RAPID REPAIR AND RETROFIT OF TIMBER PILES USING UHPC

Quarterly Progress Report
For the period ending May 31, 2020

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1. Background and Introduction

Timber piles are often in bridge substructure in rural areas and in coastal touristic piers (such as Santa Monic Pier) and are subject physical agents (mechanical damage, steel corrosion contact, etc.) as well as to damage from surrounding water stream or due to biological effects (bacteria, fungi, insects, etc.). Nowadays preservative as well as retrofitting techniques are applied to old timber structures for maintenance and repair. For preservation, Creosote, Chromated Copper Arsenate and other chemical products are available to treat timber and extent durability. For repair and retrofit concrete/steel jacketing, besides other methods, had been proved effective. The cost of repairing/retrofitting timber piles would be much cheaper compared to replacing them. The best repair technique should restore the load-carrying capacity of the timber piles and at the same time should be cost-effective. In this research, we propose the use of UHPC as repair/retrofit material for timber piles. Our research approach includes the investigation of bond strength between timber as substrate material and UHPC as repair material in addition to studying the load-carrying mechanism of repaired/retrofitted timber piles using UHPC. The proposed research will be conducted experimentally in two phases: 1) small-scale testing including push-out test to evaluate the bond strength between timber and UHPC and compressive tests to evaluate the load-carrying capacity of the repaired timber specimens; 2) large-scale testing where repaired timber piles using UHPC will be tested under axial and lateral load schemes. Numerical modeling using finite element models will be conducted on the tested specimens to better understand the behavior of repaired timber piles using UHPC.

2. Problem Statement

One of bridge substructure system utilizes a pier consists of a beam supported over timber piles. This substructure system is common practice in county bridges. Many reasons can lead to the deterioration of these timber piles over an extended period of time such as biological damage caused by fungi, termites, powderpost beetle, carpenter ants, and bacteria or physical damage due to floating in water, overload, failure of adjacent piles, and firs. (A. Mohammadi, 2014). Figure 1 shows some possible locations for the damage in timber piles and proposed partial or full UHPC encasement.

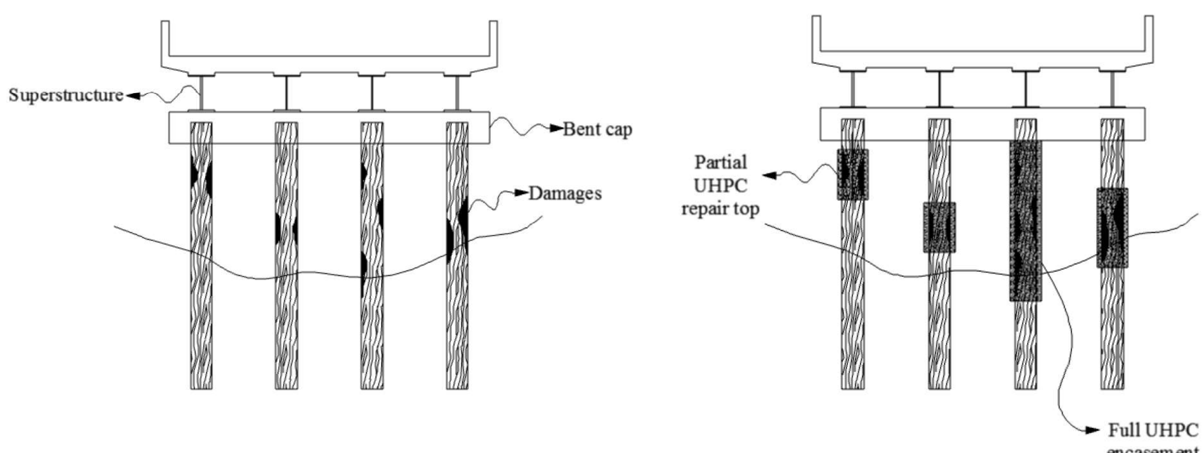


Figure 1. Common damages in timber piles (left) and proposed UHPC repair/retrofit (right).

