Contract ID: SC-INF01-1469
Our File #: 18-304

Sanayut Consulting Professional Engineers Corporation

Deline Health Centre
Foundation Pile Condition Assessment

PREPARED BY:

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Covering Letter

August 29, 2018

Government of the Northwest Territories
Department of Infrastructure
Projects Division
3rd floor, GNWT Multiuse Building
Bag Service #1
106 Veterans Way
Inuvik, NT X0E 0T0

Attn: Joao Nuncio

Dear Sir:

Regarding: **Deline Health Centre-Foundation Pile Condition Assessment**
Location: **Lots 3 – 6, Plan 5182, Deline, NT**

Sanayut Consulting Professional Engineers Corporation (**Sanayut**) is pleased to provide the following report regarding the foundation pile condition assessment for the above-referenced building.

This report has been prepared under my direct supervision.

We appreciate the opportunity to work with you. Please feel free to contact us if you have any questions regarding the enclosed report.

Sincerely,
Sanayut Consulting Professional Engineers Corporation

Mark Hasegawa, P.Eng.
Enclosures
MH/cms

Table of Contents

List of Tables

Appendices

EXECUTIVE SUMMARY

An assessment of the foundations of the building located at the aforementioned-address was conducted. A site map showing the building footprint and pile locations is shown in **Figure 1**, Appendix A.

Overall 71 of the 75 piles of varying construction were inspected at the Deline Health Centre. An assessment of the extent of pile deterioration was conducted on each pile by measuring depth of impact and observing impact extents in order to assess the extent of impact below the ground surface. In addition, an evaluation of drainage patterns was conducted. Overall the drainage onsite was from north to south. A significant degree of standing water or lack of drainage was observed at this location. As such, the drainage classification for this site, with regard to foundation pile impact, is severe and drainage modifications will be required. A combination of creating a swale to the south and filling low spots under the building with gravel (20mm minus) is recommended.

The results of this and previous analysis indicate that the majority of impact to the piles is within 250 mm of the ground surface. A structural analysis was conducted to determine at what point the deterioration affected the structural integrity of the piles. The depth of impact that affected the structural integrity varied due to loading differences and the overall diameter of the piles. It was also determined that impact depths over 10 mm, although not structural, would need remedial action to slow future deterioration of those piles.

Of the piles inspected,13 had been replaced with concrete caps; 5 were damaged to the point of affecting structural integrity and need full repair (B7, C14, B5, B6, & C16); and 6 had non-structural surface damage that require surface repair (A7, E15, F3, & H2 to H4). Also, there is some concern over the sizing of piles A9 to A13, which are sized smaller than the indicated evaluation criteria. The loading on these piles should be confirmed.

Remedial options are recommended for both structural and surface impacted piles and a cost analysis is included in this report.

1. EXISTING CONDITIONS

The Deline Health Centre rests on 75 piles of various construction. Floor plans and approximate pile spacings are shown in **Figure 1,** Appendix A and further described in subsequent sections. It appears that 13 piles have been repaired with concrete caps. The metal mesh skirting on the northwest corner has been pulled up and requires repair.

There is a concern that, based on the age of these untreated wood piles, some of the piles are damaged to the point of affecting the structural integrity of the pile. Key concerns regarding the piles include:

1. The wooden structural piles are exposed to pooling water from runoff or are permanently sitting in permafrost soil that is not able to drain.
2. Some of the untreated or unrepaired piles are approaching the end of their service life. The piles have outer layers of wood that are deteriorating, and mould is growing. It is not known if the piles are pressure treated with wood preservative. The saline content of the permafrost is not known but may have played a role in the deterioration.

2. METHODOLOGY

The following section includes a summary of the assessment methodology for the existing pile conditions as documented in the previous section.

2.1 Project Objectives

The project objectives stated in the TOR are as follows:

"The GNWT requires consultant engineering services to complete a foundation investigation for wooden pile foundations for Beaufort Delta and Sahtu buildings and to determine remedial work required which may include the change of foundation type as part of a final report."

2.2 Project Implementation

The following is the action taken to fulfill the scope of work set forth in the TOR.

2.2.1 Data Acquisition

There was a previous inspection report completed in December of 2006; however, we were not provided any design or construction documentation of the building such as as-builts, building plans or date of construction.

2.2.2 Code Review and References

Code and reference reviews were conducted of key codes and regulations and include the following items:

- Applicable Acts, Standards and Guidelines including:
    1. *Good Building Practice for Northern Facilities*, Government of the Northwest Territories
    2. National Building Code 2015
    3. *GNWT Deteriorated Untreated Wood Piles: Cause, Detection and Correction* document
    4. Pile remediation contractors.

The National Building Code does not include specific directions as to pile repair and design for deteriorating wood piles. It does reference structural loading and design of buildings. The loading and structural design calculations performed in this analysis comply with the building code process for design considerations.

The *Good Building Practice for Northern Facilities* document includes a section on deep pile design and recommends practices to be followed when constructing new foundation systems. However, it does not include specific recommendations on deteriorating wood pile repair.

The GNWT has a document recommending methods for inspection and repair of deteriorating wood pile foundations (*Deteriorated Untreated Wood Piles: Cause Detection and Correction*). This document has been followed in both inspecting the piles and making recommendations for repair options (refer to Appendix B-References).

Potential repair methods and costs were discussed with two local pile repair contractors (*Artic Restoration* and the *Vince Sharpe Corporation*). These are the two primary providers of deteriorated untreated wood pile repair and replacement in Inuvik. Cost information from these firms was used in developing the Class D cost estimate below.

2.2.3 Site Visit

A site visit and inspection of the building was conducted on June 22, 2018. The inspection for the site included:

- Visual observation of the site drainage and a site plan. The drainage was classified according to whether the drainage below the building was potentially impacting the piles and possibly enhancing pile deterioration. Based on the conditions observed, the amount of water under the building was divided into one of the four categories below.
    1. Not an issue < 10%
    2. Slight impact 10-25%
    3. Moderate impact 25-50%
    4. Significant impact > 50%
- Observations and measurements as to the general building and pile dimensions
- Inspection of piles for integrity and signs of deterioration or failure including rotten or soft material. A 10 mm diameter by 100 mm length awl was used to test softness by pushing it into the side of the pile. Depth of penetration was then measured to the nearest 5 mm with 0 mm being the minimum measure threshold. Measurements were taken on a minimum of four locations on a pile. This includes digging up to 500 mm down to evaluate depth of impact on each pile.
- Basic measurements of the building dimension pile locations and height of exposed piles were taken. This information is summarized in **Figure 1**.

Photographs were also taken and a selection of photos illustrating findings is attached (refer to Appendix C-Photographs).

2.2.4 Structural Analysis

In order to evaluate the effect of deterioration on the structural integrity of the pile, a structural screening analysis was conducted. The purpose of this analysis is to provide a technical basis to determine minimum diameter of pile integrity to support the estimated loading (see below). A minimum pile diameter of solid bearing material was established. The resulting criteria determining full repair is more than 25% damage of the cross-sectional area damaged or a minimum diameter of 9 inches of remaining solid material.

Key factors that affected the structural integrity of the pile are the loading from the building, pile spacing and pile diameter. There is are no available structural construction details of the building. However, basic loading was for the roof and floor using the current building code. The analysis assumed that the outside piles carried the most load since they would carry at least 25% of the roof load. The tributary areas for the floor and roof to which the outside piles supported was measured. The resulting loading was applied to every pile to allow for a conservative estimate. The factored loading for the main floor used a live load was 8.3 kPa and 4.6 kPa for the roof.

The portion of the pile below the active rotting area, 100-200mm below ground, appears to be physically sound. Therefore, the adfreeze portion of the pile which generates the pile resistance is sound. The only check required is to confirm the bearing resistance of the sound portion of the pile for compression.

Of note, piles A9 - A13 along the south side of the building appear to support a major load; however, the 6.5” diameter is well below the estimated minimum needed diameter of 9” inches. These piles have been temporarily blocked with portable steel jacks to provide additional support in these areas. It would be prudent to check the building design to confirm the loading on these piles.

3. SUMMARY OF OBSERVATIONS

The results of this analysis are summarized in **Figure 1** (Appendix A) and **Table 2** (below) and the pile inventory form in Appendix A. The piles have been classified based on the structural criteria set forth in the previous section. Key parameters evaluated included:

- Diameter of pile
- Depth of deterioration
- Vertical extent of deterioration
- Existence of drainage issues or standing water.
- Remaining pile diameter with solid material

Due limited access or blockage, four of the piles could not be inspected. Refer to Figure 1 for pile locations.

Table 1. Summary of Pile Observations

	Deline Health Centre	Recommendations
Total Piles	**75**	
< 10% damage	47	No repair
10-25% damage	6	Surface repair – Piles A7, E15, F3, H2 – H4
25-50% damage	3	Full repair – Piles B5, B6, C16
>50% damage	2	Full repair – Piles B7 & C14
Concrete repair	13	None
Not inspected/unknown	4	Piles not accessible due to enclosure

*Piles repaired previously

Overall the drainage onsite was from north to south. A significant degree of standing water or lack of drainage was observed at this location. Drainage modification will be required.

4. REPAIR RECOMMENDATIONS

The criteria to determine the pile status is based on structural analysis design. Three primary categories have been identified based on this analysis:

1. Pile deterioration that has no short or long-term structural effect and does not require remediation.
2. Surficial damage to pile that could cause long term damage but has no current effect on structural integrity of the pile. Remove impacted material, coat and seal.
3. Damage is affecting current structural integrity of the pile and replacement of damaged sections is warranted.

Even with pile maintenance and repair there is a predicted useful life of untreated wood piles. Recent studies indicate that bacterial biodegradation plays a major role in pile deterioration and is initially at a rate of approximately 0.5 mm per year. (refer to attached references). Once decay has established itself, that rate can increase to by an additional 50%. Also, the pile's useful life varies significantly. The pile life of a well-maintained pile where minimal moisture exposure occurs can exceed 100 years. However, a pile that experiences degradation could have a life cycle of 20 years or less.

Based on the age of the piles (estimated >40 years) some of the piles have been degraded to the point where repair or replacement of damaged sections is required to extend their life. Based on the information above it is reasonable to expect an additional 15 years or more from a pile that has been repaired or replaced.

Depending on which category each pile falls under, a remedy is recommended. Current industry practices for deteriorated wood pile repairs include:

- *Surface Repair:* remove deteriorated material, insert boron rods into the pile, cover with a grease/Pentasol mixture, and wrap with plastic (refer to **Figure 2,** Appendix D-Repair andp Replacement Details).
- *Damaged Section Replacement Option 1:* remove and replace damaged section and replace with 8" x 8" post (refer to **Figure 2,** Appendix D).
- *Damaged Section Replacement Option 2:* remove damaged portion of pile and replace with gravel pad, blocking and wedges (refer to **Figure 2,** Appendix D).

The first step in remedial action is to minimize the amount of standing water and exposure to runoff. A visual assessment of the drainage and standing water was included in this analysis. Some grading and or placement of a drain to assist drainage from this location is recommended.

Overall the drainage onsite was from north to south. A significant degree of standing water or lack of drainage was observed at this location. To improve the surface drainage, a combination of creating a swale to the south and filling low spots under the building with gravel (20 mm minus) is recommended.

5. COST ANALYSIS

Based on the recommendations above, a cost analysis was performed to evaluate the costs to facilitate pile remediation. In order to provide accurate and current pricing, two local pile repair contractors (*Artic Restoration* and *The Vince Sharpe Corporation*) were contacted and consulted on potential remedial costs. The information from these contractors was compiled and used to develop the unit rates in the cost analysis. Unit costs selected for this analysis are at the higher end of the unit rates received. Costing of the two replacement options was similar. This information was then compiled with the quantities observed in the study and used to create the Class D cost estimate shown in **Table 2** below.

Table 2. Class D Cost Estimate

Description	Unit Cost	Unit	No. of Units	Total
Site Preparation	$200.00	LS	1	$200.00
Surface grading	$50.00	$/m^2	300	$15,000.00
Dig around pile for access	$400.00	$/m	9	$3,600.00
Access trenching	$600.00	$/m	15	$9,000.00
Pile scrape and surface repair	$600.00	ea	6	$3,600.00
Full repair	$1,600.00	ea	5	$8,000.00
Site restoration	$200.00	LS	1	$200.00
Engineering drawing and inspection	$5,000.00	ls	1	$5,000.00
Contingency				$4,460.00
GST				$2,453.00
Total				**$51,513.00**

6. SUMMARY AND CONCLUSIONS

Overall 71 of the 75 piles of varying construction were inspected at the Deline Health Centre. An assessment of the extent of pile deterioration was conducted on each pile by measuring depth of impact and observing impact extents. In order to assess the extent of impact below the ground surface. In addition, an evaluation of drainage patterns was conducted. Overall, the drainage onsite was from north to south. A significant degree of standing water or lack of drainage was observed at this location. As such, the drainage classification for this site with regard to foundation pile impact is severe, and drainage modifications will be required. A combination of creating a swale to the south and filling low spots under the building with gravel (20 mm minus) is recommended.

