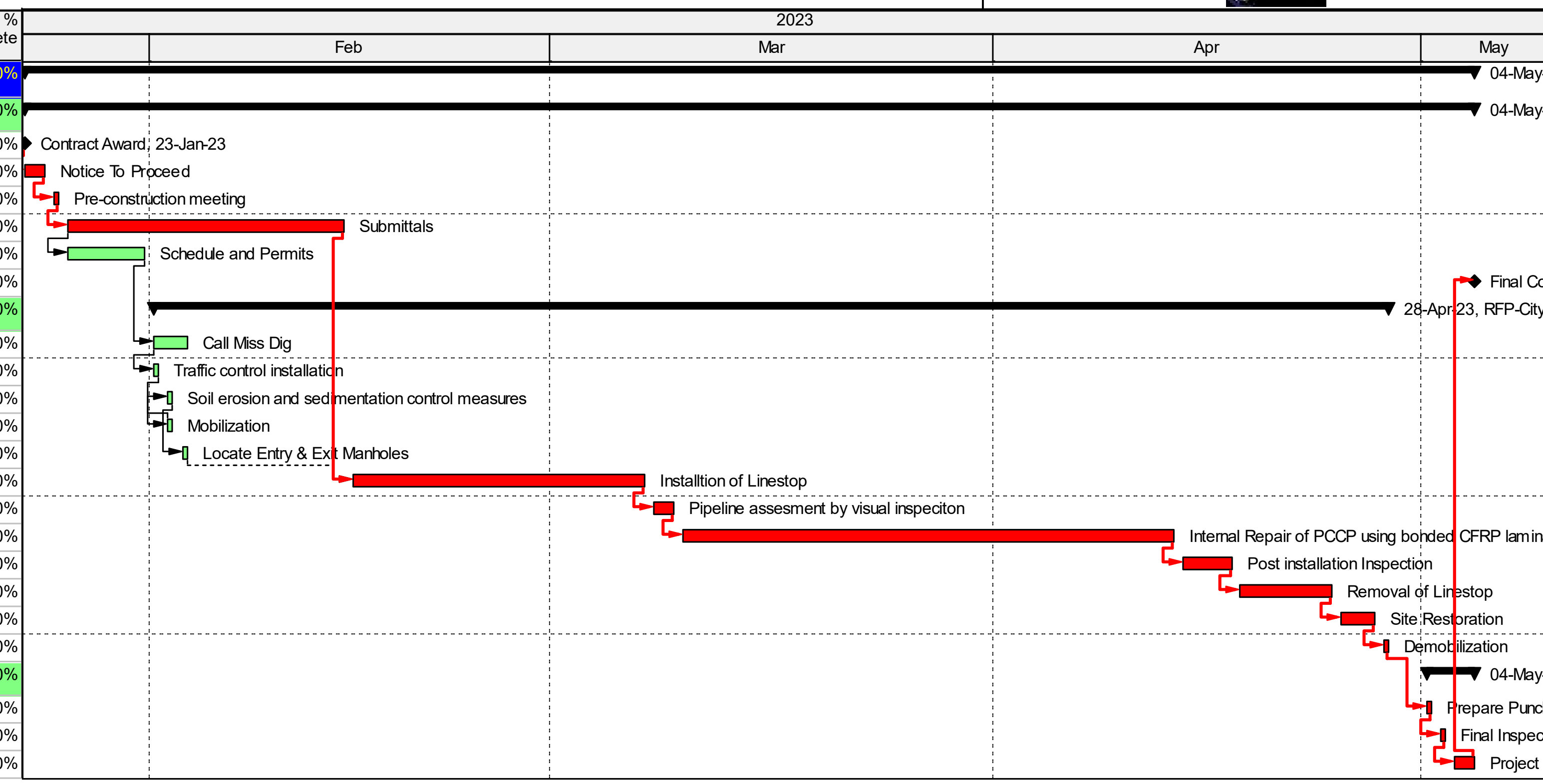
NMSDC
MBE Certified

Appendix D

DATA DATE: 23-Jan-23

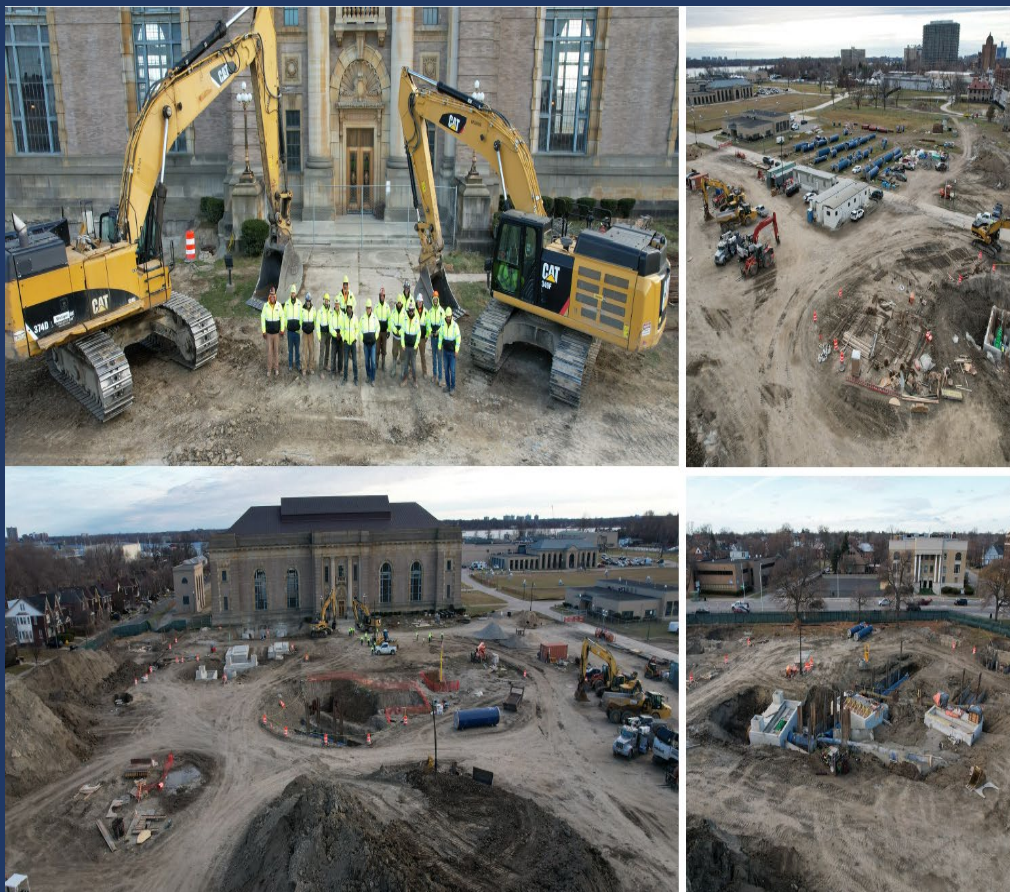
City of Novi- RFP 13 Mile Rd/Novi Rd - PCCP Watermain Renewal

#	Activity ID	Activity Name	Original Duration	Start	Finish	Total Float	Activity % Complete	Duration % Complete
1	RFP-City of Novi 13 Mile Rd / Novi Rd PCCP Watermain Renewal		74	23-Jan-23	04-May-23	0		0%
2	RFP-City of Novi.1 Pre-Construction		74	23-Jan-23	04-May-23	0		0%
3	A1000	Contract Award	0	23-Jan-23		0	0%	0%
4	A1010	Notice To Proceed	2	23-Jan-23	24-Jan-23	0	0%	0%
5	A1030	Pre-construction meeting	1	25-Jan-23	25-Jan-23	0	0%	0%
6	A1040	Submittals	14	26-Jan-23	14-Feb-23	0	0%	0%
7	A1050	Schedule and Permits	4	26-Jan-23	31-Jan-23	7	0%	0%
8	A1020	Final Completion Date	0		04-May-23	0	0%	0%
9	RFP-City of Novi.2 Construction		63	01-Feb-23	28-Apr-23	0		0%
10	A1060	Call Miss Dig	3	01-Feb-23	03-Feb-23	7	0%	0%
11	A1070	Traffic control installation	1	01-Feb-23	01-Feb-23	7	0%	0%
12	A1080	Soil erosion and sedimentation control measures	1	02-Feb-23	02-Feb-23	7	0%	0%
13	A1090	Mobilization	1	02-Feb-23	02-Feb-23	7	0%	0%
14	A1100	Locate Entry & Exit Manholes	1	03-Feb-23	03-Feb-23	7	0%	0%
15	A1110	Installtion of Linestop	15	15-Feb-23	07-Mar-23	0	0%	0%
16	A1120	Pipeline assesment by visual inspeciton	2	08-Mar-23	09-Mar-23	0	0%	0%
17	A1130	Internal Repair of PCCP using bonded CFRP laminates	25	10-Mar-23	13-Apr-23	0	0%	0%
18	A1140	Post installation Inspection	2	14-Apr-23	17-Apr-23	0	0%	0%
19	A1150	Removal of Linestop	5	18-Apr-23	24-Apr-23	0	0%	0%
20	A1160	Site Restoration	3	25-Apr-23	27-Apr-23	0	0%	0%
21	A1170	Demobilization	1	28-Apr-23	28-Apr-23	0	0%	0%
22	RFP-City of Novi.3 Post-Construction		4	01-May-23	04-May-23	0		0%
23	A1180	Prepare Punch-list	1	01-May-23	01-May-23	0	0%	0%
24	A1190	Final Inspection	1	02-May-23	02-May-23	0	0%	0%
25	A1200	Project closeout documentation	2	03-May-23	04-May-23	0	0%	0%



Actual Level of Effort | Remaining Work | Milestone
Actual Work | Critical Remaining Work | summary

Bid Schedule			
Date	Revision	Checked	Approved
06-Jan-23	Rev 00		



Date of Submittal:

January 16, 2023

City of Novi
Novi Road / 13 Mile Road PCCP Water Main Renewal – RFP
CFRP Product Data and Test Results

Submitted To:

City of Novi, Attn: Finance Department
45175 Ten Mile Road, Novi, MI 48375

Submitted By:

LGC Global Inc.
7310 Woodward Ave
Ste 500
Detroit, MI 48202

NMSDC
MBE Certified

Product Data

TREATED FUMED SILICA

creating what matters

CAB-O-SIL® TS-720

CAB-O-SIL® TS-720 treated fumed silica is a high-purity silica which has been treated with a dimethyl silicone fluid. The treatment replaces many of the surface hydroxyl groups on the fumed silica with a polydimethyl-siloxane polymer. This treatment makes the silica extremely hydrophobic.

Product Form

Powder

Typical Properties

B.E.T. Surface Area	115 m^2/g
Carbon	5.4
325 Mesh Residue (44 microns) 1.0% max.	0.5% max
Tamped Density	60 g/l
Loss on Heating*	< 0.6% max.
Specific Gravity Wt. per gallon	2.2 g/cm^3 18.3 lb
Refractive Index	1.46
X-ray Form	Amorphous
Average Particle (Aggregate) Length	0.2–0.3 microns

*At time of packaging.

Typical Applications

The unique properties of TS-720 treated fumed silica offer special benefits in many applications:

- The low moisture content of TS-720 (typically 0.2 wt. %) makes it usable without expensive drying when incorporated in moisture-sensitive systems.
- TS-720 is an excellent thixotrope for coatings, providing sag resistance, anti-settling, rheology control, and superior water resistance.
- TS-720 is a very efficient thixotrope for epoxy resins. It offers a stable sag resistance, even in high-temperature cure systems, without loss of other proeprties such as cure rate, extrusion rate, or lap shear tensile strength.
- TS-720 is an excellent thickener for greases and imparts the following attractive properties: water resistance, extremely high dropping point, and no significant loss of lubricating properties on long-term exposure to heat.
- TS-720 can dramatically improve and retain the desired free flow properties of powders stored or exposed for long periods of time.
- In high-consistency (heat-cured) silicone rubber formulations, TS-720 reduces “crepe” hardening, imparts excellent fresh and aged processing properties, and eliminates the need to use expensive processing aids, saving material costs and improving compounding flexibility.

→

Cabot Corporation
www.cabot-corp.com

CAB-O-SIL® TS-720

TREATED FUMED SILICA

creating what matters

Packaging Options

CAB-O-SIL® TS-720 treated fumed silica is packaged in North America in 10-lb multi-wall Kraft bags and is available in 21 x 10-lb poly-shrouded units. In Europe, TS-720 is packaged in 10-kg multi-wall Kraft bags and is available in 18 x 10-kg poly-shrouded units. Specific information regarding standard and custom packaging may be obtained by contacting a sales service representative at the Cabot Corporation office in your region.

MSDS

A Material Safety Data Sheet for this product may be obtained by contacting the Cabot Corporation office in your region.

NORTH AMERICA
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UNITED ARAB EMIRATES
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Fax: +971 4 8871 801

Strengthening Solutions

V-Wrap™ 770

Epoxy Adhesive

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+1-410-859-6539

Physical Properties[1]:

Tensile Strength (ASTM D638):	8,800psi (60.7 MPa)
Tensile Modulus (ASTM D638):	400,000 psi (2,760 MPa)
Elongation at Break (ASTM D638):	4.4%
Flexural Strength (ASTM D790):	16,000 psi (110.3 MPa)
Flexural Modulus (ASTM D790):	420,000 psi (2,896 MPa)
Compressive Strength (ASTM D695):	12,200 psi (84.1 MPa)
Compressive Modulus (ASTM D695):	440,000 psi (3,304 MPa)
Tg (ASTM E1640):	187°F (86°C)
Density:	
Mixed Product	9.17 lbs/gal (1.11 kg/L)
Part A	9.7 lbs/gal (1.16 kg/L)
Part B	7.9 lbs/gal (0.95 kg/L)
VOC Content (ASTM D2369):	0% VOC

(1) Curing schedule: 72 hours post cure at 140°F (60°C)

DESCRIPTION:
V-Wrap 770 is a two-part, 100% solids, epoxy for high strength composite bonding applications. V-Wrap 770 matrix material is combined with V-Wrap carbon and glass fabrics to provide a wet-layup composite for strengthening of structural members. It is formulated to provide high elongation to optimize properties of the V-Wrap composite systems. It provides a long working time for application, with no offensive odor. V-Wrap 770 may be thickened with fumed silica to produce a tack coat/putty or a finishing coat, depending upon the project requirements.

V-Wrap 770 is an environmentally friendly product with no Volatile Organic Compounds (VOC) or solvents.

PRODUCT USES:
V-Wrap 770 is a multi use epoxy that performs as a primer, tack coat/putty, and saturating resin for the V-Wrap carbon and glass fiber systems. For detailed uses see installation guides for V-Wrap strengthening systems. Fumed silica may be added to thicken the resin. The maximum ratio by volume is 1.5 of fumed silica to 1 part of resin.

ADVANTAGES:

- ICC-ES ESR-3606 listed product
- NSF/ANSI Standard 61 listed product for drinking water systems
- 100% solvent free
- Good high / low temperature properties
- High elongation

APPROXIMATE POT LIFE:
3 to 6 hours at 68°F (20°C)

APPLICATION INFORMATION

SURFACE PREPARATION:
V-Wrap 770 should be applied to substrates that are free of protrusions, dust, oils, and other surface contaminates or bond inhibiting materials. Substrates should be dry and exhibit an open pore structure.

APPLICATION:
Apply primer to repair surfaces with a medium nap roller or non-shedding brush. Ensure full saturation of fabric sheets is achieved before installation. Heavier fabrics typically require mechanical saturation. Apply thickened V-Wrap epoxy using trowels.

BASIC APPLICATION EQUIPMENT:
Application processes for V-Wrap 770 will require mixing drill, mixing paddle, 1/4" nap rollers, steel rollers, paint brushes, trowels and saturator.

MIXING:
Combine the contents of V-Wrap 770-A pail and V-Wrap 770-B pail together making sure to scrape all material from the sides of the pail and mix for 3 minutes using a mixer at a speed of 400-600 RPM until uniformly blended. Transfer the mixed epoxy into the other pail and mix for an additional 2 minutes.
Mix ratio: by volume 10 - A to 4.1 - B: by weight 100 - A to 33 - B.

COVERAGE RATES:
AS A PRIMER:

Concrete:	225 ft²/gal (5.5 m²/L)
Masonry: (Concrete)	125 ft²/gal (3.0 m²/L)
Masonry: (Clay)	200 ft²/gal (4.9 m²/L)

AS PUTTY/TACK COAT:

Filler:	60 ft²/gal (1.5 m²/L)

(Depending on surface roughness)

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AS SATURANT:

V-Wrap C100 / C100H	80 ft²/gal (1.9 m²/L)
V-Wrap C200H / C200HM	60 ft²/gal (1.5 m²/L)
V-Wrap C400H / C400HM	40 ft²/gal (1 m²/L)
V-Wrap EG50 / EG50B	60 ft²/gal (1.5 m²/L)

Coverage rates may vary based on installation procedure and fabric type. Contact STRUCTURAL TECHNOLOGIES for coverage rates.

LIMITATIONS:
Only apply V-Wrap 770 when the ambient temperature is between 40°F and 100°F (4°C to 38°C). Topcoat selection should be based upon requirements for protection from environmental exposures, aesthetics, and fire protection/burn characteristics.

CLEAN UP:
Use methyl ethyl ketone or acetone. Observe fire and health precautions when using solvents. Dispose of in accordance with local regulations.

OBSERVE WORKING TIME LIMITATIONS:
Mix no more material than can be applied within the working time. Available work time, temperature and complexity of the application will determine how much material should be mixed at one time. Keep material cool and in shaded area, away from direct sunlight in warm weather. During hot weather, work time can be extended by keeping the material cool before and after mixing or by immersing the pot in ice water.

HANDLING PROPERTIES:

Color:	
Mixed	Clear
Part A	Clear
Part B	Clear

SHELF LIFE:
Stored at 70°F (21°C): 24 months (Parts A and B)

PACKAGING:

	Volume	Weight	Package
Part A	2.8 gal	27.7 lbs	5 gal pail
Part B	1.15 gal	9.1 lbs	5 gal pail

STORAGE:
Store in a cool, dry area (40°F and 90°F [4°C to 32°C]) away from direct sunlight, flame or other hazards.

SAFETY:
WARNING: Vapor may be harmful. Contains epoxy adhesive and curing agent. May cause skin sensitivity or other allergic responses. Keep away from heat, sparks or open flame. In enclosed areas or where ventilation is poor use an approved air mask and utilize adequate safety precautions to prevent fire or explosion. In case of skin contact, wash with soap and water. For eyes, flush immediately (seconds count) with water for 15 minutes and CALL A PHYSICIAN. If swallowed, CALL A PHYSICIAN IMMEDIATELY.

HANDLING:
Approved personal protection equipment should be worn at all times. Particles mask is recommended when handling airborne particles. Gloves are recommended when handling fabrics and resins to avoid skin irritation. Safety glasses are recommended to prevent eye irritation. Wear chemical resistant clothing /gloves/goggles. Ventilate area. In absence of adequate ventilation, use properly fitted NIOSH respirator. Product Safety Data Sheets (SDS) are available and should be consulted and on hand whenever handling these products.

These products are for professional and industrial use only and are to be installed by trained and qualified applicators. Trained applicators must follow installation instructions.

MAINTENANCE:
Periodically inspect the applied material and repair localized areas as needed.

STRUCTURAL TECHNOLOGIES, LLC warrants its products to be free from manufacturing defects and to meet STRUCTURAL TECHNOLOGIES' current published properties when applied in accordance with STRUCTURAL TECHNOLOGIES' directions and tested in accordance with ASTM and STRUCTURAL TECHNOLOGIES Standards. User determines suitability of product for use and assumes all risks. Buyer's sole remedy shall be limited to the purchase price or replacement of product and excludes labor or the cost of labor. Any claim for breach of this warranty must be brought within one year of the date of purchase.

No other warranties expressed or implied including any warranty of merchantability or fitness for a particular purpose shall apply. STRUCTURAL TECHNOLOGIES shall not be liable for any consequential or special damages of any kind, resulting from any claim or breach of warranty, breach of contract, negligence or any legal theory. STRUCTURAL TECHNOLOGIES assumes no liability for use of this product in a manner to infringe on another's patent.

Strengthening Solutions

V-Wrap™ EG50-B

High Strength Glass Fiber Fabric

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Typical Data for V-Wrap EG50-B

Storage Conditions:	Store dry at 40°F – 90°F (4°C – 32°C)
Color:	White
Primary Fiber Direction:	±45° (bi-directional)
Weight:	24.6 oz/yd^2 (835 g/m^2)
Shelf life:	10 years

Fiber Properties (Dry)

Tensile Strength:	475,000 psi (3,275 MPa)
Tensile Modulus:	11.6 x 10^6 psi (79,970 MPa)
Elongation:	4.1 %
Density:	0.095 lb/in^3 (2.62 g/cm^3)

Cured Laminate Properties (In fiber direction)	Average Values(1)	Design Values(2)
Tensile Strength:	89,800 psi (620 MPa)	74,500 psi (514 MPa)
Modulus of Elasticity:	4.6 x 10^6 psi (31,700 MPa)	4.6 x 10^6 psi (31,700 MPa)
Elongation at Break:	1.94%	1.6%
Laminate Thickness:	0.034 in. (0.864 mm)	0.034 in. (0.864 mm)
Design Thickness:	0.017 in. (0.432 mm)	0.017 in. (0.432 mm)
Strength per Unit Width:	1,527 lbs/in. (0.27 kN/mm)	1,267 lbs/in. (0.22 kN/mm)

(1) Typical average test values per ASTM 3039

(2) Design properties are based on ACI 440 guidelines will vary slightly. Contact STRUCTURAL TECHNOLOGIES to confirm project specific values.

Description:

V-Wrap EG50-B is a bidirectional glass fiber fabric with fiber oriented in the ±45° directions. V-Wrap EG50-B system is field laminated using environmentally friendly, two-part 100% solids and high strength structural adhesives to form a glass fiber reinforced polymer (GFRP) system used to reinforce structural elements.

Product Uses:

V-Wrap strengthening systems can be used to resolve strength deficiencies and increase the load carrying capacity of building, bridges, silos, chimneys, and other structures.

Loading Increases:

- Increasing the live loads capacity of floor systems
- Increasing shear and flexural strengths of reinforced and prestressed beams
- Increasing the axial capacity of columns
- Increasing the live load capacity of parking garages

Seismic Strengthening:

- Column confinement for ductility improvement
- Masonry and concrete shear walls strengthening

Damage to Structural Parts:

- Correct strength deficiency due to deterioration and corrosion
- Restore strength of structural elements damaged by fire

Change in Structural System:

- Load redistribution due to removal of walls, beams or columns
- Removal of slab sections for new openings

Design or Construction Defects:

- Insufficient amount of shear or flexural reinforcement
- Insufficient size and/or layout of reinforcement
- Insufficient reinforcing bar or lap splice length
- Low compressive strength in beams, slabs, and columns

Advantages:

- ICC-ES ESR-3606 listed product
- 0% VOC
- Solvent free
- Non-corrosive reinforcement system
- Lightweight flexible fabric that can be wrapped around complex shapes
- Used for shear, confinement or flexural strengthening
- High strength
- Light weight
- Reduces crack width
- Low aesthetic impact

Packaging:

Fabric: 25 in. width x 300 ft [625 ft^2] rolls
0.635 m width x 91.4 m [58 m^2] rolls

How To Use:

Design:

Design should comply with ACI 440.2R or recognized design/ specification entity, and is typically based on GFRP contribution determined by detailed analysis. Design values will vary based on project requirements and applicable environmental and strength reduction factors. Contact STRUCTURAL TECHNOLOGIES to determine applicable design factors.

Surface Preparation:

Surfaces to receive V-Wrap EG50-B must be clean and sound. It must be dry and free of protrusions and frost. All dust, laitance, grease, curing compounds, waxes, deteriorated materials, and other bond inhibiting materials must be removed from the surface prior to application. Existing uneven surfaces must be filled with appropriate epoxy putty or repair mortar. Use abrasive blasting, pressure wash, shotblast, grind or other approved mechanical means to achieve an open-pore texture with a concrete surface profile of CSP-3 or better (ICRI). In certain applications and at the engineer's discretion, the bond between the substrate and the fabric may be determined to be non-critical (such as in column confinement applications). All corners must be rounded to 1/2" radius minimum. The adhesive strength of the concrete may be verified after surface preparation by random pull-off testing (ASTM D7522) at the discretion of the engineer. Minimum tensile strength of 200 psi must be achieved.

Cutting V-Wrap EG50-B:

Fabric can be cut to appropriate length by using a commercial quality heavy-duty scissors.

Application:

Installation of the V-Wrap EG50-B strengthening system should be performed only by a specially trained, approved contractor. The V-Wrap EG50-B strengthening system shall consist of V-Wrap EG50-B glass fabric and V-Wrap epoxy resins such as: V-Wrap 600, V-Wrap 700S, and V-Wrap 770.

Note the specified number of plies and ply widths. Mix resin components using recommended procedures on product datasheet. Apply one coat of V-Wrap epoxy as a primer to the surface using a nap roller. Fill minor concrete defects such as bug holes and other imperfections using V-Wrap 770 epoxy mixed with fumed silica (thickened epoxy) or V-Wrap PF putty. Apply thickened epoxy or putty using a roller or trowel to prime surface. Adjust the gap between saturator rollers. Using a saturator machine, pre-saturate the appropriate length of V-Wrap EG50-B with V-Wrap epoxy adhesive as a saturant. Install the saturated FRP sheet. Use a rib roller to remove all air pockets and ensure intimate contact with the surface. On multiple plies with splices, stagger the splice locations. If required, apply topcoat material.

Field Quality Control:

Record batch numbers for fabric and epoxy used each day and note locations of installations. Measure square feet of fabric and volume of epoxy used each day.

Limitations:

- Design calculations must be approved a by licensed professional engineer
- System is a vapor barrier
- Concrete deterioration and steel corrosion must be resolved prior to application
- Minimum application temperature is 40°F

Storage:

Store rolls flat, not on ends, in a cool, dark space. Low humidity is recommended. Store at 40°F to 90°F (4°C to 32°C).

Handling:

Approved personal protection equipment should be worn at all times. Particle mask is recommended for possible airborne particles. Gloves are recommended when handling fabrics and resins to avoid skin irritation. Safety glasses are recommended to prevent eye irritation. Wear chemical resistant clothing/gloves/goggles. Ventilate area. In absence of adequate ventilation, use properly fitted NIOSH respirator.

Cleanup:

Dispose of material in accordance with local disposal regulations. Uncured material can be removed with approved solvents. Cured materials can only be removed mechanically.

First Aid:

In case of skin contact, wash thoroughly with soap and water. For eye contact, flush immediately with plenty of water; contact physician immediately. For respiratory problems, remove to fresh air. Wash clothing before reuse.

Strengthening Solutions

V-Wrap™ C400HM

High Modulus Carbon Fiber Fabric

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Typical Data for V-Wrap C400HM

Storage Conditions:	Store dry at 40°F – 90°F (4°C – 32°C)
Color:	Black
Primary Fiber Direction:	0° (unidirectional)
Weight:	38 oz/yd² (1300 g/m²)
Shelf life:	10 years

Fiber Properties (Dry)

Tensile Strength:	790,000 psi (5,440 MPa)
Tensile Modulus:	42 x 10^6 psi (289,550 MPa)
Elongation:	1.9 %

Cured Laminate Properties	Average Values	Design Values*
Tensile Strength:	180,000 psi (1,241 MPa)	155,000 psi (1,068 MPa)
Modulus of Elasticity:	14.24 x 10^6 psi (98,181 MPa)	14.0 x 10^6 psi (96,527 MPa)
Elongation at Break:	1.27%	1.1%
Thickness:	0.08 in. (2.03 mm)	0.08 in. (2.03 mm)
Strength per Unit Width:	14,400 lbs/in. (2.52 kN/mm)	12,400 lbs/in. (2.17 kN/mm)

*Design properties are based on ACI 440.2R using average minus three standard deviations.

Description:

V-Wrap C400HM is a unidirectional carbon fiber fabric with fiber oriented in the 0° direction. V-Wrap C400HM system is field laminated using environmentally friendly, two-part 100% solids and high strength structural adhesives to form a carbon fiber reinforced polymer (CFRP) system used to reinforce structural elements.

Product Uses:

V-Wrap strengthening systems can be used to resolve strength deficiencies and increase the load carrying capacity of building, bridges, silos, chimneys, and other structures.

Loading Increases:

- Increasing the live loads capacity of floor systems
- Increasing shear and flexural strengths of reinforced and prestressed beams
- Increasing the axial capacity of columns
- Increasing the live load capacity of parking garages

Seismic Strengthening:

- Column confinement for ductility improvement
- Masonry and concrete shear walls strengthening

Damage to Structural Parts:

- Correct strength deficiency due to deterioration and corrosion
- Restore strength of structural elements damaged by fire

Change in Structural System:

- Load redistribution due to removal of walls, beams or columns
- Removal of slab sections for new openings

Design or Construction Defects:

- Insufficient amount of shear or flexural reinforcement
- Insufficient size and/or layout of reinforcement
- Insufficient reinforcing bar or lap splice length
- Low compressive strength in beams, slabs, and columns

Advantages:

- ICC-ES ESR-3606 listed product
- 0% VOC
- Solvent free
- Non-corrosive reinforcement system
- Lightweight flexible fabric can be wrapped around complex shapes
- Used for shear, confinement or flexural strengthening
- High strength and high modulus
- Light weight
- Reduces crack width
- Alkali resistant
- Low aesthetic impact

Packaging:

Fabric: 24 in. width x 150 ft rolls
0.61 m width x 45.7 m rolls

V-Wrap™ C400HM

High Modulus Carbon Fiber Fabric

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+1-410-859-6539

How To Use:

Design:

Design should comply with ACI 440.2R or recognized design/ specification entity and is typically based on CFRP contribution determined by detailed analysis. Design values will vary based on project requirements and applicable environmental and strength reduction factors. Contact STRUCTURAL TECHNOLOGIES to determine applicable design factors.

Surface Preparation:

Surfaces to receive V-Wrap C400HM must be clean and sound. It must be dry and free of frost. All dust, laitance, grease, curing compounds, waxes, deteriorated materials, and other bond inhibiting materials must be removed from the surface prior to application. Existing uneven surfaces must be filled with appropriate epoxy putty or repair mortar. Use abrasive blasting, pressure wash, shotblast, grind or other approved mechanical means to achieve an open-pore texture with a concrete surface profile of CSP-3 or better (ICRI). In certain applications and at the engineer's discretion, the bond between the substrate and the fabric may be determined to be non-critical (such as in column confinement applications). All corners must be rounded to 1/2" radius minimum. A minimum overlap [or lap splice] of 12" is required to achieve continuity. The adhesive strength of the concrete may be verified after surface preparation by random pull-off testing (ASTM D7522) at the discretion of the engineer. Minimum tensile strength of 200 psi must be achieved.

Cutting V-Wrap C400HM:

Fabric can be cut to appropriate length by using a commercial quality heavy-duty scissors.

Application:

Installation of the V-Wrap C400HM strengthening system should be performed only by a specially trained, approved contractor. The V-Wrap C400HM strengthening system shall consist of V-Wrap C400HM carbon fabric and V-Wrap epoxy resins such as: V-Wrap 600, V-Wrap 700S, and V-Wrap 770.

Note the specified number of plies, ply widths, and fiber orientation. Mix resin components using recommended procedures on product datasheet. Apply one coat of V-Wrap epoxy as a primer to the surface using a nap roller. Fill minor concrete defects such as bug holes and other imperfections using V-Wrap 770 epoxy mixed with fumed silica (thickened epoxy) or V-Wrap PF putty. Apply thickened epoxy or putty using a roller or trowel to prime surface. Adjust the gap between saturator rollers. Using a saturator machine, pre-saturate the appropriate length of V-Wrap C400HM with V-Wrap epoxy adhesive as a saturant. Install the saturated FRP sheet. Use a rib roller to remove all air pockets and ensure intimate contact with the surface. If a splice is needed, a minimum 12" overlap is required. On multiple plies with splices, stagger the splice locations. If required, apply topcoat material.

Limitations:

- Design calculations must be approved a by licensed professional engineer
- System is a vapor barrier
- Concrete deterioration and steel corrosion must be resolved prior to application
- Minimum application temperature is 40°F

Storage:

Store material in a cool, dark space. Low humidity is recommended.

Handling:

Approved personal protection equipment should be worn at all times. Particle mask is recommended for possible airborne particles. Gloves are recommended when handling fabrics and resins to avoid skin irritation. Safety glasses are recommended to prevent eye irritation. Wear chemical resistant clothing/gloves/goggles. Ventilate area. In absence of adequate ventilation, use properly fitted NIOSH respirator.

Cleanup:

Dispose of material in accordance with local disposal regulations. Uncured material can be removed with approved solvents. Cured materials can only be removed mechanically.

First Aid:

In case of skin contact, wash thoroughly with soap and water. For eye contact, flush immediately with plenty of water; contact physician immediately. For respiratory problems, remove to fresh air. Wash clothing before reuse.

CERTIFIED TEST REPORT

EVALUATION OF COMPRESSIVE PROPERTIES OF V-WRAP C400HM/770 - Per ASTM D6641 -

Report Number: R-5.10_C400HM-2_D6641
Date: February 10, 2017

REPORT PREPARED FOR:

structural TECHNOLOGIES
A Structural Group Company

Attn: Tarek Alkhrdaji
Vice President - Engineering Services
STRUCTURAL TECHNOLOGIES LLC.
10150 Old Columbia Rd., Columbia, Maryland 21046

Quality System: The Structures and Materials Laboratory (SML) maintains a quality system in compliance with ISO 17025-2005, accredited under International Accreditation Service (IAS), testing laboratory, TL-478

Procedures: All tests and services are done in accordance with the SML Quality Manual (Version 2.4) revised August 31, 2015; relevant standard operating procedures (SOPs); and with the applicable requirements of the reference standard test methods.

Test Data: All the test results presented herein are linked through unbroken chain to the raw data files recorded on the day of the test. Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results of each test.

Controls:	
Superseded Report	New Report
Reason for Revision Effective Date	n/a February 10, 2017

Test Report Approval Signatures:	
Quality review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Francisco De Caso Signature: Date: February 10, 2017
Technical review Approval	I indicate that I have reviewed this Test Report and agree with the technical contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Antonio Nanni Signature: Date: February 10, 2017

1. COMPRESSIVE PROPERTIES OF PLASTIC – ASTM D6641

1.1. TEST SUMMARY INFORMATION

Test Objective:	Determine the compressive strength and stiffness properties of polymer matrix composites under combined compression
Test Standard Method/s:	ASTM D6641/D6641M-16, Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture.
Test Set-up:	Combined loading compression (CLC) test fixture; loading rate at 1.27 mm/min (0.05 in./min); applied torque to fixture 3.0 N-m (25 in-lb)
Product:	V-Wrap C400HM fabric with V-Wrap 770 resin
Test Location:	Structures and Materials Laboratory, SML, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146
Analyst:	Ming Han Soh
Technical Test Record:	TDS_ D6641_STeC400HM
Text Matrix:	Refer to Table 1.1
Sample Dimensions:	Refer to Table 1.2
Sample Preparation:	SML
Sample Conditioning:	24 hours at 23 ± 1°C (73 ± 3°F) and 60 ± 5% RH
Specimen ID:	Specimens are labeled and uniquely identified for quality and traceability using the format PPPP_MMM#_ XXX, where P is the product (C400HM), M is the mechanical property (CLC for Combined Loading Compression), and X is the sample repetition number.

Table 1.1 – Test Matrix for Compression Testing

Specimen ID	Material Identification Lot /Batch/Roll # and Fabrication	Specimen Tested (mm.dd.yy)
C400HM_CLC_001 to 005	Panel made:10/07/16; 2 ply C400HM: Lot# 23460	01.17.17
C400HM_CLC_006 to 010	V-Wrap 770 Epoxy part A: 16-6162660 V-Wrap 770 Epoxy part B: 16-6162721	01.19.17

Table 1.2 –Specimen Nominal Dimensions

ID	Length		Nominal Thickness*	
	mm	***in.***	***mm***	***in.***
C400HM_CLC	139.7	5.50	4.06	0.16

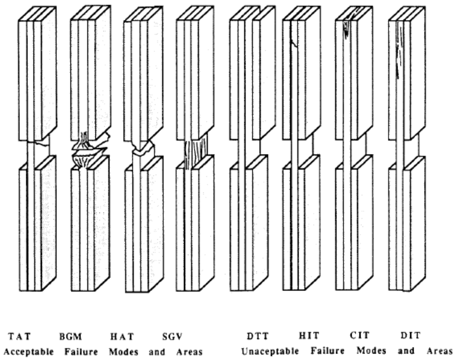
**Based on 2 plies*

1.2. TEST RESULTS

Table 1.3 – Combined Compression Test Results for V-Wrap C400HM/770 (2 ply) Per ASTM D6641

Specimen ID	Width		Length		Area		Ultimate Load		Compressive Strength		Chord Modulus		Computed Ultimate Strain	Mode of failure*
	mm	in.	mm	in.	mm^2	in^2	kN	lbf	MPa	ksi	GPa	Msi	%	
C400HM_CLC_001	12.294	0.484	141.22	5.560	49.96	0.077	17.18	3861	343.5	49.86	86.01	12.48	0.40	BGM
C400HM_CLC_002	12.065	0.475	139.95	5.510	49.03	0.076	17.28	3883	352.0	51.09	71.40	10.36	0.49	BGM
C400HM_CLC_003	12.319	0.485	139.32	5.485	50.06	0.078	13.68	3074	273.0	39.62	85.73	12.44	0.32	BGM
C400HM_CLC_004	12.548	0.494	139.27	5.483	50.99	0.079	15.97	3589	312.8	45.40	65.89	9.56	0.47	BGM
C400HM_CLC_005	13.437	0.529	139.09	5.476	54.61	0.085	19.37	4352	354.3	51.42	62.30	9.04	0.57	BGM
C400HM_CLC_006	12.421	0.489	134.62	5.300	50.48	0.078	18.57	4173	367.5	53.34	80.63	11.70	0.46	BGM
C400HM_CLC_007	12.395	0.488	138.91	5.469	50.37	0.078	16.13	3625	319.9	46.43	86.35	12.53	0.37	BGM
C400HM_CLC_008	13.386	0.527	140.21	5.520	54.40	0.084	13.90	3124	255.2	37.05	85.25	12.37	0.30	BGM
C400HM_CLC_009	12.852	0.506	140.79	5.543	52.23	0.081	13.31	2992	254.6	36.96	82.22	11.93	0.31	BGM
C400HM_CLC_010	14.122	0.556	142.19	5.598	57.39	0.089	14.60	3280	254.1	36.87	64.16	9.31	0.40	BGM
Average	12.784	0.503	139.56	5.494	51.95	0.081	16.00	3595	308.7	44.80	77.00	11.17	0.41	
S_{n-1}	0.658	0.026	2.03	0.080	2.67	0.004	2.11	474	45.7	6.64	9.94	1.44	0.09	
CV((%)	5.1	5.1	1.5	1.5	5.1	5.1	13.2	13.2	14.8	14.8	12.9	12.9	21.7	

**Mode of failure based on Figure 4 of ASTM D6641, reference Figure 1.1*



First Character

Failure Mode	Code
Angled	A
Brooming	B
end-Crushing	C
Delamination	D
Euler buckling	E
tHrough-thickness	H
Kink bands	K
Lateral	L
Multi-mode	M(xyz)
long.-Splitting	S
Transverse shear	T
eXplosive	X
Other	O

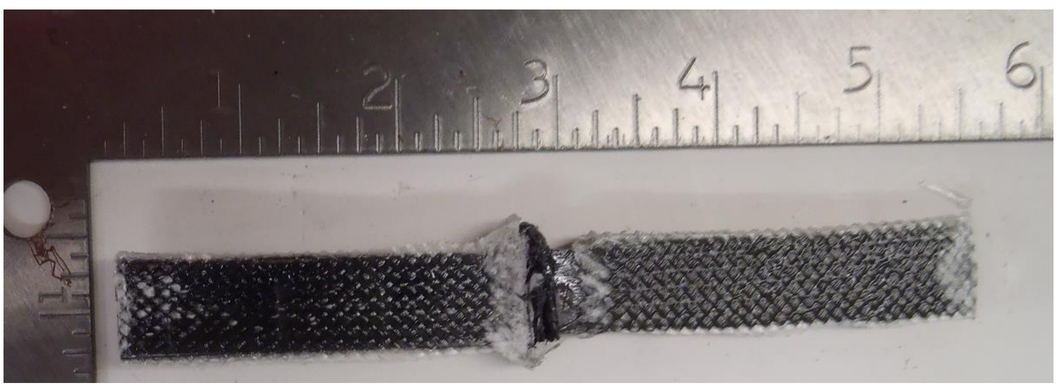
Second Character

Failure Area	Code
Inside grip/tab	I
At grip/tab	A
Gage	G
Multiple Areas	M
Tab adhesive	T
Various	V
Unknown	U

Third Character

Failure Location	Code
Bottom	B
Top	T
Left	L
Right	R
Middle	M
Various	V
Unknown	U

(a)



(b)

Figure 1.1 – (a) Compression Test Specimen Three-Part Failure Identification Codes from ASTM D6641, and (b) representative failure mode, BGM (Brooming, gauge, middle)

♦ END OF TEST REPORT ♦

Intertek

Testing	:	**Flexural Properties Of Plastics**
Test Method	:	ASTM D790-15$^{\varepsilon 1}$
Project Number	:	P20164346
Customer	:	Structural Technologies LLC Purchase Order # : INT-111516 rev 1
Attention	:	Andy Sartor
Analyst	:	J. Storie
Date	:	December 2, 2016

ACCREDITED
Cert. No. 0619.01
TESTING LABORATORY

Material	:	**V-Wrap C400HM/770, Fiber C400HM, Lot# 23460, Roll# 97, Resin V-Wrap 770 Batch# A - 16-6162660, Batch# B - 16-6162721, Panel made: 9/30/16 2-ply sample**
Sample Preparation	:	Machined by Intertek PTL
Sample Dimensions	:	0.504" x 0.153" x 7" Avg
Sample Type	:	ASTM Flex Bar
Span Length (in)	:	4.896
Cross-Head Speed (in/min)	:	0.261
Span-To- Depth Ratio	:	32±1:1
Procedure	:	A (0.01 in/in/min strain rate)
Deflection Measurement	:	Type I (crosshead)
Radius Of Supports (in)	:	0.197
Radius Of Loading Nose (in)	:	0.197
Conditioning	:	Unconditioned
Test Conditions	:	23°C ± 2°C / 50% ± 10% RH
Significance	:	ASTM D790 specifies all data to be reported to 3 significant figures and standard deviation be reported to 2 significant figures.

Test Number	**Flexural Strength (PSI)**	**Flexural Strain at Break (%)**	**Flexural Modulus (tangent *) (PSI)**
1	115000	0.987	11800000
2	109000	0.938	11900000
3	114000	0.938	12400000
4	108000	0.852	12800000
5	120000	0.984	12400000
6	104000	0.978	11300000
7	115000	1.01	11600000
8	110000	0.904	12300000
9	102000	0.856	12100000
10	118000	1.01	11800000
Average	**112000**	**0.946**	**12000000**
Std. Dev.	5900	0.059	450000

* = computer generated curve fit

50 Pearl Street, Pittsfield, MA 01201
Phone: (413) 499-0983 Fax: 499-2339
http://www.ptli.com

CERTIFIED TEST REPORT

EVALUATION OF TENSILE PROPERTIES OF V-WRAP C400HM/770

- Per ASTM D3039 -

Report Number: R-5.10_C4HM77_D3039
Date: December 8, 2015

REPORT PREPARED FOR:

Tarek Alkhrdaji, PhD, PE
Vice President - Engineering Services
STRUCTURAL TECHNOLOGIES LLC.
10150 Old Columbia Rd.
Columbia, Maryland 21046
Ph. 410-340-3260

Quality System: The Structures and Materials Laboratory (SML) maintains a quality system in compliance with ISO 17025-2005, accredited under International Accreditation Service (IAS), testing laboratory, TL-478

Procedures: All tests and services are done in accordance with the SML Quality Manual (Version 2.2) revised March 18, 2013; relevant standard operating procedures (SOPs); and with the applicable requirements of the reference standard test methods.

Test Data: All the test results presented herein are linked through unbroken chain to the raw data files recorded on the day of the test. Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results of each test.

Controls:	
Superseded Report	new
Reason for Revision Effective Date	n/a December 8, 2015

Test Report Approval Signatures:	
Quality review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Francisco De Caso Signature: Date: December 8, 2015
Technical review Approval	I indicate that I have reviewed this Test Report and agree with the technical contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Antonio Nanni Signature: Date: December 8, 2015

1. TENSILE PROPERTIES – ASTM D3039

1.1. TEST SUMMARY INFORMATION

Test Objective:	Tensile Properties of Polymer Matrix Composite Materials
Test Standard Method/s:	ASTM D3039/D3039M – 14
Test Set-up:	Displacement load rate of 2 mm/min (0.05 in./min); grip pressure of 37.9 MPa (5500 psi).
Product:	V-Wrap C400HM and V-Wrap 770 resin
Test Location:	Structures and Materials Laboratory, SML, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146
Analyst:	Keith Holmes and Rebecca Tien
Technical Test Record:	R-4.13.1_STe_D3039
Text Matrix:	Refer to Table 1.1
Sample Dimensions:	Refer to Table 1.2
Sample Preparation:	Structures and Materials Laboratory
Sample Conditioning:	24+ hours at 23 ± 1°C (73 ± 3°F) and 60 ± 5% RH
Specimen ID:	Specimens are labeled and uniquely identified for quality and traceability using the format PPPP_MMM_XXX, where P is the product, M is the mechanical property, and X is the sample number.

Table 1.1 – Test Matrix For Tensile Testing

Specimen ID	Specimen #	Batch Fiber #	Batch Resin #	Specimen Tested (mm.dd.yy)
C4H77_TNS_001 to 020	20	23460/258	Part A: 14-5920036 Part B: 14-5919301	08.26.15

Table 1.2 – Tensile Specimen Nominal Dimensions

ID	Length *mm*	Length *in*	Thickness *mm*	Thickness *in*
C4H77_TNS	254.0	10.0	2.02	0.08

1.2. TEST RESULTS

Table 1.3 - Tensile Test Results for V-Wrap C400HM/770 Per ASTM D3039

Specimen ID	*Width, w*		Area, *A*		*Peak load, P^{max}*		*Load/unit width, P^{max} /w*		Strength, F^{tu}		Modulus, E^{chord}		Ultimate Strain, ε_u	Failure Mode*
	mm	in.	mm²	*in²*	*kN*	*lbs*	*kN/mm*	*lbs/in*	*MPa*	*ksi*	*GPa*	*Msi*	*%*	
C4H77_TNS_001	26.797	1.055	54.452	0.084	84.11	18902	3.14	17917	1544.1	224.0	115.99	16.83	1.33	SGM
C4H77_TNS_002	25.756	1.014	52.335	0.081	95.01	21351	3.69	21056	1814.7	263.2	120.68	17.51	1.50	SGM
C4H77_TNS_003	26.111	1.028	53.058	0.082	85.02	19105	3.26	18585	1601.7	232.3	122.74	17.81	1.30	AGM
C4H77_TNS_004	26.924	1.060	54.710	0.085	85.33	19175	3.17	18090	1559.0	226.1	117.99	17.12	1.32	AGM
C4H77_TNS_005	25.933	1.021	52.697	0.082	88.22	19825	3.40	19417	1673.5	242.7	112.20	16.28	1.49	AGM
C4H77_TNS_006	26.924	1.060	54.710	0.085	85.73	19265	3.18	18175	1566.4	227.2	122.61	17.79	1.28	AGM
C4H77_TNS_007	26.264	1.034	53.368	0.083	83.92	18859	3.20	18239	1571.9	228.0	117.78	17.09	1.33	XGM
C4H77_TNS_008	24.435	0.962	49.652	0.077	94.24	21177	3.86	22014	1897.2	275.2	109.65	15.91	1.73	AGM
C4H77_TNS_009	25.933	1.021	52.697	0.082	96.19	21615	3.71	21170	1824.6	264.6	112.68	16.35	1.62	AGM
C4H77_TNS_010	26.213	1.032	53.264	0.083	98.14	22053	3.74	21369	1841.7	267.1	117.85	17.10	1.56	SGM
C4H77_TNS_011	29.261	1.152	59.458	0.092	98.55	22146	3.37	19224	1656.8	240.3	117.71	17.08	1.41	SGM
C4H77_TNS_012	28.931	1.139	58.787	0.091	102.30	22989	3.54	20183	1739.5	252.3	117.23	17.01	1.48	AGM
C4H77_TNS_013	28.905	1.138	58.735	0.091	100.49	22581	3.48	19843	1710.1	248.0	110.82	16.08	1.54	SGM
C4H77_TNS_014	29.083	1.145	59.097	0.092	101.68	22849	3.50	19955	1719.9	249.4	109.51	15.89	1.57	SGM
C4H77_TNS_015	28.423	1.119	57.755	0.090	97.74	21965	3.44	19629	1691.7	245.4	110.20	15.99	1.53	AGM
C4H77_TNS_016	29.616	1.166	60.181	0.093	103.02	23151	3.48	19855	1711.2	248.2	113.58	16.48	1.51	AGM
C4H77_TNS_017	29.591	1.165	60.129	0.093	104.64	23514	3.54	20184	1739.5	252.3	116.88	16.96	1.49	AGM
C4H77_TNS_018	29.134	1.147	59.200	0.092	99.44	22345	3.41	19481	1679.0	243.5	118.88	17.25	1.41	AGM
C4H77_TNS_019	28.677	1.129	58.271	0.090	97.94	22008	3.42	19493	1680.0	243.7	108.61	15.76	1.55	AGM
C4H77_TNS_020	30.175	1.188	61.316	0.095	100.50	22585	3.33	19011	1638.4	237.6	119.43	17.33	1.37	SGM
Average	27.654	1.089	56.193	0.087	95.11	21373	3.44	19644	1693.1	245.6	115.65	16.78	1.47	
S_{n-1}	1.681	0.066	3.416	0.005	7.04	1582	0.20	1147	98.9	14.3	4.43	0.64	0.12	
CV((%)	6.1	6.1	6.1	6.1	7.4	7.4	5.8	5.8	5.8	5.8	3.8	3.8	8.1	

**Failure mode based on ASTM D3039 Fig 4, as follows:*

First Character

Failure Type	Code
Angled	A
edge Delamination	D
Grip/tab	G
Lateral	L
Multi-mode	M(xyz)
long. Splitting	S
eXplosive	X
Other	O

Second Character

Failure Area	Code
Inside grip/tab	I
At grip/tab	A
<1W from grip/tab	W
Gage	G
Multiple areas	M
Various	V
Unknown	U

Third Character

Failure Location	Code
Bottom	B
Top	T
Left	L
Right	R
Middle	M
Various	V
Unknown	U

♦ END OF TEST REPORT ♦

CERTIFIED TEST REPORT

EVALUATION OF TENSILE PROPERTIES OF V-WRAP C400HM / 770 - Per ASTM D3039 -

Report Number: R-5.10_STe-W19_D3039
Date: February 12, 2016

REPORT PREPARED FOR:

Dr. Tarek Alkhrdaji
STRUCTURAL TECHNOLOGIES LLC.
10150 Old Columbia Road
Columbia, MD 21046
Tel: (410) 850-7000

PROJECT:

Quality Control Tests of ICC material in stock

Quality System: The Structures and Materials Laboratory (SML) maintains a quality system in compliance with ISO 17025-2005, accredited under International Accreditation Service (IAS), testing laboratory, TL-478

Procedures: All tests and services are done in accordance with the SML Quality Manual (Version 2.2) revised March 18, 2013; relevant standard operating procedures (SOPs); and with the applicable requirements of the reference standard test methods.