Replacing the damaged timber pile may be considered an obvious option to address the damage; however, the cost of an effective repair and retrofitting of timber piles can be much cheaper. Different repair and retrofit techniques are available for the timber piles and some of the retrofit options failed to result in the expected performance levels. (J. H. Gull, 2015)

The superior mechanical properties of UHPC, such as high compressive strength, high tensile strength, and higher durability make this material a perfect solution to repair and retrofit timber piles. This study proposes the use of UHPC as repair and retrofit material for timber piles. The proposed repair method suggests the removal of the damaged portion of timber piles and filling the resulted cavity with UHPC in addition to an outer UHPC enhancement with a wall thickness which can restore the entire timber pile capacity (i.e. UHPC thickness of ½ in. can restore the capacity of timber pile with diameter of 8 in.), as shown in Figure 2. However, many research questions should be answered such as the bond strength between timber and UHPC, the surface preparation for timber piles to enhance the bond strength with UHPC, the effect of UHPC thickness of repair/retrofit. These questions, among others, will be addressed under this project.

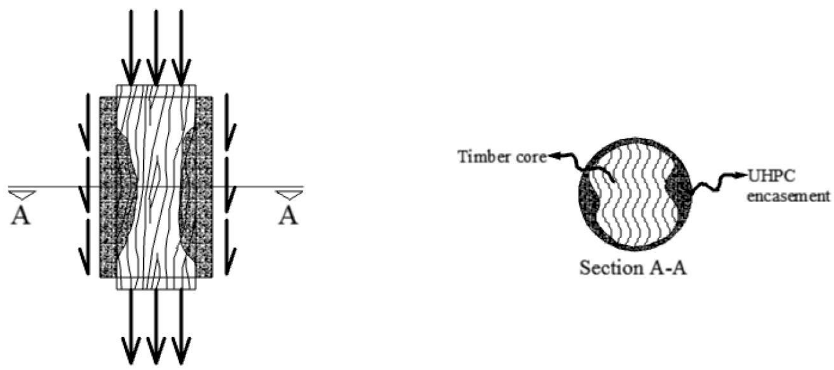


Figure 2. Force transfer sketch (left) and cross section (right) of repaired/retrofitted timber pile.

3. Objectives and Research Approach

The main objectives of this project are:

a) Studying the bond strength between timber and UHPC as repair/retrofit material.
b) Defining the best surface preparation for timber piles to enhance the bond strength
c) Studying the load carrying mechanism of timber piles repaired or retrofitted using UHPC.
d) Conducting small scale testing to study the bond strength and load carrying mechanism between timber and UHPC.
e) Conducting large scale component testing of timber piles repaired/retrofitted using UHPC under realistic axial and lateral loading schemes.
f) Studying repair methods for in service weathered piles.

g) Developing detailed finite element models for both small scale material testing and large-scale component testing for better understanding of the local and global behavior of timber piles repaired/retrofitted using UHPC.

4. Description of Research Project Tasks

The following is a description of tasks carried out to date.

Task 1 – Conducting literature review on current practice of repair and retrofit of timber piles

In this task, a comprehensive literature review will be conducted including the current repair and retrofit practices for timber piles, bond strength between timber piles and repair materials, and load carrying capacity of repaired/retrofitted timber piles.

Progress: This task is completed. Many reports and publications are collected and studied.

Task 2 – Small scale experimental work

In this task, experimental work will be conducted on small scale level specimens to study the bond strength of UHPC as repair/retrofit material for timber with different surface preparation. In addition, compressive tests will be conducted on cylindrical shape timber with UHPC shell to study the load carrying mechanism between timber piles and UHPC.

Progress: This task is complete. Small scale samples were constructed in the laboratory by shaping timber into prisms and cylinders.
For bond strength study*, timber prisms were cut with a dimension of 4"x4"x8" (width x length x height) to form a push-off test specimen. The push-off test specimens consist of intermediate timber prism and outer UHPC prisms with a dimension of 4"x4"x8" (width x length x height) as shown in Figure 3, the intermediate timber prism was then placed inside timber formwork, as shown in Figure 4. Different surface preparations were selected to enhance the bond between timber and UHPC including smooth surfaces, rough surfaces, horizontal nails, inclined nails, horizontal holes, and inclined holes, as shown in Figure 5 and Figure 6. A total of 14 specimens were tested under push-off test setup, as shown in Figure 7. Tables 1 and 2 lists the specimen notations, failure load of each specimen, and the average bond strength of each surface preparations.*