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Of the piles inspected,13 had been replaced with concrete caps; 5 were damaged to the point of affecting structural integrity and need full repair (B7, C14, B5, B6, & C16), and 6 had non-structural surface damage that requires surface repair (A7, E15, F3, & H2 to H4). Also, there is some concern over the sizing of piles A9 to A13 which are sized smaller than the indicated evaluation criteria. The loading on these piles should be confirmed.

Remedial options are recommended for both structural and surface impacted piles and a cost analysis is included in the report.

REFERENCES

1. *Untreated Submerged Timber Pile Foundations: Part 1: Understanding Biodegradation and Compressive Strength* Dec, 2013 By Giuliana Zelada-Tumialan, P.E., William Konicki, P.E., Philip Westover, P.E. and Milan Vatovec, Ph.D., P.E. In *Articles, Structural Forensics.*

2. *Untreated Submerged Timber Pile Foundations: Part 2 – Estimating Remaining Service Life* Jan, 2014 By Giuliana Zelada-Tumialan, P.E., William Konicki, P.E., Philip Westover, P.E. and Milan Vatovec, Ph.D., P.E. In *Articles, Structural Forensics.*

3. *Deteriorated Untreated Wood Piles: Cause, Detection and Correction*. By Technical Support Services, Asset Management Division, Public Works and Services, Government of the NWT http://www.pws.gov.nt.ca

Appendix A

PILE INVENTORY FORM & FIGURE

Pile Inventory Form

BUILDING ASSET NUMBER:
BUILIDNG NAME: Deline Health Center
TOTAL NUMBER OF PILES: 60
DATE INSPECTED: 22-Jun-18

WATER PONDING UNDER BUILDING: Yes
YEAR OF PILE INSTALLATION: Unknown
ADDITION: No
SKIRTING AROUND BUILDING (Y/N): Yes, mesh skirting

PILE TYPE	
W	WOOD
S	STEEL
C	CONCRETE

Notes: Moisture meter used for field tests would not measure above 33% moisture content

WEATHER CONDITIONS: Overcast

TEMPERATURE: 10ºC

	Definition - Pile Condition	Range of Rot	Count in each range	Percentage in each Range
A	Little or no rot detected, No repair req'd	0 - 10%	37	84%
B	Rotted, requires monitoring	10 - 25%	2	5%
C	Rotted, requires repair	25 - 50%	3	7%
D	Rotted, requires immediate blocking	50 to 100%	2	5%

No.	Pile Type	Pile Currently Blocked	Previously Repaired	Depth of Rot Detected	Pile Diameter	Pile Circumference	Original Area (Cross section)	Cross sectional Area of Rot	Percent Rot (Cross section)	Moisture	Standing Water	Pile Condition		Date Pile Blocked	Date Pile Repaired	Date Boron Treatment	Comments/Remarks
	W, S, C	Y/N	Y/N	inches	inches	inches	square inches	square inches		%	Y/N	Def	Date				
A1 - A3	C												2018-06-22				Concrete, not inspected
A4	W	Y	N	0.25	12	37.7	113.0	4.7	4.12%	27.90%	Y	A	2018-06-22				Standing water
A5	W	Y	N	0.25	12	37.7	113.0	4.7	4.12%	>33%	Y	A	2018-06-22				Standing water
A6	C												2018-06-22				Concrete, not inspected
A7	W	Y	N	1	12	37.7	113.0	18.1	15.97%	>33%	N	B	2018-06-22				Labelled as A6 in Pile Assessment Photos
A8	W	Y	N	0.5	13	40.8	132.7	10.0	7.54%	>33%	N	A	2018-06-22				Labelled as A7 in Pile Assessment Photos
A9	W	Y	N	0.25	6.5	20.4	33.2	2.5	7.54%	>33%	N	A	2018-06-22				Labelled as A8 in Pile Assessment Photos
A10	W	Y	N	0.25	6.5	20.4	33.2	2.5	7.54%	>33%	N	A	2018-06-22				
A11	W	Y	N	0.25	6.5	20.4	33.2	2.5	7.54%	>33%	N	A	2018-06-22				
A12	W	Y	N	0.125	6.5	20.4	33.2	1.3	3.81%	>33%	N	A	2018-06-22				
A13	W	Y	N	0.25	6.5	20.4	33.2	2.5	7.54%	>33%	N	A	2018-06-22				
B1	W	N	N	0.5	12	37.7	113.0	9.2	8.16%	>33%	N	A	2018-06-22				
B2	W	N	N	0.5	12	37.7	113.0	9.2	8.16%	>33%	N	A	2018-06-22				
B3	W	N	N	0.5	12	37.7	113.0	9.2	8.16%	>33%	Y	A	2018-06-22				Standing water
B4	C												2018-06-22				Concrete, not inspected
B5	W	N	N	2.5	12	37.7	113.0	42.2	37.33%	>33%	N	C	2018-06-22				
B6	W	N	N	2	13	40.8	132.7	37.7	28.40%	>33%	Y	C	2018-06-22				Standing water
B7	W	N	N	4	13.5	42.4	143.1	72.2	50.48%	>33%	Y	D	2018-06-22				Standing water
B8	W	N	N	0.5	13.5	42.4	143.1	10.4	7.27%	>33%	Y	A	2018-06-22				Standing water
B9	W	N	N	0.25	13	40.8	132.7	5.1	3.81%	>33%	N	A	2018-06-22				Standing water
B10	W	N	N	0.25	13.5	42.4	143.1	5.2	3.67%	>33%	Y	A	2018-06-22				Standing water
C1 - 4	C												2018-06-22				Concrete, not inspected
C5	W	N	N	0.25	13.5	42.4	143.1	5.2	3.67%	>33%	Y	A	2018-06-22				
C6	W	N	N	0.25	13	40.8	132.7	5.1	3.81%	>33%	Y	A	2018-06-22				
C7	W	N	N	0.5	13	40.8	132.7	10.0	7.54%	>33%	Y	A	2018-06-22				Standing water
C8	C												2018-06-22				Concrete, not inspected
C9, C10	W												2018-06-22				No Access, no inspected
C11	W	N	N	0.25	12.5	39.3	122.7	4.9	3.96%	31.90%	Y	A	2018-06-22				
C12	W	N	N	0.5	12	37.7	113.0	9.2	8.16%	>33%	Y	A	2018-06-22				
C13	W	N	N	0.25	13.5	42.4	143.1	5.2	3.67%	>33%	Y	A	2018-06-22				Standing water
C14	W	N	N	4	13	40.8	132.7	69.1	52.07%	>33%	Y	D	2018-06-22				Standing water
C15	W	N	N	0.5	13	40.8	132.7	10.0	7.54%	>33%	Y	A	2018-06-22				Standing water
C16	W	Y	N	2	13	40.8	132.7	37.7	28.40%	>33%	Y	C	2018-06-22				Standing water
C17	W	Y	N	0.25	12	37.7	113.0	4.7	4.12%	>33%	Y	A	2018-06-22				
C18	W	N	N	0.5	13	40.8	132.7	10.0	7.54%	>33%	Y	A	2018-06-22				
D1	W	N	N	0.25	12.5	39.3	122.7	4.9	3.96%	>33%		A	2018-06-22				Standing water
D2	W	N	N	0.5	13	40.8	132.7	10.0	7.54%	>33%		A	2018-06-22				Standing water
D3	W	N	N	0.25	12	37.7	113.0	4.7	4.12%	>33%	Y	A	2018-06-22				Labelled D1 in photos
D4	W	N	N	0.25	13	40.8	132.7	5.1	3.81%	>33%	Y	A	2018-06-22				Labelled D2 in photos
E1, E2	C												2018-06-22				
E3	W	N	N	0.25	13	40.8	132.7	5.1	3.81%	>33%		A	2018-06-22				
E4	W	N	N	0.25	12.5	39.3	122.7	4.9	3.96%	>33%		A	2018-06-22				
E5	W		N	0.5	12	37.7	113.0	9.2	8.16%	>33%		A	2018-06-22				Labelled D5 in photos
E6	W												2018-06-22				No Access, no inspected
E7	W	N	N	0.25	12	37.7	113.0	4.7	4.12%	>33%	Y	A	2018-06-22				
E8	C												2018-06-22				Concrete, not inspected
E9	W	Y	N	0.25	13	40.8	132.7	5.1	3.81%	>33%		A	2018-06-22				Labelled D9 in photos, standing water
E10	W	Y	N	0.5	13	40.8	132.7	10.0	7.54%	>33%		A	2018-06-22				Labelled D10 in photos, standing water
E11	W	Y	N	0.25	13.5	42.4	143.1	5.2	3.67%	>33%	Y	A	2018-06-22				Labelled D11 in photos, standing water
E12	W	Y	N	0.25	12.5	39.3	122.7	4.9	3.96%	>33%	Y	A	2018-06-22				Labelled D12 in photos, standing water
E13	W	Y	N	0.25	12	37.7	113.0	4.7	4.12%	>33%	Y	A	2018-06-22				Standing water
E14	W	Y	N	0.25	12	37.7	113.0	4.7	4.12%	>33%	Y	A	2018-06-22				Labelled D14 in photos, standing water
E15	W	Y	N	1.5	12.5	39.3	122.7	27.7	22.56%	>33%	Y	B	2018-06-22				Labelled D15 in photos, standing water

Piles requiring repair

Original wood piles

Pile Inventory Form

BUILDING ASSET NUMBER:
BUILIDNG NAME: Deline Health Center
TOTAL NUMBER OF PILES: 15
DATE INSPECTED: 22-Jun-18

WATER PONDING UNDER BUILDING: Yes
YEAR OF PILE INSTALLATION: Unknown
ADDITION: No
SKIRTING AROUND BUILDING (Y/N): Yes, mesh skirting

PILE TYPE	
W	WOOD
S	STEEL
C	CONCRETE

Notes: Moisture meter used for field tests would not measure above 33% moisture content

WEATHER CONDITIONS: Overcast

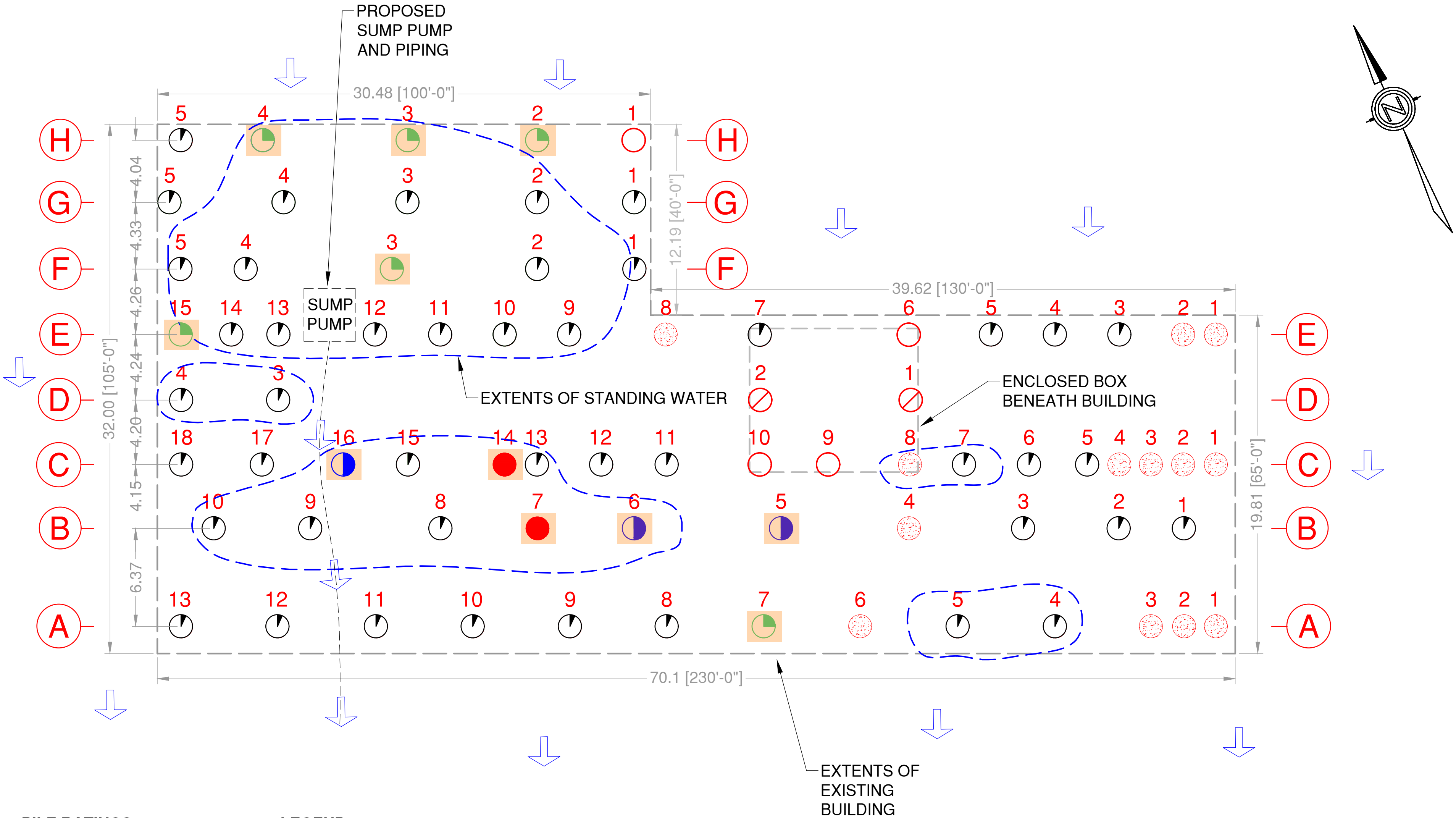
TEMPERATURE: 10ºC

	Definition - Pile Condition	Range of Rot	Count in each range	Percentage in each Range
A	Little or no rot detected, No repair required	0 - 10%	10	71%
B	Rotted, requires monitoring	10 - 25%	4	29%
C	Rotted, requires repair	25 - 50%	0	0%
D	Rotted, requires immediate blocking	50 to 100%	0	0%