Test Data: All the test results presented herein are linked through unbroken chain to the raw data files recorded on the day of the test. Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results of each test.

Controls:	
Superseded Report	New report
Reason for Revision	n/a
Effective Date	February12, 2016

Test Report Approval Signatures:	
Quality review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Francisco De Caso Signature: Date: February12, 2016
Technical review Approval	I indicate that I have reviewed this Test Report and agree with the technical contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Antonio Nanni Signature: Date: February12, 2016

1. TENSILE PROPERTIES – ASTM D3039

1.1. TEST SUMMARY INFORMATION

Project Name:	Quality Control Tests of ICC material in stock
Test Objective:	Tensile Properties of Polymer Matrix Composite Materials
Test Standard Method/s:	ASTM D3039/D3039M – 14
Test Set-up:	Displacement load rate of 2 mm/min (0.05 in./min); grip pressure of 37.9 MPa (5500 psi).
Product:	Fabric V-Wrap C400HM with V-Wrap 770 resin
Test Location:	Structures and Materials Laboratory, SML, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146
Analyst/s:	Keith Holmes and Christian Marquina
Technical Test Record:	R-4.13.1-STe-W19
Text Matrix:	Refer to Table 1.1
Sample Dimensions:	Length 254 mm (10 in.) and nominal thickness 2.03 mm (0.08 in)
Sample Preparation:	Structures and Materials Laboratory
Sample Conditioning:	24+ hours at 23 ± 1°C (73 ± 3°F) and 60 ± 5% RH
Specimen ID:	Specimens are labeled and uniquely identified for quality and traceability using the format PPPP_MMM_RR_XXX, where P is the product (C400HM); M is the mechanical property (TNS for tensile strength); and X is specimen repetition number.

Table 1.1 – Test Matrix For Tensile Testing

Specimen ID	Material Identification Lot /Batch/Roll # and Fabrication	Test date (mm.dd.yy)
C400HM_TNS_001 to 005	Lot – 23692 Batch A-14-5924459; B-14-5923165 Made: 10/29/15	02.05.16

1.2. TEST RESULTS

Table 1.2 - Tensile Test Results for C400HM fabric with V-Wrap 770 resin (C400HM) witness panels, per ASTM D3039

Specimen ID	*Width, w*		Area, *A*		*Peak load, P^{max}*		*Load/unit width, P^{max} /w*		Strength, F^{tu}		Modulus, E^{chord}		Ultimate Strain, ε_u	Failure Mode*
	mm	in.	mm^2	*in^2*	*kN*	*lbs*	*kN/mm*	*lbs/in*	*MPa*	*ksi*	*GPa*	*Msi*	*%*	
C400HM_TNS_001	20.42	0.804	41.50	0.064	69.98	15725	3.43	19558	1685.6	244.5	93.5	13.6	1.80	MGM
C400HM_TNS_002	23.09	0.909	46.92	0.073	73.95	16618	3.20	18282	1575.6	228.5	99.5	14.4	1.58	SGM
C400HM_TNS_003	21.51	0.847	43.72	0.068	73.34	16482	3.41	19459	1677.1	243.2	103.2	15.0	1.62	MGM
C400HM_TNS_004	20.50	0.807	41.65	0.065	68.65	15426	3.35	19115	1647.4	238.9	102.5	14.9	1.61	MGM
C400HM_TNS_005	22.12	0.871	44.95	0.070	70.63	15872	3.19	18223	1570.5	227.8	98.0	14.2	1.60	SGM
AVERAGE	21.53	0.85	43.75	0.07	71.31	16025	3.32	18927	1631.3	236.6	99.4	14.4	1.64	
ST.DEV.	1.13	0.04	2.29	0.00	2.26	508	0.11	638	55.0	8.0	3.9	0.6	0.09	
C.O.V. (%)	5.2	5.2	5.2	5.2	3.2	3.2	3.4	3.4	3.4	3.4	3.9	3.9	5.5	

**Failure mode based on ASTM D3039 Fig 4, as follows:*

First Character

Failure Type	Code
Angled	A
edge Delamination	D
Grip/tab	G
Lateral	L
Multi-mode	M(xyz)
long. Splitting	S
eXplosive	X
Other	O

Second Character

Failure Area	Code
Inside grip/tab	I
At grip/tab	A
<1W from grip/tab	W
Gage	G
Multiple areas	M
Various	V
Unknown	U

Third Character

Failure Location	Code
Bottom	B
Top	T
Left	L
Right	R
Middle	M
Various	V
Unknown	U

1.3. VISUAL DOCUMENTATION

Figure 1.1 – Witness panel received prior testing

Figure 1.2 – Representative failure mode MGM: Multiple (Longitudinal Splitting and Lateral), at Gage, in the Midele

♦ END OF TEST REPORT ♦

CERTIFIED TEST REPORT

EVALUATION OF TENSILE PROPERTIES OF V-WRAP C400HM / 770 - Per ASTM D3039 -

Report Number: R-5.10_STe-W18a_D3039
Date: December 17, 2015

REPORT PREPARED FOR: Dr. Tarek Alkhrdaji STRUCTURAL TECHNOLOGIES LLC. 10150 Old Columbia Road Columbia, MD 21046 Tel: (410) 850-7000
PROJECT: STP #421049

Quality System: The Structures and Materials Laboratory (SML) maintains a quality system in compliance with ISO 17025-2005, accredited under International Accreditation Service (IAS), testing laboratory, TL-478

Procedures: All tests and services are done in accordance with the SML Quality Manual (Version 2.2) revised March 18, 2013; relevant standard operating procedures (SOPs); and with the applicable requirements of the reference standard test methods.

Test Data: All the test results presented herein are linked through unbroken chain to the raw data files recorded on the day of the test. Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results of each test.

Controls:	
Superseded Report	New report
Reason for Revision Effective Date	n/a December 17, 2015

Test Report Approval Signatures:	
Quality review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Francisco De Caso Signature: Date: December 17, 2015
Technical review Approval	I indicate that I have reviewed this Test Report and agree with the technical contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Antonio Nanni Signature: Date: December 17, 2015

1. TENSILE PROPERTIES – ASTM D3039

1.1. TEST SUMMARY INFORMATION

Project Name:	STP #421049
Test Objective:	Tensile Properties of Polymer Matrix Composite Materials
Test Standard Method/s:	ASTM D3039/D3039M – 14
Test Set-up:	Displacement load rate of 2 mm/min (0.05 in./min); grip pressure of 37.9 MPa (5500 psi).
Product:	Fabric C400HM with V-Wrap 770 resin
Test Location:	Structures and Materials Laboratory, SML, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146
Analyst/s:	Keith Holmes and Tais Hamilton
Technical Test Record:	R-4.13.1-STe-W18
Text Matrix:	Refer to Table 1.1
Sample Dimensions:	Length 254 mm (10 in.) and nominal thickness 2.03 mm (0.08 in)
Sample Preparation:	Structures and Materials Laboratory
Sample Conditioning:	24+ hours at 23 ± 1°C (73 ± 3°F) and 60 ± 5% RH
Specimen ID:	Specimens are labeled and uniquely identified for quality and traceability using the format PPPP_MMM_RR_XXX, where P is the product (C400HM); M is the mechanical property (TNS for tensile strength); R is the panel ID reference number (namely 01 an 02); and X is specimen repetition number.

Table 1.1 – Test Matrix For Tensile Testing

Specimen ID	Material Identification Lot /Batch/Roll # and Fabrication	Test date (mm.dd.yy)
C400HM_TNS_01_001 to 005	Fiber lot No: 23854 mfgt-08/12/2015 made 11/03/15	12.11.15
C400HM _TNS_02_001 to 005	Fiber lot No: 23854 mfgt-08/25/2015 made 11/05/15	

1.2. TEST RESULTS

Table 1.2 - Tensile Test Results for C400HM fabric with V-Wrap 770 resin (C400HM) witness panels, per ASTM D3039

Specimen ID	*Width, w*		Area, *A*		*Peak load, P^{max}*		*Load/unit width, P^{max} /w*		Strength, F^{tu}		Modulus, E^{chord}		Ultimate Strain, ε_u	Failure Mode*
	mm	in.	mm²	*in²*	*kN*	*lbs*	*kN/mm*	*lbs/in*	*MPa*	*ksi*	*GPa*	*Msi*	*%*	
C400HM_TNS_01_001	23.91	0.942	48.59	0.075	79.94	17964	3.34	19080	1644	238.5	102.34	14.85	1.61	XGV
C400HM_TNS_01_002	20.41	0.804	41.47	0.064	78.36	17608	3.84	21914	1889	273.9	103.10	14.96	1.83	XGV
C400HM_TNS_01_003	24.99	0.984	50.79	0.079	84.53	18996	3.38	19305	1664	241.3	103.03	14.95	1.61	XGV
C400HM_TNS_01_004	24.94	0.982	50.68	0.079	81.69	18358	3.28	18695	1611	233.7	102.48	14.87	1.57	XGV
C400HM_TNS_01_005	24.38	0.960	49.55	0.077	89.20	20045	3.66	20880	1800	261.0	109.37	15.87	1.64	XGV
AVERAGE					82.74	18594	3.50	19975	1722	249.7	104.07	15.10	1.65	
ST.DEV.					4.28	961	0.24	1366	118	17.1	2.99	0.43	0.10	
C.O.V. (%)					5.2	5.2	6.8	6.8	6.8	6.8	2.9	2.9	6.2	
C400HM _TNS_02_001	23.60	0.929	47.95	0.074	80.31	18047	3.40	19426	1674	242.8	98.90	14.35	1.69	XGV
C400HM _TNS_02_002	24.84	0.978	50.48	0.078	90.10	20247	3.63	20702	1784	258.8	103.58	15.03	1.72	XGV
C400HM _TNS_02_003	25.30	0.996	51.41	0.080	93.85	21089	3.71	21174	1825	264.7	103.45	15.01	1.76	XGV
C400HM _TNS_02_004	22.89	0.901	46.50	0.072	80.05	17988	3.50	19964	1721	249.6	102.62	14.89	1.68	XGV
C400HM _TNS_02_005	23.75	0.935	48.26	0.075	78.31	17598	3.30	18821	1622	235.3	105.65	15.33	1.53	XGV
AVERAGE					84.52	18994	3.51	20018	1725	250.2	102.84	14.92	1.68	
ST.DEV.					6.97	1567	0.17	947	82	11.8	2.47	0.36	0.09	
C.O.V. (%)					8.2	8.2	4.7	4.7	4.7	4.7	2.4	2.4	5.2	

**Failure mode based on ASTM D3039 Fig 4, as follows:*

First Character

Failure Type	Code
Angled	A
edge Delamination	D
Grip/tab	G
Lateral	L
Multi-mode	M(xyz)
long. Splitting	S
eXplosive	X
Other	O

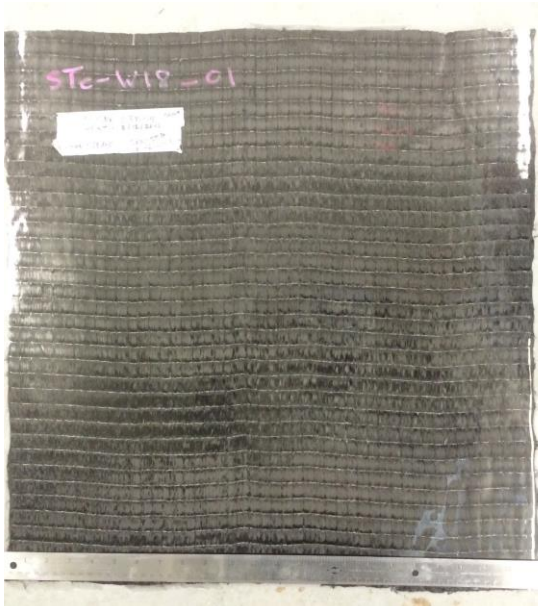
Second Character

Failure Area	Code
Inside grip/tab	I
At grip/tab	A
<1W from grip/tab	W
Gage	G
Multiple areas	M
Various	V
Unknown	U

Third Character

Failure Location	Code
Bottom	B
Top	T
Left	L
Right	R
Middle	M
Various	V
Unknown	U

1.3. VISUAL DOCUMENTATION



(a) **(b)**

Figure 1.1 – Witness panel received prior testing, Panel 01 (a); and Panel 02 (b)

Figure 1.2 – Representative failure mode XGV: eXplosive, at Gage, in the Various locations

♦ END OF TEST REPORT ♦

CERTIFIED TEST REPORT

EVALUATION OF TENSILE PROPERTIES OF V-WRAP C400HM / 770 - Per ASTM D3039 -

Report Number: R-5.10_STe-W29_D3039
Date: September 7, 2016

REPORT PREPARED FOR:

Dr. Tarek Alkhrdaji
STRUCTURAL TECHNOLOGIES LLC.
10150 Old Columbia Road
Columbia, MD 21046
Tel: (410) 850-7000

PROJECT:

ICC Quality Control Testing
Lot #24072

Quality System: The Structures and Materials Laboratory (SML) maintains a quality system in compliance with ISO 17025-2005, accredited under International Accreditation Service (IAS), testing laboratory, TL-478

Procedures: All tests and services are done in accordance with the SML SML Quality Manual (Version 2.4) revised August 31, 2015; relevant standard operating procedures (SOPs); and with the applicable requirements of the reference standard test methods.

Test Data: All the test results presented herein are linked through unbroken chain to the raw data files recorded on the day of the test. Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results of each test.

Controls:	
Superseded Report	New report
Reason for Revision Effective Date	n/a September 7, 2016

Test Report Approval Signatures:	
Quality review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Francisco De Caso Signature: Date: September 7, 2016
Technical review Approval	I indicate that I have reviewed this Test Report and agree with the technical contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Antonio Nanni Signature: Date: September 7, 2016

1. TENSILE PROPERTIES – ASTM D3039

1.1. TEST SUMMARY INFORMATION

Project Name:	ICC Quality Control Testing
Test Objective:	Tensile Properties of Polymer Matrix Composite Materials
Test Standard Method/s:	ASTM D3039/D3039M – 14
Test Set-up:	Displacement load rate of 2 mm/min (0.05 in./min); grip pressure of 37.9 MPa (5500 psi).
Product:	Fabric C400HM with V-Wrap 770 resin
Test Location:	Structures and Materials Laboratory, SML, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146
Analyst/s:	Phillip Lavonas and Christian Marquina
Technical Test Record:	R-4.13.1-STe-W29
Text Matrix:	Refer to Table 1.1
Sample Dimensions:	Length 254 mm (10 in.) and nominal thickness 2.03 mm (0.08 in)
Sample Preparation:	Structures and Materials Laboratory
Sample Conditioning:	24+ hours at 23 ± 1°C (73 ± 3°F) and 60 ± 5% RH
Specimen ID:	Specimens are labeled and uniquely identified for quality and traceability using the format PPPP_MMM_XXX, where P is the product (C400HM); M is the mechanical property (TNS for tensile strength); and X is specimen repetition number.

Table 1.1 – Test Matrix For Tensile Testing

Specimen ID	Material Identification Lot /Batch/Roll # and Fabrication	Test date (mm.dd.yy)
C400HM_TNS_001 to 005	C400HM: Lot 24072 V-Wrap 770 Epoxy part A: 15-6089868 V-Wrap 770 Epoxy part B: 15-6089869	09.01.16

1.2. TEST RESULTS

Table 1.2 - Tensile Test Results for C400HM fabric with V-Wrap 770 resin (C400HM) witness panels, per ASTM D3039

Specimen ID	*Width, w*		Area, *A*		*Peak load, P^{max}*		*Load/unit width, P^{max}/w*		Strength, F^{tu}		Modulus, E^{chord}		Ultimate Strain, ε_u	Failure Mode*
	mm	in.	mm²	*in²*	*kN*	*lbs*	*kN/mm*	*lbs/in*	*MPa*	*ksi*	*GPa*	*Msi*	*%*	
C400HM_TNS_01	24.03	0.946	48.83	0.076	64.79	14560	2.70	15391	1326.5	192.4	110.6	16.05	1.20	M(S,A)GM
C400HM_TNS_02	20.50	0.807	41.65	0.065	55.18	12401	2.69	15367	1324.4	192.1	108.2	15.70	1.22	M(S,A)GM
C400HM_TNS_03	24.54	0.966	49.86	0.077	66.25	14887	2.70	15411	1328.2	192.6	109.8	15.94	1.21	M(S,A)GM
C400HM_TNS_04	21.67	0.853	44.03	0.068	59.99	13480	2.77	15803	1362.0	197.5	117.6	17.07	1.16	M(S,A)GM
C400HM_TNS_05	21.21	0.835	43.10	0.067	62.61	14069	2.95	16849	1452.1	210.6	102.0	14.80	1.42	M(S,A)GM
Average	**22.39**	**0.881**	**45.49**	**0.071**	**61.76**	**13879**	**2.76**	**15764**	**1358.6**	**197.1**	**109.6**	**15.91**	**1.24**	
S_{n-1}	1.79	0.070	3.63	0.006	4.37	982	0.11	633	54.5	7.9	5.6	0.81	0.10	
CV((%)	8.0	8.0	8.0	8.0	7.1	7.1	4.0	4.0	4.0	4.0	5.1	5.1	8.4	

**Failure mode based on ASTM D3039 Fig 4, as follows:*

First Character

Failure Type	Code
Angled	A
edge Delamination	D
Grip/tab	G
Lateral	L
Multi-mode	M(xyz)
long. Splitting	S
eXplosive	X
Other	O

Second Character

Failure Area	Code
Inside grip/tab	I
At grip/tab	A
<1W from grip/tab	W
Gage	G
Multiple areas	M
Various	V
Unknown	U

Third Character

Failure Location	Code
Bottom	B
Top	T
Left	L
Right	R
Middle	M
Various	V
Unknown	U

1.3 VISUAL DOCUMENTATION

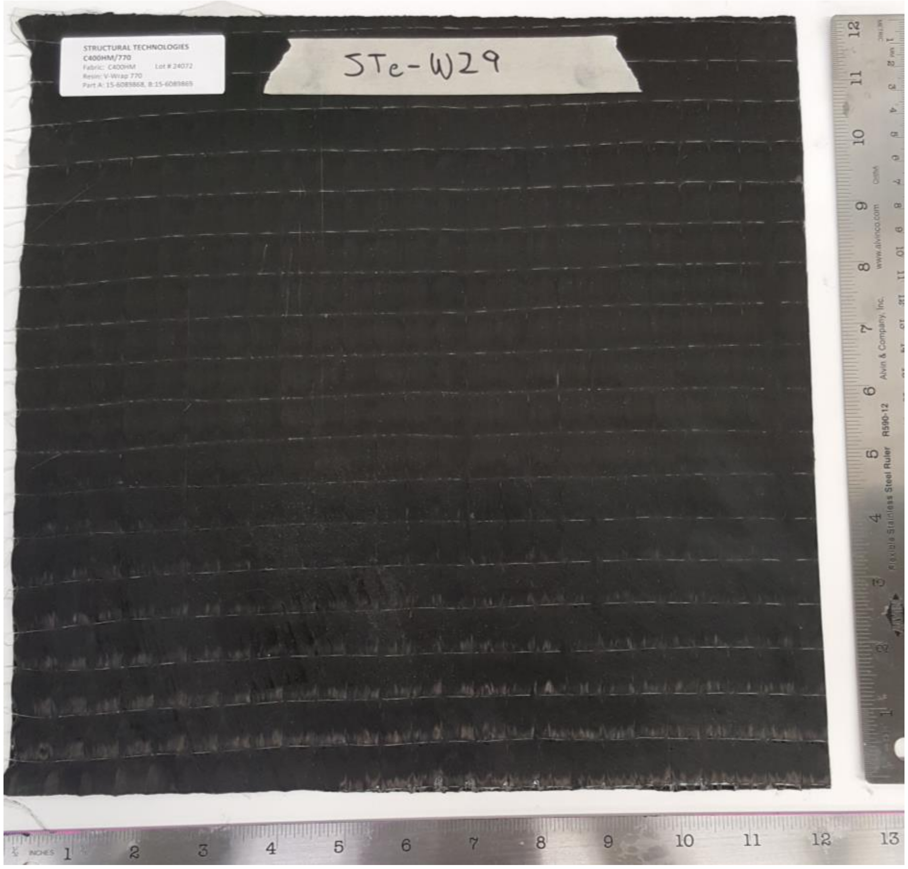


Figure 1.1 – Witness panel received prior testing

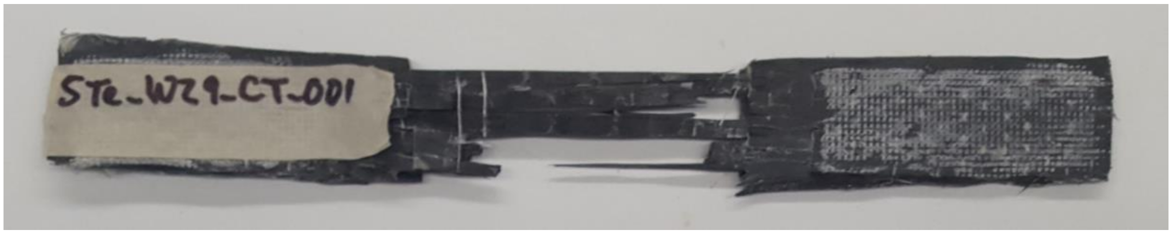


Figure 1.2 – Representative failure mode, M(S,A)GM, Multiple (Longitudinal Splitting and Angled), at Gage, in the Middle

♦ END OF TEST REPORT ♦

CERTIFIED TEST REPORT

EVALUATION OF TENSILE PROPERTIES OF V-WRAP C400HM / 770 - Per ASTM D3039 -

Report Number: R-5.10_STe-W34a_D3039
Date: November 9, 2016

REPORT PREPARED FOR:

Attn: Tarek Alkhrdaji
Vice President - Engineering Services
STRUCTURAL TECHNOLOGIES LLC.
10150 Old Columbia Rd., Columbia, Maryland 21046
Ph. 410-340-3260

PROJECT:

Verification of C400HM/770: Lot 24483, Rolls 302 and 200

Quality System: The Structures and Materials Laboratory (SML) maintains a quality system in compliance with ISO 17025-2005, accredited under International Accreditation Service (IAS), testing laboratory, TL-478

Procedures: All tests and services are done in accordance with the SML SML Quality Manual (Version 2.4) revised August 31, 2015; relevant standard operating procedures (SOPs); and with the applicable requirements of the reference standard test methods.

Test Data: All the test results presented herein are linked through unbroken chain to the raw data files recorded on the day of the test. Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results of each test.

Controls:	
Superseded Report	New report
Reason for Revision	n/a
Effective Date	November 9, 2016

Test Report Approval Signatures:	
Quality review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Francisco De Caso Signature: Date: November 9, 2016
Technical review Approval	I indicate that I have reviewed this Test Report and agree with the technical contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Antonio Nanni Signature: Date: November 9, 2016

1. TENSILE PROPERTIES – ASTM D3039

1.1. TEST SUMMARY INFORMATION

Project Name:	Verification of C400HM/770
Test Objective:	Tensile Properties of Polymer Matrix Composite Materials
Test Standard Method/s:	ASTM D3039/D3039M – 14
Test Set-up:	Displacement load rate of 2 mm/min (0.05 in./min); grip pressure of 38.0 MPa (5500 psi).
Product:	Fabric C400HM, with V-Wrap 770 resin
Test Location:	Structures and Materials Laboratory, SML, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146
Analyst/s:	Ming Han Soh, Tais Hamilton and Christian Marquina
Technical Test Record:	TDS_D3039_STe-W34
Text Matrix:	Refer to Table 1.1
Sample Dimensions:	Length 254 mm (10 in.) and nominal thickness 2.04 mm (0.08 in.).
Sample Preparation:	Structures and Materials Laboratory
Sample Conditioning:	24+ hours at 23 ± 1°C (73 ± 3°F) and 60 ± 5% RH
Specimen ID:	Specimens are labeled and uniquely identified for quality and traceability using the format PPPP_MMM#_XXX, where P is the product (C400HM); M is the mechanical property (TNS for tensile strength); # is the panel number (1 to 2); and X is specimen repetition number.

Table 1.1 – Test Matrix For Tensile Testing

Specimen ID	Material Identification Lot /Batch/Roll # and Fabrication	Test date (mm.dd.yy)
C400HM_TNS1_01 to 05	Panel made:10/7/2016 C400HM: Lot#24483, Roll#302 V-Wrap 770 Epoxy part A: 15-6036514 V-Wrap 770 Epoxy part B: 15-6036515	10.31.16
C400HM_TNS2_01 to 05	Panel made:10/7/2016 C400HM: Lot#24483, Roll#200 V-Wrap 770 Epoxy part A: 15-6036514 V-Wrap 770 Epoxy part B: 15-6036515	10.28.16

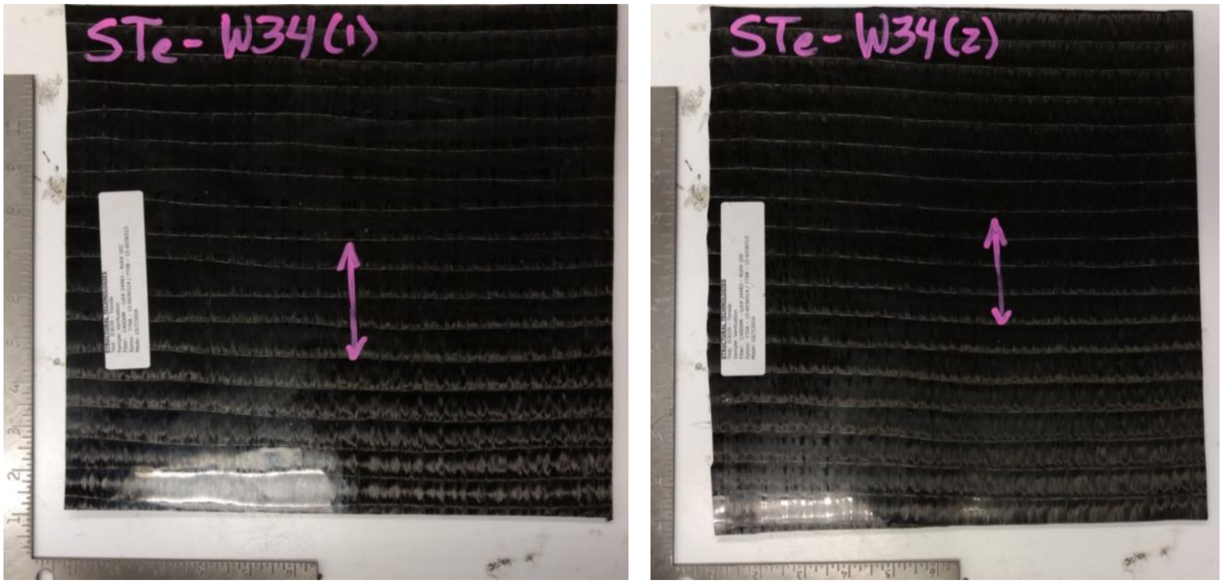
1.2. TEST RESULTS

Table 1.2 - Tensile Test Results for C400HM fabric with V-Wrap 770 resin witness panels 1 and 2, per ASTM D3039

Specimen ID	*Average Width, w*		Area, *A*		*Peak load, P^{max}*		*Load/unit width, P^{max} /w*		Strength, F^{tu}		Modulus, E^{chord}		Ultimate Strain, ε_u	Failure Mode*
	mm	in.	mm²	*in²*	*kN*	*lbs*	*kN/mm*	*lbs/in*	*MPa*	*ksi*	*GPa*	*Msi*	*%*	
C400HM_TNS1_01	22.02	0.867	44.75	0.069	61.68	13861	2.80	15988	1377.9	199.8	111.7	16.21	1.23	SGR
C400HM_TNS1_02	22.73	0.895	46.19	0.072	66.84	15020	2.94	16782	1446.4	209.8	106.9	15.51	1.35	SGM
C400HM_TNS1_03	22.28	0.877	45.26	0.070	66.65	14978	2.99	17079	1471.9	213.5	110.5	16.03	1.33	SGM
C400HM_TNS1_04	21.92	0.863	44.54	0.069	69.82	15690	3.19	18181	1566.9	227.3	129.6	18.80	1.21	SGL
C400HM_TNS1_05	22.99	0.905	46.71	0.072	73.22	16454	3.19	18181	1566.9	227.3	109.9	15.95	1.42	SGM
Average	**22.39**	**0.881**	**45.49**	**0.071**	**67.64**	**15201**	**3.02**	**17242**	**1486.0**	**215.5**	**113.7**	**16.50**	**1.31**	
S_{n-1}	0.46	0.018	0.93	0.001	4.27	960	0.17	945	81.5	11.8	9.0	1.31	0.09	
CV((%)	2.1	2.1	2.1	2.1	6.3	6.3	5.5	5.5	5.5	5.5	7.9	7.9	6.8	
C400HM_TNS2_01	22.61	0.890	45.94	0.071	72.88	16377	3.22	18401	1585.9	230.0	99.8	14.48	1.59	SGM
C400HM_TNS2_02	22.30	0.878	45.32	0.070	63.52	14275	2.85	16259	1401.2	203.2	105.0	15.24	1.33	SGM
C400HM_TNS2_03	23.19	0.913	47.12	0.073	68.27	15342	2.94	16804	1448.2	210.0	100.8	14.62	1.44	SGM
C400HM_TNS2_04	22.81	0.898	46.35	0.072	67.76	15227	2.97	16957	1461.4	212.0	108.3	15.72	1.35	SGM
C400HM_TNS2_05	23.32	0.918	47.38	0.073	67.00	15056	2.87	16401	1413.5	205.0	99.2	14.40	1.42	SGM
Average	**22.84**	**0.899**	**46.42**	**0.072**	**67.89**	**15255**	**2.97**	**16964**	**1462.1**	**212.1**	**102.6**	**14.89**	**1.43**	
S_{n-1}	0.42	0.016	0.85	0.001	3.35	753	0.15	852	73.5	10.7	3.9	0.57	0.10	
CV((%)	1.8	1.8	1.8	1.8	4.9	4.9	5.0	5.0	5.0	5.0	3.8	3.8	7.1	

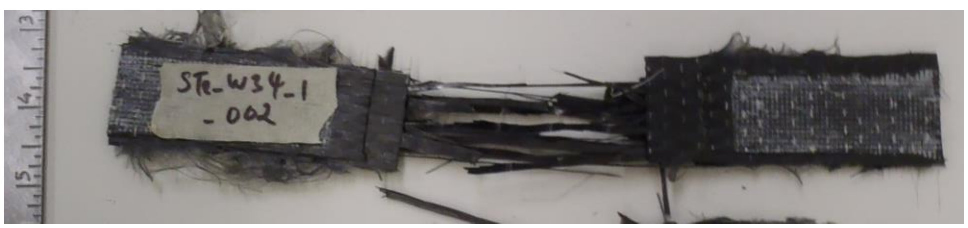
**Failure mode based on ASTM D3039, refer to Figure 1.2.*

1.3 VISUAL DOCUMENTATION

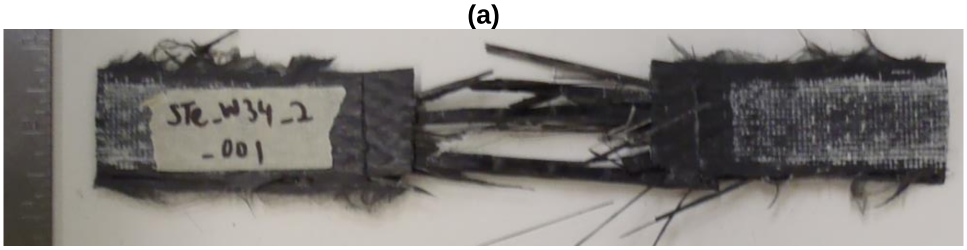


(a) (b)

Figure 1.1 – Witness panel C400HM received prior testing (a) panel 1 (lot 24483, roll 302); And (b) panel 2 (lot 24483, roll 200). (Scale in inches)



(a)



(b)

Figure 1.2 – Representative SGM failure modes for: (a) panel 1; and (b) panel 2; where SGM is longitudinal splitting, at gage, in the middle'

♦ END OF TEST REPORT ♦

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STRUCTURES and MATERIALS LABORATORY
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IAS ACCREDITED

CERTIFIED TEST REPORT

DURABILTY EVALUATION OF TENSILE PROPERTIES OF V-WRAP C400H and C400HM / 770 POST AGING IN SALTWATER AT 140ºF - Per ASTM D1141 & ASTM D3039 -

Report Number: R-5.10_STE-SW140_D3039.1
Date: March 12, 2018

REVISION 1

REPORT PREPARED FOR:

structural TECHNOLOGIES
A Structural Group Company

Attn: Tarek Alkhrdaji
Vice President - Engineering Services
STRUCTURAL TECHNOLOGIES LLC.
10150 Old Columbia Rd., Columbia, Maryland 21046

PROJECT:
Aging of V-Wrap immersed in saltwater solution up to 10,000 hrs at 140ºF

Quality System: The Structures and Materials Laboratory (SML) maintains a quality system in compliance with ISO 17025-2005, accredited under International Accreditation Service (IAS), testing laboratory, TL-478

Procedures: All tests and services are done in accordance with the SML Quality Manual (Version 2.4) revised January 31, 2017; relevant standard operating procedures (SOPs); and with the applicable requirements of the reference standard test methods.

Test Data: All the test results presented herein are linked through unbroken chain to the raw data files recorded on the day of the test. Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results of each test.

Controls:	
Superseded Report	R-5.10_STE-SW140_D3039
Reason for Revision Effective Date	Addition of test results post exposure to 10,000hrs. March 12, 2018
Superseded Report	New report
Reason for Revision Effective Date	n/a December 7, 2017

Test Report Approval Signatures:	
Quality review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Francisco De Caso Signature: Date: March 12, 2018
Technical review Approval	I indicate that I have reviewed this Test Report and agree with the technical contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Antonio Nanni Signature: Date: March 12, 2018

1. RESIDUAL TENSILE PROPERTIES – ASTM D3039

1.1. TEST SUMMARY INFORMATION

Project Name:	Durability Tensile Testing
Test Objective:	Residual tensile properties of polymer matrix composite materials post aging in saltwater solution immersion at 140ºF.
Test Standard Method/s:	ASTM D1141-98(2013) and ASTM D3039/D3039M – 17
Test Set-up:	Displacement load rate of 2 mm/min (0.05 in./min); grip pressure of 37.9 MPa (5500 psi).
Product:	Fabric C400H and C400HM, with V-Wrap 770 resin
Test Location:	Structures and Materials Laboratory, SML, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146
Analyst/s:	Ming Han Soh and Christian Marquina
Technical Test Record:	TDS_D3039_STe-DS
Text Matrix:	Refer to Table 1.1
Sample Dimensions:	Length 254 mm (10 in.) and nominal thickness 2.04 mm (0.08 in.).
Sample Preparation:	Structures and Materials Laboratory
Sample Conditioning:	Immersion in saltwater solution (substitute ocean water per ASTM1141) for 1,000; 3,000; 7,000 and 10,000 hrs at 60 ± 2°C (140 ± 5°F). Post immersion, conditioned for 72+ hours at 23 ± 1°C (73 ± 3°F) and 60 ± 5% RH.
Specimen ID:	Specimens are uniquely identified for quality and traceability purposes using the format PPPP_MMM-EEEE-TT_XX, where P is the product (C400H or C400HM); M is the mechanical property (TNS for tensile strength); E is the aging exposure (SW140 for immersion in saltwater at 140ºF); T is the time of exposure (01, 03, 07, 10 for 1000, 3000, 7000, and 10000 hrs); and X is specimen number (1 to 5).

Table 1.1 – Test Matrix For Tensile Testing

Specimen ID	Material Identification Lot /Batch/Roll # and Fabrication	Aging Exposure Start (mm.dd.yy)	Aging Exposure Finish (mm.dd.yy)	Test date (mm.dd.yy)
C400H_TNS-SW140-01_01 to 05	V-Wrap C400H Lot# 23193, Roll#1071 V-Wrap 770 A: 16-6157670 V-Wrap 770 B: 16-6157671 Made 11/18/2016	12.26.16	02.06.17	02.17.17
C400H_TNS-SW140-03_01 to 05			04.30.17	05.16.17
C400H_TNS-SW140-07_01 to 05		01.17.17	11.04.17	11.20.17
C400H_TNS-SW140-10_01 to 05			03.09.18	03.12.18
C400HM_TNS-SW140-01_01 to 05	V-Wrap C400HM Lot# 23854 V-Wrap 770 A: 16-6157670 V-Wrap 770 B: 16-6157671 Made 12/9/2016	12.26.16	02.06.17	02.17.17
C400HM_TNS-SW140-03_01 to 05			04.30.17	05.16.17
C400HM_TNS-SW140-07_01 to 05		01.17.17	11.04.17	11.20.17
C400HM_TNS-SW140-10_01 to 05			03.09.18	03.12.18

1.2. TEST RESULTS

Table 1.2 – Average Reference Unaged Experimental V-Wrap FRP Tensile Properties

V-Wrap FRP System	Strength F^{tu}		Modulus E^{chord}		Ultimate Strain ε_u
	MPa	*ksi*	*GPa*	*Msi*	*%*
C400H	1365	198	75.1	10.89	1.82
C400HM	1241	180	98.1	14.24	1.27

Table 1.3 – Residual Tensile Test Results for C400H and C400HM fabrics with V-Wrap 770 resin, per ASTM D3039 post Aging by Immersion in Saltwater at 140ºF for 1,000 hrs

Specimen ID	*Average width, w*		Area, *A*		*Peak load, P^{max}*		*Load/unit width, P^{max} / w*		Strength, F^{tu}		Modulus, E^{chord}		Ultimate Strain, ε_u	Failure Mode*	Residual Properties⁺ F^{tu}	Residual Properties⁺ E^{chord}	Residual Properties⁺ ε_u
	mm	*in.*	*mm²*	*in²*	*kN*	*lbs*	*kN/mm*	*lbs/in.*	*MPa*	*ksi*	*GPa*	*Msi*	*%*		%	%	%
C400H_TNS-SW140-01_01	18.52	0.729	37.63	0.058	49.65	11157	2.68	15305	1319.0	191.3	83.1	12.06	1.59	M(S,D)GM	97	111	87
C400H_TNS-SW140-01_02	18.82	0.741	38.25	0.059	53.73	12075	2.85	16296	1404.4	203.7	81.2	11.78	1.73	SGM	103	108	95
C400H_TNS-SW140-01_03	17.45	0.687	35.46	0.055	47.86	10754	2.74	15654	1349.1	195.7	87.1	12.64	1.55	M(S,D)GT	99	116	85
C400H_TNS-SW140-01_04	17.91	0.705	36.39	0.056	47.61	10699	2.66	15176	1307.9	189.7	76.3	11.07	1.71	M(S,D)GM	96	102	94
C400H_TNS-SW140-01_05	19.08	0.751	38.76	0.060	49.62	11151	2.60	14848	1279.7	185.6	79.5	11.53	1.61	SGM	94	106	88
Average	**18.35**	**0.723**	**37.30**	**0.058**	**49.69**	**11167**	**2.71**	**15456**	**1332.0**	**193.2**	**81.4**	**11.82**	**1.64**		**98**	**108**	**90**
S_{n-1}	0.67	0.026	1.36	0.002	2.45	551	0.10	551	47.5	6.9	4.0	0.59	0.08				
CV((%)	3.6	3.6	3.6	3.6	4.9	4.9	3.6	3.6	3.6	3.6	5.0	5.0	4.9				
C400HM_TNS-SW140-01_01	23.04	0.907	46.81	0.073	72.38	16266	3.14	17934	1545.6	224.2	106.7	15.48	1.45	SGM	125	109	114
C400HM_TNS-SW140-01_02	22.17	0.873	45.06	0.070	72.67	16331	3.28	18707	1612.2	233.8	113.8	16.51	1.42	SGM	130	116	112
C400HM_TNS-SW140-01_03	24.41	0.961	49.60	0.077	78.45	17630	3.21	18345	1581.1	229.3	112.4	16.31	1.41	SGV	127	115	111
C400HM_TNS-SW140-01_04	21.67	0.853	44.03	0.068	68.35	15360	3.15	18007	1551.9	225.1	112.3	16.29	1.38	SGB	125	114	109
C400HM_TNS-SW140-01_05	23.67	0.932	48.10	0.075	78.36	17608	3.31	18893	1628.3	236.2	114.6	16.63	1.42	SGV	131	117	112
Average	**22.99**	**0.905**	**46.72**	**0.072**	**74.04**	**16639**	**3.22**	**18377**	**1583.8**	**229.7**	**112.0**	**16.24**	**1.41**		**128**	**114**	**111**
S_{n-1}	1.11	0.044	2.25	0.003	4.33	974	0.07	421	36.3	5.3	3.1	0.45	0.02				
CV((%)	4.8	4.8	4.8	4.8	5.9	5.9	2.3	2.3	2.3	2.3	2.8	2.8	1.7				

**Failure mode based on ASTM D3039, refer to Figure 1.1.*
⁺Residual properties computed based on the average of 20 experimental test repetitions of unaged (control) tests as reported in Table 1.2

Table 1.4 – Residual Tensile Test Results for C400H and C400HM fabrics with V-Wrap 770 resin, per ASTM D3039 post Aging by Immersion in Saltwater at 140ºF for 3,000 hrs

Specimen ID	Average width, w		Area, A		Peak load, P^{max}		Load/unit width, P^{max} / w		Strength, F^{tu}		Modulus, E^{chord}		Ultimate Strain, ε_u	Failure Mode*	Residual Properties⁺		
															F^{tu}	E^{chord}	ε_u
	mm	in.	mm²	in²	kN	lbs	kN/mm	lbs/in.	MPa	ksi	GPa	Msi	%		%	%	%
C400H_TNS-SW140-03_01	22.91	0.902	46.55	0.072	64.51	14497	2.82	16072	1385.2	200.9	81.6	11.84	1.70	M(S,D)GT	101	109	93
C400H_TNS-SW140-03_02	20.98	0.826	42.63	0.066	60.68	13635	2.89	16507	1422.7	206.3	76.6	11.11	1.86	SGB	104	102	102
C400H_TNS-SW140-03_03	18.29	0.720	37.16	0.058	49.86	11205	2.73	15563	1341.2	194.5	75.9	11.02	1.77	M(S,D)GM	98	101	97
C400H_TNS-SW140-03_04	21.41	0.843	43.51	0.067	60.78	13659	2.84	16203	1396.4	202.5	93.8	13.62	1.49	M(S,D)GV	102	125	82
C400H_TNS-SW140-03_05	20.22	0.796	41.08	0.064	54.60	12270	2.70	15415	1328.5	192.7	75.9	11.01	1.75	SGM	97	101	96
Average	**20.76**	**0.817**	**42.19**	**0.065**	**58.09**	**13053**	**2.79**	**15952**	**1374.8**	**199.4**	**80.8**	**11.72**	**1.71**		**101**	**108**	**94**
S_{n-1}	1.70	0.067	3.45	0.005	5.81	1306	0.08	454	39.2	5.7	7.7	1.12	0.14				
CV((%)	8.2	8.2	8.2	8.2	10.0	10.0	2.8	2.8	2.8	2.8	9.5	9.5	8.1				
C400HM_TNS-SW140-03_01	23.39	0.921	47.54	0.074	71.66	16104	3.06	17485	1507.0	218.6	94.1	13.66	1.60	SGM	121	96	126
C400HM_TNS-SW140-03_02	26.47	1.042	53.78	0.083	84.28	18940	3.18	18177	1566.5	227.2	93.2	13.52	1.68	SGV	126	95	132
C400HM_TNS-SW140-03_03	23.32	0.918	47.38	0.073	74.44	16729	3.19	18223	1570.6	227.8	101.6	14.74	1.55	SGV	127	104	122
C400HM_TNS-SW140-03_04	26.19	1.031	53.21	0.082	83.56	18777	3.19	18212	1569.6	227.7	101.7	14.76	1.54	SGT	126	104	121
C400HM_TNS-SW140-03_05	23.70	0.933	48.15	0.075	70.65	15876	2.98	17016	1466.5	212.7	96.9	14.06	1.51	SGV	118	99	119
Average	**24.61**	**0.969**	**50.01**	**0.078**	**76.92**	**17285**	**3.12**	**17823**	**1536.0**	**222.8**	**97.5**	**14.15**	**1.58**		**124**	**99**	**124**
S_{n-1}	1.57	0.062	3.20	0.005	6.55	1471	0.10	548	47.2	6.9	4.0	0.58	0.07				
CV((%)	6.4	6.4	6.4	6.4	8.5	8.5	3.1	3.1	3.1	3.1	4.1	4.1	4.2				

**Failure mode based on ASTM D3039, refer to Figure 1.1.*
⁺Residual properties computed based on the average of 20 experimental test repetitions of unaged (control) tests as reported in Table 1.2

Table 1.5 – Residual Tensile Test Results for C400H and C400HM fabrics with V-Wrap 770 resin, per ASTM D3039 post Aging by Immersion in Saltwater at 140ºF for 7,000 hrs