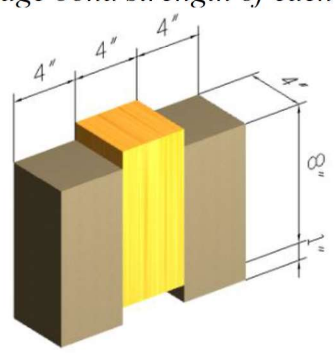


Figure 3. *Construction for push-off specimens*

Figure 4. *Formwork for pull-off specimens prior to casting UHPC.*

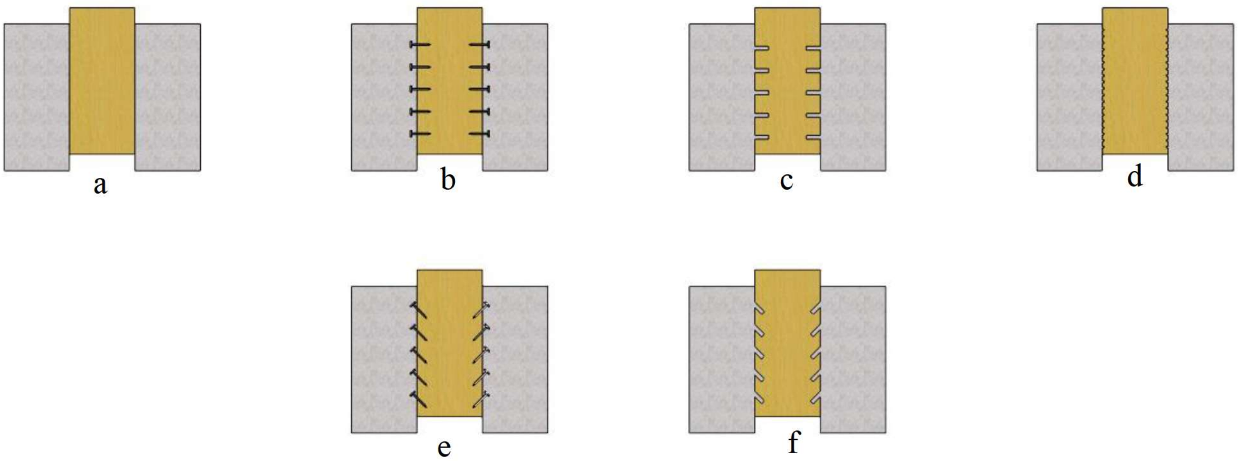


Figure 5. *Schematic for pull-off test specimens different surface preparation between timber (inner) and UHPC (outer), (a) plain, (b) horizontal nails, (c) horizontal holes, (d) rough surface, (e) inclined nails and (f) inclined holes.*

Figure 6. *Different surface preparation for timber prisms*

Figure 7. *Push-off test setup.*

Table 1. *Specimen notation and description for push-off shear samples.*

Specimen notation	Description
P	Timber's plain surface
R	Timber's rough surface
H90	Holes in timber perpendicular to bonding surface
H45	Holes in timber inclined 45 degrees to bonding surface
N90	Nails inside timber perpendicular to bonding surface
N45	Nails inside timber inclined 45 degrees to bonding surface

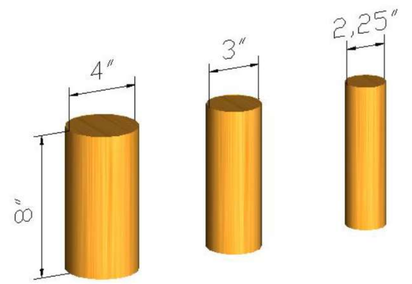
Table 2 *Push-off shear test results.*

Specimen notation	Max load (kip)	Stress (psi)	Average per type	Standard deviation
H90-1	3.3	53.7	69.3	13.6
H90-2	4.4	75.5		
H90-3	4.8	78.7		
H-45	2.7	47.1	47.1	-
R-1	3.8	62.5	73.8	16.9
R-2	5.1	93.3		
R-3	3.9	65.7		
N90-1	9.8	159.3	168.8	8.3
N90-2	9.6	171.7		
N90-3	10.1	175.2		
N-45	4.5	76.6	76.6	-
P01	0.8	13.9	-	-
P02	0	0.0*		
P03	0	0.0*		