No.	Pile Type	Pile Currently Blocked	Pile Previously Repaired	Depth of Rot Detected	Pile Diameter	Pile Circumference	Original Area (Cross section)	Cross sectional Area of Rot	Percent Rot (Cross section)	Moisture	Standing Water	Pile Condition		Date Pile Blocked	Date Pile Repaired	Date Boron Treatment	Comments/Remarks
	W, S, C	Y/N	Y/N	inches	inches	inches	square inches	square inches	%	%	Y/N	Def	Date				
F1	W	N	N	0.25	12.5	39.3	122.7	4.9	3.96%	27.90%	Y	**A**	2018-06-22	**N/A**			
F2	W	N	N	0.25	12.5	39.3	122.7	4.9	3.96%	>33%	Y	**A**	2018-06-22	**N/A**			
F3	W	N	N	0.75	13.5	42.4	143.1	15.5	10.80%	>33%	Y	**B**	2018-06-22	**N/A**			
F4	W	N	N	0.5	13.5	42.4	143.1	10.4	7.27%	>33%	Y	**A**	2018-06-22	**N/A**			
F5	W	N	N	0.25	13.5	42.4	143.1	5.2	3.67%	>33%	Y	**A**	2018-06-22	**N/A**			
G1	W	N	N	0.5	13	40.8	132.7	10.0	7.54%	>33%	Y	**A**	2018-06-22	**N/A**			
G2	W	N	N	0.25	13	40.8	132.7	5.1	3.81%	>33%	Y	**A**	2018-06-22	**N/A**			Labelled F4 in photos, standing water
G3	W	N	N	0.5	13	40.8	132.7	10.0	7.54%	>33%	N	**A**	2018-06-22	**N/A**			Labelled F3 in photos, standing water
G4	W	N	N	0.5	12	37.7	113.0	9.2	8.16%	>33%	N	**A**	2018-06-22	**N/A**			Labelled F2 in photos, standing water
G5	W	N	N	0.5	13.5	42.4	143.1	10.4	7.27%	>33%	N	**A**	2018-06-22	**N/A**			Labelled F1 in photos, standing water
H1	W	N	N											**N/A**			No Access, not inspected
H2	W	N	N	1.25	13.5	42.4	143.1	25.3	17.66%	>33%	Y	**B**	2018-06-22	**N/A**			Labelled G9 in photos, standing water
H3	W	N	N	1	13	40.8	132.7	19.6	14.79%	>33%	Y	**B**	2018-06-22	**N/A**			Labelled D3 in photos, standing water
H4	W	N	N	1.5	13	40.8	132.7	28.8	21.75%	>33%	Y	**B**	2018-06-22	**N/A**			Labelled G4 in photos, standing water
H5	W	N	N	0.5	13	40.8	132.7	10.0	7.54%	>33%	Y	**A**	2018-06-22	**N/A**			Standing water

Piles requiring repair

Original wood piles



PILE RATINGS
(% CROSS-SECTION LOSS)

- <10%
- 10% to 25%
- 25% to 50%
- >50%
- NOT EXCAVATED
- CONCRETE PILE
- NOT INSPECTED

LEGEND

- A — PILE GRID ALIGNMENT
- 1 — PILE NUMBER
- APPARENT OVERLAND DRAINAGE DIRECTION
- PILE TO BE REPAIRED

NOTE:
- BUILDING DIMENSIONS SHOWN ARE APPROXIMATE AND FOR REFERENCE ONLY
- DIMENSIONS SHOWN ARE IN METERS (m) UNLESS OTHERWISE SHOWN

DRAWING STATUS: FOR REPORT

#	REVISION	DATE	BY

NOTES

CONTRACTOR TO CHECK AND VERIFY ALL DIMENSIONS BEFORE CONSTRUCTION, ANY ERRORS AND OMISSIONS SHALL BE REPORTED TO THE ENGINEER IMMEDIATELY

DRAWING SHALL NOT BE USED FOR CONSTRUCTION UNTIL APPROVED

DO NOT SCALE THE DRAWING

ALL CONSTRUCTION SHALL BE IN ACCORDANCE WITH THE LATEST CODES, MAY IT BE CONSTRUCTION, MECHANICAL, ETC

CLIENT: GOVERNMENT OF NWT

PROJECT TITLE: PILE ASSESSMENT JUNE 22, 2018

DRAWING TITLE: DELINE HEALTH CENTER DELINE, NT

HASEGAWA
CONSULTING PROFESSIONAL ENGINEERS
330, 3120 - 32nd Street South Lethbridge Alberta T1K 7B4
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INSPECTED BY	MO
DRAWN	MO
CHECKED	MH
APPROVED	MH
SCALE	NTS
PROJECT NUMBER	18-304
VERSION NUMBER	IFA1-1
DATE DRAWN	JULY 4, 2018
SHEET NUMBER	FIG. 1

Appendix B

REFERENCES

Untreated Submerged Timber Pile Foundations: Part 1: Understanding Biodegradation and Compressive Strength

Dec, 2013 By Giuliana Zelada-Tumialan, P.E., William Konicki, P.E., Philip Westover, P.E. and Milan Vatovec, Ph.D., P.E. In Articles,Structural Forensics Comments 0

The use of untreated timber piles as foundation support in Europe and the U.S became more wide-spread at the end of the 19th century and beginning of the 20th century, when industrialization led to the rapid expansion of urban areas. Their use was common in regions with natural soft soils, or where urban-fill was used for land development, such as in the northeastern U.S. Thousands of historic structures across Europe and the U.S. currently remain supported on untreated timber piles; their continued use and maintenance costs highly depend on the condition of the piles after tens or hundreds of years of in-ground service.

Early on, it was recognized that untreated timber piles needed to be submerged to provide anoxic (i.e. little to no oxygen) conditions, which was thought to prevent pile deterioration due to wood-destroying fungi and/or soft rot attack. Therefore, the installation of untreated timber piles typically required the pile cutoff to be below the lowest expected in-service groundwater level. Unfortunately, urban development resulting from the industrial revolution brought with it underground construction; and as a consequence, groundwater levels became lowered due to long-term construction dewatering, new underground structures acting as obstructions to groundwater flow, and leaks into poorly sealed basements and underground utilities. The lowered groundwater levels resulted in exposure of the timber pile tops to oxygen, leading to significant pile-top deterioration due to fungal attack, and ultimately, significant settlement of the structures.

The typical foundation repair method for deteriorated untreated timber piles is cut-and-post underpinning; an access pit is excavated along the length of the foundation and the tops of the timber piles are exposed, removed, and replaced with new structural elements, e.g. concrete posts or concrete-encased steel posts.

It took until the 1970s to identify that biodeterioration of timber piles can also be caused by bacteria (Boutelje et. al. 1968, Klaassen 2008-1). And it was not until recently that more comprehensive studies performed in Europe, specifically the BAC-POLES scientific project funded by the European Commission in 2001 (Klaassen 2005), have been able to quantify the rate of bacterial attack and of related degradation of the submerged wood strength.

This article, Part 1 of a 2-Part series, provides a summary of the state of knowledge on bacterial biodeterioration on submerged and untreated timber piles, as well as a discussion on the impacts of time and deterioration on the in-service compressive strength of the piles. A method for performing qualitative assessment of the likely effectiveness and durability of cut-and-post underpinning remediation of untreated timber-pile supported structures will be proposed in Part 2.

Biodegradation of Untreated Submerged Timber Piles

Until recently, bacterial attack on submerged wood was the least understood biodeterioration mechanism. The European BAC-POLES research project, which investigated causes and patterns of bacterial decay in timber piles in the early 2000s, as well as subsequent research performed primarily in the Netherlands, have shed much needed light on the nature of bacterial deterioration mechanisms. It is now thought that bacterial decay of timber piles occurs always, at all sites and in all conditions, although the rate and degree of attack may vary depending on site specific conditions The following list is a summary of the most salient results and conclusions in the literature, relative to bacterial attack of submerged timber piles, reached to date:

http://www.structuremag.org/?p=1235 http://www.structuremag.org/?p=1299
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- Bacterial wood degradation can occur under a wide range of conditions due to the variety of bacteria species, each with its own optimal environmental settings (Klaassen 2008-1, Nilson et. al. 2008).
- In addition to low levels of oxygen, wood-degrading bacteria also appear to thrive best in environments with low levels of nitrogen (Huisman et. al. 2008).
- Bacterial wood degradation occurs uniformly along the entire pile length (pile lengths of up to about 46 feet were included in the BAC-POLES study). Thus, in terms of assessment of bacterial degradation, the condition of the pile tops is representative of the entire pile (Klaassen 2008-1).
- Slight cell wall deterioration due to bacterial attack results in no major loss of compressive strength (Klaassen 2008-1). On the other hand, severe cell wall deterioration due to bacterial attack results in softening of the wood, significantly reducing the compressive strength of the wood in the affected areas and, thus, the effective available load-bearing pile cross-section.
- The velocity of bacterial decay is variable between wood species and is generally slow, ranging between almost 0 to more than 1 mm/year (0.04 inch/year). Based on a database that included about 1000 spruce piles and 1000 pine piles with a service life ranging between 80 to 200 years, the rate of initial advancement of bacterial invasion before significant wood strength loss occurs is about 0.5 mm/year (0.02 inch/year) in pine, whereas in spruce it ranges between 0.1 to 0.5 mm/year (0.004 to 0.02 inch/year). Once bacterial invasion is well established, the rate of deterioration increases; the average rate of severe bacterial attack causing significant wood strength loss was calculated to be about 0.25 mm/year (0.01 inch/year) in pine piles, and about 0.13 mm/year (0.005 inch/year) in spruce piles (Klaassen 2009).
- The advancement of bacterial decay occurs inwards, starting from the pile perimeter. For spruce and pine piles with an in-service age of 650 years or less, the rate of bacterial attack decreases significantly at the heartwood-sapwood interface. Bacterial degradation of the heartwood was only observed in oak piles about 2000 years old; the degree of deterioration in the heartwood varied from moderate at the heartwood-sapwood interface to weak near the pith (Klaassen 2009).
- Wood species with more permeable tissue structures (e.g. alder, poplar, and the sapwood of pine and oak) are more susceptible to bacterial decay than those with less permeable tissue structures (e.g. spruce and the heartwood of pine and oak). More permeable tissue structures, i.e. wood species with larger open cross-field pits, allow more flow of water and therefore transport of wood-degrading bacteria in the water stream across the pile cross-section (Figure 1). In the presence of pressure gradients between the tops and bottoms of piles (i.e. the bottom and top of the piles are embedded in different soil layers with different groundwater levels), water flow and transport of wood-degrading bacteria is facilitated along the length of the piles (Klaassen 2008-2).

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Figure 1: Deteriorated timber pile cross-section.

The authors' observations, and observations by others, regarding a large number of piles exposed over most of their length confirm that bacterial decay occurs over the entire pile length. In addition, microscopic evaluations on spruce timber pile samples from one of the authors' projects in the northeastern U.S. (for which historic records on timber-pile condition assessments are available), indicate the following:

- Slight to no cell wall deterioration combined with the presence of bacteria was observed at depths ranging from 0.25 to 4 inches (6 to 100 mm) for piles with 67 to 117 years in service. The calculated average rate of advance of bacterial invasion is 0.41 mm/year (0.016 inch/year).
- Severe cell wall deterioration with significant strength loss was observed in the outer 0.5 to 0.75 inches (13 to 19 mm) for piles with 103 years to 117 years in service. The calculated average rate of advance of severe degradation is 0.13 mm/year (0.005 inch/year).

Therefore, the behavior of microbial decay under submerged conditions in the U.S. appears to be similar to that observed by others in European piles of the same species and of equal or greater age.