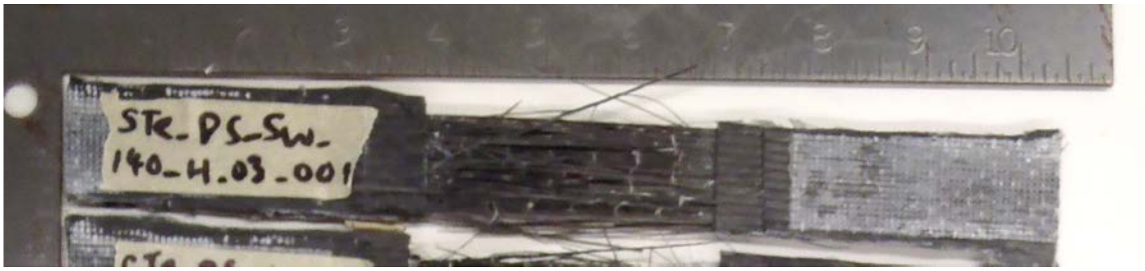
Specimen ID	*Average width, w*		*Area, A*		*Peak load, P^{max}*		*Load/unit width, P^{max} / w*		**Strength, F^{tu}**		**Modulus, E^{chord}**		**Ultimate Strain, ε_u**	**Failure Mode***	**Residual Properties⁺**		
															F^{tu}	E^{chord}	ε_u
	mm	*in.*	*mm²*	*in²*	*kN*	*lbs*	*kN/mm*	*lbs/in.*	*MPa*	*ksi*	*GPa*	*Msi*	*%*		%	%	%
C400H_TNS-SW140-07_01	17.90	0.705	36.37	0.056	50.94	11447	2.85	16243	1399.9	203.0	90.1	13.08	1.55	SGM	103	120	85
C400H_TNS-SW140-07_02	18.34	0.722	37.26	0.058	52.33	11759	2.85	16287	1403.7	203.6	83.5	12.11	1.68	SGM	103	111	92
C400H_TNS-SW140-07_03	18.92	0.745	38.45	0.060	54.36	12216	2.87	16397	1413.2	205.0	85.6	12.43	1.65	SGM	104	114	91
C400H_TNS-SW140-07_04	17.55	0.691	35.66	0.055	55.11	12385	3.14	17923	1544.7	224.0	95.9	13.91	1.61	SGM	113	128	88
C400H_TNS-SW140-07_05	17.55	0.691	35.66	0.055	48.28	10849	2.75	15700	1353.1	196.3	89.7	13.01	1.51	SGM	99	119	83
Average	**18.05**	**0.711**	**36.68**	**0.057**	**52.20**	**11731**	**2.89**	**16510**	**1422.9**	**206.4**	**89.0**	**12.91**	**1.60**		**104**	**119**	**88**
S_{n-1}	0.58	0.023	1.19	0.002	2.75	617	0.15	835	71.9	10.4	4.8	0.69	0.07				
CV((%)	3.2	3.2	3.2	3.2	5.3	5.3	5.1	5.1	5.1	5.1	5.4	5.4	4.4				
C400HM_TNS-SW140-07_01	22.50	0.886	45.73	0.071	74.27	16690	3.30	18837	1623.5	235.5	100.9	14.64	1.61	DGM, SGV	131	103	127
C400HM_TNS-SW140-07_02	21.82	0.859	44.34	0.069	69.18	15545	3.17	18097	1559.6	226.2	107.5	15.60	1.45	DGM, SGV	126	110	114
C400HM_TNS-SW140-07_03	21.79	0.858	44.28	0.069	72.50	16293	3.33	18990	1636.6	237.4	105.5	15.31	1.55	DGM, SGV	132	108	122
C400HM_TNS-SW140-07_04	23.39	0.921	47.54	0.074	81.98	18423	3.50	20003	1724.0	250.0	91.2	13.23	1.89	DGM, SGV	139	93	149
C400HM_TNS-SW140-07_05	22.48	0.885	45.68	0.071	72.69	16335	3.23	18458	1590.8	230.7	108.3	15.71	1.47	DGM, SGV	128	110	116
Average	**22.40**	**0.882**	**45.51**	**0.071**	**74.12**	**16657**	**3.31**	**18877**	**1626.9**	**236.0**	**102.7**	**14.90**	**1.59**		**131**	**105**	**125**
S_{n-1}	0.65	0.026	1.33	0.002	4.77	1072	0.13	719	62.0	9.0	7.0	1.02	0.18				
CV((%)	2.9	2.9	2.9	2.9	6.4	6.4	3.8	3.8	3.8	3.8	6.9	6.9	11.2				

**Failure mode based on ASTM D3039, refer to Figure 1.2.*
⁺Residual properties computed based on the average of 20 experimental test repetitions of unaged (control) tests as reported in Table 1.2

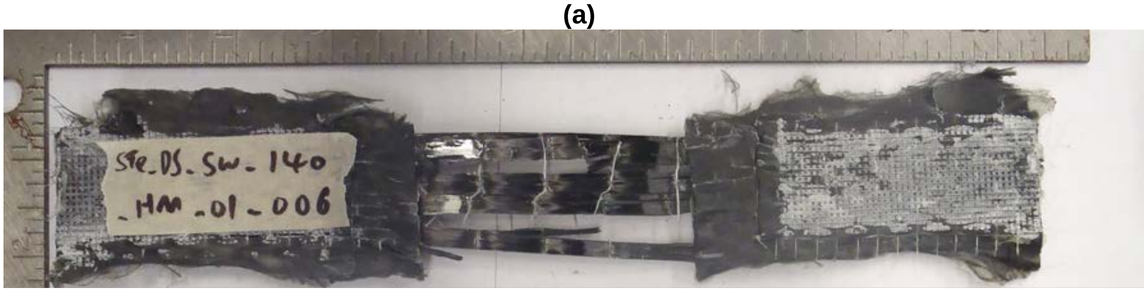
Table 1.6 – Residual Tensile Test Results for C400H and C400HM fabrics with V-Wrap 770 resin, per ASTM D3039 post Aging by Immersion in Saltwater at 140ºF for 10,000 hrs

Specimen ID	*Average width, w*		*Area, A*		*Peak load, P^{max}*		*Load/unit width, P^{max} / w*		Strength, F^{tu}		Modulus, E^{chord}		Ultimate Strain, ε_u	Failure Mode*	Residual Properties+		
															F^{tu}	E^{chord}	ε_u
	mm	*in.*	*mm²*	*in²*	*kN*	*lbs*	*kN/mm*	*lbs/in.*	*MPa*	*ksi*	*GPa*	*Msi*	*%*		%	%	%
C400H_TNS-SW140-10_01	17.17	0.676	34.89	0.054	47.06	10576	2.74	15645	1348.4	195.6	74.2	10.77	1.82	SGM	99	99	100
C400H_TNS-SW140-10_02	18.03	0.710	36.65	0.057	48.52	10903	2.69	15356	1323.5	192.0	79.4	11.51	1.67	SGM	97	106	92
C400H_TNS-SW140-10_03	17.73	0.698	36.03	0.056	46.12	10364	2.60	14848	1279.7	185.6	74.8	10.86	1.71	SGM	94	100	94
C400H_TNS-SW140-10_04	18.26	0.719	37.11	0.058	46.09	10358	2.52	14406	1241.6	180.1	68.6	9.96	1.81	SGM	91	91	99
C400H_TNS-SW140-10_05	17.50	0.689	35.56	0.055	44.05	9898	2.52	14366	1238.1	179.6	73.8	10.71	1.68	SGM	91	98	92
Average	**17.74**	**0.698**	**36.05**	**0.056**	**46.37**	**10420**	**2.61**	**14924**	**1286.2**	**186.6**	**74.2**	**10.76**	**1.74**		**94**	**99**	**95**
S_{n-1}	0.43	0.017	0.87	0.001	1.63	366	0.10	568	49.0	7.1	3.8	0.55	0.07				
CV((%)	2.4	2.4	2.4	2.4	3.5	3.5	3.8	3.8	3.8	3.8	5.1	5.1	4.1				
C400HM_TNS-SW140-10_01	21.67	0.853	44.03	0.068	65.82	14790	3.04	17339	1494.3	216.7	110.8	16.07	1.35	M(S,A)GM	120	113	106
C400HM_TNS-SW140-10_02	22.10	0.870	44.90	0.070	64.28	14444	2.91	16602	1430.9	207.5	100.5	14.58	1.42	SGM	115	102	112
C400HM_TNS-SW140-10_03	24.00	0.945	48.77	0.076	75.74	17021	3.16	18012	1552.3	225.1	90.9	13.19	1.71	M(S,A)GT	125	93	134
C400HM_TNS-SW140-10_04	23.93	0.942	48.62	0.075	69.33	15580	2.90	16539	1425.4	206.7	95.9	13.91	1.49	M(S,A)GT	115	98	117
C400HM_TNS-SW140-10_05	22.96	0.904	46.66	0.072	66.83	15018	2.91	16613	1431.8	207.7	102.3	14.85	1.40	SGM	115	104	110
Average	**22.93**	**0.903**	**46.60**	**0.072**	**68.40**	**15371**	**2.98**	**17021**	**1466.9**	**212.8**	**100.1**	**14.52**	**1.47**		**118**	**102**	**116**
S_{n-1}	1.05	0.041	2.14	0.003	4.50	1011	0.11	643	55.5	8.0	7.4	1.08	0.14				
CV((%)	4.6	4.6	4.6	4.6	6.6	6.6	3.8	3.8	3.8	3.8	7.4	7.4	9.5				

1.3 VISUAL DOCUMENTATION

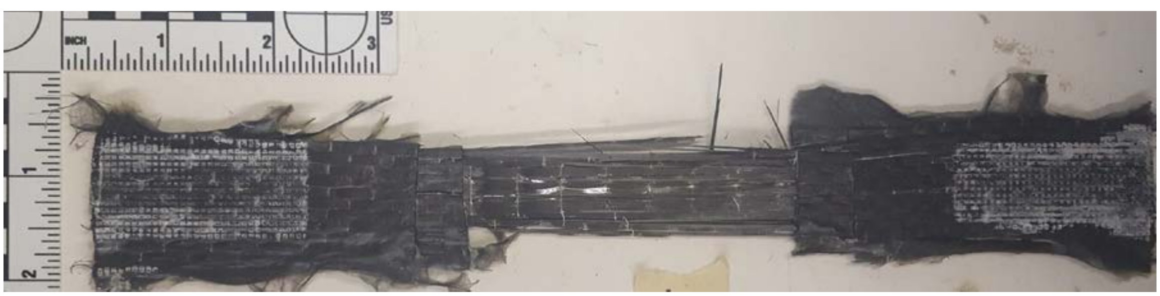


(a)



(b)

Figure 1.1 – 1000 and 3000 hrs exposure representative failure modes a) C400H: ‘M(S,D)GV’ and b) C400HM: ‘SGV.’ Where ‘M’ is multiple mode ‘S for longitudinal and ‘X’ for explosive; ‘G’ is at failure at gauge area; and V is various (either ‘M, T or B’ for middle, top or bottom locations). Scale in inches



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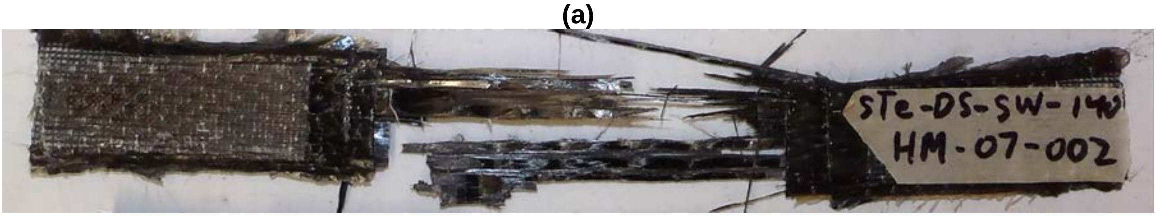

(b)

Figure 1.2 – 7000 and 10000 hrs exposure representative failure modes a) C400H: ‘SGM’ and b) C400HM: ‘M(S,A)GV.’ Where ‘S for longitudinal and ‘A’ for angled; ‘G’ is at failure at gauge area; and V is various (either ‘M, T or B’ for middle, top or bottom locations). Scale in inches

♦ END OF TEST REPORT ♦

CERTIFIED TEST REPORT

AGING EVALUATION OF FRP V-WRAP C400HM/770 STRENGTHENING COMPOSITE SYSTEM - As per acceptance criteria AC125 -

Report Number: R-5.10_C4H77_AC125
Date: December 8, 2015

REPORT PREPARED FOR:

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Vice President - Engineering Services
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Quality System: The Structures and Materials Laboratory (SML) maintains a quality system in compliance with ISO 17025-2005, accredited under International Accreditation Service (IAS), testing laboratory, TL-478

Procedures: All tests and services are done in accordance with the SML Quality Manual (Version 2.2) revised March 18, 2013; relevant standard operating procedures (SOPs); and with the applicable requirements of the reference standard test methods.

Test Data: All the test results presented herein are linked through unbroken chain to the raw data files recorded on the day of the test. Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results of each test.

Controls:	
Superseded Report	new
Reason for Revision	n/a
Effective Date	December 8, 2015

Test Report Approval Signatures:	
Quality review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Francisco De Caso Signature: Date: December 8, 2015
Technical review Approval	I indicate that I have reviewed this Test Report and agree with the technical contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Antonio Nanni Signature: Date: December 8, 2015

TABLE OF CONTENTS

1. TENSILE PROPERTIES – ASTM D3039

1.1. TEST SUMMARY INFORMATION

Test Objective:	Determine the tensile properties of polymer matrix composite materials after exposure to: a) Freeze thaw (FT) cycles; where each cycle consisted of a minimum of 4 hours in a freeze-thaw chamber at -18°C (0°F) followed by a minimum of 12 hours in a humidity chamber at 38°C (100°F) with 100% relative humidity (according to AC125 Section 5.10). b) Water resistance (WR) environment, at a temperature of 38 ± 2°C (100 ± 4°F) and 100% relative humidity, for a duration period of 3000 hours prior testing (according to ASTM D2247). c) Salt water resistance (SW) environment, submerged in a salt water tank at a temperature of 23 ± 2°C (73 ± 2°F), for a duration period of 3000 hours prior testing (according to ASTM D1141). d) Alkaline resistance (AR) environment, submerged in an alkali solution $Ca(CO_3)$ environmental chamber at a constant temperature of 23 ± 2°C (73 ± 2°F) for a duration period of 3000 hours prior testing (according to ASTM C581). e) Dry heat (DH) resistance, in an environmental chamber at a constant temperature of 60 ± 2°C (140 ± 5°F) for a duration period of 3000 hours prior testing (according to ASTM D3045). Note all conditions of acceptance are based on AC125-2013.
Test Standard Method/s:	ASTM D3039/D3039M – 14
Test Set-up:	Displacement load rate of 2 mm/min (0.05 in./min); grip pressure of 34.5 MPa (5000 psi).
Product:	V-Wrap C400HM fabric with V-Wrap 770 resin
Test Location:	SML
Analyst:	Keith Holmes, Alexis Wells and Diana Arboleda
Text Matrix:	Refer to Table 1.1
Sample Dimensions:	Refer to Table 1.2
Sample Preparation:	SML

Specimen ID: Specimens are labeled and uniquely identified for quality and traceability in this report using the format PPPP_MMM_EE_XX_RRR, where P refers to the product (C4H77); M refers to the mechanical property (TNS for tensile properties); EE refers to the environmental aging exposure (FT for Freeze Thaw, WR for water resistance, SW for Seawater resistance, AR for alkaline resistance, and DH for dry heat resistance); XX refers to the exposure period (03 for 3000 hrs); and RRR refers to the sample repetition number.

Table 1.1 – Test Matrix For Tensile Testing

Specimen ID	Specimen #	Batch/Lot # Fiber #	Batch/Lot # Resin A/B #	Specimen Tested (mm.dd.yy)
C4H77_TNS_FT_00_001 to 005	5	23460/258	Part A: 14-5920036 Part B: 14-5919301	09.03.15
C4H77_TNS_WR_03_001 to 005	5			09.07.15
C4H77_TNS_SW_03_001 to 005	5			09.04.15
C4H77_TNS_AR_03_001 to 005	5			09.09.15
C4H77_TNS_DH_03_001 to 005	5			09.10.15

Table 1.2 – Tensile Specimen Nominal Dimensions

ID	Length *mm*	Length *in*	Width *mm*	Width *in*	Thickness *mm*	Thickness *in*
C4H77_TNS_FT_001 to 005 C4H77_TNS_WR_001 to 005 C4H77_TNS_SW_001 to 005 C4H77_TNS_AR_001 to 005 C4H77_TNS_DH_001 to 005	254.0	10.0	25.4	1.0	2.03	0.08

1.2. TEST RESULTS

Table 1.3 - Tensile Test Results (ASTM D3039) for V-Wrap C400HM/770 post freezing and thawing conditioning (AC125, Section 5.10)

Specimen ID	*A*		*P^max^*		*F^tu^*		*E^chord^*		ε_u	FM	% Retention*		
	mm²	in²	kN	lbs	MPa	ksi	GPa	Msi	%		ε_u	F^{tu}	E^{chord}
C4H77_TNS_FT_001	50.322	0.078	83.05	18663	1649.70	239.27	117.92	17.11	1.40	SGM	95	97	102
C4H77_TNS_FT_002	51.871	0.080	93.49	21008	1801.56	261.29	116.95	16.97	1.54	AGM	105	106	101
C4H77_TNS_FT_003	54.503	0.084	86.76	19496	1591.15	230.78	113.09	16.41	1.41	AGM	96	94	98
C4H77_TNS_FT_004	52.129	0.081	93.71	21058	1796.90	260.62	121.16	17.58	1.48	AGM	101	106	105
C4H77_TNS_FT_005	51.768	0.080	88.66	19924	1712.00	248.31	109.86	15.94	1.56	SGM	106	101	95
Average	52.119	0.081	89.13	20030	1710.26	248.05	115.80	16.80	1.48		101	101	100
S_{n-1}	1.508	0.002	4.55	1022	91.79	13.31	4.39	0.64	0.07				
CV((%)	2.9	2.9	5.1	5.1	5.4	5.4	3.8	3.8	5.0				

**Condition of acceptance is equivalent to 90% retention*

Table 1.4 - Tensile Test Results (ASTM D3039) for V-Wrap C400HM/770 post water resistance conditioning (ASTM D2247)

Specimen ID	*A*		*P^max^*		*F^tu^*		*E^chord^*		ε_u	FM	Exposure	% Retention*		
	mm²	in²	kN	lbs	MPa	ksi	GPa	Msi	%		hrs	ε_u	F^{tu}	E^{chord}
C4H77_TNS_WR_001	52.026	0.081	84.94	19087	1631.95	236.69	114.06	16.55	1.43	AGM	3000	98	96	99
C4H77_TNS_WR_002	61.471	0.095	92.48	20783	1503.92	218.13	110.82	16.08	1.36	SGM	3000	92	89	96
C4H77_TNS_WR_003	54.039	0.084	89.49	20110	1655.37	240.09	117.09	16.99	1.41	AGM	3000	96	98	101
C4H77_TNS_WR_004	50.529	0.078	73.84	16593	1460.73	211.86	110.13	15.98	1.33	SGM	3000	90	86	95
C4H77_TNS_WR_005	57.187	0.089	93.42	20994	1632.99	236.85	117.44	17.04	1.39	AGM	3000	95	96	102
Average	55.050	0.085	86.83	19513	1576.99	228.72	113.91	16.53	1.38			94	93	98
S_{n-1}	4.370	0.007	7.98	1794	88.25	12.80	3.41	0.49	0.04					
CV((%)	7.9	7.9	9.2	9.2	5.6	5.6	3.0	3.0	3.1					

**Condition of acceptance is equivalent to 85% retention post 3000hrs exposure*

Table 1.5 - Tensile Test Results (ASTM D3039) for V-Wrap C400HM/770 post salt water resistance conditioning (ASTM D1141)

Specimen ID	A		P^{max}		F^{tu}		E^{chord}		ε_u	FM	Exposure	% Retention*		
	mm²	in²	kN	lbs	MPa	ksi	GPa	Msi	%		hrs	ε_u	F^{tu}	E^{chord}
C4H77_TNS_SW_001	49.393	0.077	80.14	18008	1621.75	235.21	124.05	18.00	1.31	AGM	3000	89	96	107
C4H77_TNS_SW_002	47.587	0.074	75.49	16964	1585.72	229.99	106.00	15.38	1.50	XGM	3000	102	94	92
C4H77_TNS_SW_003	50.529	0.078	84.75	19045	1676.59	243.17	116.06	16.84	1.44	AGM	3000	98	99	100
C4H77_TNS_SW_004	49.084	0.076	78.08	17545	1590.02	230.61	115.78	16.80	1.37	SGM	3000	94	94	100
C4H77_TNS_SW_005	54.039	0.084	89.03	20007	1646.89	238.86	118.54	17.20	1.39	AGM	3000	95	97	102
Average	50.126	0.078	81.50	18314	1624.19	235.57	116.09	16.84	1.40			96	96	100
S_{n-1}	2.426	0.004	5.41	1215	38.45	5.58	6.55	0.95	0.07					
CV((%)	4.8	4.8	6.6	6.6	2.4	2.4	5.6	5.6	5.1					

**Condition of acceptance is equivalent to 85% retention post 3000hrs exposure*

Table 1.6 - Tensile Test Results (ASTM D3039) for V-Wrap C400HM/770 post alkaline resistance conditioning (ASTM C581)

Specimen ID	A		P^{max}		F^{tu}		E^{chord}		ε_u	FM	Exposure	% Retention*		
	mm²	in²	kN	lbs	MPa	ksi	GPa	Msi	%		hrs	ε_u	F^{tu}	E^{chord}
C4H77_TNS_AR_001	56.929	0.088	90.98	20445	1597.50	231.70	118.68	17.22	1.35	XGM	3000	92	94	103
C4H77_TNS_AR_002	51.871	0.080	86.32	19398	1663.49	241.27	124.26	18.03	1.34	XGM	3000	91	98	107
C4H77_TNS_AR_003	51.355	0.080	84.94	19088	1653.36	239.80	113.65	16.49	1.45	SGM	3000	99	98	98
C4H77_TNS_AR_004	51.458	0.080	80.58	18107	1565.24	227.02	114.27	16.58	1.37	AGM	3000	93	92	99
C4H77_TNS_AR_005	57.755	0.090	87.06	19563	1506.73	218.53	112.61	16.34	1.34	AGM	3000	91	89	97
Average	53.873	0.084	85.97	19320	1597.26	231.66	116.69	16.93	1.37			93	94	101
S_{n-1}	3.185	0.005	3.76	845	64.72	9.39	4.82	0.70	0.05					
CV((%)	5.9	5.9	4.4	4.4	4.1	4.1	4.1	4.1	3.6					

**Condition of acceptance is equivalent to 85% retention post 3000hrs exposure*

Table 1.7 - Tensile Test Results (ASTM D3039) for V-Wrap C400HM/770 post dry heat conditioning (ASTM D3045)

Specimen ID	A		P^{max}		F^{tu}		E^{chord}		ε_u	FM	Exposure	% Retention*		
	mm^2	*in^2*	*kN*	*lbs*	*MPa*	*ksi*	*GPa*	*Msi*	*%*		*hrs*	ε_u	F^{tu}	E^{chord}
C4H77_TNS_DH_001	53.729	0.083	88.21	19823	1641.15	238.03	122.61	17.79	1.34	AGM	3000	91	97	106
C4H77_TNS_DH_002	50.993	0.079	81.86	18396	1604.71	232.74	117.08	16.99	1.37	SGL	3000	93	95	101
C4H77_TNS_DH_003	51.148	0.079	88.38	19861	1727.26	250.52	131.01	19.01	1.32	XGM	3000	90	102	113
C4H77_TNS_DH_004	48.981	0.076	75.41	16947	1539.06	223.22	121.85	17.68	1.26	AGM	3000	86	91	105
C4H77_TNS_DH_005	54.400	0.084	84.77	19049	1557.62	225.91	118.19	17.15	1.32	AGM	3000	90	92	102
Average	51.850	0.080	83.73	18815	1613.96	234.08	122.15	17.72	1.32			90	95	106
S_{n-1}	2.207	0.003	5.37	1207	74.91	10.86	5.48	0.80	0.04					
CV((%)	4.3	4.3	6.4	6.4	4.6	4.6	4.5	4.5	3.0					

**Condition of acceptance is equivalent to 85% retention post 3000hrs exposure*

2. BOND STRENGTH SHEAR – LABORATORY METHOD

2.1. TEST SUMMARY INFORMATION

Test Objective: Determine the shear bond strength to concrete substrate of the FRP systems under after exposure to:

a) Freeze thaw (FT) cycles; where each cycle consisted of a minimum of 4 hours in a freeze-thaw chamber at -18°C (0°F) followed by a minimum of 12 hours in a humidity chamber at 38°C (100°F) with 100% relative humidity (according to AC125 Section 5.10).

b) Water resistance (WR) environment, at a temperature of 38 ± 2°C (100 ± 4°F) and 100% relative humidity, for a duration period of 3000 hours prior testing (according to ASTM D2247).

c) Salt water resistance (SW) environment, submerged in a salt water tank at a temperature of 23 ± 2°C (73 ± 2°F), f for a duration period of 3000 hours prior testing (according to ASTM D1141).

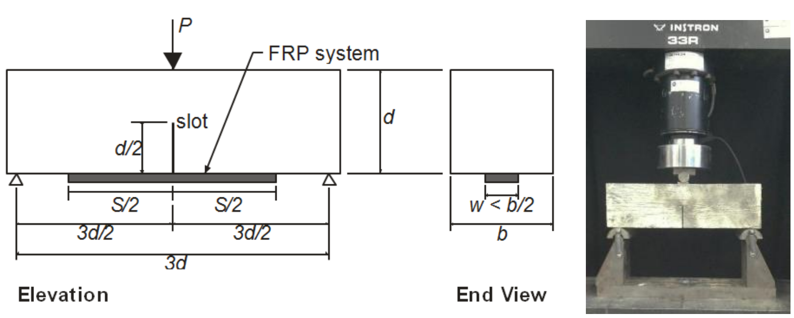
d) Alkaline resistance (AR) environment, submerged in an alkali solution $Ca(CO_3)$ environmental chamber at a constant temperature of 23 ± 2°C (73 ± 2°F) for a duration period of 3000 hours prior testing (according to ASTM C581).

e) Dry heat (DH) resistance, in an environmental chamber at a constant temperature of 60 ± 2°C (140 ± 5°F) for a duration period of 3000 hours prior testing (according to ASTM D3045).

Note all conditions of acceptance are based on AC125-2013.

Test Standard Method/s: An internal laboratory developed standard test procedure was used for the shear bond strength test derived from a test method currently under evaluation by ACI and an ASTM (Standard Test Method for Evaluation of Performance for FRP Bonded to Concrete Substrate using Beam Test). Refer to Figure 2.1. The concrete substrate 28 day compressive strength as determined by ASTM C39/C39M-14 (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens), was equivalent to 38.02 MPa (5514 psi) based on 5 compressive cylinder tests.

Test Set-up:	Displacement load rate of 0.5 mm/min (0.02 in./min), to ensure failure within 1 to 10 minutes. Refer to Figure 2.1.
Product:	V-Wrap C400HM fabric with V-Wrap 770 resin
Test Location:	SML
Analyst:	Keith Holmes and Christian Marquina
Text Matrix:	Refer to Table 2.1
Sample Dimensions:	The FRP system was applied on plain concrete beams of nominal dimension equivalent to 350 mm (14 in.) long, with a square cross-section of 100 mm (4 in.). The concrete surface was strengthened with one ply of FRP strip with nominal dimensions of 203 mm (8.00 in.) long by 25 mm (1.0 in.) wide. Before the installation of the FRP strengthening system the concrete substrate surface was prepared to ensure proper surface roughness of CSP 3, as defined by ICRI.
Sample Preparation:	SML
Specimen ID:	Specimens are labeled and uniquely identified for quality and traceability in this report using the format PPPP_MMM_EE_XX_RRR, where P refers to the product (C4H77); M refers to the mechanical property (BSC for shear bond strength on concrete); EE refers to the environmental aging exposure (FT for Freeze Thaw, WR for water resistance, SW for Seawater resistance, AR for alkaline resistance, and DH for dry heat resistance); XX refers to the exposure period (03 for 3000 hrs); and RRR refers to the sample repetition number.



(a) (b)

Figure 2.1 - Shear bond specimen layout (a); and test set up (Lab method) (b).

Table 2.1 – Test Matrix for Shear Bond Strength Testing

Specimen ID	Specimen #	Batch/Lot # Fiber #	Batch/Lot # Resin A/B #	Specimen Tested (mm.dd.yy)
C4H77_BSC_FT_00_001 to 005	5	23460/258	Part A: 14-5920036 Part B: 14-5919301	09.03.15
C4H77_BSC_WR_03_001 to 005	5			09.04.15
C4H77_BSC_SW_03_001 to 005	5			09.03.15
C4H77_BSC_AR_03_001 to 005	5			09.08.15
C4H77_BSC_DH_03_001 to 005	5			09.11.15

Table 2.2 – Shear Bond Strength Specimen Nominal Dimensions

ID	Length		Width		Thickness	
	mm	*in*	*mm*	*in*	*mm*	*in*
C4H77_BSC_FT_001 to 005 C4H77_BSC_WR_001 to 005 C4H77_BSC_SW_001 to 005 C4H77_BSC_AR_001 to 005 C4H77_BSC_DH_001 to 005	203.2	8.00	25.4	1.0	2.03	0.08

2.2. TEST RESULTS

Table 2.3 – Tabulated results for shear bond strength (Lab Method) for V-Wrap C400HM/770 post freezing and thawing conditioning (AC125, Section 5.10)

Specimen ID	*w*		*S*		*P*		τ_d		*Failure Mode*	*Pass/Fail**
	mm	*in*	mm	*in*	*kN*	*lbf*	*MPa*	*psi*		τ_d
C4H77_BSC_FT_001	25.40	1.00	203.20	8.00	9.73	2187	2.98	432	FRP debonding	Pass
C4H77_BSC_FT_002	25.40	1.00	203.20	8.00	11.16	2508	3.41	495	FRP debonding	Pass
C4H77_BSC_FT_003	25.40	1.00	203.20	8.00	8.85	1989	2.71	393	FRP debonding	Pass
C4H77_BSC_FT_004	25.40	1.00	203.20	8.00	10.40	2337	3.19	462	FRP debonding	Pass
C4H77_BSC_FT_005	25.40	1.00	203.20	8.00	10.92	2454	3.34	485	FRP debonding	Pass
Average					10.21	2295	3.13	453		
S_{n-1}					0.94	211	0.29	42		
CV((%)					9.2	9.2	9.2	9.2		

**Condition of acceptance is equivalent to τ_d > 200 psi*

Table 2.4 – Tabulated results for shear bond strength (Lab Method) for V-Wrap C400HM/770 post water resistance conditioning (ASTM D2247)

Specimen ID	*w*		*S*		*P*		τ_d		*Failure Mode*	*Exposure*	*Pass/Fail*
	mm	*in*	mm	*in*	*kN*	*lbf*	*MPa*	*psi*		*hrs.*	
C4H77_BSC_WR_001	25.40	1.00	203.20	8.00	12.92	2903	3.95	573	FRP debonding	3000	Pass
C4H77_BSC_WR_002	25.40	1.00	203.20	8.00	9.54	2144	2.92	424	FRP debonding	3000	Pass
C4H77_BSC_WR_003	25.40	1.00	203.20	8.00	10.57	2376	3.23	469	FRP debonding	3000	Pass
C4H77_BSC_WR_004	25.40	1.00	203.20	8.00	11.17	2510	3.42	496	FRP debonding	3000	Pass
C4H77_BSC_WR_005	25.40	1.00	203.20	8.00	8.93	2007	2.73	396	FRP debonding	3000	Pass
Average					10.63	2388	3.25	472			
S_{n-1}					1.55	348	0.47	69			
CV((%)					14.6	14.6	14.6	14.6			

**Condition of acceptance is equivalent to τ_d > 200 psi*

Table 2.5 Tabulated Results for shear bond strength (Lab Method) for V-Wrap C400HM/770 post salt water resistance conditioning (ASTM D1141)

Specimen ID	w		S		P		τ_d		Failure Mode	Exposure	Pass/Fail*
	mm	in	mm	in	kN	lbf		psi		hrs.	
C4H77_BSC_SW_001	25.40	1.00	203.20	8.00	9.42	2116	2.88	418	FRP debonding	3000	Pass
C4H77_BSC_SW_002	25.40	1.00	203.20	8.00	13.43	3018	4.11	596	FRP debonding	3000	Pass
C4H77_BSC_SW_003	25.40	1.00	203.20	8.00	12.34	2774	3.78	548	FRP debonding	3000	Pass
C4H77_BSC_SW_004	25.40	1.00	203.20	8.00	11.08	2491	3.39	492	FRP debonding	3000	Pass
C4H77_BSC_SW_005	25.40	1.00	203.20	8.00	11.61	2608	3.55	515	FRP debonding	3000	Pass
Average					11.58	2601	3.54	514			
S_{n-1}					1.49	336	0.46	66			
CV((%)					12.9	12.9	12.9	12.9			

**Condition of acceptance is equivalent to τ_d > 200 psi*

Table 2.6 - Tabulated Results for shear bond strength (Lab Method) for V-Wrap C400HM/770 post alkaline resistance conditioning (ASTM C581)

Specimen ID	w		S		P		τ_d		Failure Mode	Exposure	Pass/Fail*
	mm	in	mm	in	kN	lbf		psi		hrs.	
C4H77_BSC_AR_001	25.40	1.00	203.20	8.00	10.04	2256	3.08	446	FRP debonding	3000	Pass
C4H77_BSC_AR_002	25.40	1.00	203.20	8.00	11.09	2493	3.39	492	FRP debonding	3000	Pass
C4H77_BSC_AR_003	25.40	1.00	203.20	8.00	9.61	2159	2.94	427	FRP debonding	3000	Pass
C4H77_BSC_AR_004	25.40	1.00	203.20	8.00	9.11	2047	2.79	404	FRP debonding	3000	Pass
C4H77_BSC_AR_005	25.40	1.00	203.20	8.00	11.17	2509	3.42	496	FRP debonding	3000	Pass
Average					10.20	2293	3.12	453			
S_{n-1}					0.91	204	0.28	40			
CV((%)					8.9	8.9	8.9	8.9			

**Condition of acceptance is equivalent to τd > 200 psi*

Table 2.7 - Tabulated Results for shear bond strength (Lab Method) for V-Wrap C400HM/770 post dry heat conditioning (ASTM D3045)

Specimen ID	*w*		*S*		*P*		τ_d		*Failure Mode*	*Exposure*	*Pass/Fail**
	mm	***in***	**mm**	***in***	***kN***	***lbf***	***MPa***	***psi***		***hrs.***	
C4H77_BSC_DH_001	25.40	1.00	203.20	8.00	11.13	2502	3.41	494	FRP debonding	3000	Pass
C4H77_BSC_DH_002	25.40	1.00	203.20	8.00	11.89	2672	3.64	528	FRP debonding	3000	Pass
C4H77_BSC_DH_003	25.40	1.00	203.20	8.00	9.85	2214	3.01	437	FRP debonding	3000	Pass
C4H77_BSC_DH_004	25.40	1.00	203.20	8.00	8.93	2006	2.73	396	FRP debonding	3000	Pass
C4H77_BSC_DH_005	25.40	1.00	203.20	8.00	11.59	2604	3.54	514	FRP debonding	3000	Pass
Average					10.68	2400	3.27	474			
S_{n-1}					1.25	281	0.38	56			
CV((%)					11.7	11.7	11.7	11.7			

**Condition of acceptance is equivalent to τd > 200 psi*

Table 3– Summary results of 3000hrs aged tensile tests per ASTM D3039

Aging exposure	***FRP System***	***% retention*** ε_u	F^{tu}	E^{chord}	**Reference Table**	**Result per AC125**
Post Freezing and Thawing	C400HM	101	101	100	12.2	Pass
Post Water Resistance	C400HM	94	93	98	13.2	Pass
Post Salt Water Resistance	C400HM	96	96	100	14.2	Pass
Post-Alkali Resistance	C400HM	93	94	101	15.2	Pass
Post Dry Heat Resistance	C400HM	90	95	106	16.2	Pass

Table 4 – Summary results of 3000hrs aged shear bond tests per Lab method

Aging exposure	***FRP System***	τ_d ***MPa***	***psi***	**Reference Table**	**Result per AC125**
Post Freezing and Thawing	C400HM	3.13	453	12.3	Pass
Post Water Resistance	C400HM	3.25	472	13.3	Pass
Post Salt Water Resistance	C400HM	3.54	514	14.3	Pass
Post-Alkali Resistance	C400HM	3.12	453	15.3	Pass
Post Dry Heat Resistance	C400HM	3.27	474	16.3	Pass

♦ END OF TEST REPORT ♦

CERTIFIED TEST REPORT

EVALUATION OF COEFFICIENT OF THERMAL EXPANSION OF V-WRAP 770 RESIN - Per ASTM E831 -

Report Number: R-5.10_VW77_E831.1
Date: July 28, 2015

Revision 1

REPORT PREPARED FOR:
Tarek Alkhrdaji, PhD, PE
Vice President - Engineering Services
STRUCTURAL TECHNOLOGIES LLC.
7455 New Ridge Rd, Suite T
Hanover, Maryland 21076
Ph. 410-340-3260

Quality System: The Structures and Materials Laboratory (SML) maintains a quality system in compliance with ISO 17025-2005, accredited under International Accreditation Service (IAS), testing laboratory, TL-478

Procedures: All tests and services are done in accordance with the SML Quality Manual (Version 2.2) revised March 18, 2013; relevant standard operating procedures (SOPs); and with the applicable requirements of the reference standard test methods.

Test Data: All the test results presented herein are linked through unbroken chain to the raw data files recorded on the day of the test. Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results of each test.

Controls:	
Superseded Report	R-5.10_VW77_E831
Reason for Revision Effective Date	Addition of test data July 28, 2015
Superseded Report	new
Reason for Revision Effective Date	n/a May 6, 2014

Test Report Approval Signatures:	
Quality review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Francisco De Caso Signature: Date: July 28, 2015
Technical review Approval	I indicate that I have reviewed this Test Report and agree with the technical contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Antonio Nanni Signature: Date: July 28, 2015

1. COEFFICIENT OF THERMAL EXPANSION – ASTM E831

1.1. TEST SUMMARY INFORMATION

Test Objective:	Determine the average apparent coefficient of linear thermal expansion.
Test Standard Method/s:	ASTM E831 – 12
Test Set-up:	Heating rate, 5°C/min, in Nitrogen (UHP Grade)
Product:	V-Wrap 770 resin
Test Location:	Advanced Plastic & Material Testing, Inc.
Analyst:	Courtney Doll
Technical Test Record:	APM Reports: P140183C and P150484
Text Matrix:	Refer to Table 1.1
Sample Dimensions:	Refer to Table 1.2
Sample Preparation:	Machined by Structural Technologies
Sample Conditioning:	24+ hours at 23 ± 1°C (73 ± 3°F) and 60 ± 5% RH
Specimen ID:	Specimens are labeled and uniquely identified for quality and traceability using the format PPPP#_MMM_ XXX, where P is the product, M is the mechanical property, # is the product batch number, and X is the sample number.

Table 1.1 – Test Matrix For CTE Testing

Specimen ID	#	Batch Fiber #	Batch Resin #	Specimen Tested (mm.dd.yy)
VW77_CTE0	3	N.A.	14-5879355-A; 14-5879357-B	04.03.14
VW77_CTE1	3	N.A.	14-5924458-A; 14-5923167-B	07.24.15

Table 1.2 – CTE Specimen Nominal Dimensions

Specimen ID	Length		Width		Thickness	
	mm	*In*	*mm*	*in*	*mm*	*in*
VW77_CTE0	5.2	0.20	10	0.39	5.2	0.20
VW77_CTE1	7.0	0.26	10	0.39	7.0	0.26

1.2. TEST RESULTS

Table 1.3- CTE Results for V-Wrap 770 resin Per ASTM E831

Specimen ID	*L*		T_s		T_e		α_m	
	mm	*in*	*°C*	*°F*	*°C*	*°F*	*µm/(m·°C)*	*µin/(in°F)*
VW77_CTE0_001	4.902	0.193	-30	-22	50	122	58.8	32.7
VW77_CTE0_002	5.259	0.207	-30	-22	50	122	59.6	33.1
VW77_CTE0_003	5.381	0.212	-30	-22	50	122	59.1	32.8
VW77_CTE1_001	9.970	0.393	-30	-22	50	122	64.5	35.8
VW77_CTE1_002	9.977	0.393	-30	-22	50	122	67.2	37.3
VW77_CTE1_003	9.883	0.389	-30	-22	50	122	63.7	35.4
AVERAGE							62.2	34.5
ST.DEV.							3.5	1.9
C.O.V. (%)							5.6	5.6

♦ END OF TEST REPORT ♦

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Fax +1 413 499 2339
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intertek.com

January 15, 2018

Mr. Andy Sartor
Structural Technologies LLC
10150 Old Columbia Road
Columbia, MD 21046
USA

PO # INT-010818
Intertek PTL # P20180114

Dear Mr. Sartor:

Enclosed you will find the results of the testing you requested.

If you have any questions regarding the data, please do not hesitate to contact me.

Yours sincerely,

Kevin E. Schuman
Quality Manager

KES/jh
Enclosures

intertek
Total Quality. Assured.

Testing	:	**Linear Thermal Expansion And Glass Transition Temperatures By Thermomechanical Analysis**	
Test Method	:	ASTM E831-14	
Project Number	:	P20180114	
Customer	:	Structural Technologies LLC	PO #: INT-010818
Attention	:	Andy Sartor	
Analyst	:	K. Johnson	Attachments : 5
Date	:	January 12, 2018	

A2LA ACCREDITED Cert. No. 0619.01 TESTING LABORATORY

Instrument	:	TA Q400
Atmosphere	:	Helium
Flow Rate	:	100 ml/min (per manufacturer's specification)
Probe Diameter And Shape	:	2.54mm, Flat
Calibration Procedure	:	Calibrated vs. Melting Point Of Indium and Water
Probe Force	:	20mN
Heating Rate	:	5°C/min
Sample Conditioning	:	Unconditioned
Sample Dimensions	:	9mm x 9mm x 8mm (nominal)
Sample Preparation	:	Machined by Intertek PTL
Starting Temperature	:	**-30°C**
Final Temperature	:	**30°C**
Significance	:	ASTM E831 specifies that CLTE be calculated to the nearest 0.1 µm/(m·°C)

Test Direction: 0° Direction with respect to fiber orientation

Sample Name	Sample Height (mm)	C.T.E. **(x 10^{-6} / °C)**	C.T.E. **(x 10^{-6} / °F)**
V-Wrap C400HM Carbon	8.790	4.9	2.7
Fabric / V- Wrap 770 Epoxy	8.789	5.4	3.0
Fabric Lot#: 24483 Resin Lot#:	8.784	3.7	2.1
A- 15-6228013/ B- 15-6228015	8.746	5.8	3.2
Panel 2	8.789	4.7	2.6
	Average	**4.9**	**2.7**

Level of expansion is below the sensitivity of the instrument. Results are to be considered best effort.

Intertek, 50 Pearl Street, Pittsfield, MA 01201
Phone: +1 413-499-0983, Fax: +1 413-499-2339
http://www.intertek.com

Sample: P20180114 - Structural Tech. LL
Size: 8.7901 mm
Method: Ramp
Comment: V-Wrap C400HM Carbon Fabric/V-Wrap 770 Epoxy Panel 2 0°#1

TMA

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Operator: KJ
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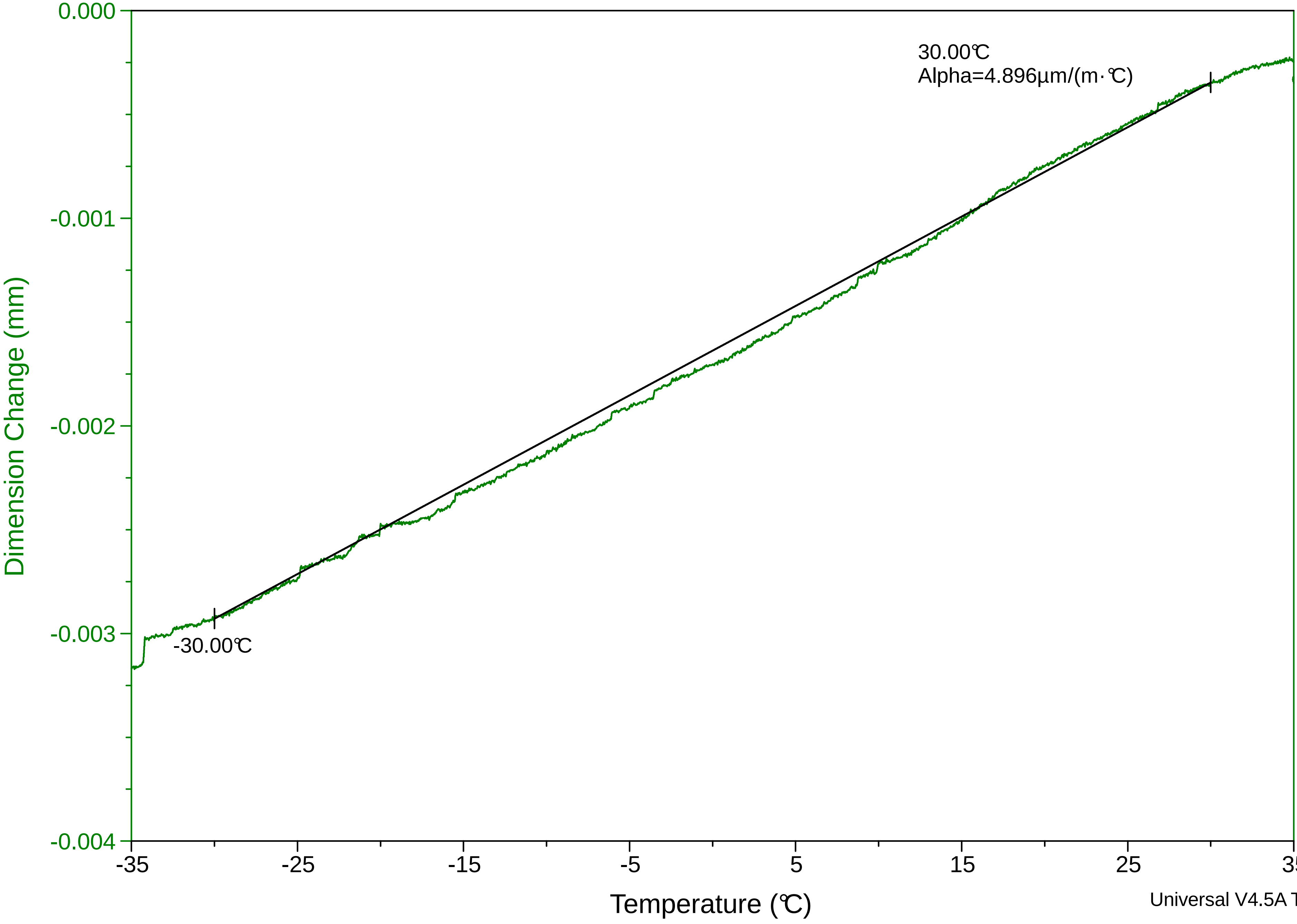
Instrument: TMA Q400 V22.5 Build 31



Universal V4.5A TA Instruments

Sample: P20180114 - Structural Tech. LL
Size: 8.7894 mm
Method: Ramp
Comment: V-Wrap C400HM Carbon Fabric/V-Wrap 770 Epoxy Panel 2 0°#2

TMA

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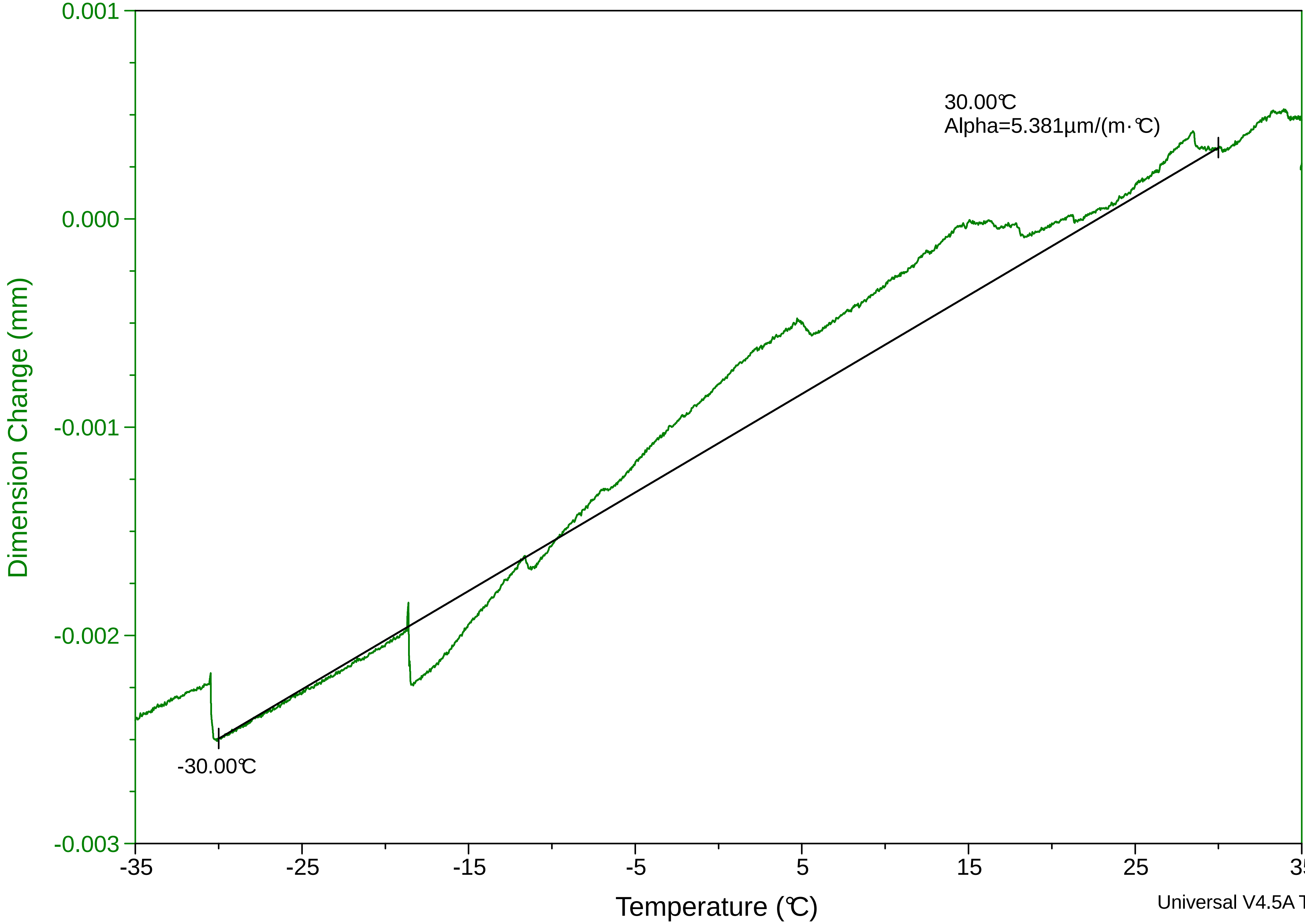
Instrument: TMA Q400 V22.5 Build 31