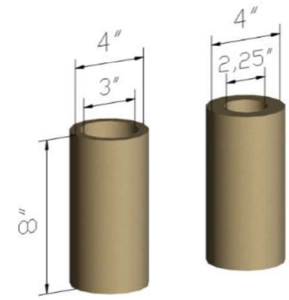
For load-carrying capacity, *timber cylinders were cut by woodturning as shown in Figure 8, some of them were cast with an outer UHPC shell and other specimens were just UHPC shells molded by the use of cylindrical inner cylindrical styrofoams, as shown in Figure 9. Two diameter-to-thickness ratios between the inner timber cylinder and outer UHPC shell (d/t) of 6 and 2.57 were selected in this test as shown in Figure 9. All the specimens required cylindrical plastic molds for forming UHPC, as shown in Figure 10. Same surface preparations as bond strength specimens were replicated in the load-carrying capacity test as shown in Figures 11 and 12. Figure 13 shows the compression test setup and Figure 14 shows the final damage of one specimen. It should be noticed that two timber moister preparations were conducted by (1) soaking timber in a water tank prior to casting UHPC (2) by spraying timber with water prior to casting UHPC. Tables 3 and 4 lists all specimen notations, failure load, and average failure load for each group.*

(a) (b)

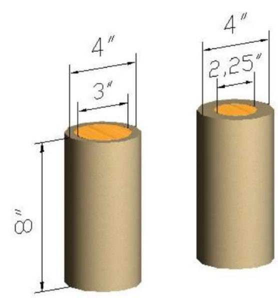
Figure 8. *Timber cylinders. (a) hexagons as cut form large timber pile, (b) cylindrical shape using wood turning.*



(a)



(b)



(c)

Figure 9. *Specimens for load-carrying capacity. (a) Timber cylinders, (b) UHPC shells, (c) timber cylinder with UHPC enhancement.*

Figure 10. *Sample for final timber cylinders with UHPC encasement.*

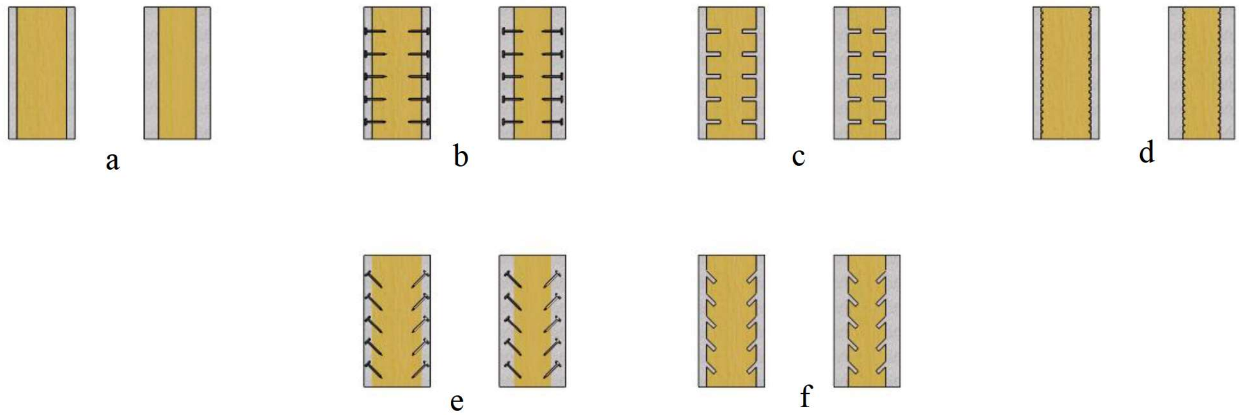


Figure 11. *Schematic for load-carrying capacity test specimens different surface preparation between timber (inner) and UHPC (outer), (a) plain, (b) horizontal nails, (c) horizontal holes, (d) rough surface, (e) inclined nails and (f) inclined holes.*

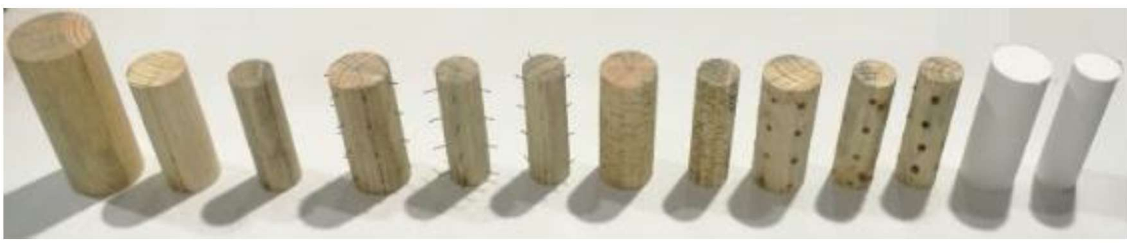


Figure 12. *Different surface preparation for timber prisms*

Figure 13. *Test setup for load-carrying capacity. (a) timber specimen, (b) timber cylinder with UHPC encasement.*