Compressive Strength of In-Service Timber Piles

Current design standards for new timber pile foundations (ASTM D245-06 and ASTM D2899-03) reference and use the allowable compressive strength of timber piles, rather than the ultimate compressive strength (strength at failure). The design strengths are based on, but are lower than, the representative ultimate compressive strength obtained from testing of clear, straight-grained, green wood samples. The ultimate compressive strength value is multiplied by a series of adjustment coefficients that are meant to account for a safety factor, duration of load (DOL) effects, grade/quality of wood, pile group effects, test sample size, variability, and potential defects in the wood. Of all these factors, the most significant in terms of reduction in compressive strength is the DOL factor, which imposes approximately a 40% reduction in the compressive strength for permanent (constant) loads (ASTM D245-06). The DOL factor accounts for the laboratory-testing proven effects of duration of the applied load on the strength properties – the longer the wood is subjected to a constant load, the lower its strength. This is due to unrecoverable micro-damage that takes place during the period the pile is loaded. Although the use of all these adjustment factors for design purposes is prudent and necessary, their use for evaluation of existing conditions is likely conservative.

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Other than reductions in strength due to the DOL factor, current design standards assume no reduction in the compressive strength of wood due to aging effects, (provided no biodeterioration is present). This is reportedly based on strength tests of old timbers, 100 or more years old, which showed no appreciable deterioration of the wood's strength or stiffness due to age alone (ASTM D245-06). Klaassen (2008-1) reached a similar conclusion when comparing the compressive strength of foundation piles that had been in use for more than 80 years (and suffered no bacterial or other degradation) with compressive strength of samples obtained from freshly sawn timbers.

Van Kuilen (2007), however, concluded that the compressive strength of submerged timber decreases with time. He presented results of compressive strength tests performed on clear wood samples obtained from submerged untreated European pine, spruce, larch, oak and alder piles with varying in-ground service ages (between 70 and 640 years). The results are presented as the ratio of the measured compressive strength (parallel to the grain) of the aged wood to the average strength of new wood in a wet condition, versus the time in service in the ground below the groundwater level (Figure 2). Van Kuilen further determined that the residual strength of the timber piles appears to be governed by the amount of heartwood in the cross-section (based on the results of tests on full pile cross-sections), and provided best-fit lines for estimating the decrease in timber pile compressive strength of the heartwood and sapwood as a function of time in service and under load. Van Kuilen did not elaborate on the cause of strength reduction with time beyond indicating that the magnitude of applied load (i.e. accumulation of mechanical damage under sustained loading) and the degree of decay likely play a role.

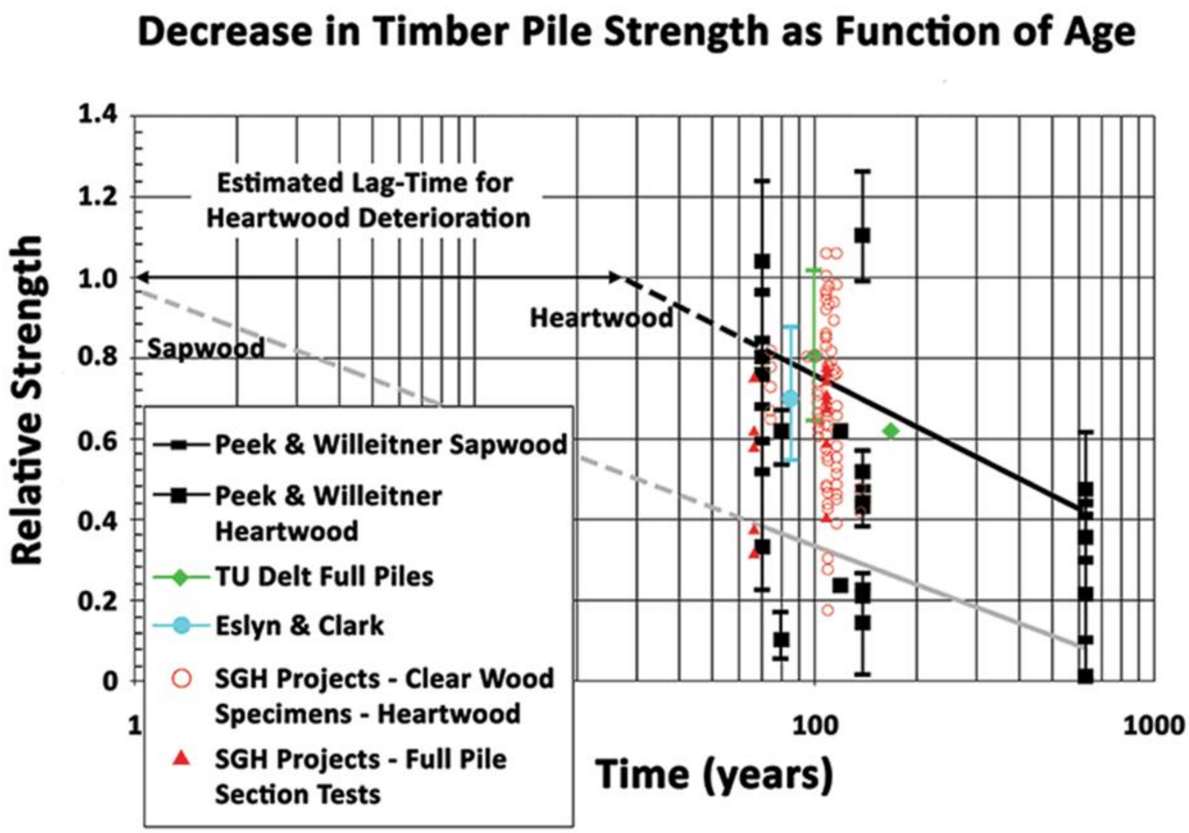

Figure 2: Decrease in timber pile compressive strength with in-service age (Base figure from Van Kuilen, 2007).

To validate the use of Van Kuilen's curve for estimating the decrease in compressive strength of heartwood, the author's calculated strength ratios (i.e. ratio of measured compressive strength of aged pile to the expected

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compressive strength of a new pile) for full timber pile cross-sections and clear wood samples obtained from piles exposed at various projects throughout northern U.S. All full-timber pile samples considered were eastern spruce; clear wood samples considered were eastern spruce, red pine, and elm. The in-service age of the samples ranged from 67 to 137 years. Only non-deteriorated heartwood samples were included in this evaluation.

For comparison with Van Kuilen's curve, the expected average clear wood ultimate compressive strengths parallel-to-the-grain of 2650, 3280, and 3780 psi (18.2, 22.6, and 26 MPa) were used for spruce, pine, and elm piles respectively. These values were obtained from published average strength values for each wood species grown in the U.S. and Canada, as provided in Tables 2 and 3 of ASTM D-2555-06. Figure 2 shows a plot of the calculated strength ratios superimposed on Van Kuilen's graph. In general, the data is reasonably centered and distributed around the best-fit line for decrease in compressive strength of submerged untreated pile heartwood proposed by Van Kuilen.

The laboratory compressive strength testing of samples obtained from existing timber piles includes the effects of any micro-damage, i.e. duration of load effects, that has taken place during the period the pile has been in service. Conversely, the laboratory compressive strength testing of samples from freshly-sawn timbers do not, and the published ultimate strength values are applicable for short-term loading only. Therefore, it appears that Van Kuilen's curves reflect the decrease in compressive strength of submerged, undeteriorated heartwood due to aging under prolonged continuous loading (i.e. DOL).

The spread in the values of compressive strength parallel-to-the-grain obtained at various service ages could be related to variations in the level of applied compressive stress on the piles. Microscopic mechanical damage to timber piles under sustained loading, however, becomes less significant if the piles are loaded to a smaller fraction of their capacity. Hoyle and Woeste (1989) report that when the applied stress is at less than 55% of the short-term ultimate wood strength, creep deflection levels off and additional deflection does not occur. As the applied stress levels increase to more than 55% of the short-term ultimate wood strength, creep continues indefinitely and ultimately results in failure. Thus, a pile loaded to 10% of its ultimate short term test capacity is likely to experience less damage under sustained loading than a pile loaded to 50% of its ultimate short term test capacity. For example, in large historic structures, where the number of in-place timber piles sometimes exceeds the minimum number of piles required to support the applied loads by design, the piles can be expected to have experienced a low level of sustained applied loads and hence less "aging/DOL" effects.

Interim Remarks

The authors' experiences confirm that bacterial attack in the submerged portion of the timber piles can play an important role in limiting the estimated remaining service life of pile-supported structures, even after cut-and-post underpinning has been performed. Given the magnitude of involved costs, the presence and impact of bacterial attack may ultimately govern the choice of the underpinning method to be used. The current understanding of the rates of deterioration, loss of strength and loss of stiffness of wood with time is still developing. However, there is sufficient information available to allow for a qualitative assessment of the likely effectiveness and durability of cut-and-post underpinning remediation of untreated timber-pile supported structures.

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Untreated Submerged Timber Pile Foundations: Part 2 – Estimating Remaining Service Life

Jan, 2014 By *Giuliana Zelada-Tumialan, P.E.*, *William Konicki, P.E.*, *Philip Westover, P.E.* and *Milan Vatovec, Ph.D., P.E.* In *Articles*,*Structural Forensics* Comments *0*

As discussed previously in ***Untreated Submerged Timber Pile Foundations – Part 1*** (STRUCTURE® magazine, December 2013), deterioration of pile tops exposed above groundwater levels is a well-known problem. It is less known that submerged portions of timber piles can also deteriorate with time, albeit at a slower rate, due to bacterial attack. This may become critical when considering underpinning methods aimed at extending service life of structures supported on timber piles.Historically, timber-pile supported structures have been underpinned by the cut-and-post method, where the top portion of the timber piles is cut and replaced with concrete posts or concrete-encased steel posts. Although the cut-and-post method appears to be relatively straight forward and simple to execute, it remains an expensive undertaking due to accessibility issues, required temporary shoring and bracing, dewatering, and labor costs. Klaassen (2008-1) reports that, in the Netherlands, foundation replacement or repair sometimes involves up to 50% of the total renovation costs for a structure. The authors' experience in the Boston, Massachusetts area indicates cut-and-post underpinning of a typical downtown row house costs approximately $200,000 to $250,000. Bacterial attack in the remaining, submerged portion of the timber piles, however, may limit the effectiveness of the cut-and-post method, as well as the estimated remaining service life of the piles.

Remaining Service Life

The aim of any foundation remediation/repair design is similar to that of new foundation design: its design and execution must be able to (1) safely sustain all likely applied loads without failure (i.e. without overloading beyond the strength capacity of the foundation system), and (2) remain serviceable for the required use of the structure (e.g. without excessive settlement) during its intended service life. Hence, one of the greatest challenges in pile foundation remediation/repair design, and a key item for its success, is performing a reliable assessment of the current in-situ foundation's material properties and loading history, after years in service and exposure to the surrounding natural environment. This forms the basis for the estimation of the remaining service life of the foundation system, if it is to be re-used.

The estimated remaining service life of any foundation system is governed by the determined minimum structural capacity (dependent on material properties and level of deterioration), the geotechnical capacity (dependent on soil properties and soil-structure interaction), and the magnitude of expected movements (e.g. settlement) compared to the allowable movements that a structure can sustain.

Determining Remaining Structural Capacity

Based on the review of published literature and on relevant experience, the following approach is proposed to determine the remaining structural capacity of continuously submerged timber piles:

Step 1 – Estimate the applied compressive stress acting on the timber pile cross-section versus time, considering the reduction in available load-bearing pile cross-section due to continued bacterial decay penetration. For spruce and pine piles, an estimated rate of advance of severe degradation of 0.0051 inch/year and 0.0098 inch/year, respectively, can be used (Klaassen 2009). The following considerations should be included:

- Current measured penetration of severe bacterial deterioration (based on probing to determine depth to sound wood) to be used as the starting point from which future reductions in pile cross-section will occur.
- Determine the taper of the timber pile for estimation of the pile tip diameter based on pile top diameter. Timber piles in many cases tend to derive their capacity by end bearing on a suitable soil stratum;

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therefore, the critical pile section is located at or near the pile tip. The rate of severe bacterial degradation should be applied uniformly over the entire pile length.

- The rate of bacterial attack decreases significantly beyond the heartwood-sapwood interface in spruce and pine piles. Therefore, for these species at least, it is reasonable to assume that for the most typical required service life of structures (i.e. 100 years or less), only the sapwood will deteriorate significantly and no further reduction in pile cross-section due to bacterial decay is expected once the sapwood thickness has been expended. The determination of the sapwood/heartwood boundary requires microscopic examination for heartwood signs, and for bacterial invasion and deterioration at different depths within the pile; this can be subjectively influenced by the examiner's experience. Without detailed microscopic observations, the depth to the heartwood/sapwood boundary can only be roughly estimated from obvious color changes in the wood, or based on publications like *The Wood Handbook* (USDA, 2010) or the *Textbook of Wood Technology* (McGraw-Hill, 1980).
- Although the deteriorated sapwood has some measurable compressive strength, it seems prudent to ignore its contribution to the timber pile strength capacity. Measured values of elastic modulus for specimens of deteriorated sapwood obtained from piles (from previous projects) indicate that the ratio of elastic moduli between deteriorated sapwood and sound heartwood is in the range of 0.1 or less. Therefore, it would be expected that more than 90% of the applied load is resisted by the stiffer and stronger heartwood.