Universal V4.5A TA Instruments

Sample: P20180114 - Structural Tech. LL
Size: 8.7841 mm
Method: Ramp
Comment: V-Wrap C400HM Carbon Fabric/V-Wrap 770 Epoxy Panel 2 0°#3

TMA

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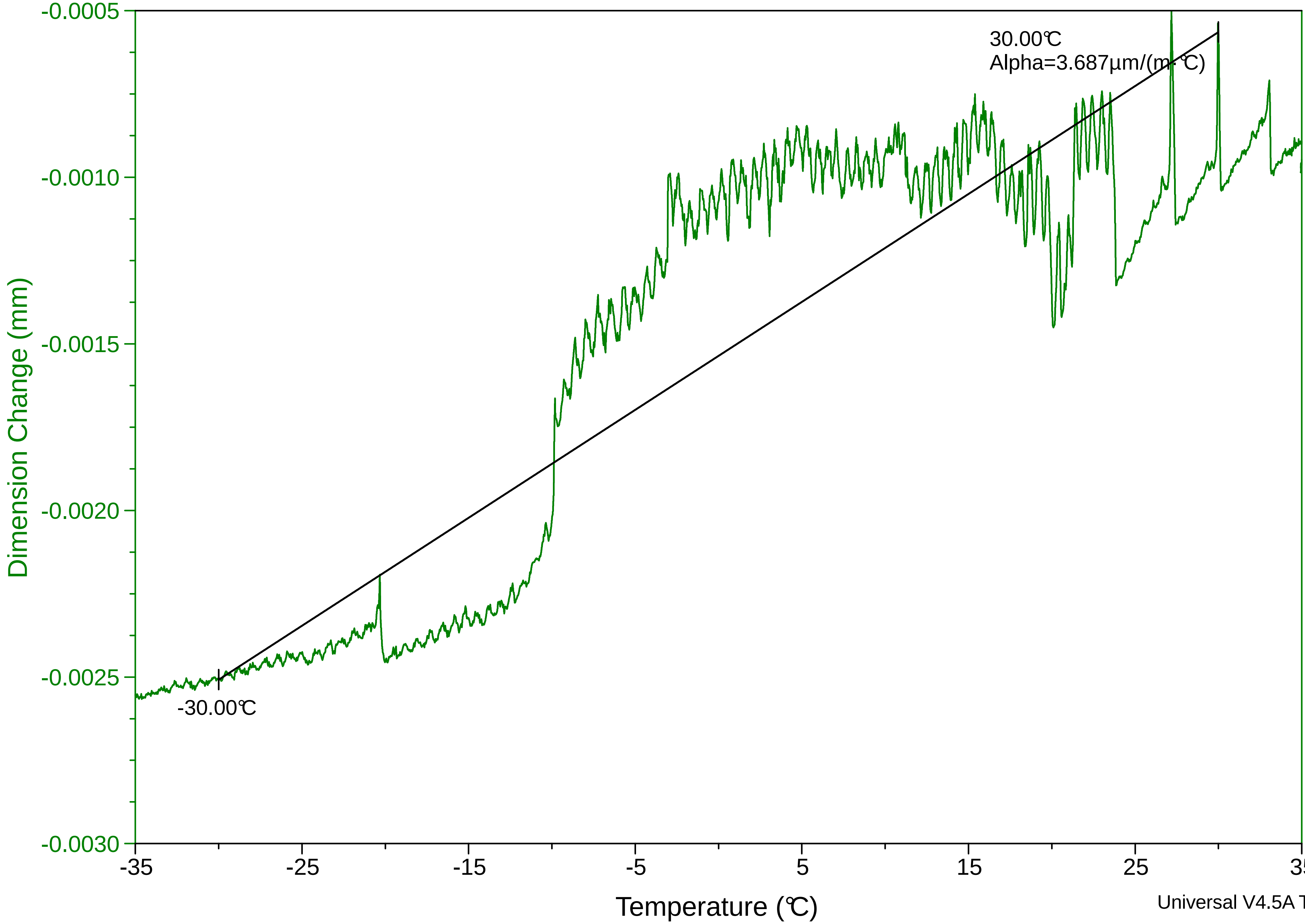
Instrument: TMA Q400 V22.5 Build 31



Universal V4.5A TA Instruments

Sample: P20180114 - Structural Tech. LL
Size: 8.7460 mm
Method: Ramp
Comment: V-Wrap C400HM Carbon Fabric/V-Wrap 770 Epoxy Panel 2 0°#4

TMA

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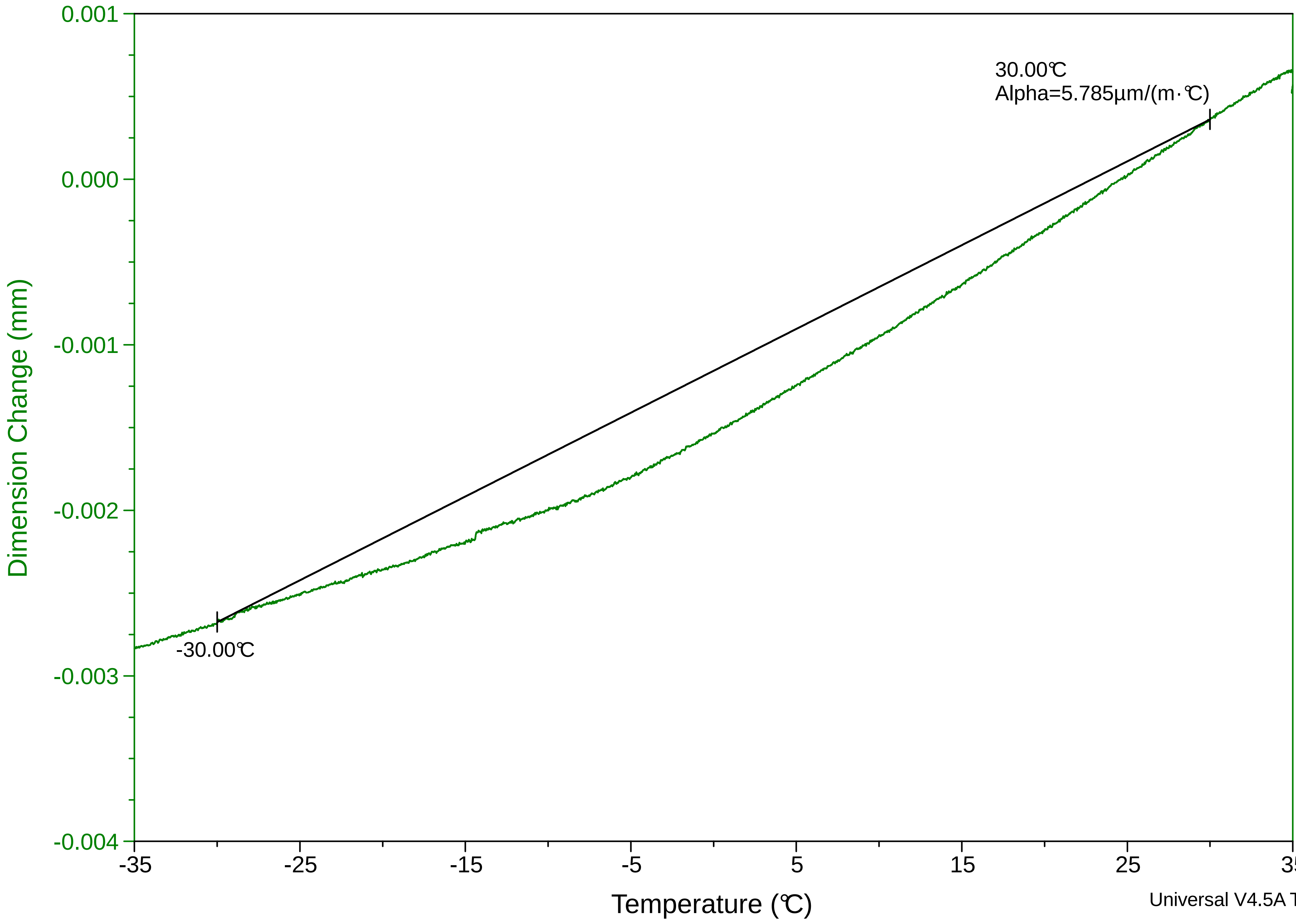
Operator: KJ
Run Date: 11-Jan-2018 15:20
Instrument: TMA Q400 V22.5 Build 31

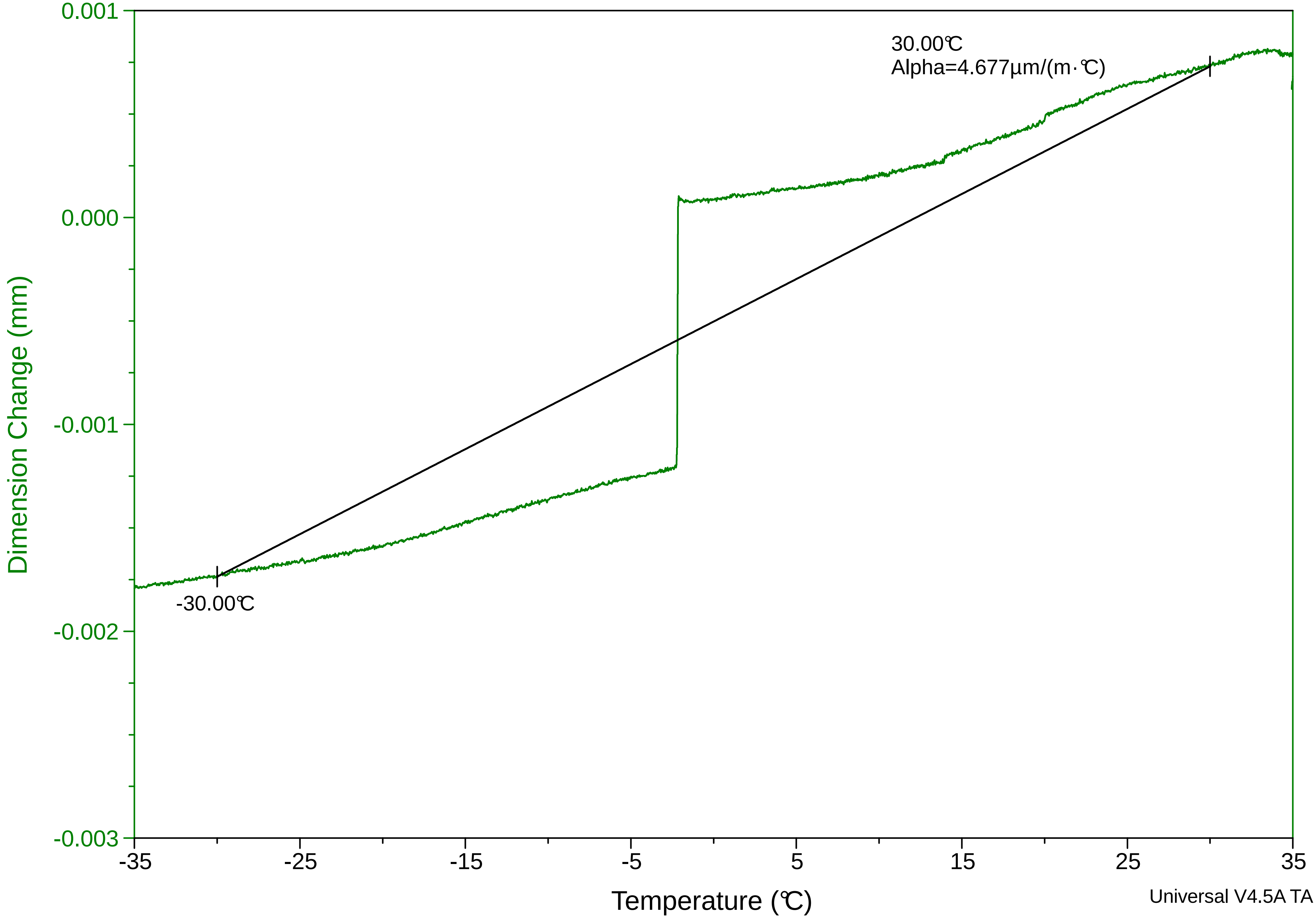


Universal V4.5A TA Instruments

Sample: P20180114 - Structural Tech. LL
Size: 8.7890 mm
Method: Ramp
Comment: V-Wrap C400HM Carbon Fabric/V-Wrap 770 Epoxy Panel 2 0°#5

TMA

File: N:\Instrument\TA TMA Q400\0114-2.005
Operator: KJ
Run Date: 12-Jan-2018 09:38
Instrument: TMA Q400 V22.5 Build 31



Universal V4.5A TA Instruments

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50 Pearl Street
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Fax +1 413 499 2339
Customer.service@intertek.com
intertek.com

October 2, 2017

Mr. Andy Sartor
Structural Technologies LLC
10150 Old Columbia Road
Columbia, MD 21046
USA

PO # INT-091517
Intertek PTL # P20173816

Dear Mr. Sartor:

Enclosed you will find the results of the testing you requested.

If you have any questions regarding the data, please do not hesitate to contact me.

Yours sincerely,

Kevin E. Schuman
Quality Manager

KES/jh
Enclosures

intertek
Total Quality. Assured.

Testing	:	**Linear Thermal Expansion And Glass Transition Temperatures By Thermomechanical Analysis**
Test Method	:	ASTM E831-14
Project Number	:	P20173816 Purchase Order # : INT-091517
Customer	:	Structural Technologies LLC
Attention	:	Andy Sartor
Analyst	:	K. Johnson Attachments : 5
Date	:	September 29, 2017

A2LA ACCREDITED Cert. No. 0619.01 TESTING LABORATORY

Instrument	:	TA Q400
Atmosphere	:	Helium
Flow Rate	:	100 ml/min (per manufacturer's specification)
Probe Diameter And Shape	:	2.54mm, Flat
Calibration Procedure	:	Calibrated vs. Melting Point Of Indium and Water
Probe Force	:	20mN
Heating Rate	:	5°C/min
Sample Conditioning	:	40+ hours at 23°C ± 2°C / 50% ± 10% RH
Sample Dimensions	:	6mm x 7mm x 6mm (nominal)
Sample Preparation	:	Machined by Intertek PTL
Starting Temperature	:	**-30°C**
Final Temperature	:	**30°C**
Significance	:	ASTM E831 specifies that CLTE be calculated to the nearest 0.1 µm/(m·°C)

Test Direction: 90°

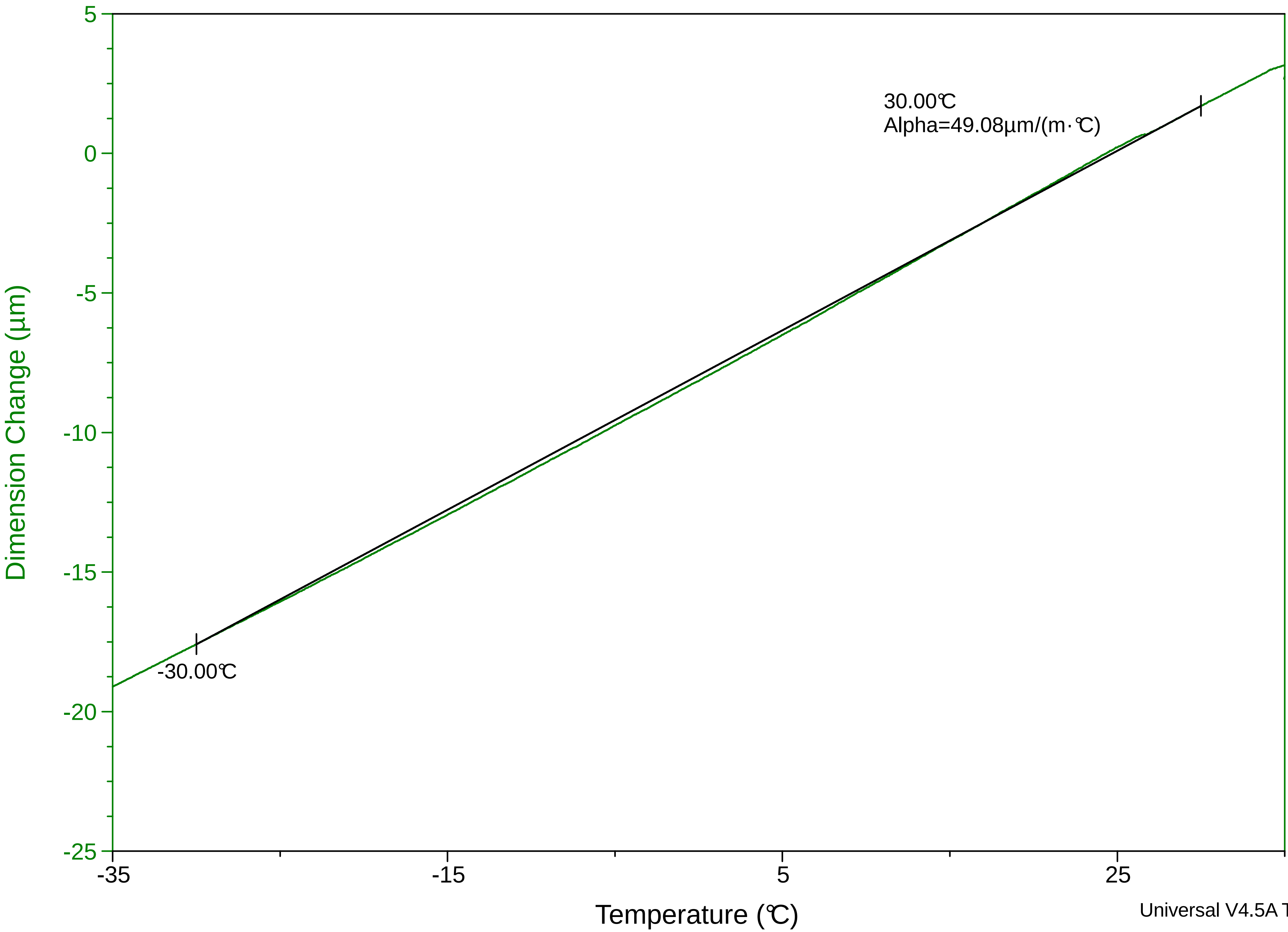
Sample Name	Sample Height (mm)	C.T.E. (x 10^{-6} / °C)	C.T.E. (x 10^{-6} / °F)
V-Wrap C400HM Carbon Fabric / V-Wrap 770 epoxy Fabric lot#: 23854 Resin lot #: A-15-6036514 / B-15-6036515 3 ply specimen	6.549	49.1	27.3
	6.556	47.4	26.3
	6.622	47.2	26.2
	6.505	47.7	26.5
	6.560	48.5	27.0
	Average	**48.0**	**26.6**

Intertek, 50 Pearl Street, Pittsfield, MA 01201
Phone: +1 413-499-0983, Fax: +1 413-499-2339
http://www.intertek.com

Sample: P20173816 - Structural Tech.
Size: 6.5486 mm
Method: Ramp
Comment: V-Wrap C400 Carbon fabric / V-Wrap 770 epoxy 90° Specimen #1

TMA

File: N:\Instrument\TA TMA Q400\2017\3816.001
Operator: KJ
Run Date: 25-Sep-2017 09:44
Instrument: TMA Q400 V22.5 Build 31

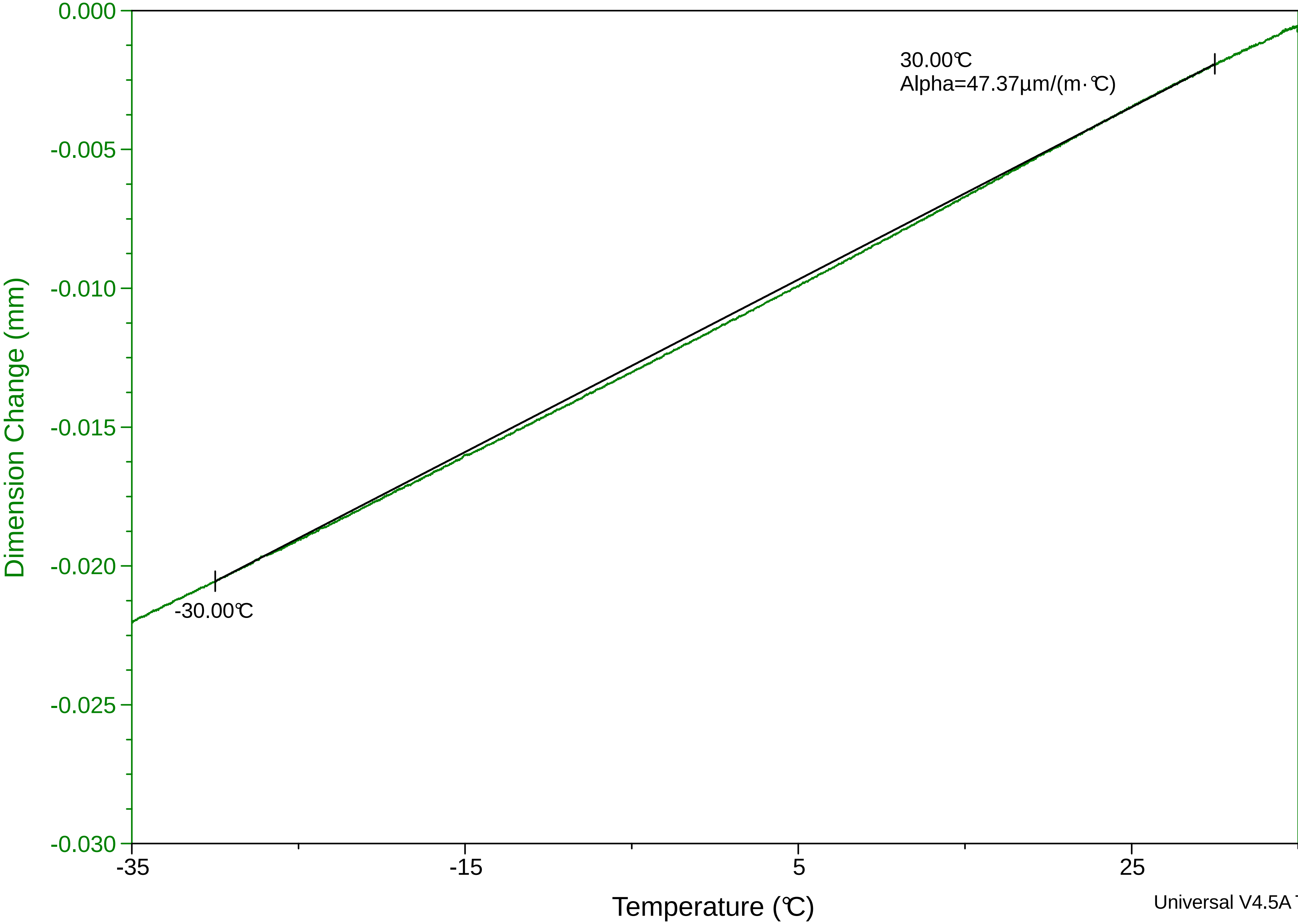


Universal V4.5A TA Instruments

Sample: P20173816 - Structural Tech.
Size: 6.5559 mm
Method: Ramp
Comment: V-Wrap C400 Carbon fabric / V-Wrap 770 epoxy 90° Specimen #2

TMA

File: N:\Instrument\TA TMA Q400\2017\3816.002
Operator: KJ
Run Date: 25-Sep-2017 10:50
Instrument: TMA Q400 V22.5 Build 31

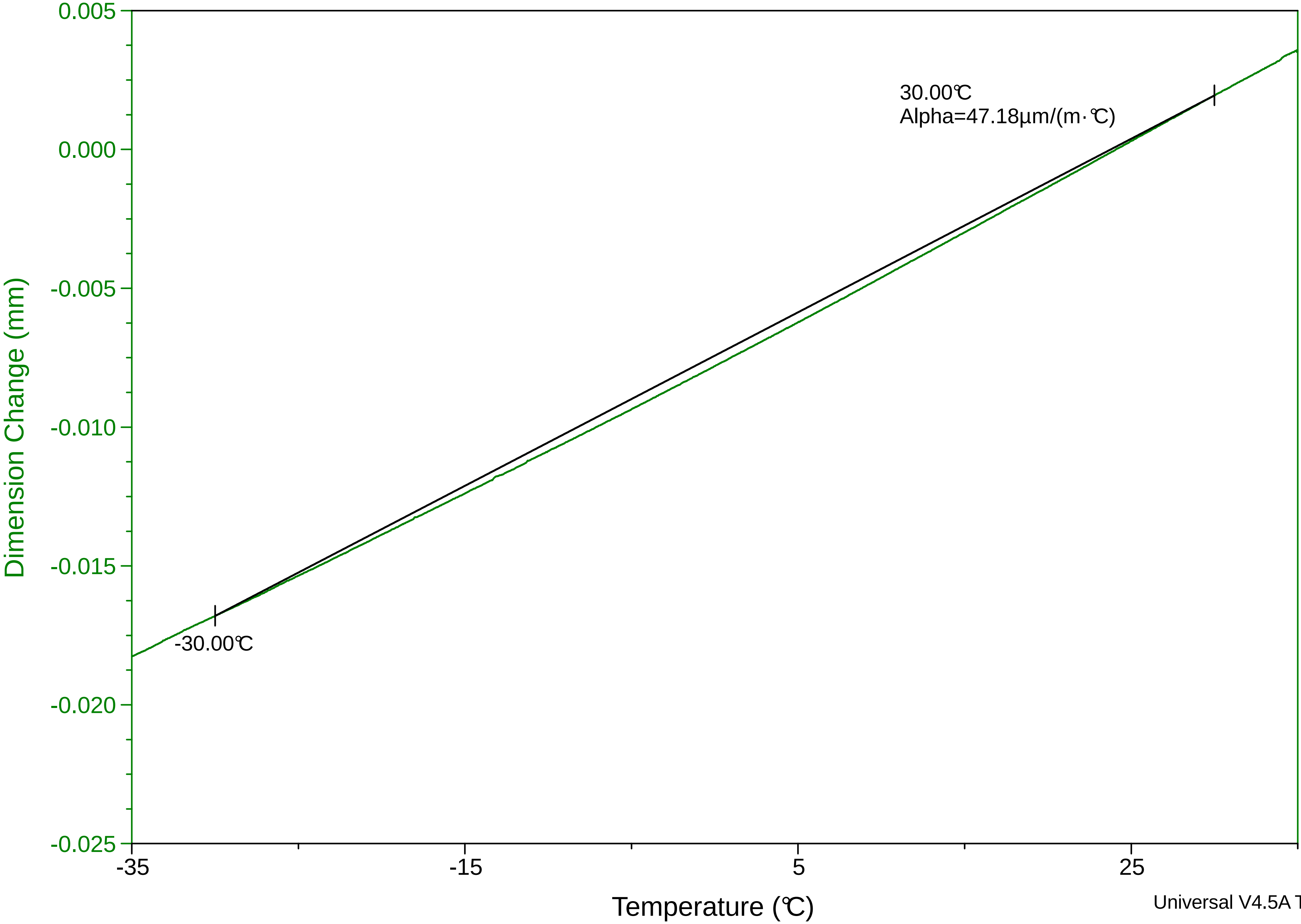


Universal V4.5A TA Instruments

Sample: P20173816 - Structural Tech.
Size: 6.6217 mm
Method: Ramp
Comment: V-Wrap C400 Carbon fabric / V-Wrap 770 epoxy 90° Specimen #3

TMA

File: N:\Instrument\TA TMA Q400\2017\3816.003
Operator: KJ
Run Date: 25-Sep-2017 11:32
Instrument: TMA Q400 V22.5 Build 31

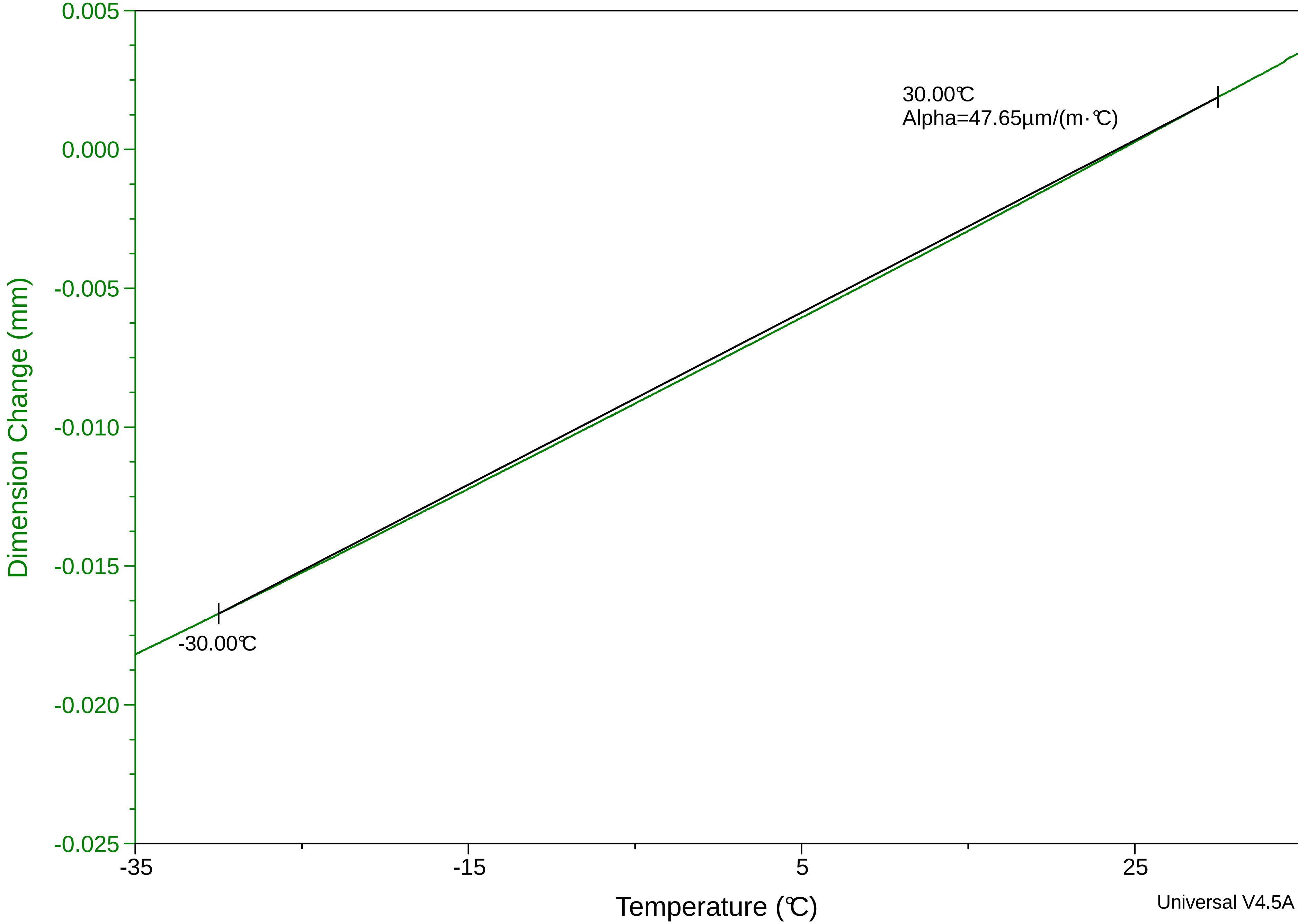


Universal V4.5A TA Instruments

Sample: P20173816 - Structural Tech.
Size: 6.5054 mm
Method: Ramp
Comment: V-Wrap C400 Carbon fabric / V-Wrap 770 epoxy 90° Specimen #4

TMA

File: N:\Instrument\TA TMA Q400\2017\3816.004
Operator: KJ
Run Date: 25-Sep-2017 12:29
Instrument: TMA Q400 V22.5 Build 31

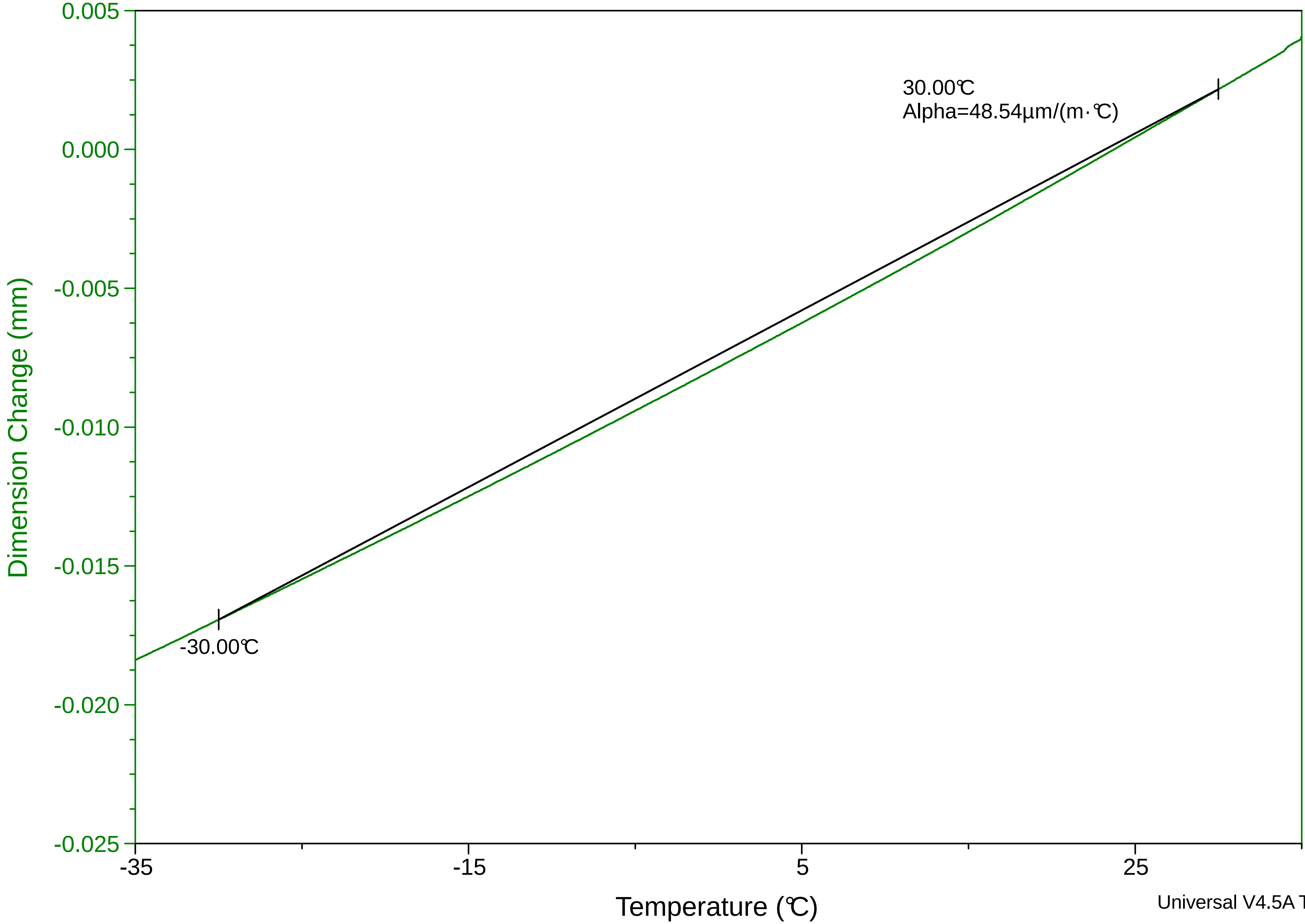


Universal V4.5A TA Instruments

Sample: P20173816 - Structural Tech.
Size: 6.5604 mm
Method: Ramp
Comment: V-Wrap C400 Carbon fabric / V-Wrap 770 epoxy 90° Specimen #5

File: N:\Instrument\TA TMA Q400\2017\3816.005
Operator: KJ
Run Date: 25-Sep-2017 13:33
Instrument: TMA Q400 V22.5 Build 31

TMA



Universal V4.5A TA Instruments

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ICC-ES Evaluation Report

ESR-3606

Reissued January 2022

This report is subject to renewal January 2023.

DIVISION: 03 00 00—CONCRETE
Section: 03 01 00—Maintenance of Concrete
Section 03 01 30—Maintenance of Cast-in-Place Concrete

DIVISION: 04 00 00—MASONRY
Section 04 01 00—Maintenance of Masonry
Section 04 01 20—Maintenance of Unit Masonry

REPORT HOLDER:

STRUCTURAL TECHNOLOGIES, LLC

EVALUATION SUBJECT:

V-WRAP FIBER-REINFORCED POLYMER COMPOSITE SYSTEM WITH OR WITHOUT V-WRAP FPS FIRE PROTECTION SYSTEM

1.0 EVALUATION SCOPE

Compliance with the following codes:

- 2021, 2018, 2015, 2012, 2009 and 2006 *International Building Code®* (IBC)
- 2021, 2018, 2015, 2012, 2009 and 2006 *International Residential Code®* (IRC)
- 1997 *Uniform Building Code™* (UBC)
- 2013 *Abu Dhabi International Building Code* (ADIBC)†

†The ADIBC is based on the 2009 IBC. 2009 IBC code sections referenced in this report are the same sections in the ADIBC.

For evaluation of compliance with codes adopted by Los Angeles Department of Building and Safety (LADBS), see ESR-3606 LABC Supplement.

For evaluation of compliance with codes adopted by California Office of Statewide Health Planning and Development (OSHPD) and California Division of State Architects (DSA), see the ESR-3606 CBC Supplement.

Properties evaluated:

- Structural
- Toxicity
- Fire resistance
- Fire propagation
- Durability

2.0 USES

The V-Wrap Fiber-reinforced Polymer (FRP) Composite System, with or without the V-Wrap FPS fire protection system, is used to externally strengthen normal-weight reinforced concrete and unreinforced masonry structural elements as an alternative to those systems as permitted by Section 104.11 of the IBC and UBC (Alternative Materials, Designs, and Methods of Construction and Equipment). For structures regulated under the IRC, the V-Wrap Fiber-reinforced Polymer (FRP) Composite System may be used where an engineering design is submitted in accordance with Section R301.1.3 and where approved by the building official in accordance with IRC Section R104.11. For use as an interior finish, see Section 4.2.5. For use as a fire-resistance-rated assembly, see Sections 4.2.6 and 5.4.

3.0 DESCRIPTION

3.1 General:

The V-Wrap FRP Composite System, is comprised of high-strength fibers combined with a polymer matrix to create the FRP composite system. The V-Wrap FRP Composite System, when installed with the V-Wrap FPS fire protection system, is used in the construction of the fire-resistance-rated assemblies described in Section 4.2.6.

3.2 Material:

All materials must comply with the approved specifications outlined in the Structural Technologies, LLC, quality documentation.

3.2.1 V-Wrap Fabric Sheets: The V-Wrap C100, C100H, C100HM, C200H, C400H, C200HM, C400HM and C220B fabric sheets are made from carbon fibers, and the V-Wrap EG50 and EG50B fabric sheets are made from glass fibers that resist tensile stresses. Standard rolls of fabric are available in widths of 12 and 24 inches (305 and 610 mm) and in lengths up to 100 yards (91.4 m). The rolls of fabric are packaged in boxes.

3.2.2 Polymer Matrix (epoxy resins): V-Wrap 700S and V-Wrap 770 are two-component, 100-percent solids, two-phase epoxy matrices used for impregnating the dry fabric sheets and binding the fibers together for the transfer of stresses. V-Wrap 700S and V-Wrap 770 epoxy matrices are ambient cure epoxy resins.

V-Wrap PF putty filler is a two component, 100 percent solids epoxy, used prior to or after application of V-Wrap composite systems. Use of V-Wrap PF is optional, and must comply with manufacturer's installation instructions.

Components A and B of each V-Wrap epoxy are packaged in 1-, 5-, and 55-gallon (3.79, 18.9 and 208.18 L) containers, and are mixed at the jobsite prior to application in accordance with V-Wrap Installation Manual dated, October 12, 2020 (Rev. 5).

3.2.3 V-Wrap™ Composite: The V-Wrap composites are comprised of materials described in Sections 3.2.1 and 3.2.2.

3.2.3.1 V-Wrap C100 Composite: V-Wrap composite C100 is comprised of V-Wrap C100 carbon fabric sheet and V-Wrap 700S polymer matrix. In the primary (0°) direction, the composite has a design tensile strength of 140 ksi (965 MPa), a design tensile modulus of 9,600 ksi (66.5 GPa), and a corresponding elongation of 1.4 percent. The layer thickness is 0.023 inch (0.58 mm).

3.2.3.2 V-Wrap C100H Composite: V-Wrap composite C100H is comprised of V-Wrap C100H carbon fabric sheet and V-Wrap 770 polymer matrix. In the primary (0°) direction, the composite has a design tensile strength of 165 ksi (1,138 MPa), a design tensile modulus of 11,000 ksi (75.8 GPa), and a corresponding elongation of 1.5 percent. The layer thickness is 0.02 inch (0.51 mm).

3.2.3.3 V-Wrap C200H Composite: V-Wrap C200H composite is comprised of V-Wrap C200H carbon fabric sheet and V-Wrap 770 epoxy resin. In the primary (0°) direction, the composite has a design tensile strength of 150 ksi (1,034 MPa), a design tensile modulus of 10,700 ksi (73.7 GPa), and a corresponding elongation of 1.4 percent. The layer thickness is 0.04 inch (1.02 mm).

3.2.3.4 V-Wrap C400H Composite: V-Wrap C400H composite is comprised of V-Wrap C400H carbon fabric sheet and V-Wrap 770 epoxy resin. In the primary (0°) direction, the composite has a design tensile strength of 150 ksi (1,034 MPa), a design tensile modulus of 10,700 ksi (73.7 GPa), and a corresponding elongation of 1.4 percent. The layer thickness is 0.08 inch (2.03 mm).

3.2.3.5 V-Wrap C100HM Composite: V-Wrap composite C100HM is comprised of V-Wrap C100HM carbon fabric sheet and V-Wrap 770 polymer matrix. In the primary (0°) direction, the composite has a design tensile strength of 165 ksi (1,138 MPa), a design tensile modulus of 15,000 ksi (103.40 GPa), and a corresponding elongation of 1.1 percent. The layer thickness is 0.02 inch (0.51 mm).

3.2.3.6 V-Wrap C200HM Composite: V-Wrap C200HM composite is comprised of V-Wrap C200HM carbon fabric sheet and V-Wrap 770 epoxy resin. In the primary (0°) direction, the composite has a design tensile strength of 155 ksi (1,070 MPa), a design tensile modulus of 14,000 ksi (96.5 GPa), and a corresponding elongation of 1.1 percent. The layer thickness is 0.04 inch (1.02 mm).

3.2.3.7 V-Wrap C400HM Composite: V-Wrap C400HM composite is comprised of V-Wrap C400HM carbon fabric sheet and V-Wrap 770 epoxy resin. In the primary (0°) direction, the composite has a design tensile strength of 155 ksi (1,070 MPa), a design tensile modulus of 14,000 ksi (96.5 GPa), and a corresponding elongation of 1.1 percent. The layer thickness is 0.08 inch (2.03 mm).

3.2.3.8 V-Wrap C220B Composite: V-Wrap C220B bi-directional composite is comprised of V-Wrap C220B carbon fabric sheet and V-Wrap 770 epoxy resin. In both (0°/90°) directions, the composite has a design tensile strength of 155 ksi (1,070 MPa), a design tensile modulus of 14,000 ksi (96.5 GPa), and a corresponding elongation of 1.1 percent. Design of FRP to resist tension force must only consider the contribution of FRP fibers oriented in the direction of the tension force. The layer thickness is 0.02 inch (0.51 mm).

3.2.3.9 V-Wrap EG50 composite: V-Wrap EG50 composite is comprised of V-Wrap EG50 glass fabric sheet and V-Wrap 770 epoxy resin. In the primary (0°) direction, the fiber direction is 0°, the composite has a design tensile strength of 70.6 ksi (487 MPa), a design tensile modulus of 3,870 ksi (26,680 MPa), and a corresponding elongation of 1.8 percent. The layer thickness is 0.04 inch (1.016 mm).

3.2.3.10 V-Wrap EG50B composite: V-Wrap EG50B bidirectional composite is comprised of V-Wrap EG50B glass fabric sheet and V-Wrap 770 epoxy resin. In both directions (±45° from the roll length), the composite has a design tensile strength of 74.5 ksi (514 MPa), a design tensile modulus of 4,600 ksi (31,700 MPa), and a corresponding elongation of 1.6 percent. Design of FRP to resist tension force must only consider the contribution of FRP fibers oriented in the direction of the tension force. The layer thickness in each direction is 0.017 inch (0.432 mm).

3.2.4 V-Wrap FPS Fire Protection System: V-Wrap FPS Fire Protection System consists of a cementitious-based dry mix that when mixed with water in the field forms a spray-applied fireproofing material designed to be used with the V-Wrap FRP Composite system to increase the fire-resistance-rating of existing structural concrete members as described in Section 4.2.6 of this report. The dry mix is available in 30 lb. (13.6 kg) bags. The mixing ratio is 1 part V-Wrap FPS dry mix to 1.2 to 1.4 parts water by weight.

3.2.5 Tstrata TC: Tstrata TC is a one component, acrylic based, protective top coat for use with V-Wrap FRP systems, concrete, and masonry. It is packaged in 5 Gallon (18.9 L) containers.

3.2.6 Storage Recommendations: The materials must be stored in a clean, dry area at an ambient temperature between 40°F (4.4°C) and 90°F (32.2°C). When properly stored under these conditions, V-Wrap C100, V-Wrap C100H, V-Wrap C200H, V-Wrap C400H, V-Wrap C100HM, V-Wrap C200HM, V-Wrap C400HM, V-Wrap C220B, V-Wrap EG50, and V-Wrap EG50B have an unlimited shelf life. The V-Wrap 700S, V-Wrap 770 and V-Wrap PF epoxy resins have a shelf life of two years under the same conditions and in unopened containers. The V-Wrap FPS fire protection dry mix has a shelf-life of 36 months when stored at a minimum of 70°F (21°C) in unopened bags.

4.0 DESIGN AND INSTALLATION

4.1 Design:

Design of the composite system is based on strength design in accordance with Chapter 19 of the IBC or the UBC. The registered design professional is responsible for determining, through analysis, the strengths and demands of the structural elements to be enhanced by the V-Wrap system, subject to the approval of the code official.

4.1.1 Design Details: Design of the V-Wrap FRP Composite System is based on test results and principles of structural analysis as set forth in Section 1604.4 of the IBC. The bases of design include strain compatibility, load equilibrium and limit states. All designs must follow procedures as detailed in the IBC or UBC, and in the V-Wrap System Design Manual, dated December 9, 2020 (Rev. 9). A copy of the Design Manual must be submitted to the code official for approval of each project that uses the V-Wrap FRP Composite System.

4.1.2 Design Strength: Design strengths must be taken as the nominal strength, computed in accordance with Section 4.1.1 of this report, multiplied by strength reduction factors in Section 21.2 of ACI 318-19 (2021 IBC) and 318-14 (2018 and 2015 IBC), Section 9.3 of ACI 318-05 (2006 IBC), ACI 318-08 (2009 IBC), or ACI 318-11 (2012 IBC), or Chapter 19 of the UBC, as applicable.

4.1.3 Load Combinations: The load combinations used in design must comply with Section 1605 of the IBC and Section 5.3 of ACI 318-19 and ACI 318-14 (Section 9.2 of ACI 318-11, -08 and -05), or Section 1612 of the UBC.

4.1.4 Columns:

4.1.4.1 Potential Applications: V-Wrap FRP Composite Systems are applied to concrete columns to enhance ductility, flexural and axial and shear strength for gravity, seismic (dynamic), and wind loads. V-Wrap FRP Carbon Composite Systems are also applied as confinement to lap splices of steel reinforcement for gravity, seismic (dynamic), and wind loads in concrete columns. The V-Wrap FRP Composite System can also be utilized to improve the confinement of concrete columns.

4.1.4.2 Structural Design Requirements: Concrete column design must comply with the V-Wrap Design Manual and with Chapter 19 of IBC or UBC, as applicable.

4.1.5 Beams and Slabs:

4.1.5.1 Potential Applications: V-Wrap FRP Composite System is applied to concrete beams to enhance their flexural and shear strengths for gravity loads, seismic (dynamic) or wind loads, as applicable. V-Wrap FRP Composite System is applied to concrete slabs to enhance their flexural and in-plane shear strengths for gravity, seismic (dynamic) or wind loads, as applicable.

4.1.5.2 Structural Design Requirements: Concrete beam and slab design must comply with the V-Wrap Design Manual and Chapter 19 of IBC or UBC, as applicable.