Figure 14. *Failure mode of one of tested specimen*

Table 3 *Specimen notation and description for small scale compression samples*

Specimen notation	Description
T	Timber only
TC	Timber core
P	Plain smooth surface of timber core
N	Nailed surface
H	Holes at timber´s surface
R	Rough surface of timber core
V	Void due to the use of internal foam in UHPC shell
90	90 degrees with respect timbers surface (perpendicular)
45	45 degrees with respect timbers surface (inclined)
sk	Soaked timber when casting UHPC
sp	Sprayed timber when casting UHPC

Table 4 *Load-carrying capacity results*

Specimen notation	Max load (kip)	Average per type	Standard deviation
P03-01 sp	68	68.7	8.0
P03-02 sp	77		
P03-03 sp	61		
P03-04 sk	97	96.0	11.5
P03-05 sk	84		
P03-06 sk	107		
TC3-01	34	35.3	2.3
TC3-02	38		
TC3-03	34		
V3-01	96	94.7	17.0
V3-02	77		
V3-03	111		
P2.25-01 sp	74	99.3	23.0
P2.25-02 sp	105		
P2.25-03 sp	119		
P2.25-04 sk	218	195.7	22.5
P2.25-05 sk	196		
P2.25-06 sk	173		
TC2.25-01	13	14.3	5.1
TC2.25-02	10		
TC2.25-03	20		
V2.25-01	210	200.3	9.5
V2.25-02	191		
V2.25-03	200		

Cont. Table 4 *Load-carrying capacity results*

Specimen notation	Max load (kip)	Average per type	Standard deviation
N90-3-01 sp	66	59.7	5.5
N90-3-02 sp	57		
N90-3-03 sp	56		
N90-3-04 sk	-	114.3	-
N90-3-05 sk	114.326		
N90-3-06 sk	-		
N90-2.25-01 sp	73	79.3	23.2
N90-2.25-02 sp	60		
N90-2.25-03 sp	105		
N90-2.25-04 sk	189	188.3	8.0
N90-2.25-05 sk	180		
N90-2.25-06 sk	196		
N45-2.25 sp	46	46.0	-
H90-3-01 sp	42	45.7	6.4
H90-3-02 sp	42		
H90-3-03 sp	53		
H90-2.25-01 sp	83	72.3	9.5
H90-2.25-02 sp	69		
H90-2.25-03 sp	65		
H45-2.25 sp	87	87.0	-
R3-01 sp	46	50.0	7.8
R3-02 sp	59		
R3-03 sp	45		
R2.25-01 sp	96	81.7	17.6
R2.25-02 sp	87		
R2.25-03 sp	62		
T4-01	53	53.0	3.0
T4-02	56		
T4-03	50		

Task 3 – Large scale experimental work

In this task, experimental work will be conducted on the first specimen. The column will be tested under constant axial and lateral cyclic loads.

Progress: Researcher are designing the specimens for full-scale testing based on the results and recommendation from small-scale testing. Schematic illustration of the tested specimens is show in Figure 15.