Step 2 – Estimate timber pile compressive strength versus time by using the reduction in compressive strength due to aging/duration of loading for heartwood shown in Figure 1. This assumes that all of the remaining pile section (based on probing to measure the depth to sound wood), including any small amount of sapwood present, can be represented by the reduced average compressive strength for heartwood.

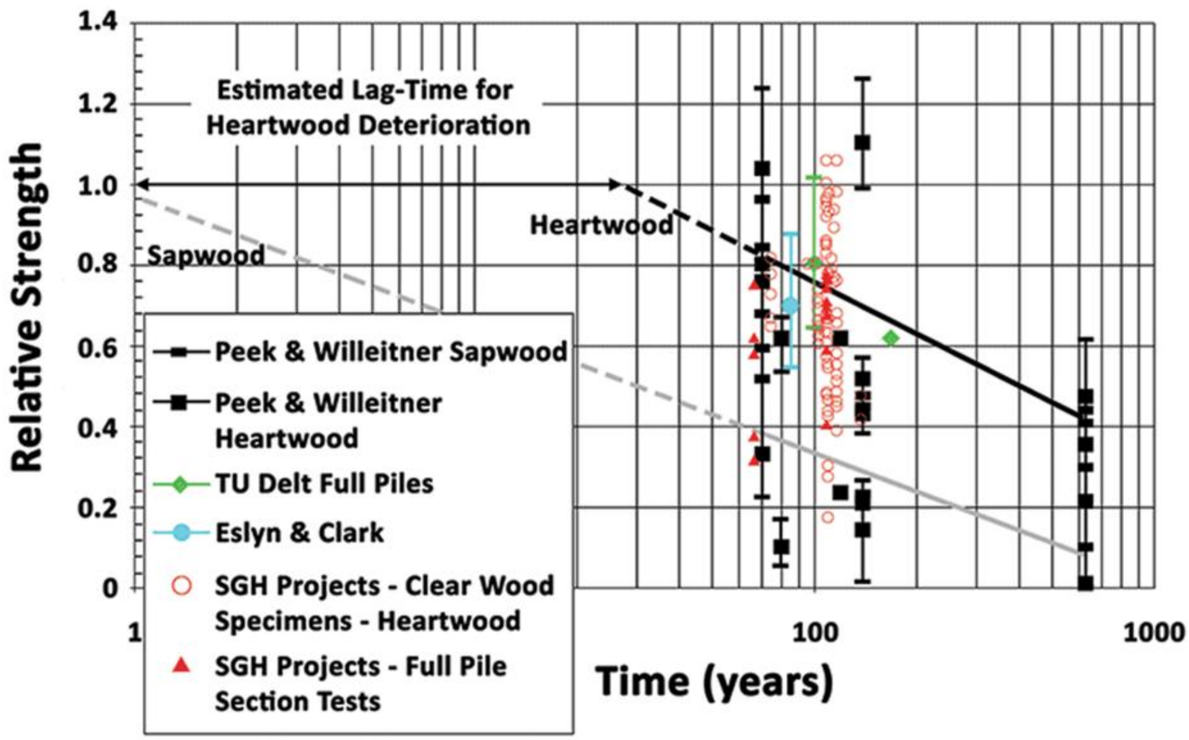

Figure 1: Decrease in timber pile compressive strength with in-service age (Base figure from Van Kuilen, 2007).

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Step 3 – Determine estimated remaining structural service life of submerged timber piles by determining the time (from present) at which the demand-to-capacity (D/C) ratio for the various timber pile diameters considered (i.e. the ratio of applied compressive stress to the remaining compressive strength) is equal to the desired factor of safety level. Alternatively, the designer may choose to use a target minimum allowable percent loss in pile cross-section to determine the remaining structural service life of the submerged timber pile.

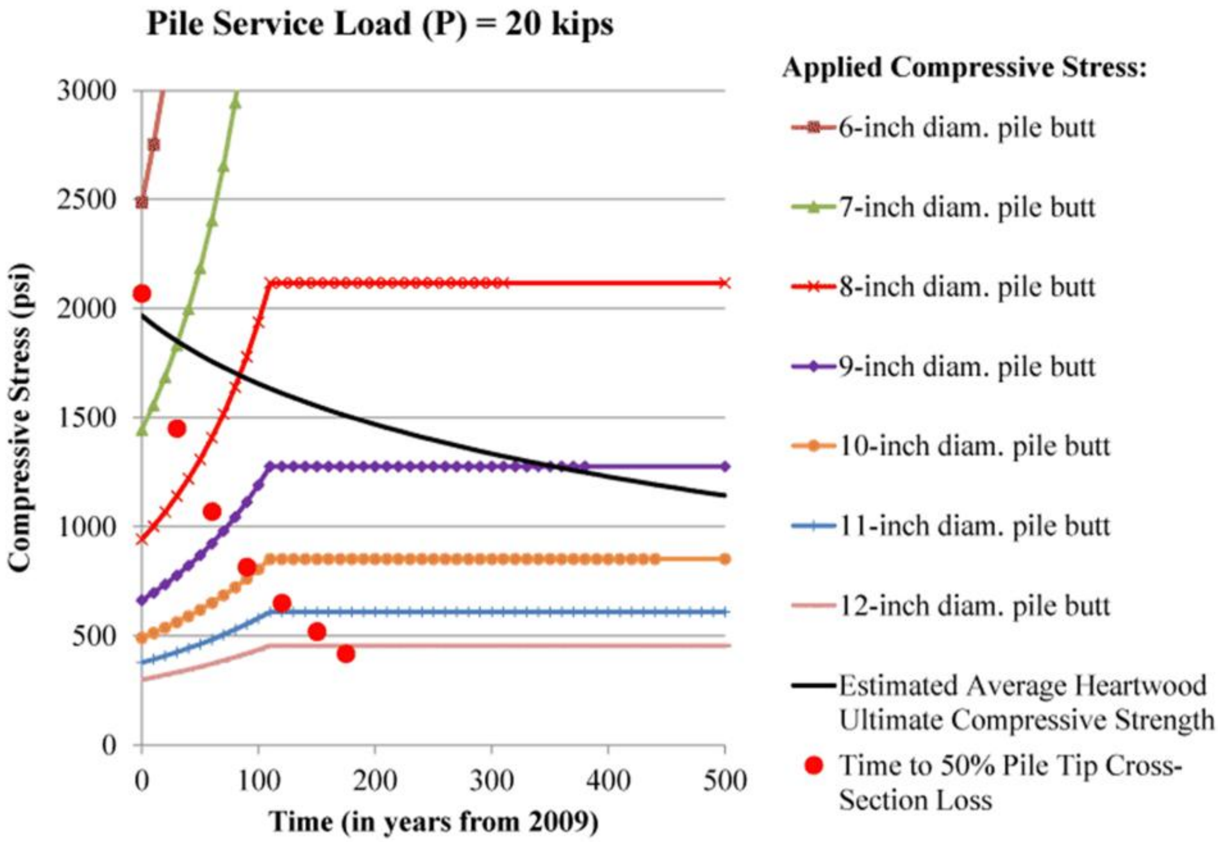

Figure 2: Sample plots of applied compressive stress and estimated heartwood compressive strength vs. time.

Figure 2 shows a sample plot of the calculated reduced heartwood compressive strength with time (Step 2), superimposed on plots of the applied compressive stress curves developed for various timber pile diameters as bacterial decay penetrates to the heartwood/sapwood boundary for a service load of 20 kips (Step 1). The intersection of the time under load dependent ultimate heartwood compressive strength curve and the applied compressive stress curves defines the expected remaining pile service life for each pile diameter at the expected load combination, with no factor of safety included. Figure 2 was developed for spruce piles with an in-service age of 109 years, 2-inch sapwood thickness, and measured severe bacterial attack penetration of about 0.75 inches at time zero. The plot of applied compressive stress is shown in relation to the pile butt (pile top) diameter, rather than the critical pile section (i.e. pile tip) used to calculate the applied stresses for ease of use during investigations where, typically, just the pile tops are exposed. Figure 2 also shows the time for 50% loss of original pile cross-section for reference.

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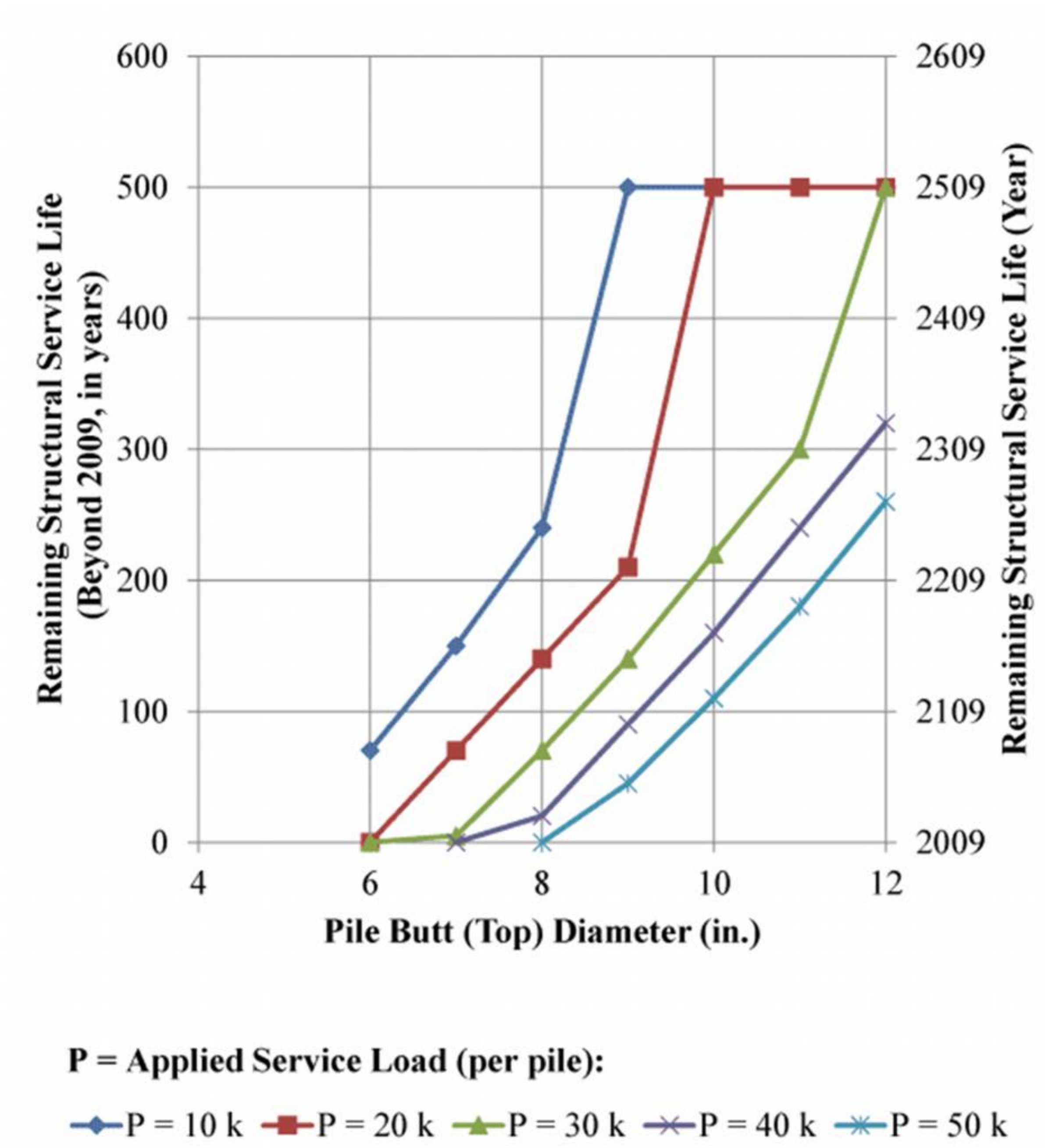

Figure 3: Sample plots of estimated remaining structural service life of submerged timber piles.

Figure 3 shows plots of the estimated remaining service life for each timber pile butt (top) diameter and different levels of applied service load calculated similarly to Figure 2, and considering a D/C ratio of 1.0 (i.e. no factor of safety is included). Since Figure 2 only considers time up to 500 years, the curves in Figure 3 level off at 500 years.

Evaluation of Remaining Geotechnical Capacity

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The Table summarizes the results of load testing on five timber piles from separate areas of a single project site in downtown Boston. Two of these piles were extracted after the load tests were performed.

Results of the pile load tests indicate no apparent adverse impact of timber pile deterioration on the geotechnical bearing capacity of the piles. Area 1-1, which showed a larger penetration depth of severe deterioration (with 75% or more loss of pile cross-section), performed stiffer and had a higher measured unit end bearing capacity than the Area 1-2 pile which showed less deterioration (about 34% loss of pile cross-section). However, the data evaluated in this analysis is too limited to draw more in-depth conclusions regarding the impact of deterioration on the geotechnical capacity of the submerged timber piles.