4.1.6 Walls:

4.1.6.1 Potential Applications: V-Wrap FRP Composite systems (excluding EG50B) are applied to unreinforced and reinforced masonry walls to enhance their out-of-plane flexural strength, and in-plane shear strength for gravity, seismic (dynamic), and wind loads, as applicable. V-Wrap FRP Composite systems are applied to reinforced concrete walls to enhance their in-plane flexural and shear strengths for gravity, seismic (dynamic), and wind loads, as applicable.

4.1.6.2 Structural Design Requirements: Masonry wall design must comply with the V-Wrap Design Manual and Chapter 21 of the IBC or UBC. Reinforced concrete wall design must comply with the V-Wrap Design Manual and Chapter 19 of the IBC or UBC.

4.1.7 Wall-to-Floor Joints:

4.1.7.1 Potential Applications: V-Wrap EG50B Composite system is applied to concrete wall-to-floor joints to enhance shear strength for gravity, seismic (dynamic) and wind loads.

4.1.7.2 Structural Design Requirements: Concrete wall to floor design must comply with the V-Wrap Design Manual and Chapter 19 of the IBC or UBC.

4.1.8 Concrete Diaphragms and Collectors:

4.1.8.1 Potential Applications: V-Wrap FRP Composite systems are applied to reinforced concrete diaphragms to enhance their in-plane flexural and shear strengths for wind or dynamic loading applications. V-Wrap FRP Composite systems are also applied to enhance the axial tension capacity of drag struts (collectors) elements for wind or seismic (dynamic) loads.

4.1.8.2 Structural Design Requirements: Reinforced concrete diaphragm design must comply with the V-Wrap Design Manual and Chapter 19 of the IBC or UBC.

4.1.9 Bond Strength: Where the performance of the FRP composite material depends on bond, the bond strength must not be less than 200 psi (1378 kPa) for concrete, or 2.5√f'm for masonry. Bond testing must exhibit failure in the concrete or masonry substrate. Testing in accordance with ASTM D7234 or D7522 may be used to estimate the bond strength of bond-critical installations.

4.2 Installation:

Installation of V-Wrap FRP Composite System must be performed by certified applicators in accordance with. V-Wrap Installation Manual dated October 12, 2020 (Rev. 5).

4.2.1 Saturation: The fibers and the matrix must be combined in accordance with an established weight-and-volume ratios, as defined in the V-Wrap Installation Manual dated October 12, 2020 (Rev 5). Saturation can be achieved using the calibrated V-Wrap Saturator machine or manual methods.

4.2.2 Application: The saturated composite fabric is applied to the substrate using manual methods. Surface preparation, fiber orientation and removal of air voids and bubbles must be performed in accordance with installation procedures in the V-Wrap Installation Manual dated October 12, 2020 (Rev 5). The standard pot life for resin is listed in the product literature. The actual pot life varies with temperature: higher temperatures usually result in a shorter pot life while lower temperatures can result in a longer pot life.

4.2.3 Finishing: A final protective layer of thickened V-Wrap 700S, V-Wrap 770 or V-Wrap PF epoxy resin can be applied as a finish coat. Paints may be applied to the composite system as required for environmental and aesthetic considerations. For use as an interior finish, see Section 4.2.5.

4.2.4 Health Effects Coating: V-Wrap 770 or V-Wrap PF epoxy resins are formulated for potable water contact and complies with ANSI/NSF 61 as referenced by Section 605 of the 2021, 2018, 2015, 2012, 2009 and 2006 *International Plumbing Code* (IPC). The top coat of the 770 or PF epoxy resin material must have a maximum total thickness of 40 wet mils (1.02 mm). All surfaces must be cleaned, dry, and free of contaminants. Surfaces must be prepared by abrasive blasting. Cured composite surfaces must be prepared by hand-sanding the surface to remove the gloss of the cured composite, and then cleaning with water to remove the residues. The final curing must be 24 hours at 75°F (24°C).

4.2.5 Surface Burning Characteristics (Interior Finish):

4.2.5.1 Class A (IBC Section 803.1) or Class I (UBC Section 802.2):

The V-Wrap FRP Composite System, consisting of Albi Cote FRL-X by StanChem Inc. top coat and V-Wrap 770 epoxy resin applied with a maximum six layers of V-Wrap C400H, or C400HM, C200H, C200HM, EG50, EG50B, or C220B, C100H or C100HM has a Class 1 flame spread classification and smoke density per UBC Section 802.2 and a Class A interior finish per IBC Section 803.1. Albi Cote FRL-X must be applied in two coats of minimum 10 mils wet film thicknesses [two coats of 0.01 inch (0.25 mm)].

The V-Wrap FRP composite system consisting of Tstrata TC top coat and V-Wrap 770 epoxy resin with a maximum of four layers of V-Wrap C400H, C400HM, C200H, C200HM, EG50, EG50B, C220B, C100H or C100HM, has Class 1 flame-spread classification and smoke density in accordance with UBC Section 802.2, and a Class A interior finish per IBC Section 803.1. Tstrata TC top coat must be applied in two coats of minimum 16 mils wet film thicknesses [two coats of 0.016 inch (0.41 mm)].

The V-Wrap FRP Composite System, consisting of a maximum of eight plies of V-Wrap C400H, C400HM, C200H, C200HM, EG50, EG50B, C220B, C100H or C100HM with V-Wrap 770 epoxy resin and covered with a ¾-inch (19 mm) thickness of the V-Wrap FPS fire protection system, has a Class I flame-spread classification and smoke-density in accordance with UBC Section 802.2 and a Class A interior finish per IBC Section 803.1.

4.2.5.2 Class B (IBC Section 803.1) or Class II (UBC Section 802.2): The V-Wrap FRP Composite System, consisting of V-Wrap 770 epoxy resin applied with a maximum of one layer of V-Wrap C400H, C400HM, C200H, C200HM, EG50, EG50B, C220B, C100H or C100HM (without any finishing described in Section 4.2.3), has a Class II flame-spread classification and smoke-density in accordance with UBC Section 802.2, and a Class B interior finish per IBC Section 803.1.

4.2.6 Fire-resistance-rated assemblies:

The use of the V-Wrap FPS fire protection system provides up to a four-hour fire-resistance rating for concrete beams (Section 4.2.6.1) and joists (Section 4.2.6.2), and three-hour fire-resistance rating for concrete floor slabs and roof slabs (Section 4.2.6.3), provided that the demand for these elements when used in fire-resistance-rated construction is less than, or equal to 71 percent of the design strength determined in accordance with this report. The use of V-Wrap FPS fire protection system also provides a three-hour fire rating for columns (section 4.2.6.4) provided that the demand for these elements when used in fire-resistance-rated construction is less than, or equal to 76 percent of the design strength determined in accordance with this report. The V-Wrap FPS fire protection system consists of a single component that is sprayed-applied over the V-Wrap FRP Composite System and concrete in accordance with the V-Wrap Installation Manual.

4.2.6.1 Concrete Beams: The V-Wrap FPS fire protection system must be applied over the V-Wrap FRP Composite System that is applied to concrete beams measuring 12 in. (305 mm) web width, 10 in. (254 mm) web depth, 6 in. (150 mm) flange thickness, and 4 ft (1.2 m) flange width. The minimum 28-day normal-weight concrete compressive strength must be 4,000 psi (27.6 MPa). Steel reinforcement must consist of the following: No. 5 bottom longitudinal bars in the web, No. 4 bars spaced at 12 in. (305 mm) on-center in both directions in the flange (topside), and No. 3 stirrups spaced at 6 in. (150 mm) on-center. The V-Wrap FRP Composite System must consist of one layer of V-Wrap C200HM carbon fabric saturated with V-Wrap 770 epoxy resin and applied to the soffit of the web as flexural reinforcement, and/or one layer of V-Wrap C200H carbon fabric U-wraps saturated with V-Wrap 770 epoxy resin and applied at the ends of the beam as shear reinforcement. The V-Wrap FPS fire protection system must be spray-applied with a minimum average thickness of $^3/_4$-inches (19 mm).

4.2.6.2 Concrete Joists: The V-Wrap FPS protection system must be applied to concrete joists measuring 8 in. (200 mm) web width, 10 in. (254 mm) web depth, 6 in. (150 mm) flange thickness, and 4 ft (1.2 m) flange width. The minimum 28-day normal-weight concrete compressive strength must be 4,000 psi (27.6 MPa). Steel reinforcement must consist of the following: No. 5 bottom longitudinal bars in the web, No. 4 bars spaced at 12 in. (300 mm) on-center in both directions in the flange (topside), and No. 3 stirrups spaced at 6 in. (150 mm) on-center. FRP reinforcement must consist of one layer of V-Wrap C400H carbon fabric saturated with V-Wrap 770 epoxy resin and applied to the soffit of the web as flexural reinforcement, and/or one layer of V-Wrap EG50 glass fabric U-wraps saturated with V-Wrap 770 epoxy resin and applied at the ends of the joists as shear reinforcement. The V-Wrap FPS fire protection system must be spray-applied with a minimum average thickness of 1 in. (25.4 mm).

4.2.6.3 Concrete Slabs: The V-Wrap FPS fire protection system must be applied to 6 in. thick concrete slabs. The minimum 28-day normal-weight concrete compressive strength must be 4,000 psi (27.6 MPa). Steel reinforcement must consist of the following: No. 4 bottom longitudinal bars spaced at 6 in. (150 mm) on-center and No. 3 bottom transverse bars spaced at 9 in. (230 mm) on-center. FRP reinforcement must consists of one layer of V-Wrap C200H carbon fabric saturated with V-Wrap 770 epoxy resin and applied to the soffit of the slab as flexural reinforcement. The V-Wrap FPS fire protection system must be spray-applied with a minimum average thickness of 1 in. (25.4 mm) and must extend minimum of 5 inches beyond the V-Wrap C200H carbon fabric.

4.2.6.4 Concrete Columns: The V-Wrap FPS fire protection system must be applied to 16 in. x 16 in. (406 mm x 406 mm) columns. The minimum 28-day normal-weight concrete compressive strength must be 6,000 psi (41.4 MPa). Steel reinforcement must consist of the following: eight No. 8 vertical bars and No. 3 ties spaced at 12 in. (305 mm) on center. FRP reinforcement must consist of two layers of V-Wrap C400HM carbon fabric saturated with V-Wrap 770 epoxy resin. The V-Wrap FPS fire protection system must be spray-applied with a minimum average thickness of 3/4 in. (19 mm).

4.3 Special inspection:

Special inspection during the installation of the system must be in accordance with the ICC-ES Acceptance Criteria for Inspection and Verification of Concrete and Unreinforced Masonry Strengthening Using Fiber-reinforced Polymer (FRP) Composite Systems (AC178), dated October 2017 (editorially revised December 2020). A statement of special inspection must be prepared in accordance with 2021, 2018, 2015 or 2012 IBC Section 1704.3, or 2009 or 2006 IBC Section 1705. Inspection must also comply with Sections 1704 and 1705 of the 2021, 2018, 2015 or 2012 IBC, or Sections 1704 through 1707 of the 2009 or 2006 IBC, or Section 1701 of the UBC, and with the V-Wrap Installation Manual dated October 12, 2020 (Rev 5).

5.0 CONDITIONS OF USE

The V-Wrap Fiber-reinforced Polymer Composite System described in this report complies with, or is a suitable alternative to what is specified in, those codes listed in Section 1.0 of this report, subject to the following conditions:

5.1 Design and installation must be in accordance with this report, the manufacturer's instructions, the V-Wrap Design Manual as referenced in Section 4.1.1, and the IBC or UBC.

5.2 Copies of the Structural Technologies V-Wrap Installation Manual dated October 12, 2020 (Rev. 5), and the V-Wrap Design Manual, dated December 9, 2020 (Rev. 9) must be submitted to the code official for approval on each project that uses the system.

5.3 Complete construction documents, including plans and calculations verifying compliance with this report, must be submitted to the code official for each project at the time of permit application. The construction documents must be prepared and sealed by a registered design professional where required by the statutes of the jurisdiction in which the project is to be constructed.

5.4 For the fire-resistance rating of V-Wrap Composite Systems:

5.4.1 The fire-resistance rating of the assembly with V-Wrap FRP Composite System, without the V-Wrap FPS fire protection system described in Sections 3.2.4 and 4.2.6, must comply with Chapter 7 of the IBC or UBC, and is not reduced by the application of the V-Wrap FRP Composite System. The structural load-carrying capacities of fire-resistance-rated assemblies must be based on the design of the concrete without the V-Wrap FRP Composite System in accordance with the IBC or UBC. Fire resistance of assemblies with structural load-carrying capacities increased beyond the levels permitted by the UBC or IBC is beyond the scope of this report.

5.4.2 The fire-resistance rating of the assemblies with V-Wrap FRP Composite System and V-Wrap FPS fire protection system must comply with Sections 3.2.4 and 4.2.6 of this report, and Chapter 7 of the IBC and UBC.

5.5 Special inspection must be provided in accordance with Section 4.3 of this report.

5.6 Application of the systems to concrete members at a fabricator's facility must be performed by an approved fabricator complying with Section 1704.2 of the IBC or Section 1701.7 of the UBC, or at a jobsite with continuous special inspections in accordance with Section 1704.4 of the IBC or Sections 1701.5.1 and 1701.5.3 of the UBC.

5.7 V-Wrap materials are manufactured under a quality-control program with inspections by ICC-ES.

6.0 EVIDENCE SUBMITTED

Data in accordance with the ICC-ES Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Fiber-reinforced Polymer (FRP) Composite Systems (AC125), dated October 2019 (editorially revised December 2020); and quality documentation.

7.0 IDENTIFICATION

7.1 Components of the V-Wrap Fiber-reinforced Polymer (FRP) Composite System and V-Wrap FPS fire protection system are labeled with the Structural Technologies, LLC, name and address; the product name and shelf life; epoxy resins mixing ratio; and the evaluation report number (ESR-3606). Additionally, epoxy resin labels must show mixing ratio.

7.2 The report holder's contact information is the following:

STRUCTURAL TECHNOLOGIES, LLC
10150 OLD COLUMBIA ROAD
COLUMBIA, MARYLAND 21046
(410) 850-7000
www.structuraltechnologies.com

ICC-ES Evaluation Report

ESR-3606 LABC and LARC Supplement

Reissued January 2022

This report is subject to renewal January 2023.

www.icc-es.org | (800) 423-6587 | (562) 699-0543 *A Subsidiary of the International Code Council®*

DIVISION: 03 00 00—CONCRETE
Section: 03 01 00—Maintenance of Concrete
Section 03 01 30—Maintenance of Cast-in-Place Concrete

DIVISION: 04 00 00—MASONRY
Section 04 01 00—Maintenance of Masonry
Section: 04 01 20—Maintenance of Unit Masonry

REPORT HOLDER:

STRUCTURAL TECHNOLOGIES, LLC

EVALUATION SUBJECT:

V-WRAP FIBER-REINFORCED POLYMER COMPOSITE SYSTEM WITH OR WITHOUT V-WRAP FPS FIRE PROTECTION SYSTEM

1.0 REPORT PURPOSE AND SCOPE

Purpose:

The purpose of this evaluation report supplement is to indicate that the Structural Technologies Composite Systems, described in ICC-ES evaluation report ESR-3606, have also been evaluated for compliance with the codes noted below as adopted by the Los Angeles Department of Building and Safety (LADBS).

Applicable code editions:

- 2020 *City of Los Angeles Building Code* (LABC)
- 2020 *City of Los Angeles Residential Code* (LARC)

2.0 CONCLUSIONS

The Structural Technologies Composite Systems, described in Sections 2.0 through 7.0 of the evaluation report ESR-3606, comply with the LABC Chapters 19 and 21, and the LARC, and are subject to the conditions of use described in this supplement.

3.0 CONDITIONS OF USE

The Structural Technologies Composite Systems, described in this evaluation report supplement must comply with all of the following conditions:

- All applicable sections in the evaluation report ESR-3606.
- The design, installation, conditions of use and identification of the composite strengthening systems are in accordance with the 2018 *International Building Code®* (IBC) provisions noted in the evaluation report ESR-3606.
- The design, installation and inspection are in accordance with additional requirements of LABC Chapters 16, 17, and 95, as applicable.
- Use of the Structural Technologies Composite Systems for strengthening unreinforced masonry structures must be in accordance with Chapter A1 of the 2020 City of Los Angeles Existing Building Code.
- The Structural Technologies Composite Systems must not be used as compressive reinforcement for strengthening concrete or masonry structure..
- The Structural Technologies Composite Systems may be used on exterior side of exterior walls without additional weather protection. However, the site-specific exposure conditions must be evaluated by the registered design professional for each application.
- Under the LARC, an engineered design in accordance with LARC Section R301.1.3 must be submitted.

This supplement expires concurrently with the evaluation report, reissued January 2022.

ICC-ES Evaluation Report

ESR-3606 CBC Supplement

Reissued January 2022

This report is subject to renewal January 2023.

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DIVISION: 03 00 00—CONCRETE
Section: 03 01 00—Maintenance of Concrete
Section 03 01 30—Maintenance of Cast-in-Place Concrete

DIVISION: 04 00 00—MASONRY
Section 04 01 00—Maintenance of Masonry
Section 04 01 20—Maintenance of Unit Masonry

REPORT HOLDER:

STRUCTURAL TECHNOLOGIES, LLC

EVALUATION SUBJECT:

V-WRAP FIBER-REINFORCED POLYMER COMPOSITE SYSTEM WITH OR WITHOUT V-WRAP FPS FIRE PROTECTION SYSTEM

1.0 REPORT PURPOSE AND SCOPE

Purpose:

The purpose of this evaluation report supplement is to indicate that the V-Wrap Fiber-reinforced Polymer (FRP) Composite System, with or without the V-Wrap FPS fire protection system, described in ICC-ES evaluation report ESR-3606, has also been evaluated for compliance with the code noted below.

Applicable code edition:

2019 *California Building Code* (CBC)

For evaluation of applicable chapters adopted by the California Office of Statewide Health Planning and Development (OSHPD) and Division of State Architect (DSA), see Sections 2.1 and 2.2 below.

2.0 CONCLUSIONS

The V-Wrap Fiber-reinforced Polymer (FRP) Composite System**,** with or without the V-Wrap FPS fire protection system, described in Sections 2.0 through 7.0 of the evaluation report ESR-3606, complies with CBC Chapters 7, 8, 19 and 21, provided the design and installation are in accordance with the 2018 *International Building Code®* (2018 IBC) provisions noted in the evaluation report and the additional requirements of CBC Chapters 7, 8, 16, 17, 19 and 21, as applicable.

2.1 OSHPD:

The V-Wrap Fiber-reinforced Polymer (FRP) Composite System, with or without the V-Wrap FPS fire protection system, described in Sections 2.0 through 7.0 of the evaluation report ESR-3606, complies with CBC amended sections in Chapters 7 (OSHPD 1, 1R, 2, 4 & 5) , 8 (OSHPD 1, 1R, 2, 4 & 5), 16 (OSHPD 1R, 2 through 5), 17 (OSHPD 1R, 2 & 5), 19 (OSHPD 1R, 2 & 5) and 21 (OSHPD 1R, 2 & 5), and Chapters 16A (OSHPD 1 & 4), 17A (OSHPD 1 & 4), 19A (OSHPD 1 & 4) and 21A (OSHPD 1 & 4), provided the design and installations are in accordance with the 2018 *International Building Code®* (IBC) provisions noted in the evaluation report and the additional requirements of CBC Chapters 7, 8, 16, 16A, 17, 17A, 19, 19A, 21 and 21A, as applicable.

2.2 DSA:

The V-Wrap Fiber-reinforced Polymer (FRP) Composite System, with or without the V-Wrap FPS fire protection system, described in Sections 2.0 through 7.0 of the evaluation report ESR-3606, complies with CBC amended sections in Chapters 7 (DSA-SS and SS/CC), 8 (DSA SS and SS/CC), 16 (DSA-SS/CC), 19 (DSA-SS and SS/CC) and 21 (DSA-SS/CC), and Chapters 16A (DSA-SS), 17A (DSA-SS and SS/CC), 19A (DSA-SS) and 21A (DSA-SS), provided the design and installations are in accordance with the 2018 *International Building Code®* (IBC) provisions noted in the evaluation report and the additional requirements of CBC Chapters 7, 8, 16, 16A, 17, 17A, 19, 19A, 21 and 21A, as applicable.

This supplement expires concurrently with the evaluation report, reissued January 2022.

10 March 2021

Mr. Jason Alexander
Vice President, Operations
Structural Technologies
1332 North Miller Street
Anaheim, CA 92806

Project 191482 – Characterization of Cure Behavior of V-Wrap 770 Epoxy Adhesive

Dear Mr. Alexander:

This report presents the results of the laboratory test program we conducted to determine the curing behavior of V-Wrap 770 epoxy adhesive when subjected to various temperatures and curing durations, the tension pull strength of prepared CFRP test panels, and the pull-off or bond strength of the epoxy. This work was done based on Exelon Draft Standard NES-MS-03.4 Rev. 001 § I-2.5 and the ASME Code Case N-871 § I-2500 for CFRP repair of pipe.

1. TEST PROGRAM

1.1 Cure Test Procedure

The degree of cure is defined as the difference between the heat of reaction of an uncured sample and that of a partially reacted sample, divided by the heat of reaction of the uncured sample according to ASTM E2160 – Standard Test Method for Heat of Reaction of Thermally Reactive Materials by Differential Scanning Calorimetry. The heat of reaction is determined by performing a differential scanning calorimetry (DSC) test. In this test, a small (milligram) quantity of epoxy is placed in a small inert sample pan and heated at a controlled rate while measuring heat flow until the sample is fully cured. The heat generated by the sample over the course of the test is the heat of reaction.

The cure testing entails mixing small batches of epoxy to test it in its uncured condition and later at various states of cure. Simpson Gumpertz & Heger Inc. (SGH) personnel fabricated plaques using the epoxy, conditioned the plaques at specified temperatures, and removed test specimens from the plaques at specified exposure times to test cure progression. The specimen conditioning requirements, as specified in the ASME Code Case and Exelon Draft Standard, mandate that the tests be performed on specimens that have been curing at 50% RH at temperatures of 60°F, 70°F, 80°F, 90°F, 100°F, and 110°F.

We first performed a trial test to establish the appropriate plaque substrate material, best sample removal method, and maximum DSC heating temperature. In this trial test, the samples each had a mass off 1 to 10 mg and consisted of one piece of epoxy. The results of this test indicated that aluminum foil would be the best substrate, that samples should be cut from the plaques using a razor blade after removing epoxy from the aluminum foil, and that the maximum heating temperature should be 350°C.

For each test temperature, samples were tested using the following four steps:

1. Mix a batch of neat epoxy (Part A No. 19-6515221, Part B No. 19-6515096) using 1 kg of Part A, 0.33 kg of Part B, and a drill/paddle mixer; mix the batch for 3 min.

2. For thickened epoxy, add 1600 mL Cabosil (Lot # 4522342) after 3 min. of mixing of the neat epoxy and then mixing for additional 2 min.

3. Fabricate epoxy plaques, measuring approximately 8 in. by 8 in. by 0.03 in. thick, using only the epoxy (no fiber reinforcement), both neat and thickened. Note that plaques were made at different times for each of the conditioning temperatures.

4. From these plates, cut out DSC test samples.

In addition to the above, we also tested eighteen samples of the uncured neat epoxy and fifteen samples of the uncured thickened epoxy.

For each test temperature, the panels were placed into their respective environments immediately after preparation. For the 70°F environment, a laboratory room with a controlled temperature of 70°F +/- 1°F and humidity of 50% +/- 20% was used. Other temperature environments were created in a programmable environmental chamber which controls temperature and humidity.

At each time of testing, panels were removed from their environments, degree-of-cure tests were performed on the samples taken from each panel, and the panels were immediately placed back into their environments. The degree of cure of each tested sample was determined based on the average total heat of reaction of the uncured epoxy of batches that the sample panels were made from (see Section 2.2).

The progression of degree of cure was monitored in each environment following the test matrix shown in Table 1, where the number in each cell indicates the number of samples tested at that exposure.

Table 1 – Degree-of-Cure Test Matrix

Temperature at 50% RH	Cure Duration and Number of Samples Tested												
	6 Hrs	12 Hrs	18 Hrs	1 Day	1.5 Days	2 Days	3 Days	4 Days	5 Days	7 Days	10 Days	13 Days	16 Days
60°F (16ºC)						4	4	3	3	3	3	3	3
70°F (21ºC)				4		4	4	3	3	3			
80°F (27ºC) (Neat)		4	4	4		4	4	3	3	3	3		
80°F (27ºC) (Thickened)		4	4	4		4	4	3	3	3	3		
85°F (29ºC)				2	2	2	2	2					
90°F (32ºC)		4	4	4		4							
100°F (38ºC)	4	4	4										
110°F (43°C)	4	4	4										

1.2 Tension Test Procedure

Tension tests are used to determine the in-plane tensile properties of polymer matrix composite materials reinforced by high-modulus fibers. The tests are performed in general accordance with ASTM D3039-17 (Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials).

We fabricated three 16 in. by 24 in. CFRP panels on 3 December 2019 using the CFRP C400HM Lot # 25655 Roll # 111 and epoxy Part A Lot # 19-6515221 and Part B Lot # 19-6515096. We made a companion epoxy plaque of the same mix to test the progression of panel cure and cured the panels and companion plaque at 70°F until they reached 85% cure, as determined by a cure test of a companion epoxy plaque, at which time we proceeded to prepare the test specimens.

Sixteen test specimens were prepared by cutting the prefabricated test panels, reducing the specimens to the desired final dimensions with a water-cooled diamond saw and vertical belt sander, and conditioning them for 4 hrs at 70°F. We then placed each specimen into the testing apparatus and attached extensometers to monitor specimen elongation as load is applied. For each test, the specimen was loaded to failure, with the resulting data (applied load and elongation) used in conjunction with sample dimensions to compute the specimen's 1) cross-sectional area, 2) ultimate load per inch of sample width, 3) ultimate strength, 4) modulus of elasticity, and 5) strain at break.

Further details setting forth the step-by-step procedure used by SGH lab personnel to perform the tension pull tests can be found in SGH test procedure SGH D3039-19.

1.3 Bond Strength Test Procedure

Pull-off tests are performed to determine the bond strength of a coating system when adhered to a metal substrate and are done in general accordance with ASTM D4541-17 (Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers). In these tests, we sequentially fabricated a 12 in. x 12 in. panel with the following layers: sand-blasted steel plate, neat epoxy, thickened epoxy, GFRP, thickened epoxy, CFRP, and thickened epoxy.

To perform the tests, fifteen dollies (each with a flat circular face at one end and an opposing feature at the other that can be grabbed/pulled by the testing apparatus) were attached to the face of the test panel using thickened epoxy. We cured the panel and the companion plaque mentioned in Section 1.2 at 70ºF until they reached 85% cure, as determined by a cure test of the companion epoxy plaque. We then cored around the perimeter of each dolly to ensure that the resulting failure surface, when tested, is nearly equal to the area of the face of the dolly. The dollies were then pulled at a rate equivalent to applying 150 psi of pulling stress per second until failure. We then used the failure load, coupled with the measured diameter of the failure surface, to calculate the pull-off strength of the epoxy.

2. TEST RESULTS

2.1 Cure Testing

Degree of cure testing was performed by Brian Toney in November and December 2019 at the designated times for cure duration.

2.1.1 Total Heat of Reaction of Uncured Epoxy

The total heat of reaction of uncured epoxy and thickened, normalized by sample mass, was determined by testing twenty-two samples of neat epoxy and eighteen samples of thickened epoxy following ASTM E2160 after mixing the epoxy as described above. The results of these tests on uncured epoxy are summarized in Table 2. After removing erroneous data (see note below Table 2), the average normalized heat of reaction obtained for neat epoxy was -400 J/g and for thickened epoxy was -364 J/g. Based on the mix proportion of Cabosil, thickened epoxy has about 91% of neat epoxy by mass, indicating approximately the same total heat of reaction of neat and thickened epoxies per mass of epoxy.

Table 2 – Total Heat of Reaction of Uncured Epoxy

Neat Epoxy		
Sample	**Mass (mg)**	**Total Heat of Reaction (J/g)**
NE-x1*	2.486	n.a.
NE-x2*	1.484	n.a.
NE-x3*	1.834	n.a.
1	1.856	-393
2	2.785	-422
3	4.572	-408
4	5.079	-415
5	1.258	-468
NE-x4*	6.493	n.a.
6	2.582	-428
7	2.427	-438
8	5.359	-406
9	2.036	-356
10	4.184	-354
11	2.560	-377
12	5.082	-356
13	3.520	-394
14	2.410	-421
15	3.820	-388
16	5.238	-384
17	2.698	-392
18	3.269	-401
Average		-400
Standard Deviation		29.0
Coef. of Variation		7.3%

Thickened Epoxy		
Sample	**Mass (mg)**	**Total Heat of Reaction (J/g)**
1	2.979	-432
TE-x1*	2.756	n.a.
2	2.345	-447
3	3.288	-394
TE-x2*	3.254	n.a.
4	3.176	-392
TE-x3*	4.404	n.a.
5	2.922	-326
6	2.886	-343
7	5.795	-373
8	4.139	-351
9	4.239	-350
10	6.466	-345
11	3.242	-349
12	2.989	-354
13	3.885	-338
14	2.729	-362
15	7.735	-360
Average		-364
Standard Deviation		34.0
Coef. of Variation		9.4%

* - These specimens were excluded because their data was obscured by sample movement during testing and were therefore not suitable for use in the calculations.

2.1.2 Progression of Cure with Time and Temperature

The results of DSC tests of the progression of cure of V-Wrap 770 in the environmental conditions listed in Table 1 is presented in Figures 1a and 1b (for all test results, and tests up to seven days, respectively). All test results are provided in Appendix A and average degree of cure is summarized in Table 3.

Based on the results of tests reported herein, a degree of cure of 85% can be achieved in a 50% RH environment by using one of the following approximate duration of cure at a given temperature:

- 60°F for at least eleven days.
- 70°F for about four to seven days
- 80°F for about four days.
- 85°F for about three days
- 90°F for about 18 hrs to one day.
- 100°F for about 18 hrs.
- 110°F for about 12 hrs.

Table 3 – Average Degree-of-Cure Results

Temperature at 50% RH	Cure Duration and Number of Samples Tested																
	6 Hrs	12 Hrs	18 Hrs	1 Day	1.5 Days	2 Days	3 Days	4 Days	5 Days	6 Days	7 Days	10 Days	11 Days	13 Days	15 Days	16 Days	17 Days
60°F (16ºC)						75	80	82	82		82		86	84		80	84
70°F (21ºC)				77		82	82	85	84		88						
80°F (27ºC) (Neat)		74	71	81		84	84	88	90	83	87	90			89		
80°F (27ºC) (Thickened)		51	63	74		82	83	86	90		88	90					
85°F (29ºC)				78	82	82	85	86									
90°F (32ºC)		77	86	86		88											
100°F (38ºC)	58	82	87														
110°F (43°C)	63	89	91														

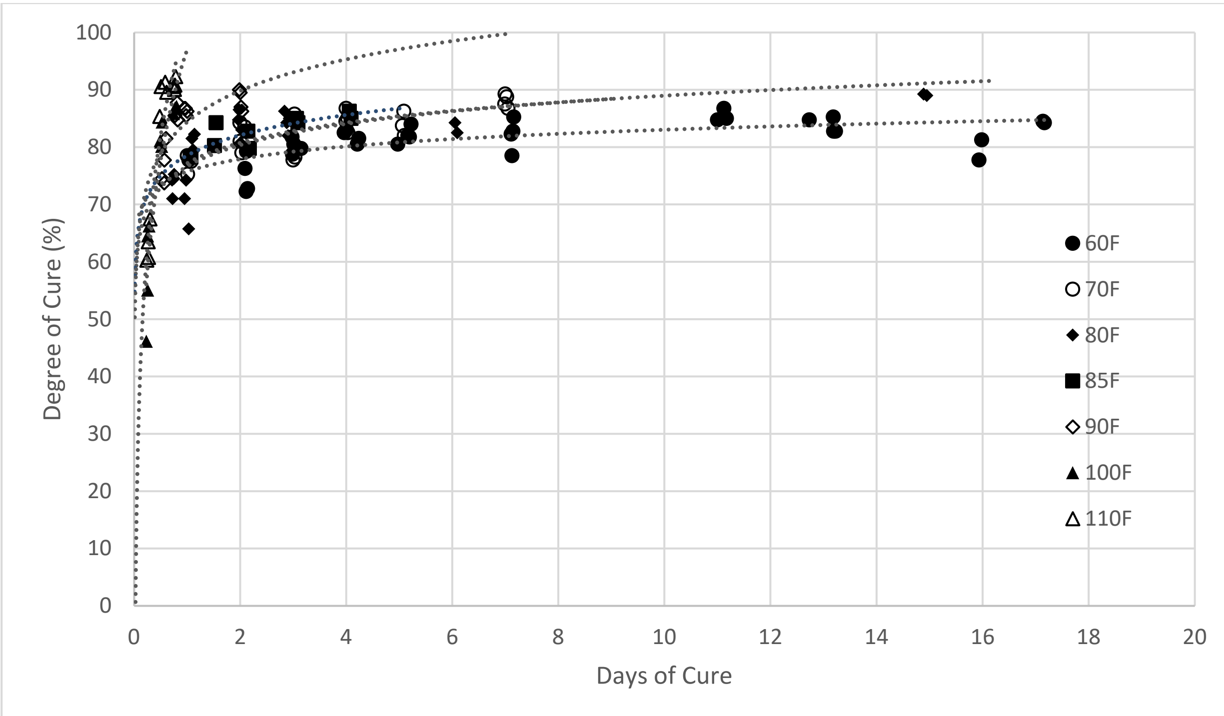

Figure 1a. Progression of Cure with Time and Temperature

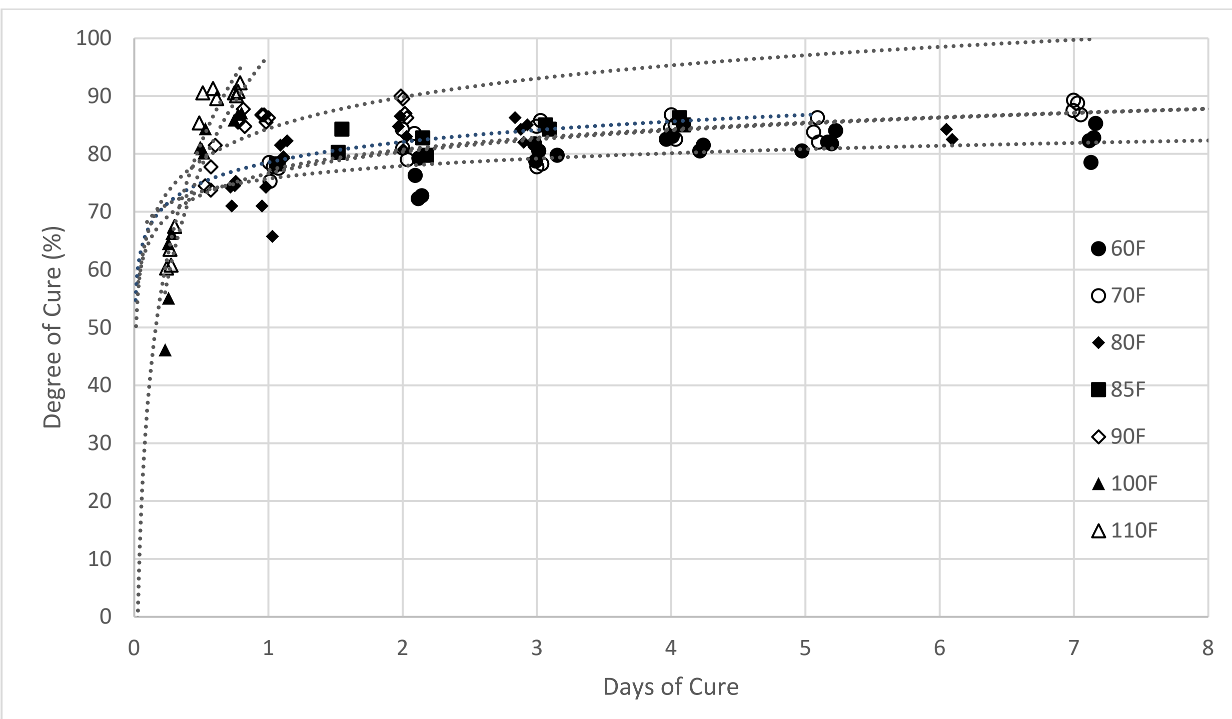

Figure 1b. Progression of Cure with Time (up to 7 days) and Temperature

2.2 Tension Testing

Tension tests were performed on sixteen specimens at the SGH laboratory in Waltham, Massachusetts on 10 December 2019 by Robert Sovie. The specimens were created at the SGH laboratory on 3 December 2019 and cured at 70°F until testing (the degree of cure on the date of testing of the companion plaque was 85% based on two consecutive DSC tests). A summary of the tension test results is shown below in Table 3.

Table 3 – Tension Test Results

Specimen No.	Avg. width (in.)	X-Sectional Area(1) (in.^{2})	Ultimate Load (lb/in.)	Ultimate Strength (ksi)	Modulus of Elasticity (10^6 psi)	Strain at Break (in./in.)	Mode of Failure
1	0.994	0.079	16,244	203.1	12.6(2)	0.015	XGR
2	0.987	0.079	15,882	198.5	13.6	0.014	XGL
3	0.996	0.080	12,314	153.9(2)	13.6	0.011	XGL
4	0.967	0.077	15,350	191.9	13.7	0.013	XGM
5	1.009	0.081	16,760	209.5	13.1	0.016	XGR
6	0.968	0.077	15,845	198.1	13.9	0.014	XGM
7	0.966	0.077	18,320	229.0	13.7	0.016	XGL
8	0.993	0.079	15,712	196.4	13.1	0.014	XGM
9	0.999	0.080	17,957	224.5	13.4	0.016	XGM
10	0.967	0.077	18,151	226.9	13.6	0.016	XGM
11	1.003	0.080	17,142	214.3	13.5	0.015	XGM
12	0.986	0.079	16,977	212.2	13.5	0.015	XGM
13	0.987	0.079	14,730	184.1	13.4	0.014	XGR
14	0.986	0.079	16,891	211.1	13.7	0.015	XGM
15	0.987	0.079	16,473	205.9	14.0	0.015	XGM
16	0.965	0.077	18,272	228.4	14.0	0.016	XGM
Average	0.985	0.079	16,439	208.9	13.6	0.0149	
St. Dev.	0.0144	0.00130	1540	13.9	0.3	0.0010	
Coef. of Var.	1.5%	1.7%	9.4%	6.7%	2.0%	6.4%	
Typical Design Value	-	-	-	152.2	12.3	0.0107	

(1) The cross-section areas were calculated by multiplying the average measured specimen width by the 0.08 in. nominal fiber thickness.
(2) Outliers. Specimen results not included in statistics.

2.3 Bond Strength Testing

The bond strength testing was performed on fifteen specimens at the SGH laboratory in Waltham, Massachusetts on 10 December 2019 by Nasjela Thodhoraqi. The specimens were created at the SGH laboratory on 3 Dec 2019 and cured at 70°F until testing (the degree of cure on the date of testing of the companion plaque was 85% based on two consecutive DSC tests). A summary of the bond strength test results is shown below in Table 4.

Table 4 – Bond Strength Test Results

Specimen No.	Cored Laminate		Failure Load (lbf)	Pull-off Strength (psi)	Failure Mode
	Diameter (in.)	Area (in.^{2})			
1	0.819	0.527	375	712	100% adhesive at dolly-to-CFRP
2	0.826	0.536	613	1,143	100% adhesive at dolly-to-CFRP
3	0.884	0.614	651	1,061	100% cohesive betw. CFRP & GFRP
4	0.836	0.549	409	745	100% adhesive at dolly-to-CFRP
5	0.835	0.548	367	670	100% adhesive at dolly-to-CFRP
6	0.825	0.535	927	1,734	100% adhesive at dolly-to-CFRP
7	0.833	0.545	782	1,435	100% adhesive at dolly-to-CFRP
8	0.822	0.531	866	1,631	100% adhesive at dolly-to-CFRP
9	0.828	0.538	782	1,453	100% adhesive at dolly-to-CFRP
10	0.889	0.621	939	1,512	100% cohesive betw. CFRP & GFRP
11	0.848	0.565	547	968	100% adhesive at dolly-to-CFRP
12	0.821	0.529	671	1,267	100% adhesive at dolly-to-CFRP
13	0.879	0.607	354	584	100% cohesive betw. CFRP & GFRP
14	0.846	0.562	932	1,658	100% cohesive betw. CFRP & GFRP
15	0.824	0.533	315	591	100% adhesive at dolly-to-CFRP
Average	0.841	0.556	635	1,144	-
St. Dev.	0.024	0.032	231	415	-
Typical Design Value	-	-	-	1,100	-

Sincerely yours,

Rasko Ojdrovic

Rasko P. Ojdrovic
Senior Principal

Brian Toney
Project Consultant

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struc'tur'al
TECHNOLOGIES
A Structural Group Company

Test: Shore D Hardness

ASTM: D2240

Date: May 1, 2014

Test Performed by: Andy Sartor

SUMMARY

This report provides test results for Shore D hardness testing per ASTM D2240 at different curing temperatures. Testing was performed on 1/4 in. thick neat resin samples, approximately 8 in. wide by 8 in. long.

1 DESCRIPTION OF SAMPLES

All test samples were composed of V-Wrap 770 Epoxy Resin. The epoxy resin samples were mixed following the procedure and mix ratio listed on the product datasheet.

2 EXPERIMENTAL TESTS AND RESULTS

Three Shore D hardness tests were performed on the cured resin samples. In the first test, the samples were cured at 75°F for 48 hours. In the second test, samples were cured at 80°F for 24 hours. In the third test, samples were cured at 90°F for 15 hours. All hardness measurements were performed using a FLEXBAR Digital Shore Durometer - Model 18881. A minimum of five measurements were taken per sample. The results for the three tests are provided in Table 1.

Table 1 – Shore D Hardness Results

Test No.	Temperature (°F)	Time (Hours)	Average Hardness
1	75	48	88
2	80	24	90
3	90	15	87.6

Andy Sartor
Research & Development Engineer

Tarek Alkhrdaji, PhD, PE
VP – Engineering Services

The Public Health and Safety Organization

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NSF/ANSI/CAN 61
Drinking Water System Components - Health Effects

NOTE: Unless otherwise indicated for Materials, Certification is only for the Water Contact Material shown in the Listing. Click here for a list of Abbreviations used in these Listings. Click here for the definitions of Water Contact Temperatures denoted in these Listings.

Structural Technologies LLC
10150 Old Columbia Road
Columbia, MD 21046
United States
410-859-6539
Visit this company's website
(http://www.structuraltechnologies.com)

Facility : Columbia, MD

Protective (Barrier) Materials

Trade Designation	Water Contact Size Restriction	Water Contact Temp	Water Contact Material
Coatings - Pipe			
V-Wrap 770[1] [G]	36" - 312"	CLD 23	EPOXY
V-Wrap PF[2] [G]	60" - 312"	CLD 23	EPOXY

[1] Product is applied in 5 layers:

Combine the contents of V-Wrap 770-A pail and V-Wrap 770-B pail together and mix for 3 minutes using a mixer speed of 400-600 RPM until uniformly blended. Transfer the mixed epoxy into the other pail and mix for an additional 2 minutes.

Layer 1: 10 wet mils of V-Wrap 770 resin. Mix ratio of V-Wrap 770 resin part A:B is 100:33 by weight.

Layer 2: 40 wet mils of thickened V-Wrap 770 resin. Thickened V-Wrap 770 is achieved by adding fumed silica to the resin at a maximum ratio of 1.5 parts fumed silica to 1 part resin by volume.

Layer 3: 8 coats of V-Wrap EG50 or V-Wrap EG50B Fabric saturated with V-Wrap 770 resin. The thickness of each coat/layer of fabric is 50 mils. No cure time required. Mix ratio of V-Wrap 770 resin part A:B is 100:33 by weight. High strength steel wire (conforming to ASTM A881 specification) may be embedded in between fabric layers with V-Wrap 770 Thickened epoxy. Wires measure 0.2-inch (5 mm) diameter and are helically wound into place with a typical spacing of 0.4 inch (10 mm) on center.

Layer 4: 8 coats of V-Wrap C100, V-Wrap C200H, or V-Wrap C400H Fabric saturated with V-Wrap 770 resin. The thickness of each coat/layer of fabric is 50 mils. The thickness of each coat/layer of fabric is 90 mils. High strength steel wire (conforming to ASTM A881 specification) may be embedded in between fabric layers with V-Wrap 770 Thickened epoxy. Wires measure 0.2-inch (5 mm) diameter and are helically wound into place with a typical spacing of 0.4 inch (10 mm) on center.

Layer 5: 40 wet mils of thickened V-Wrap 770 resin. Thickened V-Wrap 770 is achieved by adding fumed silica to the resin at a maximum ratio of 1.5 parts fumed silica to 1 part resin by volume.

The final cure time and temperature is 24 hours at 75ºF. There is no cure time required between the application of layers.

[2] Product is applied in 4 layers:

Combine the contents of V-Wrap 770-A pail and V-Wrap 770-B pail together and mix for 3 minutes using a mixer speed of 400-600 RPM until uniformly blended. Transfer the mixed epoxy into the other pail and mix for an additional 2 minutes.

Layer 1: 10 wet mils of V-Wrap 770 Resin. Mix ratio of V-Wrap 770 Resin Part A:B is 100:33 by weight.

Layer 2: 40 wet mils of V-Wrap PF Putty. Mix ratio of V-Wrap Putty is Part A:B is 100:31.5 by weight.

Layer 3: 4 coats of V-Wrap EG50 or V-Wrap EG50B Fabric saturated with V-Wrap 770 resin. The thickness of each coat/layer of fabric is 50 mils. High strength steel wire (conforming to ASTM A881 specification) may be embedded in between fabric layers with V-Wrap 770 Thickened epoxy. Wires measure 0.2-inch (5 mm) diameter and are helically wound into place with a typical spacing of 0.4 inch (10 mm) on center.

Layer 4: : 6 coats of V-Wrap C100HM, V-Wrap C200HM, V-Wrap C220Bm or V-Wrap C400HM Fabric saturated with V-Wrap 770 resin. The thickness of each coat/layer of fabric is 90 mils. High strength steel wire (conforming to ASTM A881 specification) may be embedded in between fabric layers with V-Wrap 770 Thickened epoxy. Wires measure 0.2-inch (5 mm) diameter and are helically wound into place with a typical spacing of 0.4 inch (10 mm) on center.

The final cure time and temperature for the system is 24 hours at 75°F. There is no cure time and temperature between the application of layers.

[G] Product is Certified to NSF/ANSI 372 and conforms with the lead content requirements for “lead free” plumbing as defined by California, Vermont, Maryland, and Louisiana state laws and the U.S. Safe Drinking Water Act.

Number of matching Manufacturers is 1

Number of matching Products is 2

Processing time was 0 seconds

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EVALUATION REPORT

Send To: C0177665
Dr. Tarek Alkhrdaji
Structural Technologies LLC
10150 Old Columbia Road
Columbia, MD 21046

Facility: C0247677
Structural Technologies, LLC
10150 Old Columbia Road
Columbia MD 21046
United States

Result	**PASS**	Report Date	07-APR-2020
Customer Name	Structural Technologies LLC		
Tested To	NSF/ANSI/CAN 61		
Description	Coating System (V-Wrap 770 Part A & Part B, Cabosil TS 720 Fumed Silica, EG-50 Fabric, C200H Fabric) | V-Wrap 770		
Trade Designation	V-Wrap 770		
Test Type	Annual Collection		
Job Number	A-00350940		
Project Number	W0593659		
Project Manager	Jenae Yono		

Thank you for having your product tested by NSF International.

Please contact your Project Manager if you have any questions or concerns pertaining to this report.

Report Authorization [signature] **Date** 07-APR-2020

Kathryn Foster - Technical Operations Manager, Water

General Information

Standard: NSF/ANSI/CAN 61

Monitor Code: B

Physical Description of Sample: Coating System (V-Wrap 770 Part A & Part B, Cabosil TS 720 Fumed Silica, EG-50 Fabric, C200H Fabric)

Tested DCC Number: PM14785

Trade Designation/Model Number: V-Wrap 770

Sample Id: **S-0001676304**

Description: Coating System (V-Wrap 770 Part A & Part B, Cabosil TS 720 Fumed Silica, EG-50 Fabric, C200H Fabric)

Sampled Date: 01/22/2020

Received Date: 01/22/2020

Testing Parameter	Sample	Control	Result	Normalized Result	Units
Chemistry Lab					
* Layer 1, Coatings Application Information					
Name of Product Applied	V-Wrap 770 Resin				
Number of Coats Applied	1		1		coat(s)
Application Substrate	Glass				
Coat 1 Mix ratio: A-weight	600		600		grams
Coat 1 Mix ratio: B-weight	198		198		grams
Coat 1 Wet mils applied	10		10		mils
Coat 1 Total area coated	100		100		percent
* Layer 2, Coatings Application Information					
Name of Product Applied	V-Wrap 770 Resin with Fumed Silica				
Number of Coats Applied	1		1		coat(s)
Coat 1 Mix ratio :A-weight	600		600		grams
Coat 1 Mix ratio: B-weight	198		198		grams
Coat 1 Mix ratio: C-volume	300		300		mLs
Coat 1 Wet mils applied	40		40		
Coat 1 Total area coated	100		100		percent
External Coat 1 Notes	300mL of Fumed Silica mixed with 200mL of V-Wrap 770 Resin.				
* Layer 3, Coatings Application Information					
Name of Product Applied	V-Wrap 770 Resin with EG-50 Fabric				
Number of Coats Applied	1		1		coat(s)
Coat 1 Mix ratio :A-weight	600		600		grams
Coat 1 Mix ratio: B-weight	198		198		grams
Coat 1 Mix ratio: C-units	8		8		parts
Coat 1 Wet mils applied	400		400		
Coat 1 Total area coated	100		100		percent
External Coat 1 Notes	Applied as 8 coats of EG-50 fabric saturated with V-Wrap 770 Resin.				
* Layer 4, Coatings Application Information					
Name of Product Applied	V-Wrap 770 Resin with C200H Fabric				
Number of Coats Applied	1		1		coat(s)
Coat 1 Mix ratio :A-weight	600		600		grams
Coat 1 Mix ratio: B-weight	198		198		grams
Coat 1 Mix ratio: C-units	8		8		parts
Coat 1 Wet mils applied	400		400		
Coat 1 Total area coated	100		100		percent
External Coat 1 Notes	Applied as 8 coats of C200H fabric saturated with V-Wrap 770 Resin.				