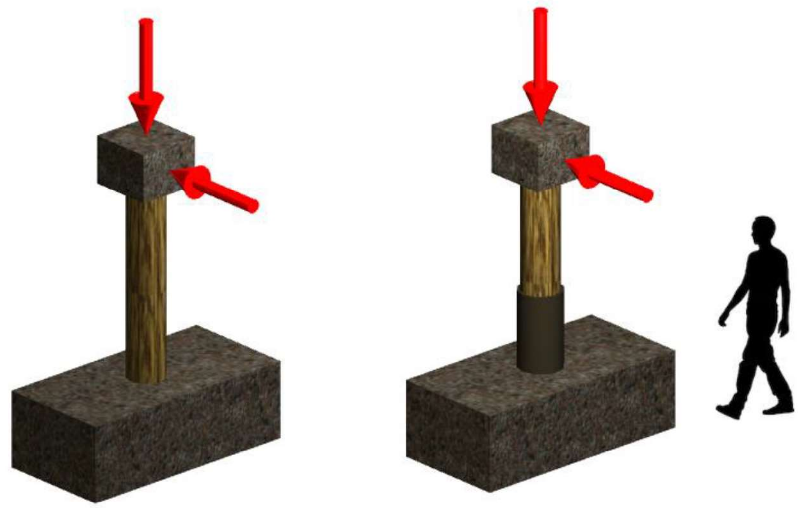


Figure 15. *Test setup for large scale testing. (a) benchmark specimen for timber pile, (b) repaired timber pile with UHPC enhancement.*

Task 4 – Numerical model verification through finite element analysis

In this task, numerical models will be developed to calibrate the test results from Task 2 and Task 3 to better understand.

Progress: Using the results from small-scale tests numerical models are being prepared using ATENA software as shown in Figure 16.

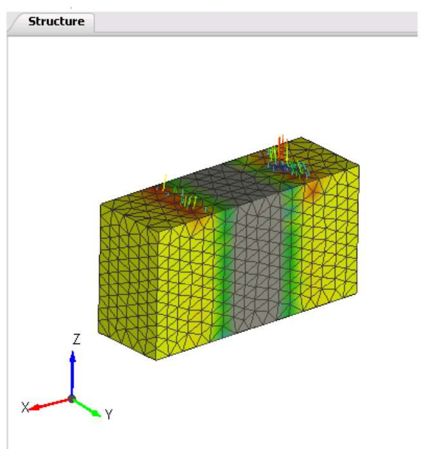


Figure 16*. Numerical model of push-off tests using ATENA software.*

Task 5 – Final Report

In this task, full assessment of the findings from Task 1 throughout Task 4 will be conducted and a report will be published including design recommendations of repairing and retrofitting timber piles using UHPC.

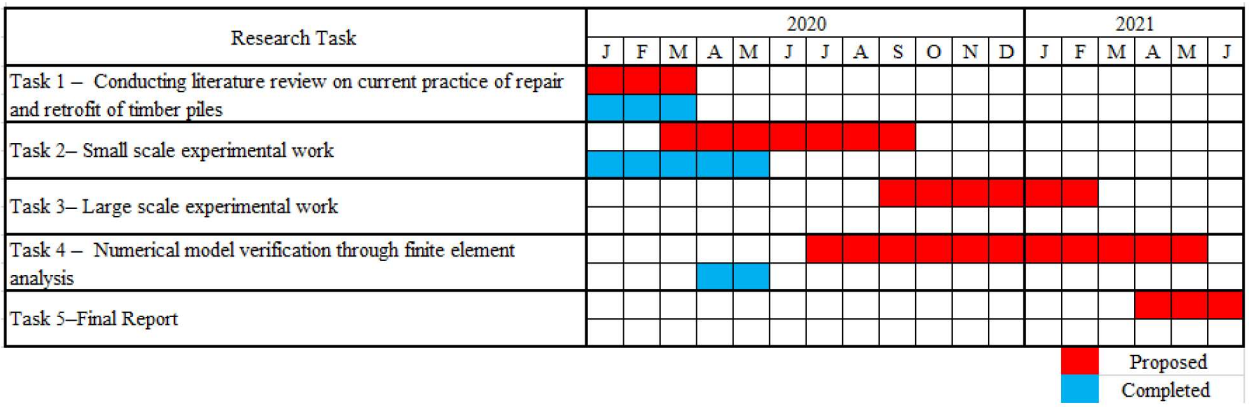
Progress: Researchers are building up this report for the final report.

5. Expected Deliverables

Final report, journal articles, design guidelines, and five-minute video presentation will be the expected deliverables

6. Schedule

Item	% Completed
Percentage of Completion of this project to Date	35%



7. Reference

J. H. Gull, A. Mohammadi, R. Taghinezhad, and A. Azizinamini, "Experimental evaluation of repair options for timber piles," *Transp. Res. Rec.*, 2015.

A. Mohammadi, P. D. Jawad H. Gull, R. Taghinezhad, and P. D. P. E. Atorod Azizinamini, "Assessment and Evaluation of Timber Piles Used in Nebraska for Retrofit and Rating," 2014.