Load Test	Pile Tip Diam (inches)	Max. Applied Load (Kips)	Max. Measured Pile Top, Total Settlement (inches)	Inferred Ultimate Unit End Bearing Capacity (ksf [1])	Theoretical Ultimate Unit End Bearing Capacity (ksf [2])
Area 1 – 1	7 [3]	70	0.56	224.5	220
Area 1 – 2	9 [4]	70	0.63	113.2	190
Area 2 – 1	6.5 [5]	40	0.57	130	130
Area 2 – 2	6 [5]	50	0.24	N/A	170
Area 2 – 3	8 [5]	60	0.71	114.5	110

(1) Based on Davisson's ***Offset*** *Criteria.*
(2) Based on ***Meyerhoff's*** *method for driven piles in sand* ***(Meyerhoff*** *1976).*
(3) Severe to moderate soft rot/bacteria deterioration penetrating about 1.5 to 2 inches into the pile at the pile tip.
(4) Severe soft rot/bacteria deterioration penetrating about 0.75 inches into the pile at the pile tip.
(5) Estimated based on pile taper. Condition of pile tip not known. Microscopy on upper pile sections indicate none to slight bacterial erosion in outer 0.5 inches.

Summary of pile load tests.

Estimated Future Settlements

Once cut-and-post underpinning is performed (i.e. no inelastic settlement due to softening of pile tops), and assuming no change in the level of applied loads or in soil or groundwater properties, the only viable mechanism for future settlement is elastic compression of the remaining submerged timber pile sections. This can be due to potential softening as a result of aging/creep, and decay (i.e. a decrease in the Young's modulus, E) of the timber piles. The *National Design Specification® (NDS®) for Wood Construction* (2005) recommends a creep factor of 2 for wet wood, i.e. the E value should be decreased by 50% under long-term permanent loads. Current design standards do not provide recommendations for further reductions in E values due to decay.

A review of limited data available from compressive-strength testing of timber pile samples from various projects throughout northern U.S. (with in-service ages ranging from about 100 years to 137 years) indicates that there may be an ongoing reduction in E values with time, similar to that of compressive strength values. However, the data spread is too broad and the breadth of time periods too limited to be able to more accurately and reliably infer a rate of degradation of the E value with time.

Assuming a 50% loss of cross-section in the timber piles, a pile length of about 10.5 feet, and using an E value of 1.2 x 10^6 psi for spruce (average published E value for fresh spruce from ASTM D2555-06), the added submerged pile settlement under sustained loads varies from less than 0.04 inches (for a service load of 50 kips combined with a 12-inch pile diameter), to about 0.2 inches (for a service load of 50 kips and a 6-inch pile diameter). Even if it is assumed that, over time, the E value has degraded to about 50% of its original value throughout the pile length, the added submerged pile settlement under sustained loads for the same assumed conditions remains low, varying from about 0.1 inches to 0.4 inches. If the applied loads are sufficiently high, longer pile lengths could result in settlements greater than 0.5 inches.

Based on the calculation case described above, added settlement solely due to pile elastic compression will likely not exceed 0.5 inches over the remaining service life of timber piles. However, detailed settlement calculations, taking into account actual pile diameters, pile lengths, measured pile properties and applied load

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magnitudes, must always be performed. Although most structures can experience differential settlements on the order of 0.5 inches without resulting in much structural distress, the foundation remediation designer will have to take into consideration the present condition of the structure. If the structure is fragile and has already undergone significant settlements, even small added settlements could have an adverse impact on its serviceability.

Conclusions

- The remaining service life of in-service timber piles appears to be controlled by the structural capacity of the timber piles, rather than their geotechnical capacity. Evaluation of a more significant amount of data is necessary for confirmation of this postulate.
- Measured rates of bacterial deterioration indicate that, for piles with 100 to 140 years of in-service age and with diameters of 6 inches or less, bacterial decay may have advanced sufficiently that little to no remaining service life is anticipated. For relatively small applied service loads (around 10 kips per pile and no factor of safety included), pile diameters of 7 inches or greater are likely have a remaining service life of 100 years or greater from present time. For larger applied loads (on the order of 40 to 50 kips per pile), pile diameters of 10 inches or greater would be required to attain the same remaining service life expectancy (100 years or more).
- Once tops of piles are replaced and the new pile cutoffs remain submerged (e.g. cut-and-post underpinning is performed), settlements due to pile elastic compression over the remaining service life of the timber piles will likely not exceed 0.5 inches.

The analysis used herein to estimate remaining service life of submerged timber piles is based on average conditions (i.e. average measured strength and/or modulus values). Although measured strength and modulus data is well distributed around the average values used, there is still a 50% probability that the actual values may be lower or higher than the ones used. In addition, other than limiting the depth of penetration of bacterial decay to include only the thickness of the sapwood of submerged piles, it is possible that local building codes may require foundation remediation/repairs be performed once a certain percentage of the original pile capacity has been lost. For the smaller-diameter timber piles, this would likely result in smaller remaining service life expectancies than those indicated above.

Final Thoughts

Further research remains to be performed regarding the impact of bacterial attack on submerged timber pile structures, especially any potential reduction of the pile’s geotechnical capacity.

There is also continued concern that soft-rot deterioration could still occur even with groundwater levels maintained above the top of the untreated pile cutoff. Recent research indicates that soft-rot attack may be supported even in submerged conditions, if the dissolved oxygen content in the groundwater is above a threshold value of 2 ppm (Klaassen 2005). Given that potable water is often used for recharging groundwater levels near timber piles to maintain submersion, and this could lead to an increase in dissolved oxygen levels in the groundwater, further research is required to confirm this potential deterioration mechanism.

Development of a large database of U.S. historic building stocks supported on untreated timber piles, similar to that currently in existence for some European countries, would be of significant value in evaluating current conditions and required foundation remediation/repair options. Based on the European studies on bacterial decay, existing untreated submerged small-diameter timber piles with more than about 100 years in service (which represents a significant percentage of the existing untreated timber pile stock in the U.S.) are likely to be reaching a level of bacterial attack at which there is little to no remaining service life. For these structures,

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significant structural settlement, with the consequent building distress, may start developing within a relatively short-time from present.

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Evaluating timber piles

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February 2013 » Features » WOOD
Engineering innovation and ingenuity critical to Union Depot project viability.

Arne P. Johnson P.E., S.E.; Mark R. Chauvin, P.E.

The historic St. Paul Union Depot was targeted by local authorities as an ideal multi-model transportation hub, capable of revitalizing local transit and re-energizing downtown St. Paul, Minn. A key to the viability of the project was an early engineering assessment of whether the 90-year-old timber pile foundations, which were suspected of deterioration, had sufficient remaining capacity to support the anticipated loads. With approximately 9,000 piles buried on the 6-acre site, with signs of foundation settlement in some areas, and with answers needed in time to secure funding, the assessment called for structural engineering innovation and ingenuity.

Years in the making
Union Depot, constructed 1917-1926 along the Mississippi River in downtown St. Paul, was an active train station through the mid-1960s. At its peak, the elevated track deck structure (Figure 1 and Figure A) accommodated 20 railroad tracks and served 20,000 passengers daily. But with the decline of the railroad era in the 1970s, train service was discontinued and the Depot was converted into a postal distribution center.

Figure 1. Historic photograph of the Union Depot, looking north, provided by the Ramsey County Historical Society.

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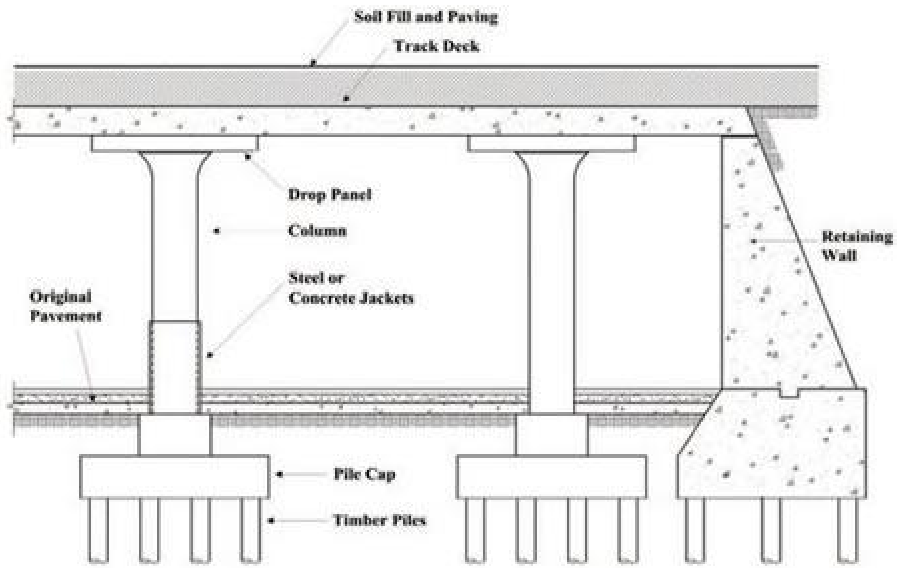

Figure A. Typical section through track deck structure.

In the 1980s and 1990s, light rail was identified as a solution to meet increasing transit demands in the St. Paul-Minneapolis area. Ground broke on the first light rail transit line in 2000. In 2002, the Ramsey County Regional Rail Authority (RCRRA) commissioned a task group to identify options for a multi-modal transportation hub in downtown St. Paul that would integrate with the light rail lines, return passenger rail services to the city, and become a "destination" that would reenergize downtown St. Paul. The largely mothballed Union Depot was identified as the prime candidate.

In 2009, RCRRA retained a design-build team led by Mortenson Construction to rehabilitate the facility into a multi-modal transportation hub that would accommodate local light rail, freight and passenger rail, buses, taxis, and bicycles, with plans for future high-speed rail service. Funding for the approximately $150 million project relied heavily on federal funds that could only be secured if the facility was substantially complete by September 2012.

A looming question

Yet, a question loomed. Could the existing track deck structure, especially the original timber pile foundations, support the anticipated loads for the desired service life of 50 years? There were signs of structural settlement and cracking in several areas of the track deck, suggesting timber pile degradation. Underpinning or replacing all the foundations would obviously add immensely to the construction cost. Even more importantly, the time associated with completing such an extensive endeavor would likely derail any chance of completing the project by the funding deadline.

Asking the structure

Direct examination of a substantial percentage of piles was not feasible due to the cost and time associated with excavation of test pits. Non-destructive testing techniques were judged not reliable for this case. Therefore, a step-by-step investigation, summarized below, was devised to obtain key information regarding the timber piles that would allow reasonable engineering analysis and conclusions regarding their future performance.

• **Step 1** - Review of site conditions. First, geotechnical surveys were conducted to define the soil characteristics and groundwater elevation relative to the tops of the timber piles. A lower water table and granular soils at the south side of the site (closest the river) suggested that pile decay was more likely there.

• **Step 2** - Visual inspections and elevation survey. Next, a comprehensive visual inspection and elevation survey were performed across the underside of the track deck. Sharp elevation gradients

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and structural cracking indicative of settlement were detected in the southwest region of the structure.

Figure 2. Overall view of track deck structure at first test pit excavation

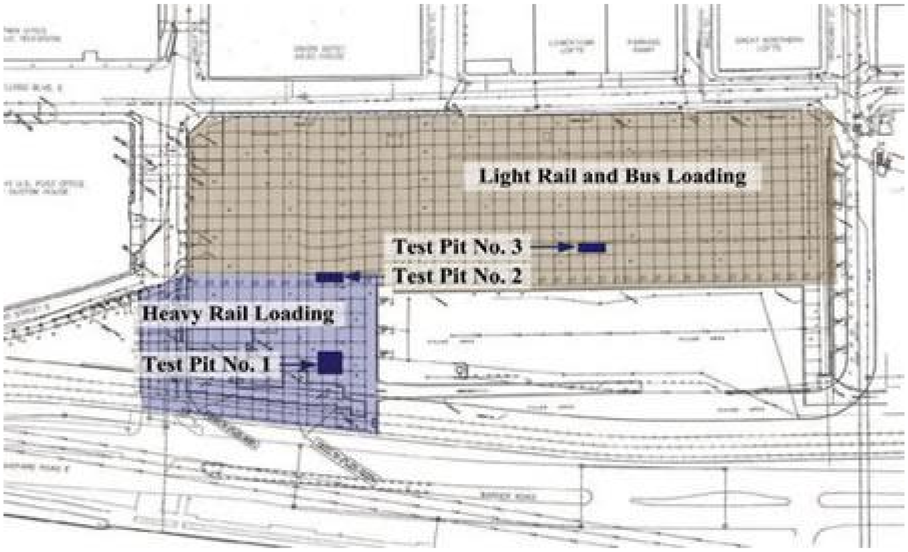

Figure B. Plan view of the track deck showing anticipated design loads and foundation test pit locations

• **Step 3** - Test pits. The investigation proceeded with the excavation of three strategically located test pits. The first pit (Figure 2) was located in the suspect southwest zone and the remaining two were located farther north, where anticipated structural loading was lighter (Figure B). At the first pit, severe pile decay was found, with some piles completely gone (Figure 3). At the two pits farther north, pile conditions were markedly better, although a few pile tops exhibited deep pockets of decay.