Sample Id: **S-0001676304**

Testing Parameter	Sample	Control	Result	Normalized Result	Units
Chemistry Lab (Continued)					
* Exposure Scheduling Information For Pipes & Related Products, Coati					
Is this an NSF applied material?	Yes				
If NSF applied, how many layers applied?	5		5		#Layers
* Layer 5, Coatings Application Information					
Name of Product Applied	V-Wrap 770 Resin with Cabosil Fumed Silica				
Number of Coats Applied	1		1		coat(s)
Coat 1 Mix ratio :A-weight	600		600		grams
Coat 1 Mix ratio: B-weight	198		198		grams
Coat 1 Mix ratio: C-volume	300		300		mLs
Coat 1 Cure temp	69.41		69.41		degrees F
Coat 1 Wet mils applied	40		40		
Coat 1 Cure time:-hours	24		24		hours
Coat 1 Total area coated	100		100		percent
Coat 1 Notes:	300mL of fumed silica mixed with 200mL of V-Wrap 770 Resin. No DFT due to nature of the product. Same mix of V-Wrap 770 Resin used for multiple layers.				

Sample Id: **S-0001676305**
Description: Sample exposed at 23C and pH 5
Sampled Date: 03/09/2020
Received Date: 01/22/2020

Normalization Information:

Date exposure completed:	09-MAR-2020	Calculated N1:	0.33	Field Exposure Time:	16 hours	Lab Exposure Time	16 hours
Field Surface Area:	6.8 in2	Lab Surface Area:	80.0 in2	Constant N2:	1	Misc. Factor:	1
Field Static Volume:	1 L	Lab Static Volume:	3.84 L				
				Calculated NFm:	1.00		
Compound Reference Key:	SPAC						

Testing Parameter	Sample	Control	Result	Normalized Result	Units
Chemistry Lab					
* Standard 61 Additives LAB SUM TEST Code					
Mass applied	1408000		1408000		mg
Metals I in water by ICPMS (Ref: EPA 200.8)					
Aluminum	ND(10)	ND(10)	ND(10)	ND(3.3)	ug/L
Arsenic	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Barium	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Beryllium	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Bismuth	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Cadmium	ND(0.2)	ND(0.2)	ND(0.2)	ND(0.07)	ug/L
Chromium	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Copper	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Mercury	ND(0.2)	ND(0.2)	ND(0.2)	ND(0.07)	ug/L
Nickel	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Lead	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L

Sample Id: **S-0001676305**

Testing Parameter	Sample	Control	Result	Normalized Result	Units
Chemistry Lab (Continued)					
Antimony	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Selenium	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Tin	ND(0.5)	0.5	ND(0.5)	ND(0.2)	ug/L
Strontium	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Thallium	ND(0.2)	ND(0.2)	ND(0.2)	ND(0.07)	ug/L
Zinc	ND(10)	ND(10)	ND(10)	ND(3.3)	ug/L
Silver	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L

Sample Id: **S-0001676307**
Description: Sample exposed at 23C and pH 8
Sampled Date: 03/09/2020
Received Date: 01/22/2020

Normalization Information:

Date exposure completed:	09-MAR-2020	Calculated N1:	0.34	Field Exposure Time:	16 hours	Lab Exposure Time	16 hours
Field Surface Area:	6.8 in2	Lab Surface Area:	80.0 in2	Constant N2:	1	Misc. Factor:	1
Field Static Volume:	1 L	Lab Static Volume:	3.98 L				
				Calculated NFm:	1.00		
Compound Reference Key:	SPAC						

Testing Parameter	Sample	Control	Result	Normalized Result	Units
Chemistry Lab					
2,4-Dichlorobenzoic acid					
2,4-Dichlorobenzoic acid	ND(4)	ND(4)	ND(4)	ND(1)	ug/L
* Standard 61 Additives LAB SUM TEST Code					
Mass applied	1410000		1410000		mg
Metals I in water by ICPMS (Ref: EPA 200.8)					
Aluminum	ND(10)	ND(10)	ND(10)	ND(3.4)	ug/L
Arsenic	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Barium	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Beryllium	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Bismuth	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Cadmium	ND(0.2)	ND(0.2)	ND(0.2)	ND(0.07)	ug/L
Chromium	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Copper	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Mercury	ND(0.2)	ND(0.2)	ND(0.2)	ND(0.07)	ug/L
Nickel	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Lead	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Antimony	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Selenium	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Tin	ND(0.5)	0.6	ND(0.5)	ND(0.2)	ug/L
Strontium	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Thallium	ND(0.2)	ND(0.2)	ND(0.2)	ND(0.07)	ug/L

Sample Id: **S-0001676307**

Testing Parameter	Sample	Control	Result	Normalized Result	Units
Chemistry Lab (Continued)					
Zinc	ND(10)	ND(10)	ND(10)	ND(3.4)	ug/L
Silver	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
BASE/NEUTRAL/ACID EPA METHOD 625 Scan for Tentatively Identified Compoun					
No Compounds Detected	ND(4)	Complete	ND(4)	ND(1)	ug/L
Scan Control Complete	TRUE				
Semivolatile Compounds, Base/Neutral/Acid Target 625, Data Workup					
Pyridine	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Nitrosodimethylamine (N-)	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
N-Nitrosomethylethylamine	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
5-Methyl-2-hexanone (MIAK)	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
1-Methoxy-2-propanol acetate	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2-Heptanone	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Cyclohexanone	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Nitrosodiethylamine (N-)	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Isobutylisobutyrate	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Aniline	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Phenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Di(chloroethyl) ether	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2-Chlorophenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2,3-Benzofuran	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
1,3-Dichlorobenzene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
1,4-Dichlorobenzene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
3-Cyclohexene-1-carbonitrile	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2-Ethylhexanol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Benzyl alcohol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
1,2-Dichlorobenzene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
bis(2-Chloroisopropyl)ether	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2-Methylphenol (o-Cresol)	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
N-Methylaniline	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Acetophenone	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
N-Nitrosodi-n-propylamine	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
N-Nitrosopyrrolidine	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
3- and 4-Methylphenol (m&p-Cresol)	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Hexachloroethane	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2-Phenyl-2-propanol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
N-Nitrosomorpholine	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Nitrobenzene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2,6-Dimethylphenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
N-Vinylpyrrolidinone	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
N-Nitrosopiperidine	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Triethylphosphate	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Isophorone	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2-Nitrophenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2,4-Dimethylphenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L

Sample Id: **S-0001676307**

Testing Parameter	Sample	Control	Result	Normalized Result	Units
Chemistry Lab (Continued)					
bis(2-Chloroethoxy)methane	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2,4-Dichlorophenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Trichlorobenzene (1,2,4-)	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Naphthalene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
4-Chloroaniline	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
1,1,3,3,-Tetramethyl-2-thiourea	ND(4)	ND(4)	ND(4)	ND(1)	ug/L
Hexachlorobutadiene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Benzothiazole	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
N-Nitrosodi-n-butylamine	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
4-Chloro-3-methylphenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
p-tert-Butylphenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2-Ethylhexyl glycidyl ether	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2,6-Di-t-butyl-4-methylphenol(BHT)	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Methylnaphthalene, 2-	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Cyclododecane	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2,4,5-Trichlorophenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2,4,6-trichlorophenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
1(3H)-Isobenzofuranone	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2-Chloronaphthalene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2-Nitroaniline	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
1,1'-(1,3-Phenylene)bis ethanone	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2,6-Di-tert-butylphenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Dimethylphthalate	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
1,1'-(1,4-Phenylene)bis ethanone	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Acenaphthylene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Benzenedimethanol, a,a,a',a'-tetramethyl-1,3-	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2,6-Dinitrotoluene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2,4-Dinitrotoluene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Benzenedimethanol, a,a,a',a'-Tetramethyl-1,4-	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
2,4-Di-tert-butylphenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Dimethyl terephthalate	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Acenaphthene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Dibenzofuran	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Ethyl-4-ethoxybenzoate	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
4-Nitrophenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Cyclododecanone	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Diethyl Phthalate	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
p-tert-Octylphenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Fluorene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
4-Chlorophenylphenylether	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
3-Nitroaniline	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
4-Nitroaniline	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Nitrosodiphenylamine (N-)	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Azobenzene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L

Sample Id: **S-0001676307**

Testing Parameter	Sample	Control	Result	Normalized Result	Units
Chemistry Lab (Continued)					
4-Bromophenylphenylether	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Hexachlorobenzene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Pentachlorophenol	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Phenanthrene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Anthracene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Diisobutyl phthalate	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Dibutyl phthalate	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Diphenyl sulfone	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Hydroxymethylphenylbenzotriazole	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Fluoranthene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Pyrene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Butyl benzyl phthalate	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Di(2-ethylhexyl)adipate	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
3,3-Dichlorobenzidine	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Benzo(a)anthracene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Di(2-ethylhexyl)phthalate	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Chrysene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Di-n-octylphthalate	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Benzo(b)fluoranthene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Benzo(k)fluoranthene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Benzo(a)Pyrene (PAH)	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Dibenzo(a,h)anthracene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Indeno(1,2,3-cd)pyrene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
Benzo(g,h,i)perylene	ND(2)	ND(2)	ND(2)	ND(0.7)	ug/L
* Epichlorohydrin (Modified EPA 524.2)					
Epichlorohydrin	ND(5)	ND(5)	ND(5)	ND(2)	ug/L
* 1,3-Dichloro-2-propanol in water, GC/FID					
1,3-Dichloro-2-propanol	ND(20)	ND(20)	ND(20)	ND(6.8)	ug/L
* Benzyl alcohol					
Benzyl Alcohol	ND(50)	ND(50)	ND(50)	ND(17)	ug/L
Bisphenol A - propylene oxide adducts, LC/UV					
Bisphenol A diglycideryl ether	ND(20)	ND(20)	ND(20)	ND(6.8)	ug/L
Bisphenol A propoxylate	ND(20)	ND(20)	ND(20)	ND(6.8)	ug/L
Bisphenol A diglycidyl ether	ND(20)	ND(20)	ND(20)	ND(6.8)	ug/L
Bisphenol A, LC/UV					
Bisphenol A	ND(10)	ND(10)	ND(10)	ND(3.4)	ug/L
* 1,2-Dichloro-3-propanol in Water, GC/FID					
1,2-Dichloro-3-Propanol	ND(20)	ND(20)	ND(20)	ND(6.8)	ug/L
* Ethylene Diamine, LC/Post-column fluorescence, in water					
Ethylene Diamine	ND(20)	ND(20)	ND(20)	ND(6.8)	ug/L
* Propylene glycol , LC/MS					
Glycol, Propylene	ND(200)	ND(200)	ND(200)	ND(68)	ug/L
Volatile Organic Compounds (Ref: EPA 524.2)					
Dichlorodifluoromethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L

Sample Id: **S-0001676307**

Testing Parameter	Sample	Control	Result	Normalized Result	Units
Chemistry Lab (Continued)					
Chloromethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Vinyl Chloride	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Bromomethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Chloroethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Trichlorofluoromethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Trichlorotrifluoroethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Methylene Chloride	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,1-Dichloroethylene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
trans-1,2-Dichloroethylene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,1-Dichloroethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
2,2-Dichloropropane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
cis-1,2-Dichloroethylene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Chloroform	0.99	ND(0.5)	0.99	0.33	ug/L
Bromochloromethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,1,1-Trichloroethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,1-Dichloropropene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Carbon Tetrachloride	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,2-Dichloroethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Trichloroethylene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,2-Dichloropropane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Bromodichloromethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Dibromomethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
cis-1,3-Dichloropropene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
trans-1,3-Dichloropropene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,1,2-Trichloroethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,3-Dichloropropane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Tetrachloroethylene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Chlorodibromomethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Chlorobenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,1,1,2-Tetrachloroethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Bromoform	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,1,2,2-Tetrachloroethane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,2,3-Trichloropropane	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,3-Dichlorobenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,4-Dichlorobenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,2-Dichlorobenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Carbon Disulfide	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L
Methyl-tert-Butyl Ether (MTBE)	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
tert-Butyl ethyl ether	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Methyl Ethyl Ketone	ND(5)	ND(5)	ND(5)	ND(2)	ug/L
Methyl Isobutyl Ketone	ND(5)	ND(5)	ND(5)	ND(2)	ug/L
Toluene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Ethyl Benzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
m+p-Xylenes	ND(1)	ND(1)	ND(1)	ND(0.3)	ug/L

Sample Id: **S-0001676307**

Testing Parameter	Sample	Control	Result	Normalized Result	Units
Chemistry Lab (Continued)					
o-Xylene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Styrene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Isopropylbenzene (Cumene)	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
n-Propylbenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Bromobenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
2-Chlorotoluene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
4-Chlorotoluene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,3,5-Trimethylbenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
tert-Butylbenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,2,4-Trimethylbenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
sec-Butylbenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
p-Isopropyltoluene (Cymene)	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,2,3-Trimethylbenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
n-Butylbenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,2,4-Trichlorobenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Hexachlorobutadiene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
1,2,3-Trichlorobenzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Naphthalene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Benzene	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L
Total Trihalomethanes	0.99	ND(0.5)	0.99	0.33	ug/L
Total Xylenes	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.2)	ug/L

Sample Id: **S-0001676309**
Description: Coating System (V-Wrap 770 Part A & Part B, Cabosil TS 720 Fumed Silica, EG-50 Fabric, C200H Fabric) | V-Wrap 770
Sampled Date: 01/22/2020
Received Date: 01/22/2020

Testing Parameter	Sample	Control	Result	Normalized Result	Units
Chemistry Lab					
Lead in solids by ICPMS					
Lead	ND(0.001)		ND(0.001)		%

Testing Laboratories:

	Id	Address
All work performed at: →	NSF_AA	NSF International 789 N. Dixboro Road Ann Arbor MI 48105

References to Testing Procedures:

NSF Reference	Parameter / Test Description
C0280	2,4-Dichlorobenzoic acid
C0528	Lead in solids by ICPMS
C1005	* Layer 1, Coatings Application Information
C1006	* Layer 2, Coatings Application Information
C1007	* Layer 3, Coatings Application Information
C1008	* Layer 4, Coatings Application Information
C1021	* Exposure Scheduling Information For Pipes & Related Products, Coati
C1031	* Standard 61 Additives LAB SUM TEST Code
C1065	* Layer 5, Coatings Application Information
C1182	Metals I in water by ICPMS (Ref: EPA 200.8)
C2023	BASE/NEUTRAL/ACID EPA METHOD 625 Scan for Tentatively Identified Compounds (TICs)
C2024	Semivolatile Compounds, Base/Neutral/Acid Target 625, Data Workup
C3364	* Epichlorohydrin (Modified EPA 524.2)
C4004	* 1,3-Dichloro-2-propanol in water, GC/FID
C4050	* Benzyl alcohol
C4056	Bisphenol A - propylene oxide adducts, LC/UV
C4057	Bisphenol A, LC/UV
C4114	* 1,2-Dichloro-3-propanol in Water, GC/FID
C4163	* Ethylene Diamine, LC/Post-column fluorescence, in water
C4330	* Propylene glycol , LC/MS
C4662	Volatile Organic Compounds (Ref: EPA 524.2)

Test descriptions preceded by an asterisk "*" indicate that testing has been performed per NSF International requirements but is not within its scope of accreditation.

Unless otherwise indicated, method uncertainties are not applied in any determinations of conformity. Testing utilizes the requested sections of any referenced standards, which may not be the entire standard.

January 12, 2023

Re: City of Novi – Novi Rd/13 Mile Rd PCCP Water Main Renewal

Subject: EPA, VOC & OSHA Compliance

To Whom It May Concern:

Structural Technologies, LLC, manufacturer, and supplier of the V-Wrap™ system, provides the following information regarding compliance required by the CFRP Specification Exhibit A Section 1.03.E.7.

The V-Wrap™ system meets all VOC's, OSHA and EPA regulations. This letter is to certify this compliance in addition to the VOC testing provided within this submission.

If you should have any questions regarding this correspondence, or need any additional information, please contact me at apridmore@structural.net or by phone at 714.869.8824.

Sincerely,

Anna Pridmore, PhD, PE
Vice-President, Pipeline Solutions

Watertightness Testing of CFRP Laminates at Hot and Cold Temperatures

17 January 2018

SGH Project 170825

SIMPSON GUMPERTZ & HEGER

Engineering of Structures
and Building Enclosures

PREPARED FOR:

Structural Technologies Inc.
1332 N. Miller Street
Annaheim, CA 92806

PREPARED BY:

Simpson Gumpertz & Heger Inc.
41 Seyon Street
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Waltham, MA 02453
Tel: 781.907.9000
Fax: 781.907.9009

SIMPSON GUMPERTZ & HEGER
Engineering of Structures
and Building Enclosures

17 January 2018

Dr. Anna Pridmore
Structural Technologies Inc.
1332 N. Miller Street
Anaheim, CA 92806

Project 170825 – Watertightness Testing of CFRP Laminates at Hot and Cold Temperatures

Dear Dr. Pridmore:

Attached please find our report presenting the results of watertightness tests conducted at hot (130°F±5°F) and cold (32°F±5°F) temperatures on a carbon-fiber-reinforced polymer (CFRP) laminate design of 1H+1L+1G+1H, where "H" and "L" represent V-Wrap C400HM layers in the hoop and longitudinal directions, respectively, and "G" represents V-Wrap EG50-B bidirectional GFRP used for watertightness. The results obtained at ambient temperature of 73°F±5°F for the same laminate design, which were previously presented in an SGH Report dated 22 December 2015, are attached in Appendix A for completeness.

Please let us know if you have any questions or comments.

Sincerely yours,

Murat Engindeniz
Associate Principal

Rasko P. Ojdrovic, P.E.
Senior Principal
MA License No. 38111

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Encls.

Table of Contents

1. INTRODUCTION

As part of the research conducted for the Water Research Foundation Projects #4510 “Watertightness of CFRP Liners – Addendum to CFRP Renewal of Prestressed Concrete Cylinder Pipe”, which forms the technical basis of the watertightness requirements of the AWWA Draft Standard C305 – CFRP Renewal and Strengthening of PCCP, Simpson Gumpertz & Heger Inc. (SGH) developed a laboratory testing apparatus for watertightness testing of carbon-fiber-reinforced polymer (CFRP) laminates up to 500 psi water pressure. One of the requirements of AWWA C305 for watertightness is to verify that the designed CFRP laminates will remain watertight up to at least twice the maximum design pressure by hydrostatic testing of a minimum of three mockup panels in a pressure chamber.

SGH previously performed watertightness tests at ambient temperature of 73°F±5°F on three nominally identical specimens with the layup of 1H+1L+1G+1H, where “H” and “L” represent V-Wrap C400H layers in the hoop and longitudinal directions, respectively, and “G” represents V-Wrap EG50-B bidirectional GFRP (SGH report, dated 22 December 2015, included in Appendix A). These tests showed that at ambient temperature the layup of 1H+1L+1G+1H remained watertight up to at least 400 psi, at which time the tests were terminated.

As the CFRP liners in pipelines may be subjected to varying temperatures in service depending on application, it is of interest to determine the effect of cold and hot temperatures on watertightness. Structural Technologies (Structural) retained SGH to prepare and test additional specimens with the 1H+1L+1G+1H layup at temperatures of 32°F±5°F and 130°F±5°F, which encompass the design temperature range of typical pipelines in which CFRP liners are used.

1.1 Purpose and Scope

This purpose of the test program presented herein was to determine the effect of cold and hot temperatures on the watertightness behavior of the above-mentioned laminate design in terms of leak pressure and measured radial expansion of the specimens. This report presents the results of tests on eight nominally identical CFRP laminates, four tested at 32°F±5°F and four tested at 130°F±5°F.

1.2 Method of Approach

The method of approach is similar to that followed for the tests previously conducted at the ambient temperature of 73°F, in that specimens were prepared over a 22 in. x 22 in., 16 ga cylindrical steel sheet, curved to a radius of 48 in. and with a 12 in. by 12 in. window in the center that allows watertightness testing of standalone CFRP laminate. Tests were conducted in a test apparatus designed and constructed for an internal pressure of up to 500 psi, which was placed in an environmental chamber that was cooled down to a temperature of about 32°F or heated up to a temperature of about 130°F as needed to perform the tests. After stabilization of the air temperature in the environmental chamber and the water temperature in the test apparatus, the water pressure was gradually increased until the test specimen ruptured, the specimen lost watertightness through the laminate, or the test was terminated at 400 psi for safety reasons. The hydrostatic water pressure and the radial expansion of the specimens were continuously recorded, and the specimens were visually examined at each pressure increment, allowing comparison of watertightness behavior of specimens tested at cold and hot temperatures.

2. TEST SETUP AND PROCEDURE

2.1 Description of Test Setup

The test setup consists of placing the pressure chamber used for watertightness tests (see ambient temperature test report included in Appendix A) into a 6 ft x 7 ft x 8 ft walk-in environmental chamber (Figure 1) at the SGH laboratory in Waltham, Massachusetts. The environmental chamber has an air conditioning unit that is capable of achieving the required cold air temperature of 32°F, and it does not have heating capability. The required hot air temperature of 130°F was achieved by placing adjustable electric heaters in the environmental chamber. As the specified temperature needed to be achieved not only in the air but also in the water to be used for filling the pressure chamber, water was drawn from a barrel placed in the environmental chamber, and cooling and heating of the water in the barrel was expedited by placing ice or electric heaters in the water, as needed.

(a) (b) (c) (d)

Figure 1 – Overview of test setup: (a) pressure chamber placed in the environmental chamber, (b, c) walk-in environmental chamber, (d) barrel for fill water.

2.2 Test Procedure

The operation of the pressure chamber was as described for the watertightness tests at ambient temperature in the report included in Appendix A. Test specimens were typically placed in the pressure chamber the day before testing, and the environmental chamber was set to achieve the specified temperature and stabilize overnight. On the test day, both air and water temperature were confirmed, and then the pressure chamber was filled with water and the test was started. The environmental chamber remained closed throughout preparation and testing, except for intermittent entries to make adjustments during preparation or observe the specimen condition at each pressure increment during testing. The pressure chamber was operated from the outside of the environmental chamber via hoses and wiring passed through a hole in the side wall of the environmental chamber.

2.3 Instrumentation

Instrumentation for each test included, as a minimum, a pressure transducer to monitor the hydrostatic pressure and an LVDT to monitor the radial expansion of the specimen (Figure 2). In addition, Specimens 32F-1 through 32F-4, 130F-1, and 130F-2 were instrumented with two strain gages with a gage length of 3 in. to measure average strains near the center in the hoop and longitudinal directions; however, these gages did not yield useful data due to changes in the curvature of the specimens during the tests, and therefore are not reported herein. The last two specimens, 130F-3 and 130-4, were instrumented with typical electrical wire strain gages directly bonded to the specimen surface in the configuration shown in Figure 3.

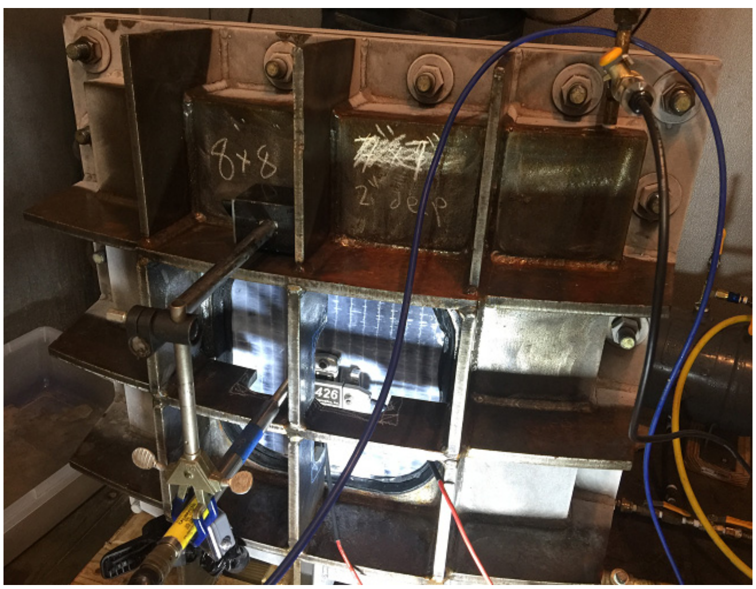
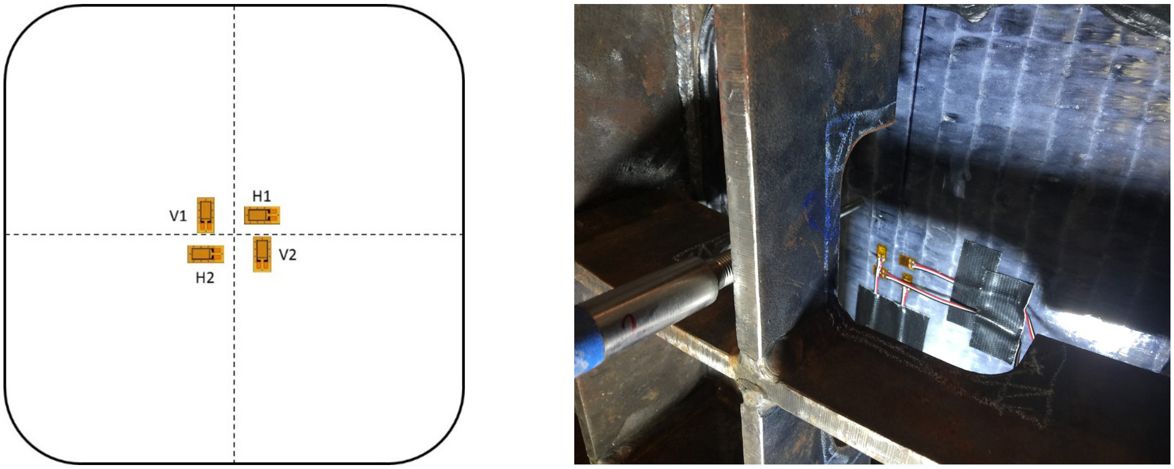


Figure 2 – Typical instrumentation



(a) (b)

Figure 3 – Additional instrumentation (strain gages) used for Specimens 130F-3 and 130F-4

2.4 Quality Assurance of Test Apparatus

The pressure transducer was calibrated in the range of 0 to 500 psi; the calibration certificate is included in Appendix B. The LVDT used to measure the radial expansion of the specimens was calibrated by the manufacturer and did not require temperature correction. The temperature in the environmental chamber was confirmed by both a thermocouple and a laser device before starting the tests.

(a) (b) (c)

Figure 4 – Typical views of temperature verification prior to the tests: (a) thermocouple inserted through hole into the environmental chamber, (b, c) measurement of specimen surface temperature prior to tests at cold and hot temperatures.

3. SPECIMEN PREPARATION

All eight specimens were nominally identical and had a laminate layup of 1H+1L+1G+1H, where "H" and "L" represent V-Wrap C400HM CFRP layers (0.08 in. thick per layer) in the hoop and longitudinal directions, respectively, and "G" represents V-Wrap EG50-B bidirectional GFRP layer (0.034 in. thick) used for watertightness. All fabrics were hand-saturated in a tray filled with V-Wrap V770 Epoxy. A thin layer of thickened epoxy, prepared by mixing V-Wrap V770 epoxy with Cab-O-Sil treated fumed silica at a ratio of 6.5% by weight of epoxy, was applied between each layer and as a top coat. All CFRP, GFRP, epoxy, and Cab-O-Sil were provided by Structural, and the carbon fabric, glass fabric, and epoxy had the manufacturing data listed in Tables 1 and 2.

Table 1 – Manufacturing Data for Carbon and Glass Fabrics

	V-Wrap C400HM Carbon	V-Wrap EG50-B Glass[1]
Lot #	24483	7352022
Roll #	76	
Date	9 February 2016	

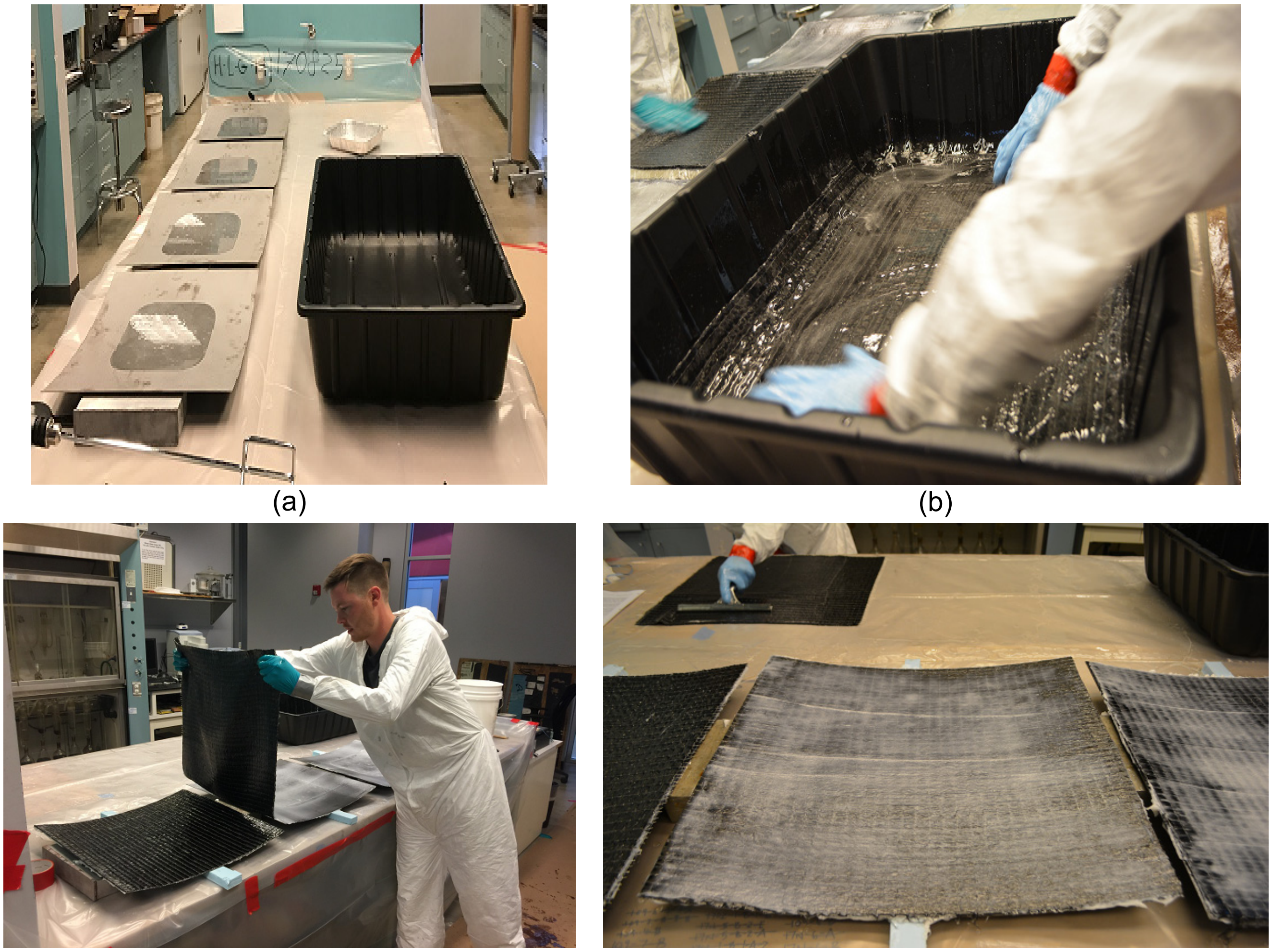
[1] Information for blank rows was not available.

Table 2 – Manufacturing Data for V-Wrap 770 Epoxy

	Component A	Component B
Manufacturing #	03/17/2017K	03/17/2017K
LOT #	17-6275570	17-6275571
Expiration Date	March 2019	March 2019

The specimens were prepared on 30 June 2017 by Casey Sturrup and Zachary Svec, under the continuous quality control inspection of Kristen Peterson and supervision of Dr. Murat Engindeniz, in the SGH Laboratory in Waltham, Massachusetts. Each specimen was constructed on a 22 in. by 22 in., 16 ga steel sheet curved to a radius of curvature of 48 in. in one direction to simulate a 96 in. diameter pipe curvature, a 12 in. x 12 in. window, and a removable curved plug sheet to allow construction of laminate with the intended curvature (Figure 5a). A drawing of the specimen steel sheet support, including manufacturing tolerances, is provided at the end of the SGH report dated 22 December 2015 in Appendix A. The steel sheets were sandblasted to an SSPC SP-10, near-white finish (Figure 5a). Saturation of both carbon and glass fabrics were performed manually in a tub, with care not to cause fiber separation or misalignment (Figure 5b). A thin layer of thickened epoxy was applied to the steel sheet before the application of the first wetted hoop CFRP layer, which was followed by the application of CFRP and GFRP layers (Figure 5c). The finished inside surface of a typical specimen is shown in Figure 5d.

After preparation, the specimens were kept in a room with controlled temperature of 73°F±5°F and relative humidity 50%±2% until the day before testing, at which time they were moved into the environmental chamber for testing. On the first day of testing, the degree of cure of epoxy was verified to be greater than the minimum cure level of 85% specified by AWWA Standard C305 – CFRP Renewal and Strengthening of PCCP, by testing small epoxy samples collected from the surface of one of the specimens using a differential scanning calorimeter (DSC) according to ASTM E2160. Based on two DSC tests on Specimen 32F-1, the average degree of cure on Test Day 1 was determined to be 85%, which was considered to verify the degree of cure of all specimens to be subsequently tested. Another degree-of-cure test performed on the same specimen after all specimens were tested indicated a degree of cure of 94%.



(a) (b) (c) (d)

Figure 5 – Typical views from sample preparation: (a) curved steel sheets with 12 in. x 12 in. window plugs to receive CFRP laminate, (b) saturation of fabrics in tub, (c) hand layup of saturated fabrics, (d) finished view if typical specimen.

4. TEST RESULTS

Specimens 32F-1 through 32F-4 were tested twenty-eight to forty-six days after preparation of the specimens. The first specimen tested at 32°F exhibited no signs of loss of watertightness, then abruptly cracked and leaked near the edge of the 12 in. x 12 in. window at 345 psi (Figure C.1a). An examination of the specimen after removal from the test setup indicated that the failure was due to local bending of the specimen at the edge as a result of improper seating within the test chamber, which was not attributable to loss of watertightness due to specimen architecture or testing environment (Figure C.1b). The seating was corrected after the first test and was not observed again in the remaining seven tests. Of the remaining three specimens tested at 32°F, 32F-2 exhibited no signs of loss of watertightness up to 400 psi, at which point the test was terminated (Figure C.2), and 32F-3 and 32F-4 exhibited visible water droplets in one of the quadrants at 400 psi (Figures C.3 and C.4).

Specimens 130F-1 through 130F-4 were tested forty-eight to fifty-three days after preparation of the specimens. The first three specimens exhibited no signs of loss of watertightness up to 400 psi, at which point the tests were terminated (Figures C.5, C.6, and C.7). Testing of the fourth specimen, 130F-4, had to be terminated at 374 psi due to the failure of the gasket in the pressure chamber, at which time the specimen had not exhibited any signs of loss of watertightness (Figure C.8).

The results of all tests, including the recorded maximum pressure and radial expansion for each specimen and the maximum strains for Specimens 130F-3 and 130F-4, are summarized in Table 3. Plots of pressure versus radial expansion for all specimens are presented in Figure 6. The results indicate that the tested laminate architecture remains watertight up to 400 psi between 32°F and 130°F, which means that the tested laminate satisfies the watertightness testing requirement of AWWA C305 within this temperature range for CFRP lining applications with maximum design pressures up to 200 psi. The laminate stiffness appears to be slightly lower at 130°F than at 32°F, as evidenced by the consistently greater radial expansions measured at 130°F; however, this is an expected characteristic of fiber-reinforced polymers and does not appear to affect the watertightness behavior within the tested temperature range.

Table 3 – Summary of Test Results

Test Temp.	Specimen No.	Date Made	Date Tested	Layup[1]	Maximum Pressure	Radial Expansion at Maximum Pressure	Strain at Maximum Pressure
32°F± 5°F	32F-1	30 June 2017	28 July 2017	1H+1L+1G+1H	345 psi [2]	0.70 in.	-
	32F-2	30 June 2017	4 August 2017	1H+1L+1G+1H	No leak at 400 psi[3]	0.70 in.	-
	32F-3	30 June 2017	14 August 2017	1H+1L+1G+1H	400 psi[4]	0.76 in.	-
	32F-4	30 June 2017	15 August 2017	1H+1L+1G+1H	400 psi[5]	0.75 in.	-
130°F± 5°F	130F-1	30 June 2017	17 August 20217	1H+1L+1G+1H	No leak at 404 psi[3]	0.91 in.	-
	130F-2	30 June 2017	18 August 2017	1H+1L+1G+1H	No leak at 404 psi[3]	0.96 in.	-
	130F-3	30 June 2017	21 August 2107	1H+1L+1G+1H	No leak at 402 psi[3]	0.82 in.	0.93%
	130F-4	30 June 2017	22 August 2107	1H+1L+1G+1H	374 psi[6]	0.92 in.	0.67%

(1) H=L=V-Wrap C400HM unidirectional CFRP, G=V-Wrap EG50-B bidirectional GFRP, all layers saturated with V-Wrap 770 epoxy.
(2) Crack and leak near edge of panel in upper left quadrant due to improper specimen seating in test chamber.
(3) Test terminated without leak.
(4) Visible drops of water on surface in the upper right and lower left quadrants.
(5) Visible drops of water on surface in the upper left and lower left quadrants.
(6) Test terminated due to pressure chamber gasket failure.

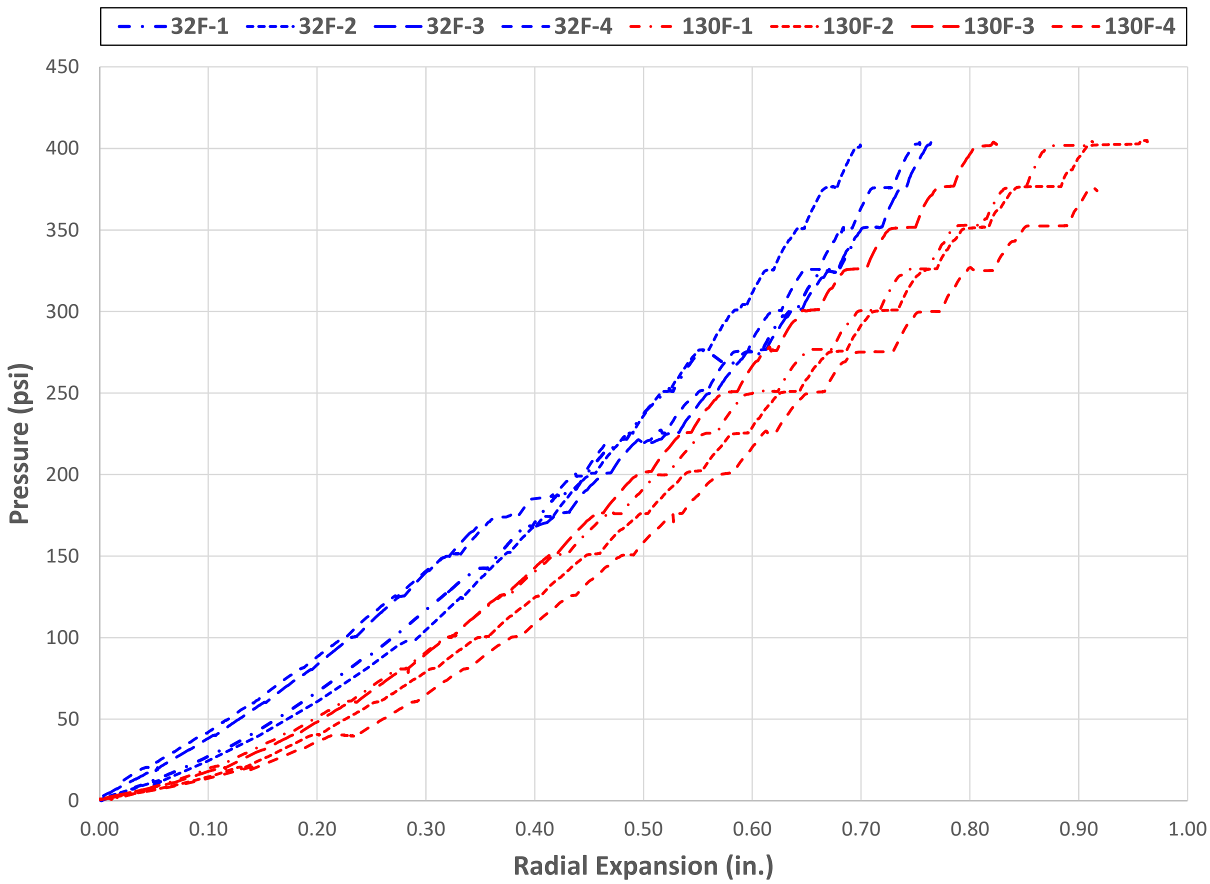


Figure 6 – Pressure versus radial expansion of test specimens.

4. CONCLUSIONS

Based on the results of watertightness testing of four specimens at 32°F±5°F and four specimens at 130°F±5°F, we conclude that the laminate of 1H+1L+1G+1H made with V-Wrap C400HM unidirectional CFRP (H and L layers) and V-Wrap EG50-B bidirectional GFRP (G layer) remains watertight up to 400 psi water pressure between 32°F and 130°F. As a result, the tested laminate satisfies the watertightness testing requirement of AWWA C305 within this temperature range for CFRP lining applications with maximum design pressures up to 200 psi. The stiffness of the laminate appears to be slightly lower at 130°F than at 32°F; however, this does not appear to affect the watertightness behavior of the tested laminate within the tested temperature range.

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APPENDIX A

SGH Report of Watertightness Tests at Ambient Temperature (73°F±5°F) dated 22 December 2015

Watertightness Testing of CFRP Laminate Design of Liners

Structural Technologies
2 April 2015
(Revised 22 December 2015)

SGH Project 150401

SIMPSON GUMPERTZ & HEGER
Engineering of Structures and Building Enclosures

PREPARED FOR:

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2 April 2015
(Revised 22 December 2015)

Dr. Anna Pridmore
Structural Technologies Inc.
7455 New Ridge Road, Suite T
Hanover, MD 21076

Project 150401 – Watertightness Testing of CFRP Liner

Dear Dr. Pridmore:

Attached please find our report presenting the results of watertightness tests conducted on the CFRP V-Wrap laminate design consisting of two hoop and one longitudinal layers of CFRP C400H fabric, and one bidirectional glass fabric layer of EG50B (with architecture 1H+1L+G+1H) using 770 Epoxy.

Please call me if you have any questions.

Sincerely yours,

Mehdi S. Zarghamee

Mehdi S. Zarghamee, Ph.D.
Senior Principal
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Encl.

Table of Contents

Letter of Transmittal

1. INTRODUCTION

Hydrostatic pressure tests conducted by Simpson Gumpertz & Heger Inc. (SGH) as a part of Water Research Foundation projects between 2011 and 2013 showed that carbon-fiber-reinforced polymer (CFRP) liners constructed using specific epoxies, laminate sequences, and cure levels may lose watertightness at pressures below the strain capacity of the liner when used for renewal of distressed prestressed concrete cylinder pipe (PCCP). CFRP materials are believed to be structurally sound and durable, but under certain conditions may experience loss of watertightness at high pressures.

SGH has developed a pressure chamber and test procedure for watertightness testing of CFRP laminate designs. The test simulates the performance of a CFRP-repaired PCCP subjected to hydrostatic pressure when the host pipe continues to degrade and develops a perforation, causing additional axial and bending strains in the laminate as it expands into and bend over the edges of perforation.

1.1 Purpose

This report presents the results of watertightness tests conducted on the CFRP V-Wrap laminate design consisting of two hoop and one longitudinal layers of CFRP C400H fabric, and one bidirectional glass fabric layer of EG50B (with architecture 1H+1L+G+1H) using 770 Epoxy.

1.2 Scope

To test for watertightness of three test specimens constructed using the V-Wrap laminate architecture 1H+1L+G+1H.

1.3 Method of Approach

In the absence of any standard test method for watertightness of CFRP laminates, SGH has developed our own test apparatus and test procedures as described below, based on a finite element model study of the performance of a laminate in a pipe with a window representing corrosion induced perforation in the host pipe. The test apparatus is a pressure chamber with a curved surface of 48 in. radius (representing a 96 in. diameter pipe) with a 12 in. by 12 in. window. CFRP test specimens 22 in. x 22 in. are constructed by layup of CFRP laminae with a glass layer added for watertightness. Specimens are constructed over a 16 ga cylindrical steel sheet support curved to a radius of 48 in. with a 12 in. by 12 in. window, with the test apparatus designed and constructed for an internal pressure of up to 500 psi. After curing of the specimens and attaching strain gages, the test specimens are placed inside the pressure chamber and against the curved surface of the chamber. The pressure chamber is then sealed and pressurized until the test specimen ruptured or the specimen lost watertightness through the laminate.

2. FINITE ELEMENT ANALYSIS OF CFRP TEST SPECIMENS

2.1 Purpose of Finite Element Analysis

The purpose of the finite-element analysis is to evaluate the strains and deflection of the CFRP laminate consisting of one longitudinal layer and one circumferential layer of 0.08 in. thick CFRP at an internal pressure of 500 psi. The laminate is inside a relatively rigid steel pipe with a 12 in. by 12 in. window that allows the CFRP laminate to bulge out and bend near the boundaries of the window, thus producing in-plane membrane stresses and bending stresses in the laminate as expected in a CFRP liner inside a host pipe which has lost stiffness over an area. The geometry of the window is chosen so that the maximum strain is not limited to a small area.

2.2 Model Description

The finite element model is a one-quarter model of a curved steel plate with a window in the center overlaid with two layers of CFRP. The steel plate measures 4 ft-6 in. in the longitudinal direction and 5 ft-0 in. in the circumferential direction, and has a radius of curvature of 48 in. The window dimensions are 12 in. x 12 in. The steel plate has a thickness of 0.25 in., a Poisson ratio of 0.3, and an effective modulus that simulates the stiffness of test apparatus. The CFRP layer has a thickness of 0.08 in. The outer layer of CFRP is oriented with fibers running in the longitudinal direction. The inner layer of CFRP (on the wet side) is oriented with the fibers running in the circumferential direction. The gasket between the test specimen and the curved plate is modelled based on the results of compression tests performed on a 2 in. by 2 in. piece. Pressure increments of 100, 200, 300, 400, and 500 psi are applied to the inner layer of CFRP and maximum membrane strains are measured at each layer.

The properties of CFRP lamina are a modulus of 12,370 ksi in the fiber direction, 910 ksi in the transverse direction, a shear modulus of 337 ksi, and a Poisson's ratio of ν_{LT} = 0.296.

2.3 Model Results

The model calculates the deflections and strains in the fiber direction and in the transverse direction of different layers at 500 psi (Figures 1 through 3). Figure 1 shows the finite element model and the deformed shape with a maximum deflection at the center of the plate of 0.63 in. Figures 2 and 3 show the maximum strains in the fiber direction of 0.55% in the circumferential direction and 0.83 in the longitudinal direction. The strain in the transverse direction of the inner layer is higher, but such a high strain may cause cracking between fiber bundles, but does not cause rupture of laminate.

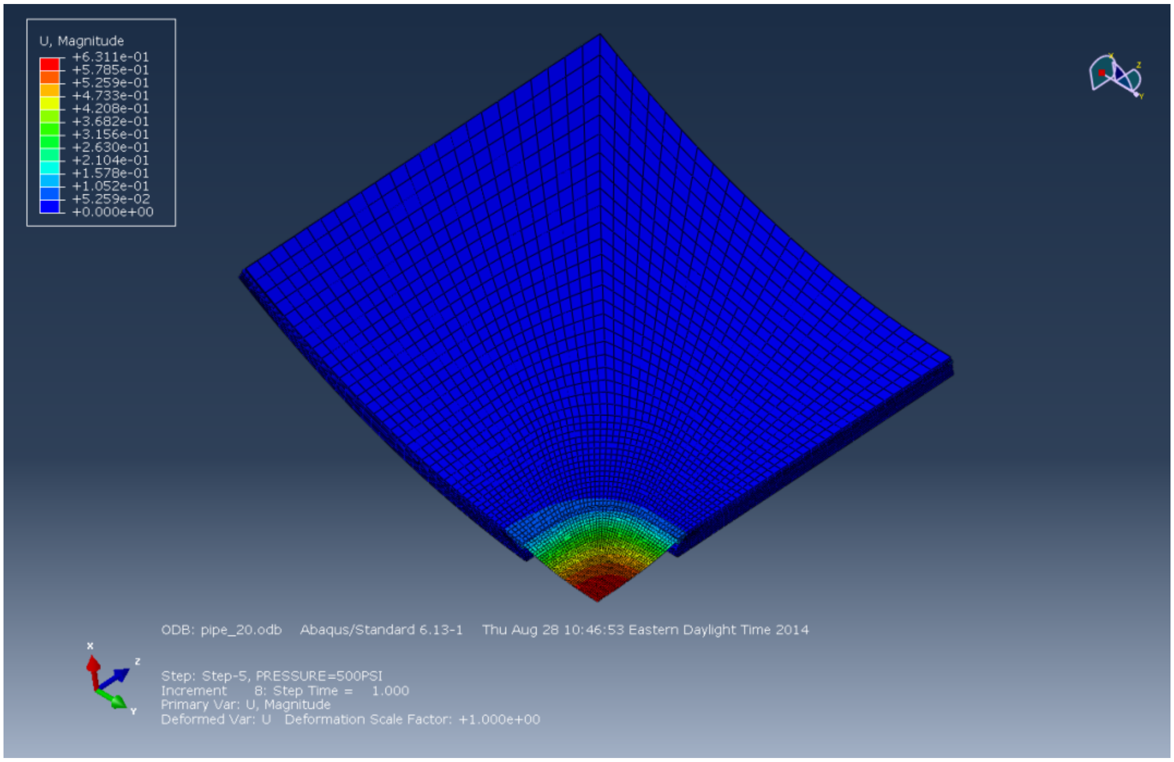


Figure 1 – Deformation of CFRP.

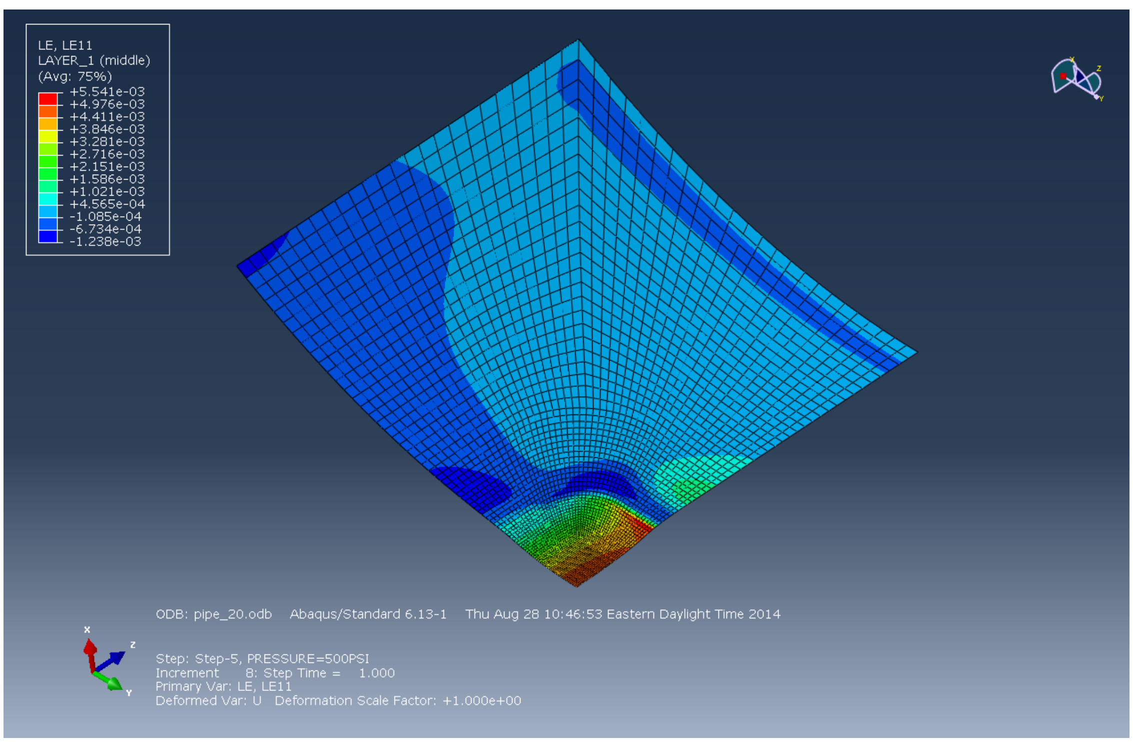


Figure 2 – Strains in the fiber direction of the inner layer of CFRP with fibers running in the circumferential direction at 500 psi pressure. Note maximum strain of 0.55%.

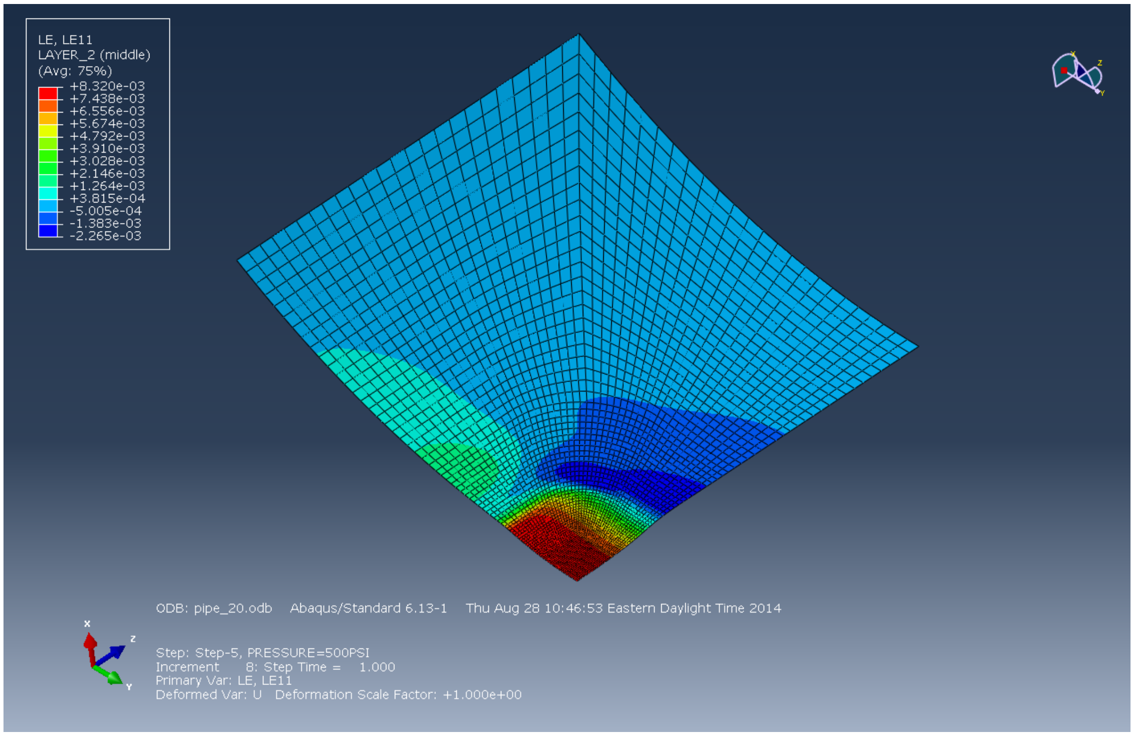


Figure 3 – Strains in the fiber direction of the outer layer of CFRP with fibers running in the longitudinal direction at 500 psi pressure. Note maximum strain is 0.83%.

3. TEST APPARATUS

3.1 Description of Test Apparatus

The test apparatus is a pressure chamber 24 in. square in plan, a high-pressure water holding tank, a compressed gas cylinder, and pressure gage and valves as described below. The apparatus is shown in Photo 1. The pressure chamber is designed to resist a pressure of 500 psi and is fabricated from welded steel and plates with stiffeners. The pressure chamber consists of two parts: a 24 in. by 24 in. rectangular top weldment consisting of a cylindrical plate with a 48 in. radius (simulating the inside surface of a 96 in. diameter pipe), and a 12 in. by 12 in. window through which the CFRP laminate is allowed to deflect (simulating a perforation in the wall of the pipe). This top weldment has a machined bottom surface for bolting to the base plate. The base plate is a shallow box with open top. The mating surfaces of the two plates are machined, and a groove is carved in the base plate mating surface to capture a silicone gasket. Once the test specimen with strain gages and soldered leads is installed inside the pressure chamber, the two plates are bolted together with sixteen high-strength bolts 3/4 in. in diameter.

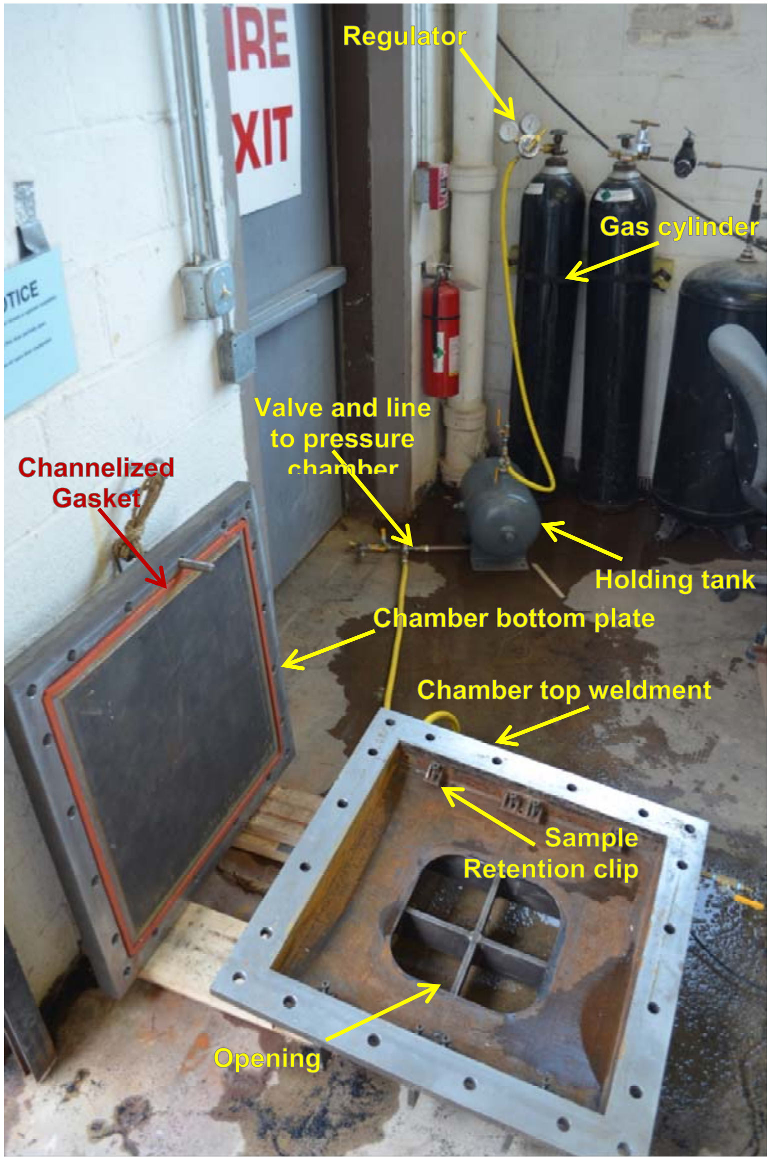
3.2 Operation of Test Apparatus

To pressurize the pressure chamber, first the chamber and the holding tank are filled with water. The holding tank is then pressurized with air from the compressed gas cylinder. Pressure is controlled by a regulator at the gas cylinder and is also monitored with a pressure transducer at the top of the pressure chamber in line with the overflow valve.

A silicone rubber gasket, 3/16 in. in thickness is placed between the specimen and the curved steel surface of pressure chamber. The water pressure seals the specimen as it presses it against the gasket placed between the specimen and curved surface of the top weldment. The sample is restrained by angles that are pressed against the test specimen along the straight edges of the specimen by bolts through clips welded to the interior of the cell wall.

3.3 Quality Assurance of Test Apparatus

The pressure transducer was calibrated in the range of 0 to 500 psi and the calibration certificate is shown in Appendix A of this report. The strain gages attached to the CFRP in the locations shown in Chapter 4 have different gage factors that were input into the computer used for data acquisition. The tests were conducted at or close to gage factor reference temperature of 24°C (75°F). No additional temperature correction was applied.



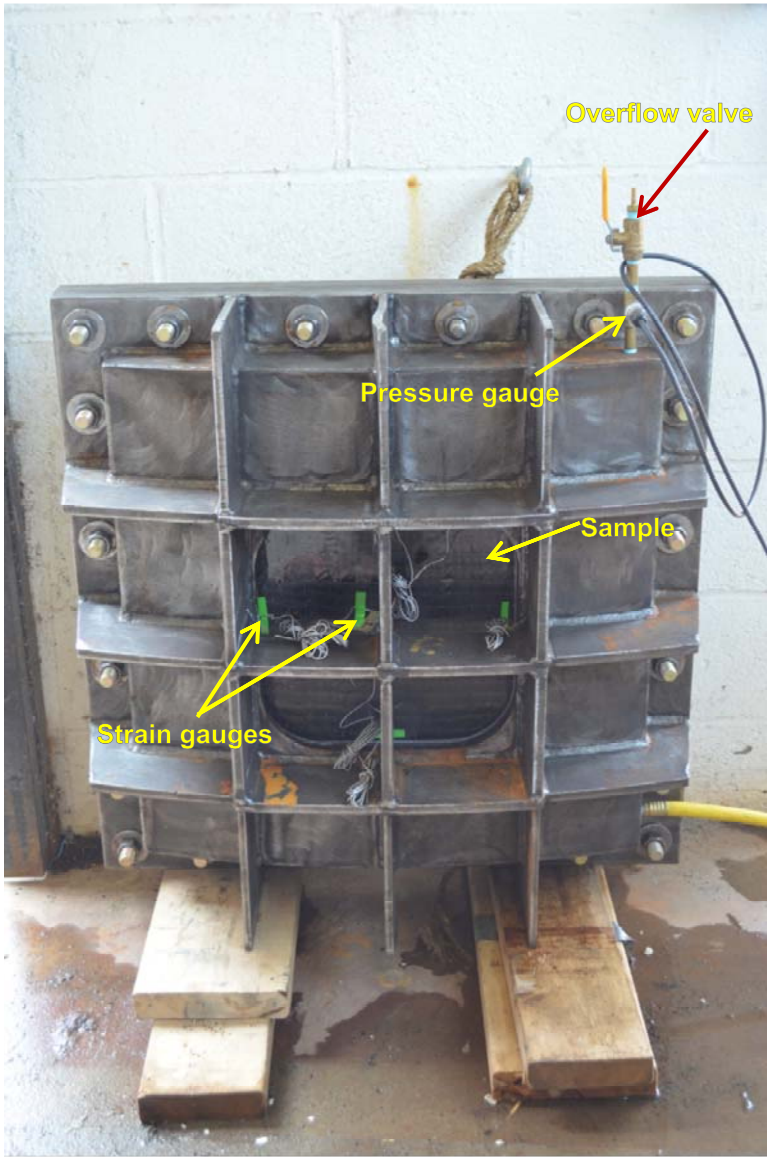


Photo 1 – Test apparatus disassembled (left) and assembled (right).

4. WATERTIGHTNESS TESTING

We conducted pilot tests on watertightness of CFRP laminates designed for repair of prestressed concrete cylinder pipe (PCCP) in the pressure chamber describe above. Test specimens were constructed by SGH in our laboratory in Boston using the same procedures as used by the installers in the field.

4.1 Construction of Test Specimens

The CFRP system consists of two component V-Warp 770 epoxy adhesive, thickened epoxy consisting of epoxy resin and Cabot Cab-o-Sil silica fume, 0.08 in. thick V-Wrap C400H unidirectional carbon fiber fabrics and, and layer of proprietary EG50B bidirectional stitched glass layer to provide watertightness. The laminate construction was 1H+1L+G+1H, where H stands for CFRP lamina running in the hoop direction, L stands for CFRP lamina running in the longitudinal direction, and G stands for glass fabric layer. The construction of the specimens was performed by Casey Sturrup and assisted by Morgan Lyew on 23 March 2015. Dr. Murat Engindeniz verified the material data and the construction procedure, and Dr. Mehdi Zarghamee supervised the specimen construction process. Before construction began, it was verified that material storage conforms with the manufacturer's instructions. Three specimens were constructed. The lot number of resins and fabrics used are given below.

V-Wrap 770 Epoxy Adhesive		
Component A	Manuf.	06/09/2014K
	LOT #	14-5919277
	Expiration Date	June 2016
Component B	Manuf.	06/11/2014K
	LOT #	14-5919301
	Expiration Date	June 2016

FABRIC		
C400H	LOT #	23460
	ROLL #	29
	DATE	2/3/2015
EG50B	LOT #	7348955
	DATE	1/6/2014

Each specimen is constructed on a 22 in. by 22 in., 16 ga steel sheet curved to a radius of curvature of 48 in. in one direction to simulate a 96 in. diameter pipe curvature, a 12 in. x 12 in. window (Photo 1), and a removable curved plug sheet to allow construction of laminate with the intended curvature. A drawing of the specimen steel sheet support, including manufacturing tolerances, is provided in Appendix B. The steel sheets were sandblasted to an SSPC-SP 10, near-white finish (Photo 2). The thickened epoxy was applied to the steel sheet before the application of the first wetted hoop CFRP layer (Photo 3), followed by the application of different layers of the laminate. Immediately after constructing the specimens, they were allowed to cure at 73°F and 50% relative humidity. Cure level of the resin measured initially and at the time of testing of the first and second specimens, using the Differential Thermal Analyzer, was found to be 85% cure at the time of first and second tests, meeting the minimum cure requirements of the draft AWWA Standard on CFRP Renewal and Strengthening of PCCP, prior to filling the pipe with water. The third specimen, constructed at the same time and tested on 7 April 2015, has a degree of cure of 89%. We installed strain gauges on the specimen in the configuration shown in Figure 4.

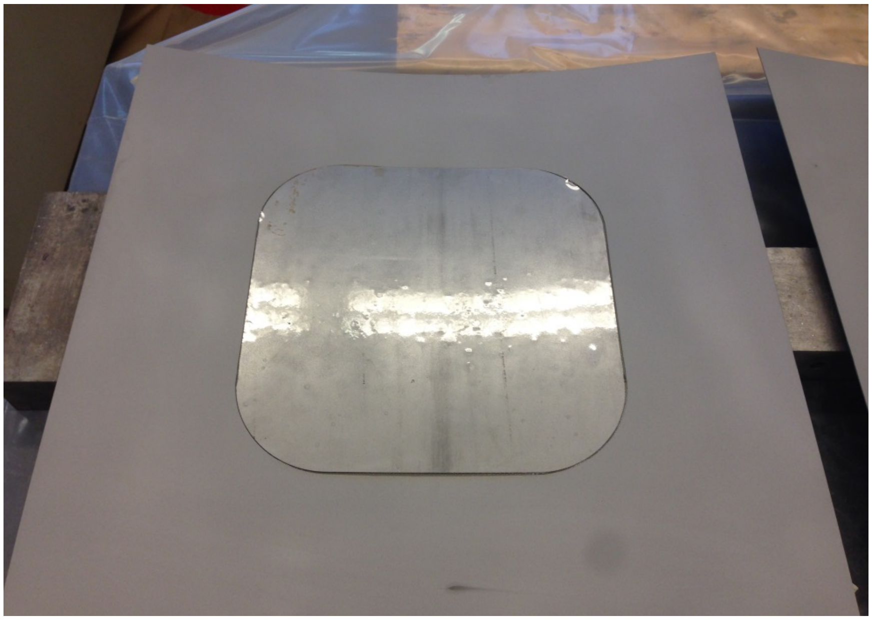
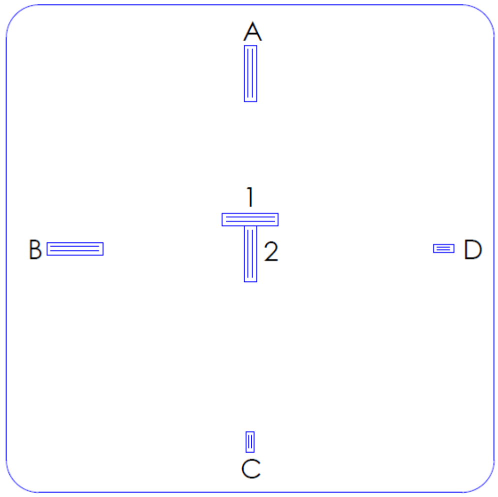


Photo 2

Sandblasted 16 gage Steel Sheet support of Test Specimen Prior to installation of test laminate.

Photo 3

Wetting CFRP lamina and construction of curved test specimens.



Round 2

Figure 4 – Strain gauge layout.

4.2 Watertightness Test Procedure

Mr. Casey Sturrup performed the testing while Dr. Murat Engindeniz verified that the test procedure was followed and Dr. Mehdi Zarghamee supervised the testing process. The tests of Specimens 1 and 2 were performed on 26 March 2015 and the test of Specimen 3 was performed on 7 April 2015.

The following summarizes our procedures for conducting watertightness testing:

a) Place the silicone gasket on the curved surface of the top plate of pressure chamber, where the test specimen will be placed (Photo 4).

b) Seat the specimen on the curved surface of the top plate of the pressure chamber by pressing down on the specimen edges with steel angles that are captured (Photo 5).

c) Connect the top plate and base plate using 3/4 in. high-strength bolts tightened with a torque wrench to 100 ft-lbs (Photo 6).

d) Apply a layer of butyl tape around the window to prevent water from leaking out during the initial seating (Photo 7).

e) Attach the pressure transducer and strain gages to the data acquisition system and mount the dial gauge to measure specimen deflection.

f) Zero the strain gauges.

g) Fill the pressure chamber with water and allowed it to reach house pressure of approximately 50 to 80 psi.

h) Apply pressure in 25 psi increments and record deflections until loss of watertightness or rupture of the specimen. The pressure increments were applied within a short period of time of less than 5 sec. Then the pressure was held constant until the CFRP was examined for leakage and the dial gage was read. Any drop of water observed was investigated to determine its source.

i) Record pressure and strain measurements at 2 Hz increments.

Photo 4

Silicone gasket placed on the curved surface of pressure chamber.

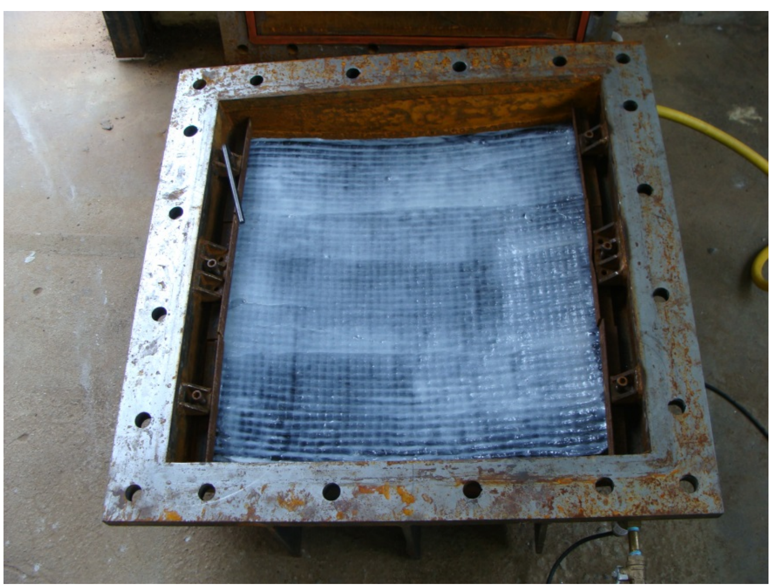


Photo 5

Angle placed at the edges of curved specimens to capture the ends for initial seating.

Photo 6

Specimen 3 at 400 psi. Photo shows test chamber with window, test specimens through the window, and dial gauge for measuring deflection of the CFRP laminate.

Photo 7

Specimen 3 at 400 psi. Photo shows the window through the pressure chamber with strain gaged CFRP laminate and dial gage visible. Butyl tape is applied at the perimeter of the window for watertightness at low pressures.

4.3 Acceptability Criterion

In accordance with draft AWWA Standard, the watertightness test is considered successful if the test specimen remains watertight up to a pressure at least twice the maximum pressure in the line.

4.4 Tests Performed

The results of tests performed are summarized below:

Specimen # and Date Tested	Description	Layup	Materials	Pressure at First Leak (psi)	Recorded Strain at Maximum Pressure
1	Laminate Design Including a Proprietary Glass Layer	1H+1L+G+1H	Carbon layer: V-Wrap C400H, V-Wrap 770 epoxy adhesive, EG50B stitched bidirectional glass fabric	No leakage was observed at 400 psi	0.0085
2	Laminate Design Including a Proprietary Glass Layer	1H+1L+G+1H	Carbon layer: V-Wrap C400H V-Wrap 770 epoxy adhesive, EG50B stitched bidirectional glass fabric	No leakage was observed at 400 psi	0.0068
3	Laminate Design Including a Proprietary Glass Layer	1H+1L+G+1H	Carbon layer: V-Wrap C400H V-Wrap 770 epoxy adhesive, EG50B stitched bidirectional glass fabric	No leakage was observed at 400 psi	0.0070 at Loc. 2 0.0082 at Loc. D

5. CONCLUSIONS

The results of tests showed watertightness of the laminate at 85% cure level when subjected to 400 psi. The design CFRP liners with laminate architecture 1H+1L+G+1H constructed with the materials V-Wrap, C400H CFRP, EG50B glass fiber fabric, and 770 epoxy, and tested following the procedure described in Section 4.2, meet and exceed the acceptability criterion of Section 4.3 and are watertight up to a pressure of at least one-half of the tested pressure of 400 psi.

APPENDIX A
Test Procedure

Laboratory Procedure

Procedure Name:	**Watertightness Testing of CFRP Laminates**
Procedure Number:	**150401-1**

Effective Date:	13 February 2015	**Author:**	Mehdi S. Zarghamee
Procedure Review Required by (date):	13 February 2016		

1. PURPOSE

This report presents the results of watertightness tests conducted on the V-Wrap laminate design consisting of two hoop and one longitudinal layers of CFRP C400H fabric, and one bidirectional glass fabric layer of EG50B (with architecture 1H+1L+G+1H) using 770 Epoxy. .

1.1 Scope

To test for watertightness of the three test specimens constructed using the V-Wrap laminate architecture 1H+1L+G+1H.

2. TEST APPARATUS

SGH has developed and constructed a watertightness test apparatus. The test apparatus is a pressure chamber designed for 500 psi water pressure with a radius of curvature of 48 in., allowing watertightness testing of 2 ft x 2 ft CFRP laminates installed on steel plates with matching curvature (e.g., 48 in. radius) that represents a 96 in. diameter pipe. The curved steel plate on which the CFRP laminate is installed has a 12 in. x 12 in. window centered in the middle, simulating a distressed region of a pipe bridged with CFRP liner, and allowing CFRP laminate alone to be exposed to the water pressure without steel pipe backing. The CFRP laminate is instrumented externally (i.e., on the exposed side of CFRP in the 12 in. x 12 in. window) with strain gages.

3. TEST SPECIMEN CONSTRUCTION

The materials proposed for repair of the pipelines including V-Wrap C400H carbon fabric, V-Wrap 770 impregnating epoxy, a thickening agent (e.g., Cab-O-Sil TS720 treated fumed silica) for thickening the epoxy, and a glass fabric to be used as a watertight layer embedded in the CFRP laminate are provided by Structural Technologies. SGH will prepare

three test panels with the layup of 1H+1L+1G+1H where “H” and “L” indicate CFRP layers in the hoop and longitudinal directions, respectively.
Six strain gages are installed on each test specimen, four near the edges of the exposed CFRP, and two at the center of the exposed CFRP. The strain gages are waterproofed by application of epoxy over the gages. Internal water pressure is monitored by a pressure transducer, and all pressure and strain data are recorded continuously by a data acquisition system.

The tests are conducted after CFRP completes a minimum degree of cure of 85% as verified by Differential Scanning Calorimetry (DSC) testing of small (1-2 mg) epoxy samples taken from the test panel according to ASTM E2160. After curing and attaching strain gages, the test specimens shall be tested.

4. WATERTIGHTNESS TESTING PROCEDURE

The test samples are placed inside the pressure chamber, and the pressure chamber is sealed, filled with water, and pressurized until the test specimen loses watertightness or ruptures. The steps in the test procedure are as follows:

a) Install the specimen on the curved surface of the pressure chamber.
b) Close the pressure chamber using 3/4 in. high strength bolts tightened with torque wrench to 100 ft-lbf.
c) Apply a layer of butyl tape around the window to prevent water from leaking out during the initial seating.
d) Connect the pressure transducer and strain gages to the data acquisition system and mount the dial gauge to measure specimen deflection.
e) Zero the strain gages.
f) Fill the pressure chamber with water and allow it to reach house pressure of approximately 50 to 80 psi.
g) Apply pressure in 25 psi increments and record deflections until loss of watertightness or rupture of the specimen. Apply pressure within a short period of time of less than 5 seconds. Hold pressure constant at each increment until the CFRP is examined for leakage and the displacement dial gage is read. Investigate any drop of water to determine its source.
h) Record pressure and strain measurements at 2 Hz increments.
i) Visually observe the laminate and record the pressure at first appearance of water through the laminate.

5. ACCEPTABILITY CRITERION

In accordance with draft AWWA Standard, the watertightness test is considered successful if the test specimen remains watertight up to a pressure at least twice the maximum pressure in the line.

6. REPORT

The report will include the following certifications and documentations:

1. The specimen ID, date of fabrication of test specimen, date of testing.

2. Name and signature of person preparing the report and the names of attendees.

3. Confirmation that material storage has been in conformance with manufacturer’s requirements.

4. Identification of each constituent material, its source, batch number, etc.

5. Confirmation that laminate layup is correct.

6. Confirmation that the test procedure has been followed.

7. Curing data and confirmation that it meets 85% cure.

8. Maximum pressure and strain recorded before loss of watertightness.

9. Certification that the specimens tested meet the acceptability criteria.

APPENDIX B
Calibration

OMEGA ENGINEERING INC.

PRESSURE TRANSDUCER
FINAL CALIBRATION

0.00 - 500.00 PSIG
Excitation 28.000 Vdc

Job: RTN4305
Model: PX309-500G5V
Date: 5/30/2014
Calibrated: 0.00 - 500.00 PSIG

Serial: 031814D348
Tested By: JP
Temperature Range: -20 to +85 C
Specfile: PX309-5V+=100G

Pressure PSIG	Unit Data Vdc
0.00	0.003
250.00	2.499
500.00	4.996
250.00	2.499
0.00	0.005

Balance 0.003 Vdc
Sensitivity 4.993 Vdc

ELECTRICAL LEAKAGE: PASS
PRESSURE CONNECTION/FITTING: 1/4-18 NPT Male
ELECTRICAL WIRING/CONNECTOR: BLACK = -EXC
WHITE = SIG
RED = +EXC

This Calibration was performed using Instruments and Standards that are traceable to the United States National Institute of Standards Technology.

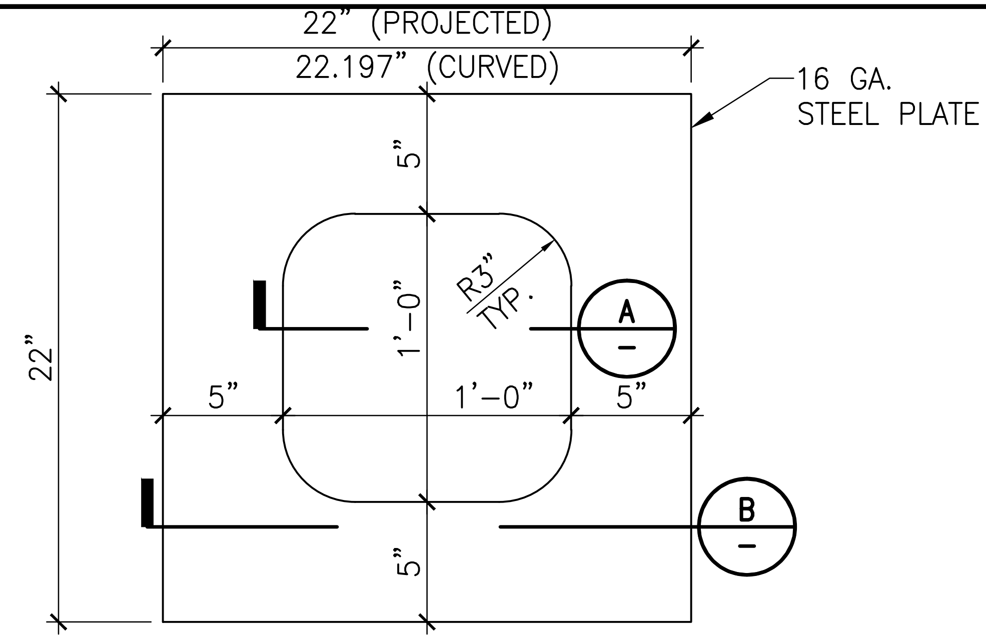
S/N	Description	Range	Reference	Cal Cert
0495/91-4	AUTO 50/500 PSI DRUC	0 - 500.00 PSIG	C-2508	C-2508
US37034809	AT34970 DMM	Unit Under Test	C-3002	C-3002

Q.A. Representative : John Piendl Date: 5/30/2014

This transducer is tested to & meets published specifications. After final calibration our products are stored in a controlled stock room & considered in bonded storage. Depending on environment & severity of use factory calibration is recommended every one to three years after initial service installation date.

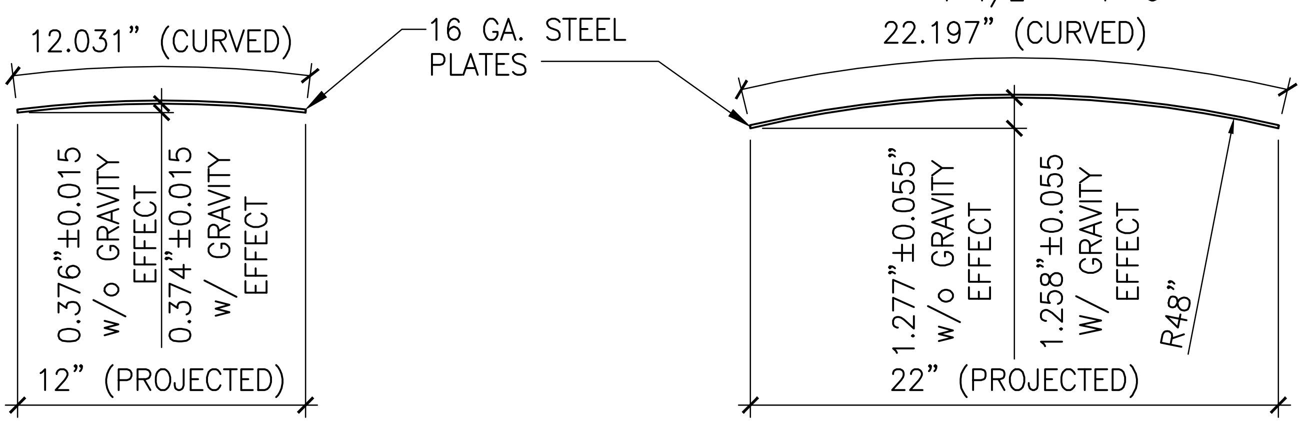
Omega Engineering Inc., One Omega Drive, Stamford, CT 06907
http://www.omega.com email: info@omega.com phone (800) 826-6342

APPENDIX C
Watertightness Test Specimen Steel Sheet Support Drawing



PLAN VIEW

1 1/2" = 1'-0"



SECTION A

SECTION B

PROFILE VIEW OF SPECIMEN SUPPORT SHEET AND CENTER PIECE

1 1/2" = 1'-0"

NOTES:

- Fabricate 22 in. by 22 in. specimen support sheet and the 12 in. by 12 in. center piece made from 16 gauge steel and both cold formed to a uniform curvature with radius of 48 in. (±2 in.). Retain the 12 in. by 12 in. center piece cut from the curved support sheet as this will be used for the application of the fiber material.
- Sandblast the interior surface of the curved support sheet to SSPC-SP 10 "Near White" condition (as defined in document SSPC-SP 10/NACE No. 2). The 12 in. by 12 in. center piece does not need to be sandblasted.
- Verify all dimensions and curvatures of the support sheet and the centerpiece after receiving from the fabricator.
- Apply a layer of 0.002 in. thick, adhesive backed Polyester (McMaster Carr # 8689K42 or similar) to the interior of the 12 in. by 12 in. center piece.
- Place the 12 in. by 12 in. center piece into the window of the specimen support sheet from which it was cut. Tape the center piece to the support sheet by applying duct tape to the exterior surface. The offset between the specimen support shell and the centerpiece shall not exceed 0.015 in.
- Support the straight edge of the specimen support sheet.
- Construct the CFRP laminate on the inside of the curved support sheet.

SIMPSON GUMPERTZ & HEGER
Engineering of Structures and Building Enclosures
Simpson Gumpertz & Heger Inc.
41 Seyon Street, Building 1, Suite 500
Waltham, Massachusetts 02453
781.907.9000
fax: 781.907.9009
www.sgh.com

Project: WATER TIGHTNESS TEST SAMPLE			Drawing No.: SK-01
Title: PLAN AND PROFILE VIEW			Scale: AS NOTED
Drawn: KMG	Checked: PGC	Approved: MSZ	Project No.: 003101.04
			Date: 03/12/15

APPENDIX B

Calibration Certificate for the Pressure Transducer

600t861

OMEGA ENGINEERING INC.

PRESSURE TRANSDUCER
FINAL CALIBRATION

0.00 - 1000.00 PSIG
Excitation 28.000 Vdc

Job: WHS0016239
Model: PX309-1KG5V
Date: 7/20/2017
Calibrated: 0.00 - 1000.00 PSIG

Serial: 021617D027
Tested By: JANE
Temperature Range: -20 to +85 C
Specfile: PX309-5V+=100G

Pressure PSIG	Unit Data Vdc
0.00	0.008
500.00	2.511
1000.00	4.999
500.00	2.512
0.00	0.007

Balance 0.008 Vdc
Sensitivity 4.991 Vdc

ELECTRICAL LEAKAGE: PASS
PRESSURE CONNECTION/FITTING: 1/4-18 NPT Male
ELECTRICAL WIRING/CONNECTOR: BLACK = -EXC
WHITE = SIG
RED = +EXC

This Calibration was performed using Instruments and Standards that are traceable to the United States National Institute of Standards Technology.

S/N	Description	Range	Reference	Cal Cert
41000FUN	AUTO Mensor 1200	0 - 1000.00 PSIG	C-3051	C-3051
US37008245	HP 34970A DMM	Unit Under Test	C-2491	N/A

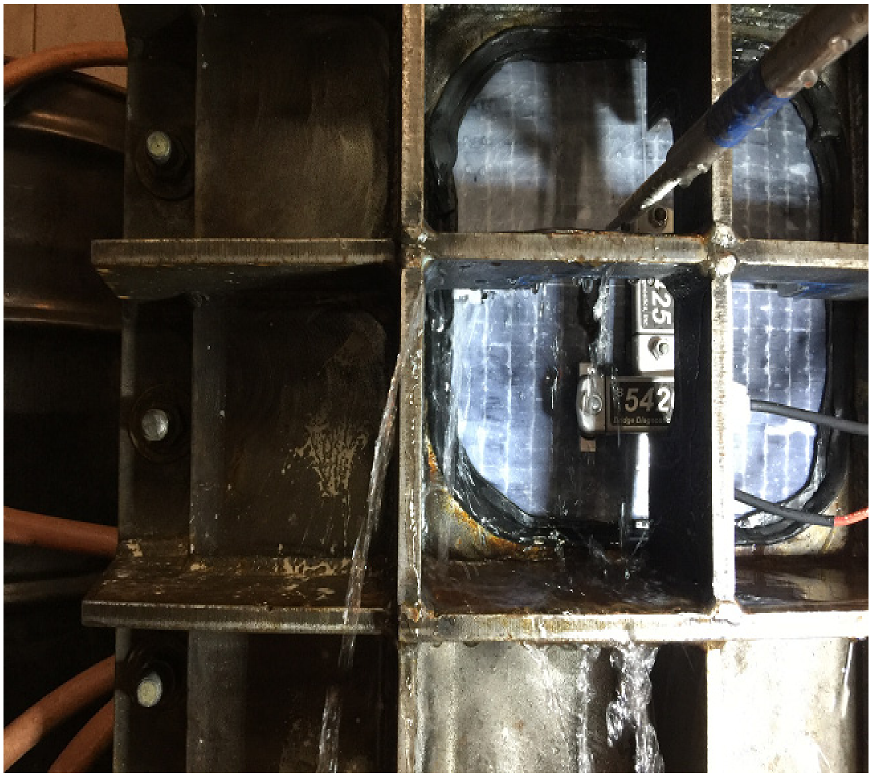
Q.A. Representative : Jane Porter   Date: 7/20/2017

This transducer is tested to & meets published specifications. After final calibration our products are stored in a controlled stock room & considered in bonded storage. Depending on environment & severity of use factory calibration is recommended every one to three years after initial service installation date.

Omega Engineering Inc., One Omega Drive, Stamford, CT 06907
http://www.omega.com email: info@omega.com phone (800) 826-6342

APPENDIX C

Typical Photographs of Specimens



(a)

(b)

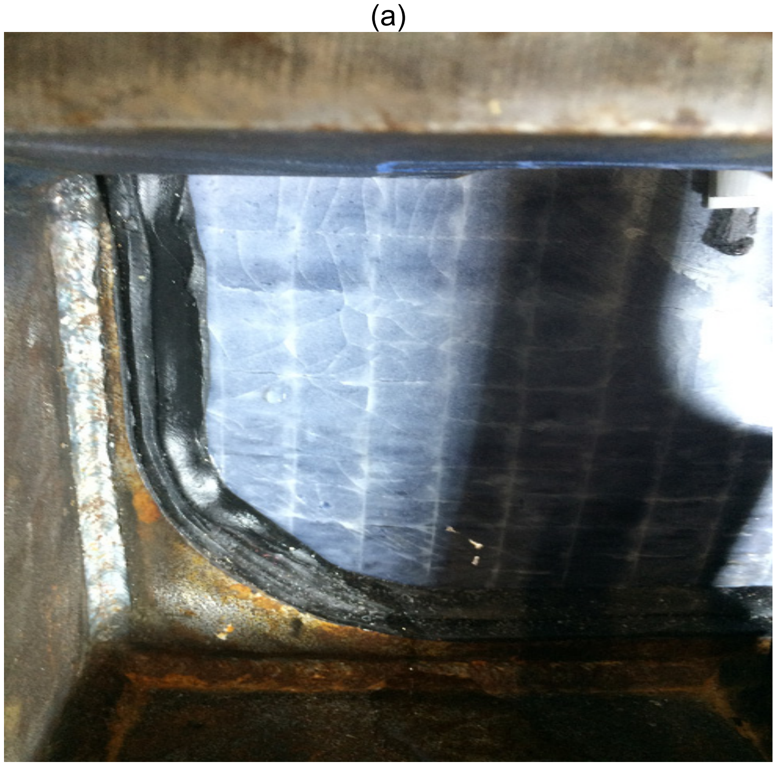
Figure C.1 – View of Specimen 32F-1, (a) at termination of test at 345 psi, and (b) edge of specimen after removal from pressure chamber. (Note that the failure was due to local bending of the specimen at the seating tabs within the chamber, and not due to the performance of the laminate architecture.)

(a)

(b)

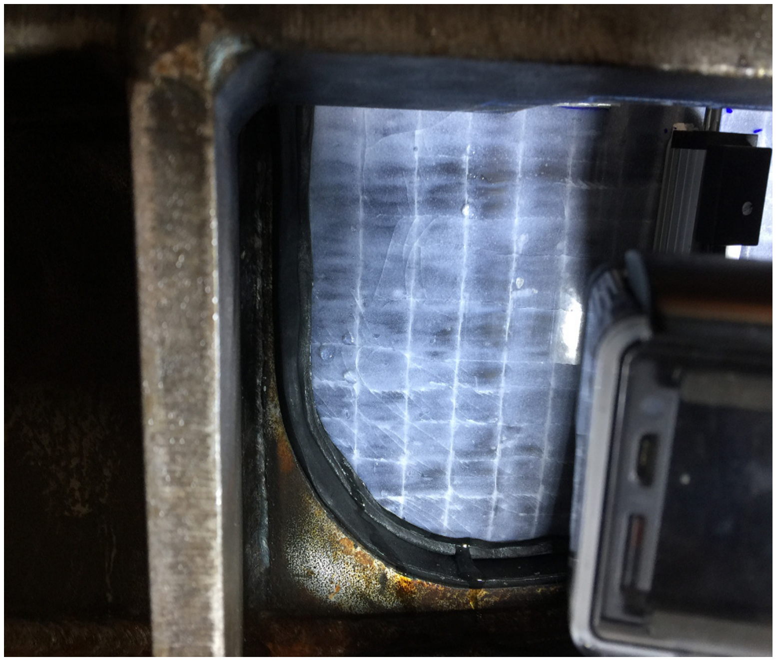
Figure C.2 – View of Specimen 32F-2 at termination of test (400 psi, no leaks).

(a)

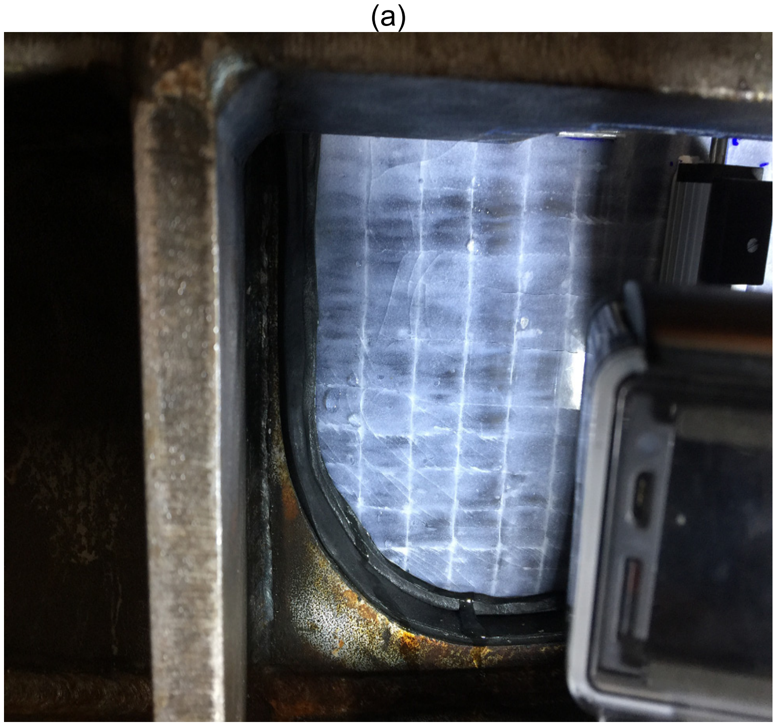


(b)

Figure C.3 – View of Specimen 32F-3 at termination of test (400 psi, water droplets in upper right and lower left quadrants).



(a)



(b)

Figure C.4 – View of Specimen 32F-4 at termination of test (400 psi, water droplets in upper left and lower left quadrants).

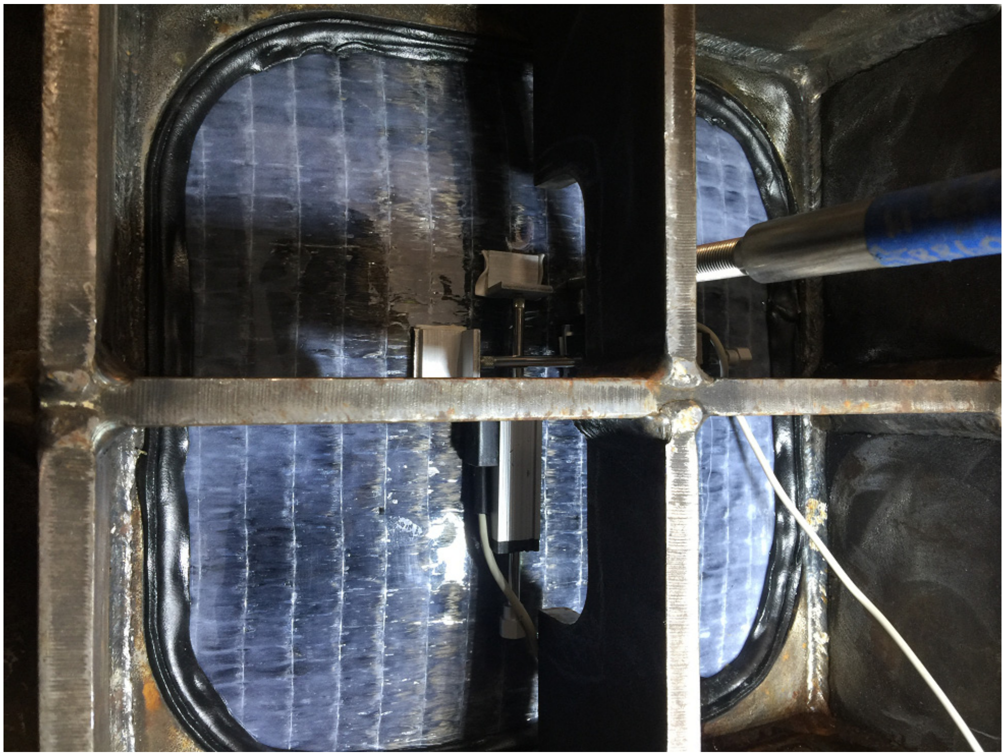


Figure C.5 – View of Specimen 130F-1 at termination of test (404 psi, no leaks).