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Figure 3. Example of severely decayed timber pile below concrete pile cap at Test Pit No. 1

• **Step 4** - Field and laboratory testing. A battery of field tests were performed on each of the 54 exposed piles. In addition, core samples and full-diameter sections were removed and examined microscopically, and small-clear samples were cut and tested. Two piles that did not exhibit decay were tested in-situ (Figure 4); both exhibited plunging capacities much greater than the 20-ton rated capacity. Three full-diameter piles tops with deep pockets of decay were removed and tested in the laboratory (Figure 5); all three sustained ultimate loads much greater than 20 tons, albeit with considerable crushing.

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Figure 4. In-situ load testing of timber pile

Figure 5. Laboratory load testing of decayed pile top

• **Step 5** - Statistical analysis. To estimate the probability that any 14-pile group and pile cap on the site has a certain vertical-load-carrying ability, Monte Carlo statistical simulations were performed considering variability in pile diameter, wood species, and percent of cross sectional area loss due to decay. Biasing to account for decay occurring in groups of piles and checks of eccentricity were performed. In the end, the simulations predicted that only 5 percent of the pile caps to the south could reliably support the anticipated heavy rail loading 50 years from now, whereas roughly 80 percent of the pile caps to the north should be able to reliably support the light rail and bus loads programmed for that area.

Findings and recommendations

Based on these results, engineers concluded that the timber pile foundations supporting the southern third of the track deck should not be relied upon to support the heavy rail loads

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programmed for that portion of the facility. Underpinning or replacement of the foundations in that region was recommended.

In the northern two-thirds of the track deck, the pile conditions were better and the anticipated loads were lower. For that area, engineers concluded that the existing foundations should have sufficient capacity for the next 50 years. However, the owner was advised that there is a relatively low risk that certain pile caps will settle. Such settlement should be slow and gradual, like that previously manifested in the southwest region of the deck. It was recommended that the owner conduct biannual elevation surveys and initiate investigations and possible underpinning, should settlement be detected.

Detailed design followed, and construction began in September 2010. In the southern third of the track deck, the majority of the deck and foundations were demolished and reconstructed to replicate the original historic appearance. In the northern two-thirds of the structure, the existing concrete deck and columns were retained and repaired, and the existing timber pile foundations were left undisturbed to support the rehabilitated facility.

A grand reopening
On Dec. 8, 2012, the public was invited to the grand reopening of Union Depot. The success of the project was attributable to the combined efforts of many people, governmental agencies, architects, engineers, contractors and tradespeople. Not least among these efforts was the early engineering evaluation of the timber pile foundations. The unique engineering approach devised provided immense value to the project, as it avoided extremely costly underpinning of hundreds of additional pile caps, the tragic loss of a greater area of the historic track deck, and schedule impacts that could have jeopardized the viability of the project. The story serves as yet another illustration of how the ingenuity of structural engineers, past and present, can be leveraged to build and sustain vital infrastructure.

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DETERIORATED UNTREATED WOOD PILES

CAUSE, DETECTION AND CORRECTION

BACKGROUND – CAUSE

Woodpiles support many buildings in the NWT. Some buildings have woodpiles that have been treated with preservative before installation. For example, the Ft. Simpson Health Centre has pressure-creosoted piles. Other piles have been installed with no wood preservative treatment, often in permafrost soils. Preservative treatment can slow the rate of wood rot, but not eliminate it. Many buildings in the Mackenzie River Valley and Delta regions are supported on untreated woodpiles, installed typically in the 1970's and earlier. Many of the piles supporting these buildings have been in service for 40 years and are reaching the end of their natural service life.

Natural Decay

Pile rotting is a natural decay process caused by microbes (fungi and bacteria) found naturally in wood and in the environment. Under certain conditions, the microbes grow by consuming the strong fibres of the wood, causing rot, and destroying the strength of the pile. These conditions usually include sufficient water, temperatures above freezing, and oxygen. Not all decay-causing microbes need oxygen.

Older Piles

Untreated woodpiles are at greater risk of losing structural support capacity as they age, compared to preservative treated piles. They eventually become too weak to safely support the building and contents, even if they were installed in permafrost ground. The reason for this is the top of the pile is exposed for part of the year to wet and warm conditions near the surface of the ground. Those conditions activate the decay-causing microbes near the ground surface, causing the wood to rot and lose strength. Eventually the pile can be weak enough to collapse from the vertical structural load.

Safety Factors

New piles are typically chosen to be larger than needed for the structural loads. The size is determined by engineering codes and standards. Part of a pile may be able to rot away before it becomes too weak to support the actual building weight. However, sometimes there can be strong horizontal forces acting on the pile system of a building. These forces may be caused by extreme wind conditions or earthquakes. The structural capacity of weakened piles that would otherwise safely support the weight of the building and contents may, under these conditions, be exceeded.

Monitoring

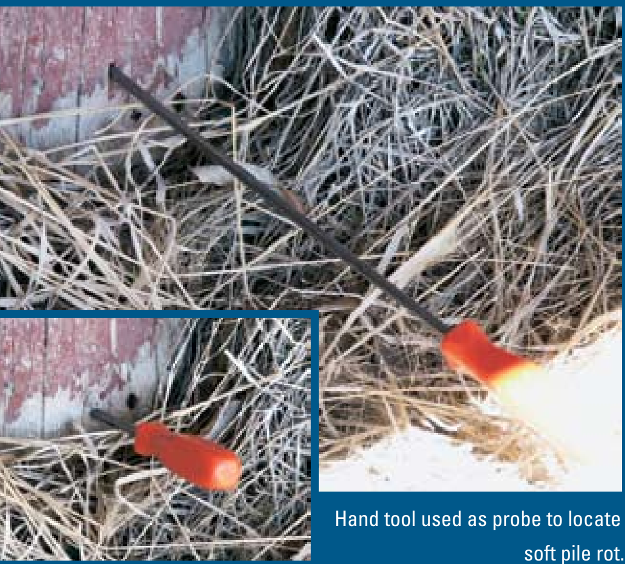
Untreated wood piles installed in cold regions with moderate summer temperatures and lots of rain, a characteristic of the Mackenzie Valley basin, have been found to be at risk of accelerated decay, compared to cold regions where the summer warming period is drier and shorter. As a result, the GNWT since the mid-1990's has investigated, monitored and remedied deteriorating untreated woodpiles supporting the buildings it operates.

Total pile collapse and shift at ground level.

Total Pile collapse at Ground level.

Depression holds water around pile, speeding up rot.

DETECTION



Hand tool used as probe to locate soft pile rot.

Rotted wood is easily penetrated by hand driven tools.

Sampling of pile interior allows detailed diagnosis of wood rot progress in a lab.

FINDING ROTTED PILES

Initial Examination

Visual examination and penetration testing is the first line of detecting untreated woodpile rot. If woodpile rot is found early, there are chemical treatments available to stop or slow the rate of decay. Diagnosing and treating rot is a technical challenge. The advice of specialized wood protection consultants should be obtained. Sophisticated investigation techniques are available to examine deteriorated woodpiles, including ultrasound and x-ray imaging.

Risk Analysis

Which buildings are at greater risk? Untreated woodpiles that support buildings in low-lying areas with poor drainage, or with water retained on or beneath the ground surface, are more likely to rot than buildings on dry, well-drained sites. Also at increased risk are buildings with un-ventilated enclosed crawl spaces that keep the ground warm and the moisture content high under the building, compared to buildings with cold ventilated crawl spaces.

Regular Examination

In cold regions woodpile foundations on all buildings more than ten years old need to be periodically checked for deterioration. Make sure drainage is adequate to remove surface water away from the pile foundation to slow the rate of woodpile rot. Annual inspections when the ground and the pile temperature are at or above 5 degrees Celsius are required to effectively investigate pile status.

Simple Detection

All building maintainers can become familiar with visual inspection techniques and simple penetration testing. Expose the pile by digging down 300 to 400 millimetres beneath the surface of the ground, until solid un-deteriorated wood is found. Use flat head screwdriver and hand pressure to probe the pile all around the outside surface in order to locate and measure the depth of rotted wood. Scrape beneath and above the rotted zone of the pile with a strong knife blade to find the un-deteriorated parts of the pile. Coat disturbed pile surfaces and holes with penetrating wood preservative.

Specialized Testing

Specialized investigation methods available today to examine deteriorated woodpiles include core sampling, ultrasound and x-ray imaging. Specialized diagnosis and treatment of woodpile rot is technically challenging, and relies on the expertise of specialized wood protection consultants. Bore holes created during testing or treatment must be plugged or filled to prevent water filling the void.

DETERMINING THE PROBLEM

Professional Inspection and Safety Review

If you find woodpile rot and determine its location and extent, it is essential to have the piles and the building substructure inspected by professional structural engineering consultants and specialists in woodpile deterioration and remediation. Consult with the local regulatory agencies responsible for building safety, such as the local building inspection department or the Office of the Fire Marshal. That authority will need to assess the life safety risk issues caused by the weakened building foundations and rotted piles.

Safety Review Outcome

The outcome of a safety review by the building safety authority may vary from a recommendation for re-testing the building at a future time, to stopping the active use of the building until remedial measures can be taken. Temporary fixes, such as blocking to support vertical loads at deteriorated piles, will not necessarily provide the required strength for wind and earthquake loads.

Short and Long Term Repairs

All untreated woodpiles subject to rot will eventually deteriorate and become too weak to safely support the building above. Before that time, they can be strengthened by putting on splints or sleeves to connect the solid portions of the pile. Another approach is that alternative short-term foundation units, such as blocking to support the building on the ground, can be introduced. Eventually, the foundation system at the end of its technical service life must be replaced or the building demolished or moved to a new foundation system.

Temporary support allows new pile sections to be installed.

New steel posts connect solid piles below the earth to the building.

CORRECTION PROCEDURES

The rotted portion of this pile has been replaced with new material.

Steel sleeves connect new piles to solid portions of original piles.

Wood crib blocking provides interim support for failed pile. Water must be drained to eliminate frost heaving.

PWS ACTION PLAN

As many of the wooden piles supporting GNWT infrastructure are reaching the end of their service life, PWS has established a formal Risk Management and Safety Program to ensure the safe operation of GNWT infrastructure. To address these concerns, PWS has implemented three new initiatives to address the problem:

1. Staffing of a Risk Management and Safety Officer/Specialist
2. Implementing a GNWT Building Condition Assessment reporting system
3. Accelerating the Wood Pile Inspection and Repair Program

For further information, please contact:

Risk Management and Safety Officer/Specialist
Facility Management
Asset Management Division
Public Works and Services
Government of the Northwest Territories
Box 1320, Yellowknife, NT, X1A 2L9

Tel: (867) 873-7028
Fax: (867) 873-0226

SAFETY IS EVERYONE'S RESPONSIBILITY

MONITORING AND OVERSIGHT

Building operators or owners can monitor woodpiles:

- **KEEP DRY.**
  Make sure there is good drainage of water away from the piles. Divert surface water. Maintain air-drying of the piles.
- **REGULARLY MONITOR AND MEASURE.**
  Make a visual and probe inspection and write down the condition, pile moisture measurement and pile softness, as part of routine building maintenance.
- **TRACK THE TREND.**
  Review the change in condition to determine if pile deterioration is increasing.

Specialists are needed to do more detailed evaluation and testing:

- **PILE CONDITION ANALYSIS**
  Detailed probing and measurement of the different types of rot that may affect a pile foundation by woodpile specialists.
- **FOUNDATION AND SUBSTRUCTURE ANALYSIS**
  Determining the operating structural capacity of the pile foundations and assessing the foundation capacity to support the building through structural engineering.
- **ENGINEERING SURVEY AND ASSESSMENT OF THE SUPERSTRUCTURE**
  To determine if the building has changed as a result of movement or settlement in the foundation system.
- **BUILDING FAILURE RISK AND STRUCTURAL SAFETY**
  Determined through reverse-engineering the existing structure, in accordance with engineering design rules and standards.
- **COST-BENEFIT REINVESTMENT ANALYSIS**
  To determine the economic cost to conserve or extend building service life.