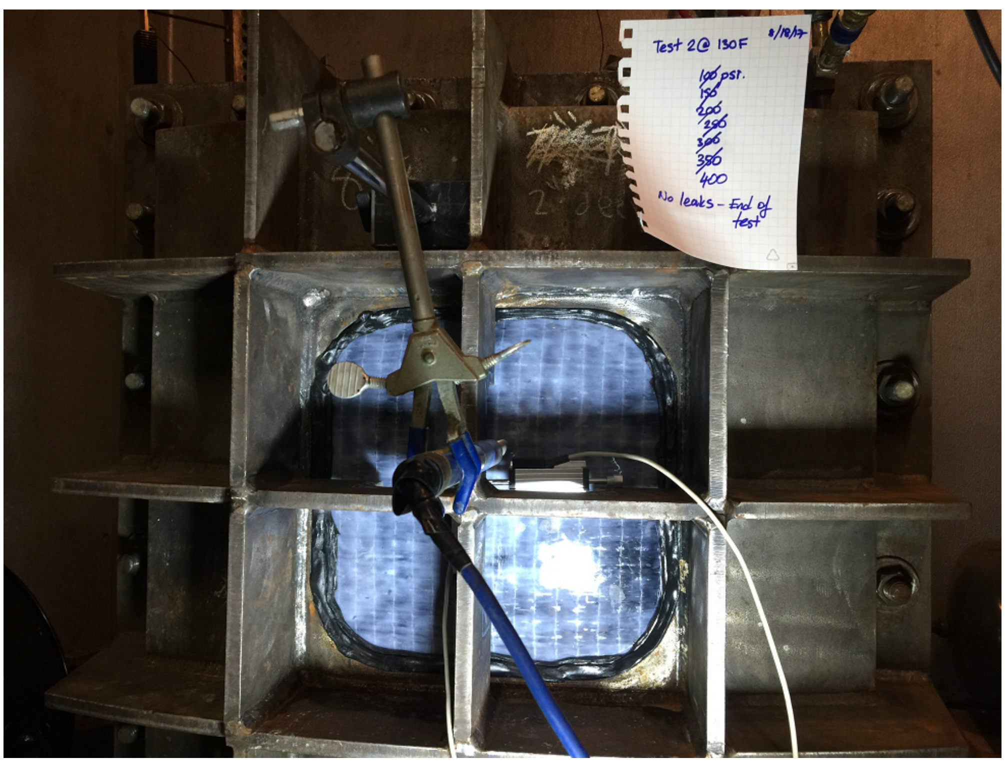


Figure C.6 – View of Specimen 130F-2 at termination of test (404 psi, no leaks).

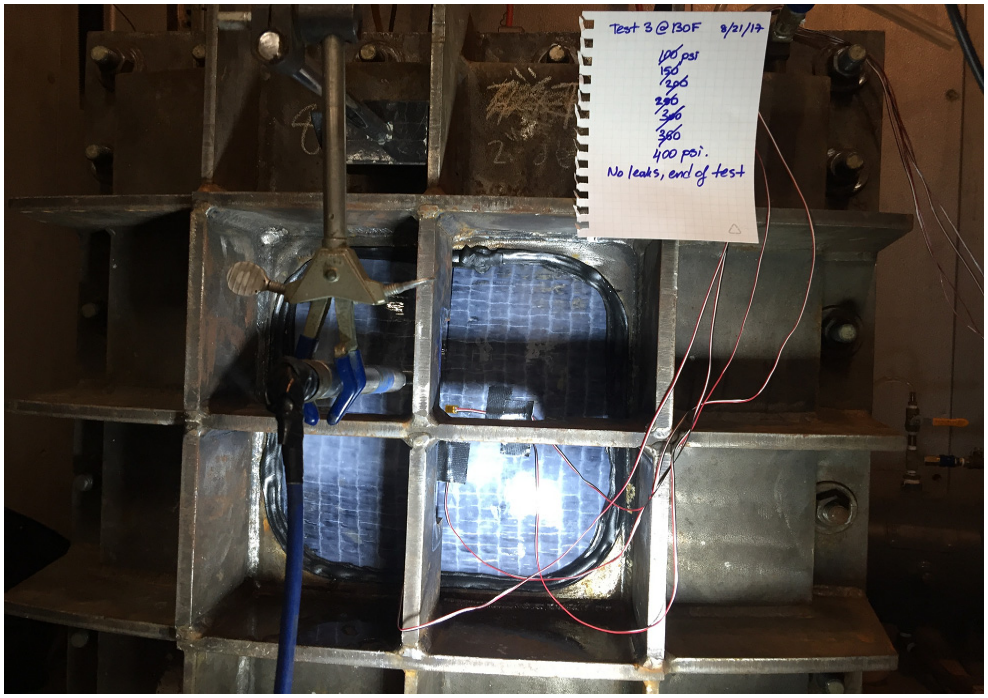


Figure C.7 – View of Specimen 130F-3 at termination of test (402 psi, no leaks).

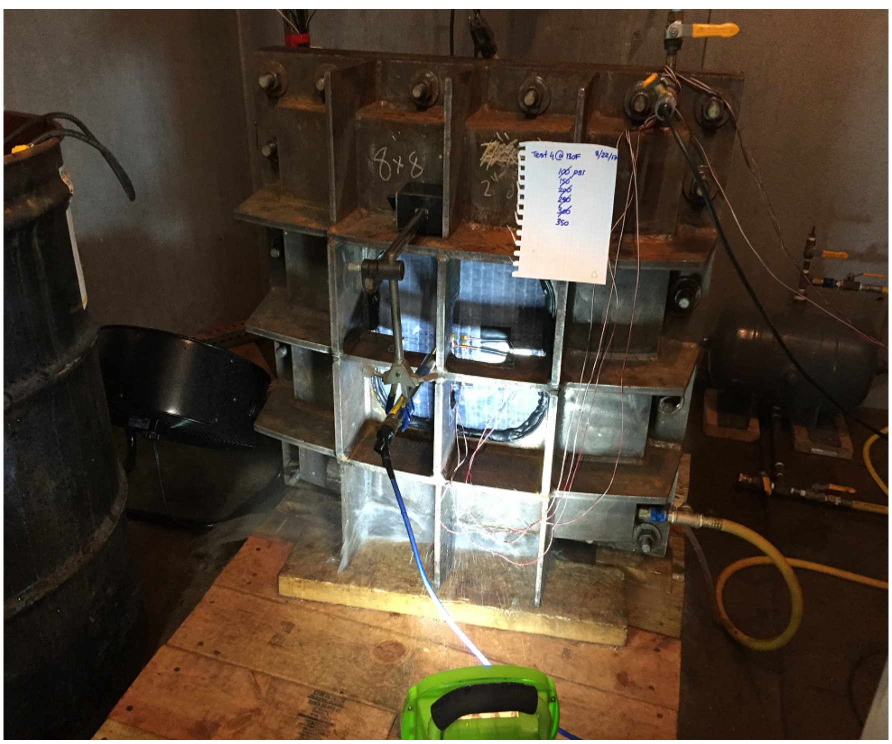


Figure C.8 – View of Specimen 130F-4 at termination of test (374 psi, gasket failure). (Note that the laminate had not exhibited any signs of watertightness loss before gasket failure.)

CERTIFIED TEST REPORT

EVALUATION OF V-WRAP CARBON FRP STRENGTHENING SYSTEM FOR LARGE DIAMETER CONCRETE PIPES
- Full Scale Test -

Report Number: R-5.10_C277_200PT.1
Date: July 22, 2014

REPORT PREPARED FOR:

Dr. Tarek Alkhrdaji
talkhrdaji@structural.net
STRUCTURAL Technologies
7455 New Ridge Rd, Suite T
Hanover, Maryland 21076

Quality System: The Structures and Materials Laboratory (SML) maintains a quality system in compliance with ISO 17025-2005, accredited under International Accreditation Service (IAS), testing laboratory, TL-478

Procedures: All tests and services are done in accordance with the SML Quality Manual (Version 2.2) revised March 18, 2013; relevant standard operating procedures (SOPs); and with the applicable requirements of the reference standard test methods.

Test Data: All the test results presented herein are linked through unbroken chain to the raw data files recorded on the day of the test. Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results of each test.

Controls:	
Superseded Report	R-5.10_C277_200PT
Reason for Revision Effective Date	Editorial changes and statement of equivalence of results to V-Wrap C400H. July 22, 2014
Superseded Report	new
Reason for Revision Effective Date	n/a May 6, 2014

Test Report Approval Signatures:	
Quality review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Francisco De Caso Signature: Date: July 22, 2014
Technical review Approval	I indicate that I have reviewed this Test Report and agree with the technical contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Derek Schesser Signature: Date: July 22, 2014

EXECUTIVE SUMMARY

This report provides a summary for the full scale test performed on a 60 in. diameter Prestressed Concrete Cylinder Pipe (PCCP) strengthened with an internal V-Wrap FRP jacket. The full-scale pressure test was performed on a 20 ft long PCCP section. Testing was conducted in three phases. In the first phase, 50 percent of the existing prestressing wires were cut to simulate partial damage of the pipe. In the second and third phases, 100 percent of the wires were cut to simulate damage of all existing prestressed wires. In the first and second phases, the pipe was pressurized to 150 psi after the damage was induced. In the third phase, the pipe was pressurized to 200 psi. No signs of failure such as excessive cracking, spalling, or leakage were observed during the test. The overall performance of the V-Wrap FRP liner as PCCP strengthening system was very satisfactory. The results of the current test should be equally applicable for pipe strengthening using V-Wrap C400H.

1. INTRODUCTION

1.1. TEST SUMMARY INFORMATION

Test Objective:	Full scale pressure test of Prestressed Concrete Cylinder Pipe (PCCP) strengthened with an internal V-Wrap FRP jacket
Test Standard Method/s:	Full scale structural test
Product:	V-Wrap C200H high strength unidirectional carbon fabric and V-Wrap 770 epoxy resin, (additional information in Section 1.2).
Test Location:	Hanson Pipe & Precast, South Beloit, IL
Analyst:	Derek Schesser
Technical Test Record:	R-4.13_C277_200PipeTest
Sample Preparation:	Installation by Structural Technologies under supervision of Structures and Materials Laboratory (SML) personnel.

1.2. DESCRIPTION OF STRENGTHENING SYSTEM

The strengthening system consisted of V-Wrap C200H high strength unidirectional carbon fabric and V-Wrap 770 epoxy resin (NSF/ANSI Standard 61 listed product for drinking water systems). The FRP liner was composed of three (3) layers of V-Wrap C200H in the circumferential direction and two (2) layers in the longitudinal direction. The system was finished with a coat of thickened V-Wrap 770 epoxy resin.

1.3. DESIGN APPROACH

Design of the V-Wrap FRP liner was achieved to support internal pressure as a standalone system. All contributions of the existing prestressing wires and steel cylinder to the strength and stiffness of the repaired pipe were discarded.

2. EXPERIMENTAL TESTING

2.1. TEST SETUP

Testing was performed on one PCCP section that was 60 in. diameter and 20 ft long (Figure 1). The pipe section was positioned in a steel test frame that featured large steel bulkheads on each end. At the bell end of the pipe the bulkhead featured a spigot detail, while at the spigot end of the pipe section the bulkhead had a bell detail. Wire cutting procedure and internal pipe pressurization was conducted as described below (Figure 2). The level of internal pressure within the pipe was monitored using two (2) pressure gauges.

Testing was conducted in three phases: the first two phases to 150 psi internal pressure (Figure 3), and the third phase to 200 psi pressure (Figure 4). In Phase 1, 50 percent of the existing prestressing wires were cut to simulate partial damage to the pipe. Phases 2 and 3 were conducted with 100 percent of the wires cut to simulate complete pipe damage.

Damage was induced by cutting of the original prestressing wires. The wire cutting areas varied in length between 1 and 3 ft. The cuts were distributed around the pipe section to simulate damage in multiple locations along the pipe and were located in the central 17 ft of the pipe (test area). No wires were cut on the 18 in. long end zones of the pipe section to avoid failure at the bulkheads. Testing was conducted as reported in Section 2.2

2.2. TESTING PHASES

Phase 1: 50 percent of the wires were cut at an internal pressure of 0 psi. The internal pressure was then gradually increased and maintained constant for 2 minutes at 50 and 100 psi. At 150 psi, the pressure was held constant for 15 minutes. The pipe was then depressurized.

Phase 2: Once cutting of 100 percent of wires was completed, the internal pressure was increased in intervals of 50 psi and maintained constant for 2 minutes at 50 and 100 psi. At 150 psi, the pressure was held constant for 15 minutes. The pipe was then depressurized.

Phase 3: With 100 percent of the wires cut, the internal pressure was increased and maintained constant for 2 minutes at 75 and 150 psi. The pressure was then increased to 200 psi and held constant for 15 minutes.

Figure 1: Installation of V-Wrap FRP Liner

Figure 2: Cutting of Prestressing Wires

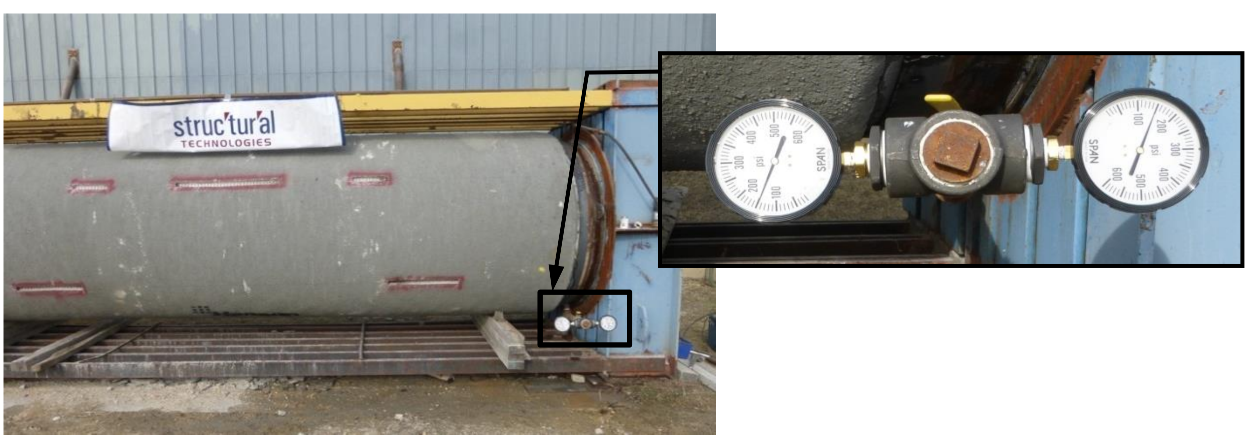


Figure 3: Maximum Pressure: 150 psi (Phases 1 and 2)

Figure 4: Maximum Pressure: 200 psi (Phase 3)

2.3. TEST RESULTS AND CONCLUSIONS

The V-Wrap FRP system was able to resist a hydrostatic pressure of 200 psi without any contribution from the prestressing wires and with no signs of failure (concrete spalling, excessive cracking, bulging, or leakage).

It should be noted that the V-Wrap C200H system and the V-Wrap C400H system have similar tensile modulus, tensile strength, and ultimate elongation. As such, the results of the test presented herein are equally applicable for pipe strengthening using V-Wrap C400H. The equivalence between the two carbon systems is such that two (2) layers of the C200H system is equivalent to one (1) layer of V-Wrap C400H system.

♦ END OF TEST REPORT ♦

January 12, 2023

Mr. Matthew Frye
Structural Preservation Systems, LLC.
6955 San Tomas Rd
Elkridge, MD 21075

P: 443.561.3612
E: mfrye@structural.net

Subject: V-Wrap™ Pot Life and Cure Time Information

Dear Mr. Frye,

Structural Technologies, LLC, manufacturer and supplier of the V-Wrap™ system, provides the following information with regard to pot life and cure time of the composite materials:

The pot life of the V-Wrap 770™ epoxy is approximately 3 hours; however, this pot life is impacted by the temperature and humidity of the surrounding environment. Any materials observed to be reaching the end of their pot life as noted through changes in viscosity, visible exothermic reactions, or other changes in material properties will not be used on the project. As part of the V-Wrap installation training process, our certified technicians are trained to identify materials that exceed to their pot life and are instructed to discard any potentially compromised materials.

The allowable time windows are as follows:

1. Between primer and thickened epoxy = from immediate to 72 hours
2. Between each layer of CFRP or GFRP = from immediate to 72 hours
3. Between CFRP or GFRP and thickened epoxy = from immediate to 72 hours
4. Between CFRP or GFRP and topcoat = from immediate to 72 hours

In accordance with product requirements, we intend to maintain a minimum temperature of 40°F inside the pipeline throughout the body of the pipe during the installation of the V-Wrap™ CFRP lining system. The humidity in the pipe will be reduced to a level such that the temperature in the pipe will be held at a minimum of 5°F above the dew point which will be verified at the beginning of each shift during installation.

To monitor curing in the field, the Quality inspector will monitor the temperature and humidity on the FRP lining system. Documented time/temperature data indicating that a minimum of 85% cure has been achieved for the V-Wrap™ CFRP lining system will be observed through additional testing prior to reinstating water back into the pipeline.

Upon completion of installation of the V-Wrap™ CFRP System, the air temperature in the pipe will be elevated to facilitate curing. Heaters will be adjusted prior to the beginning of each installation shift to allow the pipe to cool down to safe temperatures for personnel entry. Heat dissipates quickly and is anticipated to be a safe working temperature after no more than 20 minutes of the heat being adjust or turned off.

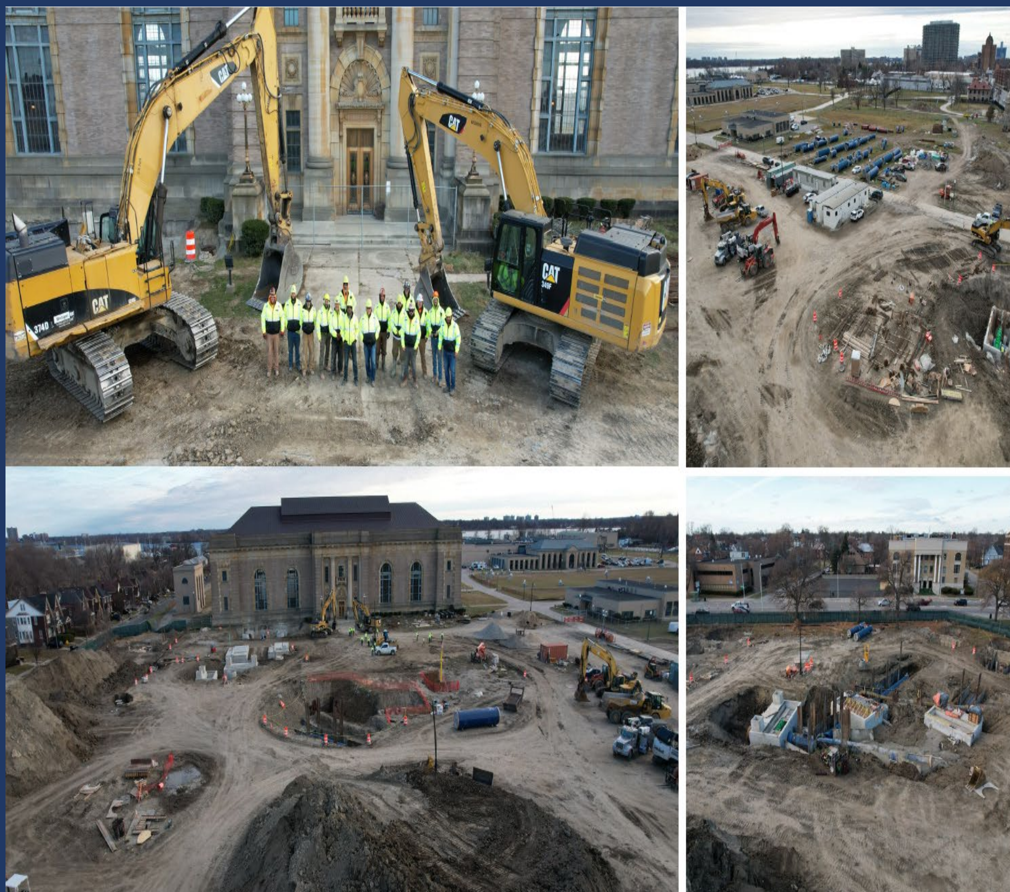
To achieve successful cure of the material, satisfy material manufacturer recommendations, and meet specification requirements, one of the following minimum cure times and temperatures will be utilized to ensure that 85% cure has been achieved prior to placing the system back in service:

- 70°F for three (3) to six (6) days, or
- 85°F for one (1) to five (5) days, or
- 90°F for a minimum of 24 hours, or
- 100°F for a minimum of 18 hours, or
- 110°F for a minimum of 12 hours.

If you should have any questions regarding this correspondence, or need any additional information, please contact me at apridmore@structuraltec.com or by phone at 714-869-8824.

Very truly yours,

Anna Pridmore, PhD, PE
Vice-President, Pipeline Solutions



City of Novi
Novi Road / 13 Mile Road PCCP Water Main Renewal – RFP
Hourly Rates

Submitted To:

City of Novi, Attn: Finance Department
45175 Ten Mile Road, Novi, MI 48375

Submitted By:

LGC Global Inc.
7310 Woodward Ave
Ste 500
Detroit, MI 48202

Date of Submittal:

January 16, 2023

LGC GLOBAL

NMSDC
MBE Certified

Hourly Rates

LAKESHORE GLOBAL

Company: LGC Global

2023 TRANSMISSION MAIN REPAIR TIME & MATERIAL RATES

LABOR RATES (Including Fringes)

DESCRIPTION	HOURLY	OVERTIME	DOUBLE TIME
PROJECT MANAGER	$175.00	$183.75	$245.00
SUPERINTENDENT	$165.00	$173.25	$231.00
PROJECT COORDINATOR	$125.00	$131.25	$175.00
PROJECT ENGINEER	$110.00	$115.50	$154.00
FOREMAN	$125.00	$131.25	$175.00
EQUIPMENT OPERATOR	$95.00	$99.75	$133.00
PIPELAYER	$95.00	$99.75	$133.00
LABORER	$85.00	$89.25	$119.00
TRUCK DRIVER	$85.00	$89.25	$119.00
FLAGGER	$90.00	$94.50	$126.00
WELDER/MECHANIC	$105.00	$110.25	$147.00

EQUIPMENT RATES

DESCRIPTION	DAILY	WEEKLY	MONTHLY
CAT EL 300 EXCAVATOR / EQUIVELANT	$1,263.45	$4,653.00	$13,960.00
CAT 325 EXCAVATOR / EQUIVELANT	$689.15	$3,645.00	$10,935.00
CAT 320 EXCAVATOR / EQUIVELANT	$666.18	$2,200.00	$6,600.00
VOLVO 160 EXCAVATOR / EQUIVELANT	$516.87	$2,400.00	$7,200.00
VOLVO 110 LOADER / EQUIVELANT	$402.00	$2,350.00	$7,050.00
VOLVO L70 LOADER / EQUIVELANT	$516.87	$1,809.03	$6,331.62
CASE 580M BACKHOE / EQUIVELANT	$287.15	$1,005.02	$3,517.57
CASE 580M BACKHOE OR HOE PACK	$344.58	$1,206.02	$4,221.07
DUMP TRUCK & TRAILER W/O DRIVER	$606.00	$1,818.00	$5,454.00
QUAD AXLE SEMI DUMP W/O DRIVER	$606.00	$1,818.00	$5,454.00
GRAVEL TRAIN W/O DRIVER	$918.87	$3,216.05	$11,256.20
LOWBOY TRAILER W/O DRIVER	$525.00	$2,625.00	$7,875.00
UTILITY TOOL TRUCK W/ HAND TOOLS W/O DRIVER	$229.72	$804.01	$2,814.05
FLATBED STAKE TRUCK W/O DRIVER	$459.44	$1,608.03	$5,628.10
GENERATOR	$70.00	$350.00	$1,050.00
COMPRESSOR 185 CFM	$114.86	$575.00	$1,723.00
3" PUMP, EA W/ HOSES	$48.00	$240.00	$720.00
LITE TOWER	$150.00	$750.00	$2,250.00
ARROW BOARD	$38.00	$190.00	$570.00
TRAFFIC CONTROL SIGNS, EA	$5.74	$20.11	$70.35
CONCRETE SAW 165 HP	$574.30	$2,010.04	$7,035.12
PIPE SAW	$34.46	$120.60	$422.11
PLATE COMPACTOR	$57.43	$201.00	$703.52
MISC. SMALL TOOLS (SPADE, JACKHAMMER, ETC.)	$17.23	$60.31	$211.05
LEAD POT BURNERS & TOOLS	$22.97	$80.40	$281.40
OXYGEN / ACETYLENE TORCHES	$57.43	$201.00	$703.52
TRENCH BOX & SHORING	$475.00	$2,375.00	$7,125.00
STEEL PLATES, LARGE	$45.94	$160.80	$562.81
STEEL PLATES, MEDIUM	$34.46	$120.60	$422.11
STEEL PLATES, SMALL	$22.97	$80.40	$281.40

Any equipment not listed above will be furnished using rented equipment, as needed or billed using Equipment Watch Rates.

Linear System Integrity Program

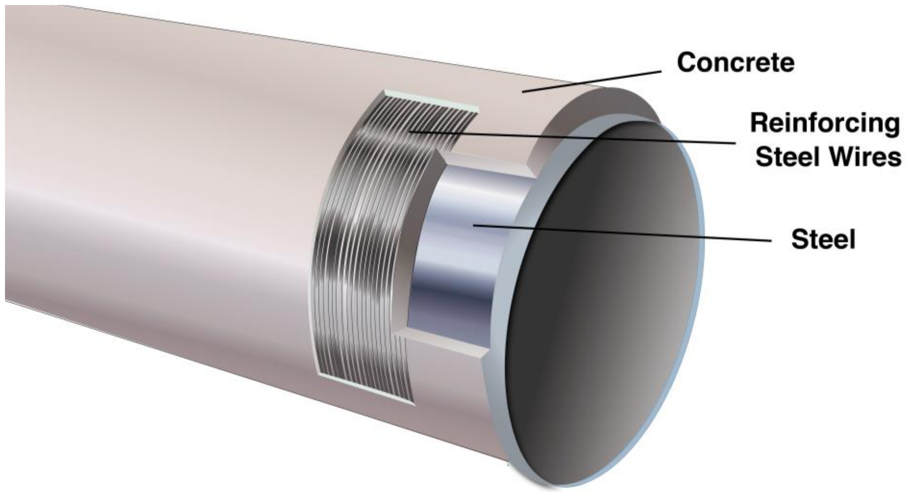
Carbon Fiber Reinforced Polymer (CFRP) Lining

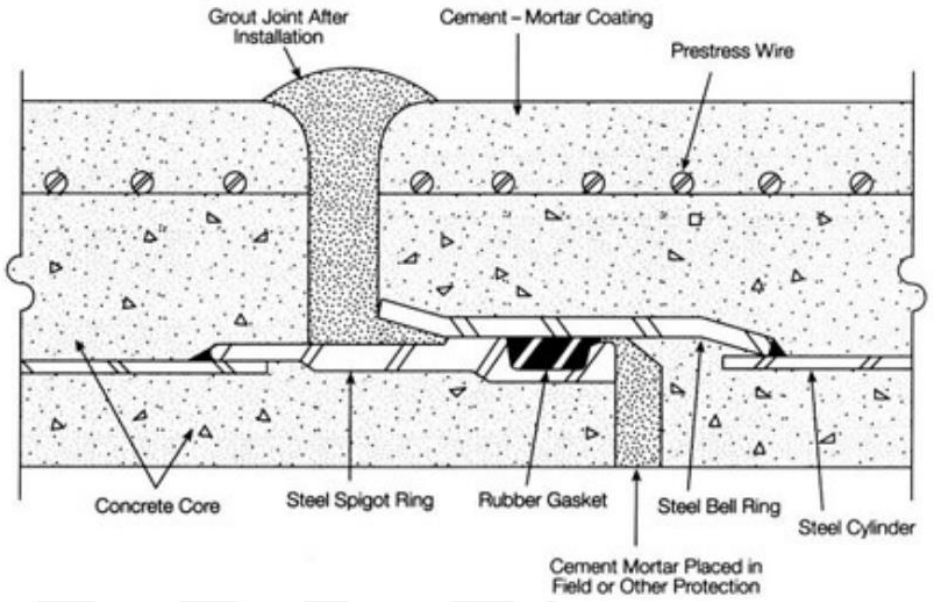
January 13, 2023

GLWA
Great Lakes Water Authority
AMSO
Asset Managemant Strategic Organization

PCCP Background

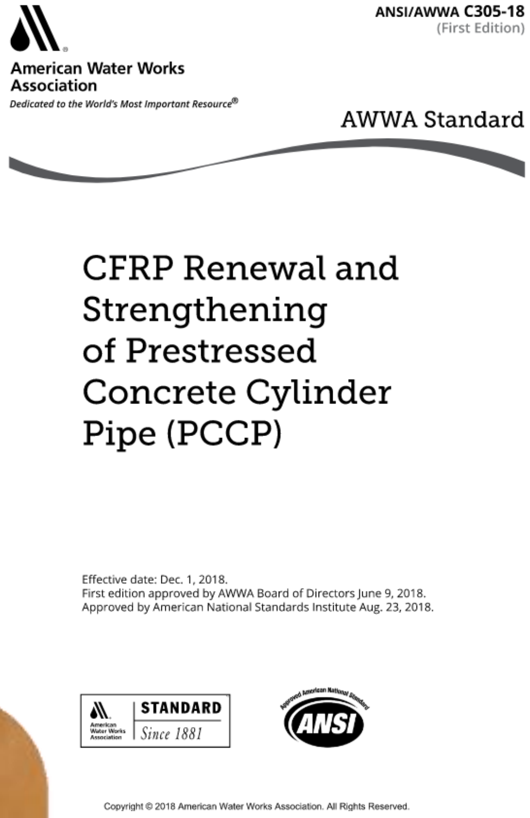
- PCCP consists of a concrete core, steel cylinder, high-strength steel prestressing wires, and a cement mortar coating
- High-strength steel prestressing wires are wrapped around the cured concrete core at 75 percent of the ultimate tensile strength of the wire
- PCCP is a rigid pipe material in which the prestressing wires are the primary structural component and the cylinder functions mainly as a water barrier
- The exterior cement mortar coating protects the prestressing wires from damage and external corrosion





PCCP Strengthening and Renewal

- Use of CFRP for strengthening of large diameter underground PCCP began in the late 1990s and became an acceptable renewal and strengthening system for PCCP by 2007
- CFRP liners are designed as flexible pipe to resist combined effects of internal pressure, external loads, internal vacuum, and external groundwater pressure
- The CFRP system can be designed as a composite system with the PCCP concrete core or a stand-alone liner.
    - For degraded PCCP, the system is designed as stand-alone


ANSI/AWWA C305-18
(First Edition)

American Water Works Association
Dedicated to the World's Most Important Resource®

AWWA Standard

CFRP Renewal and Strengthening of Prestressed Concrete Cylinder Pipe (PCCP)

Effective date: Dec. 1, 2018.
First edition approved by AWWA Board of Directors June 9, 2018.
Approved by American National Standards Institute Aug. 23, 2018.

STANDARD Since 1881

ANSI

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CFRP Composition

- Resin – polymeric material used to bind together the fibers of CFRP
- Primer – provides adhesive bond for the thickened resin
- Thickened Resin – consists of saturating resin and silica fume used to fill voids and provide uniform substrate
- Reinforcing Fabric – unidirectional carbon fiber fabric used as the structural reinforcement
- Watertight Lamina – glass fabric used for watertightness and dielectric barrier
- Top-Coat – typically thickened epoxy for abrasion resistance on the surface

Structural Technologies Materials

CAB-O-SIL® TS-720

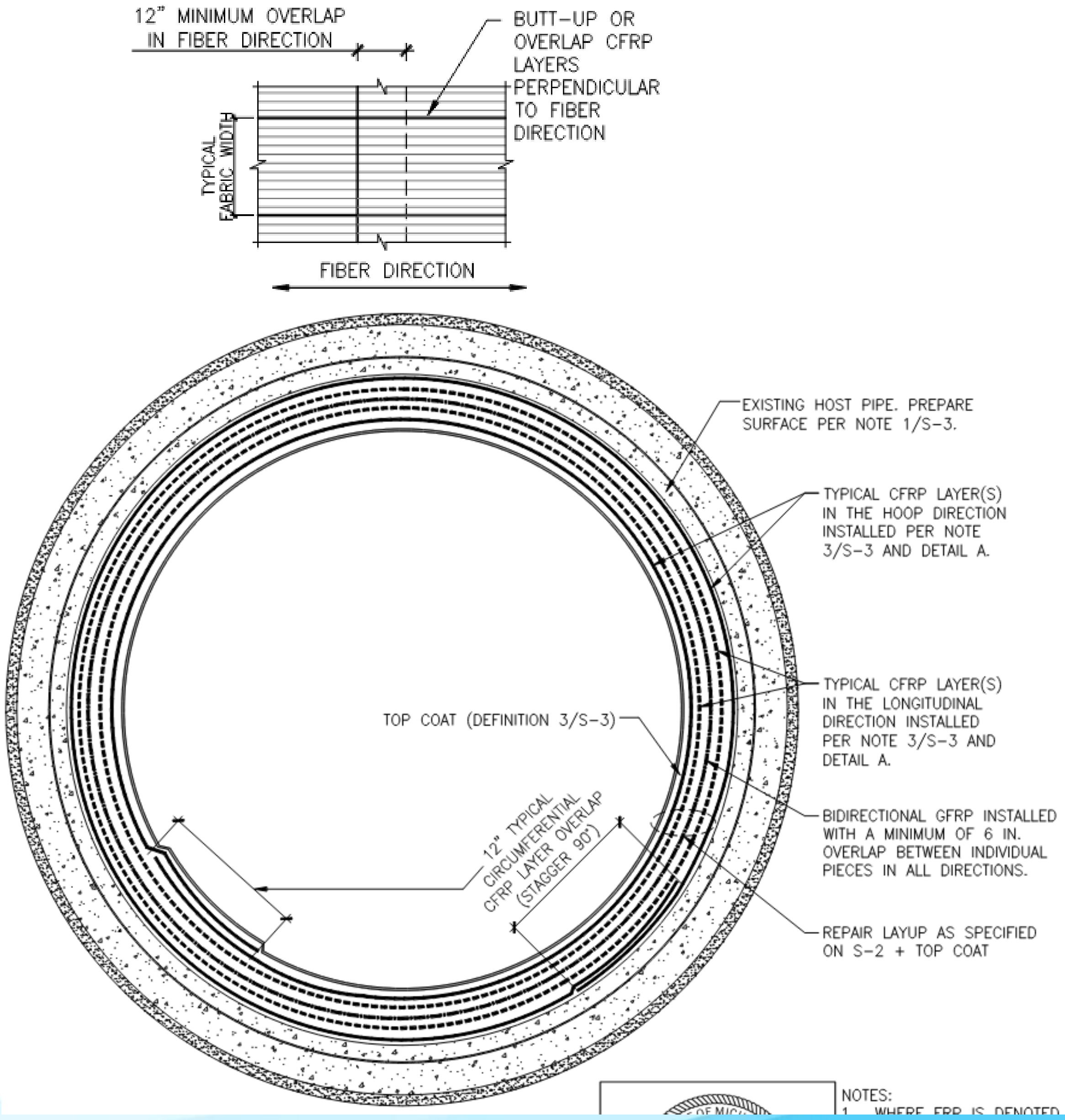
V-Wrap™ C400HM

V-Wrap™ EG50-B

V-Wrap™ 770

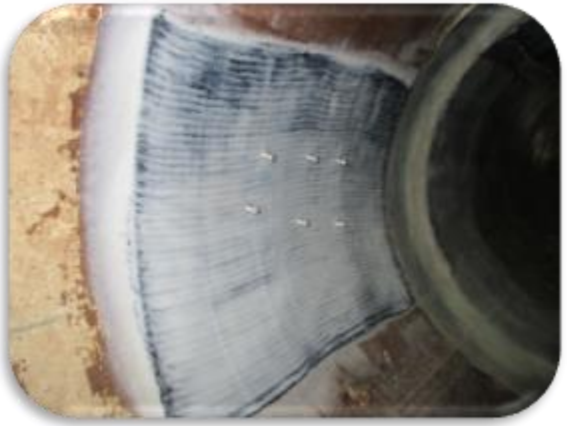
CFRP Design

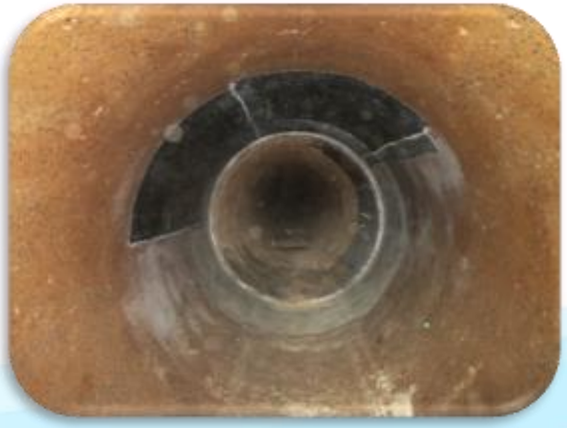
- A CFRP repair cross section contains multiple layers, depending on design
  - Example (5 layers):
    - CFRP layer in the hoop direction (0.08”)
    - CFRP layer in the longitudinal direction (0.08”)
    - Bidirectional GFRP (0.034”)
    - Additional layer of CFRP in the longitudinal direction (0.08”)
    - Additional layer of CFRP in the hoop direction (0.08”)



CFRP Lining Process

- Surface preparation
  - Concrete core
  - Steel cylinder and joint ring
- Saturation of carbon fiber
- Installation of saturated carbon fiber or glass fiber
- Termination details
- Defect repairs
- CFRP cure





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Surface Preparation – Concrete Core

- Concrete inner core of pipe inspected to determine what surface preparation will be necessary
- Localized out-of-plane variations are removed by grinding, abrasive blasting, or water blasting
- Primer/thickened epoxy applied to the prepared concrete surface

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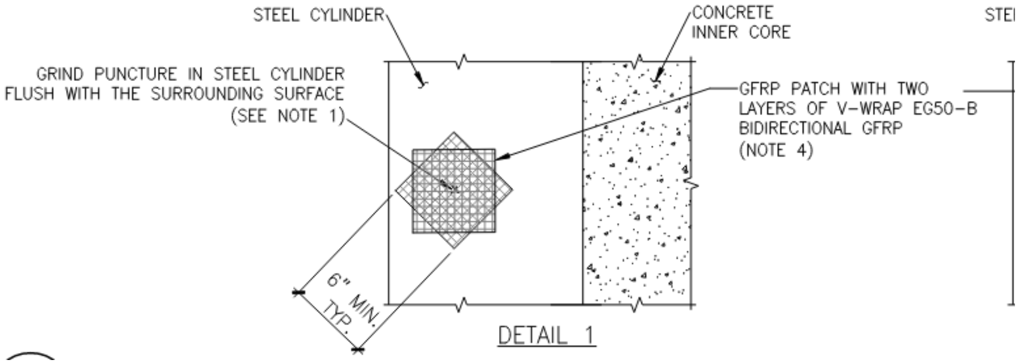
Surface Preparation – Steel Cylinder and Joint Ring

- Surface of steel cylinder and joint ring prepared to achieve adequate bond strength between the CFRP and steel substrate
- Sandblasting or other suitable methods used to achieve near-white metal finish



CFRP Saturation

- Carbon fiber lamina saturated using a mechanical saturator filled with resin
- Adhesion strength of the carbon fiber system to the concrete substrate verified by pull-off testing

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CFRP Installation

- The saturated carbon fiber lamina applied to the inside surface of the host pipe in a wet lay-up process
- The saturated fabric pressed to the inside surface of the host pipe to ensure adequate contact

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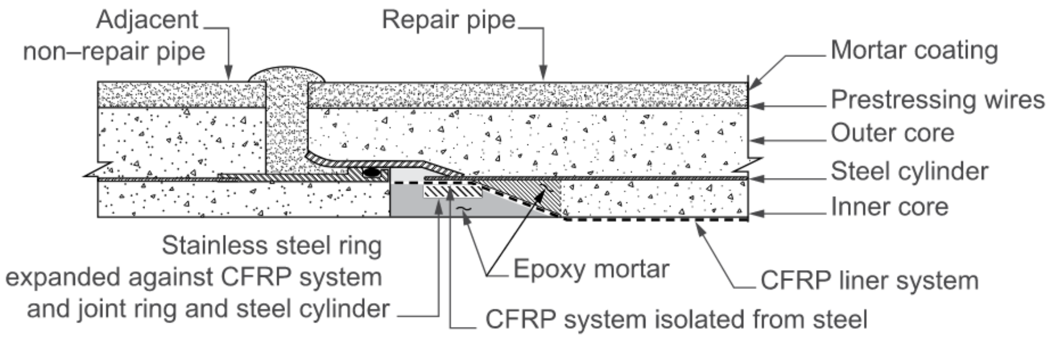
CFRP Termination

- Termination points designed such that the water pressure is not allowed to get behind the inner core in the future as degradation occurs
- If the CFRP is not sealed at termination points and water pressure is allowed to build up behind the inner core, the inner core and CFRP adhered to it will be stress-free and structurally ineffective



At bell end

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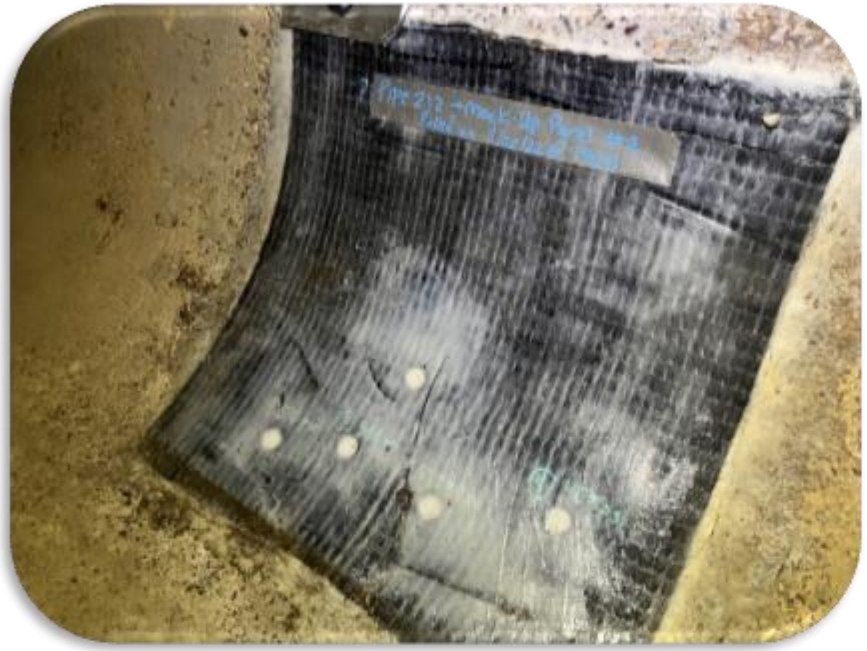
Adhesion Testing

- Adhesion Testing (ASTM D7234)
  - To validate the adequacy of the surface preparation and adhesion strength of the CFRP system, the constructor performs adhesion tests
    - These 2’ x 2’ areas are cleaned, prepared and covered with two-layer CFRP system test patches



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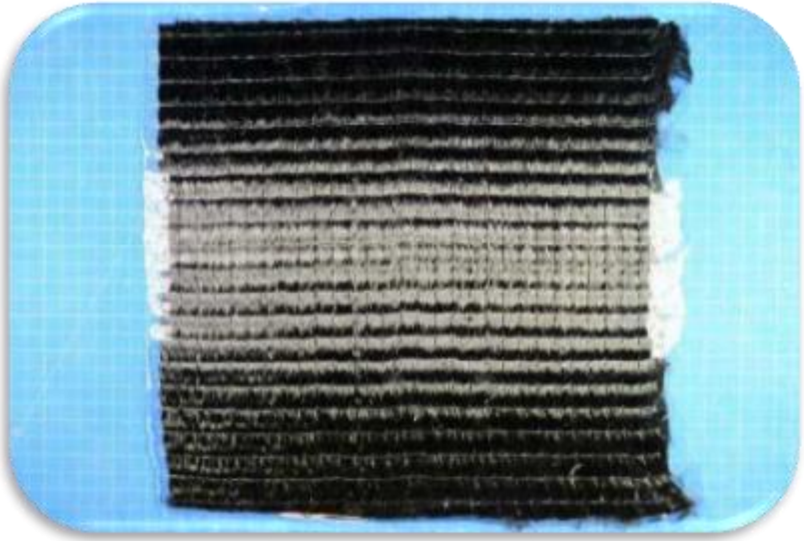
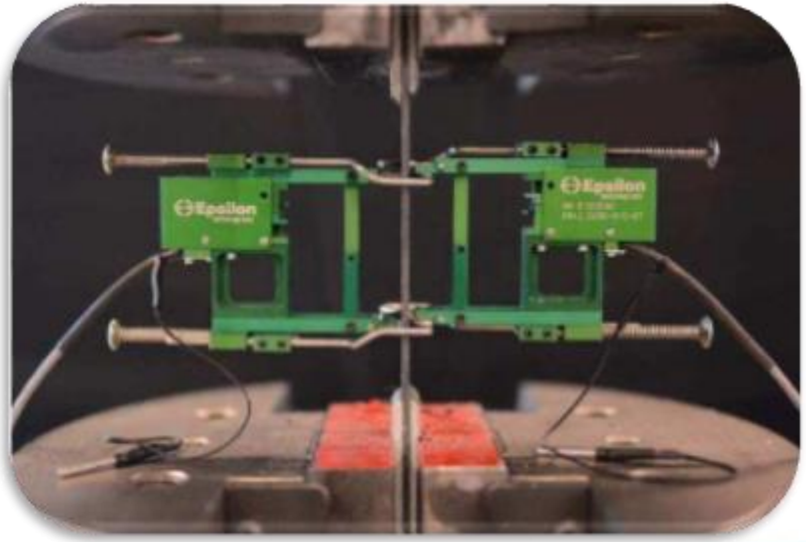
CFRP Test Panels



- Tensile Testing (ASTM D3039)
  - CFRP test panels per work shift during the repairs using one layer of CFRP and the same material preparation and application techniques used for the repair.
  - Submitted to accredited test lab to perform 10 tensile tests in the strong direction for each panel for strength, modulus, and elongation



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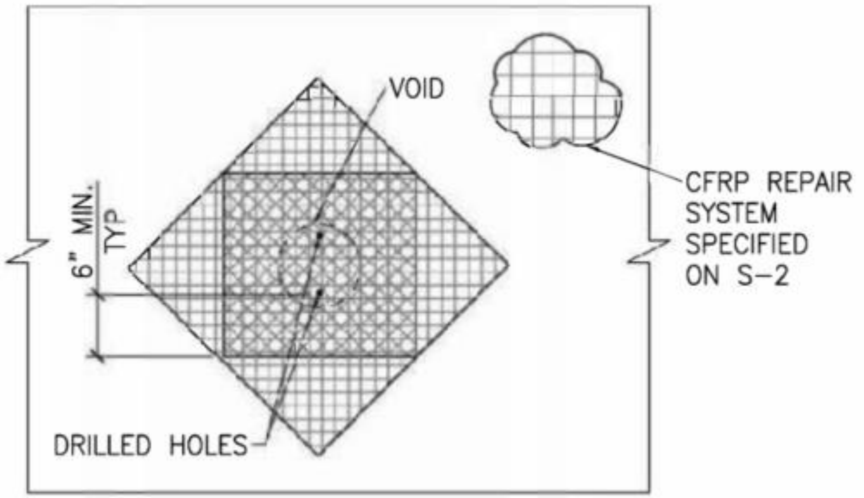
Defect Repairs and CFRP Cure

- Prior to the system achieving full cure, the CFRP system is inspected to identify defects
  - Air voids greater than 2 square-inches are injected with resin
- The CFRP system has a minimum of 85 percent cure before the pipe is returned to service
- The percent cure achieved tested in accordance with ASTM E2160 on samples retrieved from the surface after the cure cycle and prior to filling the pipe.



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