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Technical Support Services
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Northwest Territories Public Works and Services

APPENDIX C

PHOTOGRAPHS

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A8 – Incorrectly labelled as A7

A9 – Incorrectly labelled as A8


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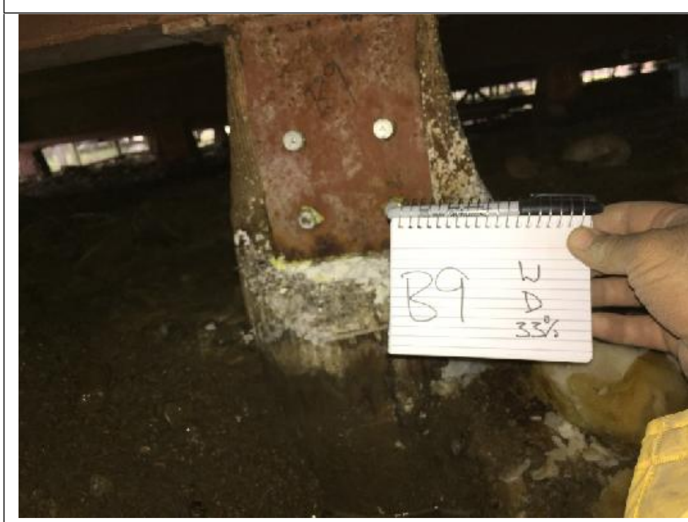
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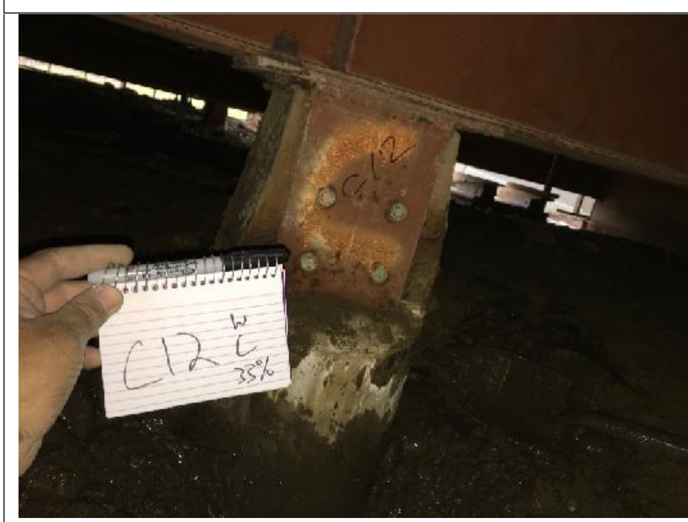
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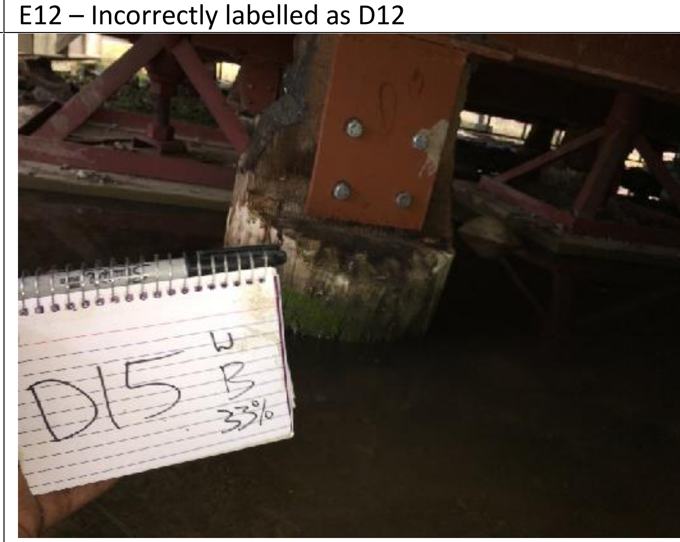

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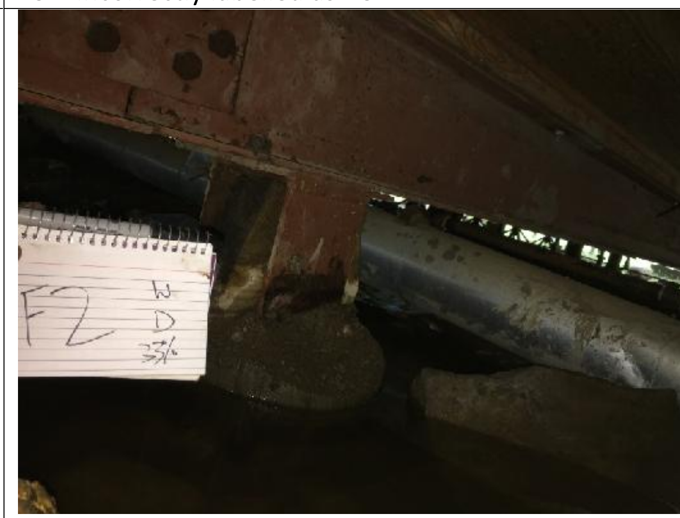
E5 – Incorrectly labelled as D5

G5 – Incorrectly labelled as F1



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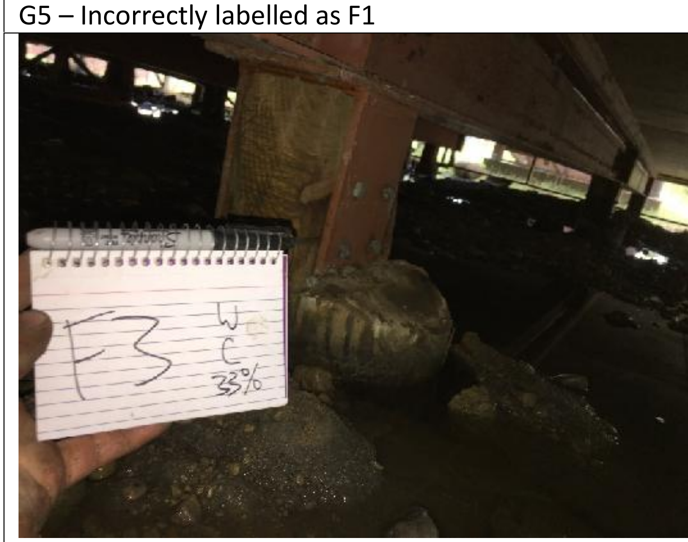


G3 – Incorrectly labelled as F3

G2 – Incorrectly labelled as F4

H4 – Incorrectly labelled as H4

H2 – Incorrectly labelled as G9


Southeast corner of building

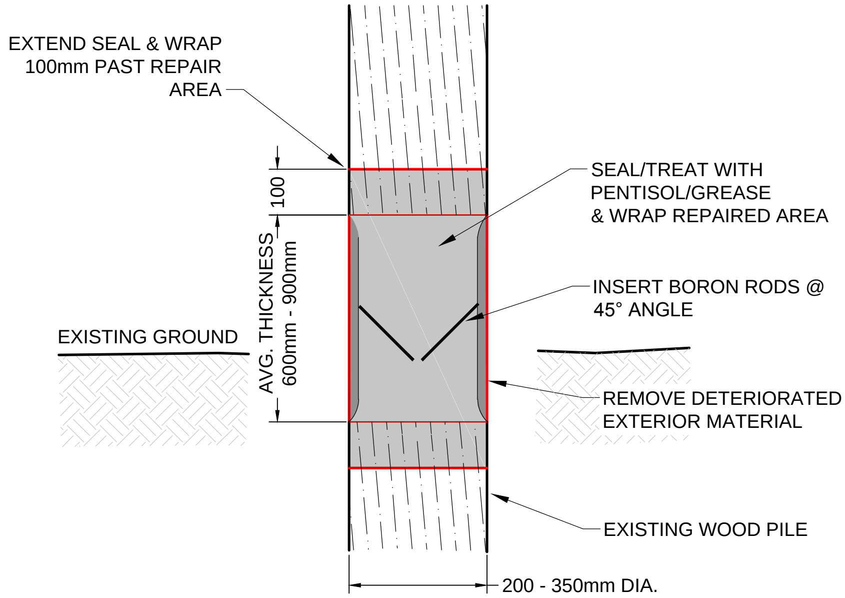

West side of building


North side (back) of building


North side (back) of building

Appendix D

PILE REPAIR AND REPLACEMENT DETAILS



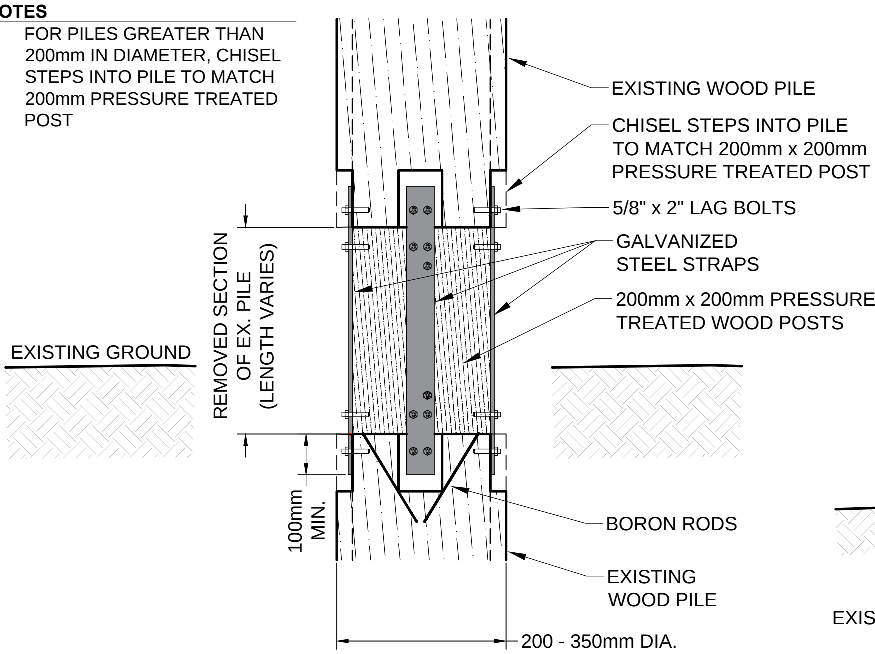
DETAIL A - TYPICAL REPAIR
SCALE: NTS

NOTES

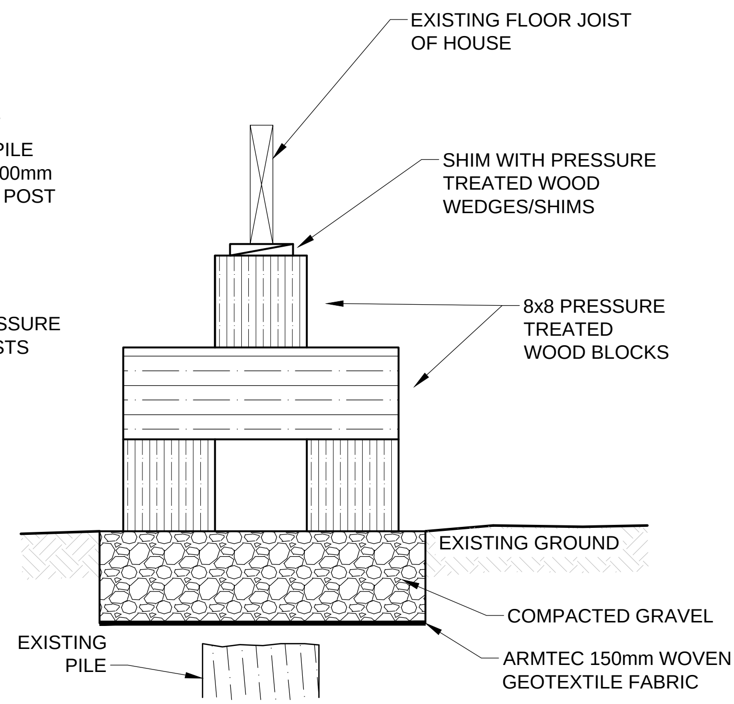
- CONCEPTUAL DESIGNS ONLY
- NOT FOR CONSTRUCTION

NOTES

- FOR PILES GREATER THAN 200mm IN DIAMETER, CHISEL STEPS INTO PILE TO MATCH 200mm PRESSURE TREATED POST



DETAIL B - REPLACEMENT OPTION 1
SCALE: NTS



DETAIL C - REPLACEMENT OPTION 2
SCALE: NTS

DRAWING STATUS	FOR REPORT		
#	REVISION	DATE	BY

NOTES

CONTRACTOR TO CHECK AND VERIFY ALL DIMENSIONS BEFORE CONSTRUCTION, ANY ERRORS AND OMISSIONS SHALL BE REPORTED TO THE ENGINEER IMMEDIATELY

DRAWING SHALL NOT BE USED FOR CONSTRUCTION UNTIL APPROVED

DO NOT SCALE THE DRAWING

ALL CONSTRUCTION SHALL BE IN ACCORDANCE WITH THE LATEST CODES, MAY IT BE CONSTRUCTION, MECHANICAL, ETC

CLIENT: GOVERNMENT OF THE NORTHWEST TERRITORIES

PROJECT TITLE: BEAUFORT DELTA/SAHTU WOODEN PILE FOUNDATION INVESTIGATION

DRAWING TITLE: PILE REPAIR & REPLACEMENT DETAILS

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DESIGN	MAH
DRAWN	MDO
CHECKED	MAH
APPROVED	MAH
SCALE	NTS

PROJECT NUMBER	18-304
VERSION NUMBER	IFA1-1
DATE DRAWN	OCT. 7, 2016
SHEET NUMBER	FIG. 2