

**EVALUATION OF PILE REPAIR SPLICE  
DESIGN**

**Research Testing Report**

**REPORT 17384**



Oregon Department of Transportation



# **EVALUATION OF PILE REPAIR SPLICE DESIGN**

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by  
Arijit Sinha, PhD  
Assistant Professor, Wood Science and Engineering  
and  
Milo Clauson  
Sr. Faculty Research Assistant  
Oregon State University  
Corvallis, Oregon 97331

for

Oregon Department of Transportation  
Research Section  
555 13<sup>th</sup> Street NE, Suite 1  
Salem OR 97301

**December 2015**

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Evaluation of Pile Repair Splice Design		5. Report Date December 2015	6. Performing Organization Code
7. Author(s) Arijit Sinha, PhD, Assistant Professor, Wood Science and Engineering and Milo Clauson, Sr. Faculty Research Assistant		8. Performing Organization Report No. 17384	
9. Performing Organization Name and Address Oregon State University Corvallis, Oregon 97331		10. Work Unit No. (TRAIS)	11. Contract or Grant No.
12. Sponsoring Agency Name and Address Oregon Dept. of Transportation Research Section 555 13 <sup>th</sup> Street NE, Suite 1 Salem, OR 97301		13. Type of Report and Period Covered Research Testing Report	14. Sponsoring Agency Code
15. Supplementary Notes			
16. Abstract <p>The ODOT Major Bridge Maintenance Engineer has proposed an in-house pile repair scheme for decayed piles. This repair scheme involves removing decayed area within the pile leaving a 2" outer shell, filling it up with rapid strength concrete and then placing a steel splice post with a 1/2" plate welded on the bottom. The design has not been validated by test results. The overall goal of the project was to characterize the new timber pile repair design. More specifically, the objectives of the study were to (a) characterize flexural and compressional properties of the timber splice repair design and (b) discern any influence of concrete plug length on the performance of the piles. The objective was achieved by conducting two tests on pile splices – compression (3) and flexure (3). Overall, the repair design performed well during testing. In compression, the piles did not fail and the testing had to be stopped as the capacity of the actuator was exceeded. The loads achieved in compression were higher than the nominal capacity of wood. In flexure the piles performed adequately albeit with a reduced moment capacity. The pile splice repair design reinforces the pile in the axial direction but expectedly reduces the moment capacity. The dependence of compressional performance of the plies on concrete plug length was not discernable from the current data set. These results cannot be statistically validated because of limited sample size and additional testing is required to achieve statistical significance. The results suggest that the design can be used in practice after accounting for the reduction in moment capacity.</p>			
17. Key Words Splice design; decay repair; concrete infill		18. Distribution Statement Copies available from NTIS, and online at <a href="http://www.oregon.gov/ODOT/TD/TP_RES/">http://www.oregon.gov/ODOT/TD/TP_RES/</a>	
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 31	22. Price



## SI\* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
<b><u>LENGTH</u></b>					<b><u>LENGTH</u></b>				
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
<b><u>AREA</u></b>					<b><u>AREA</u></b>				
in <sup>2</sup>	square inches	645.2	millimeters squared	mm <sup>2</sup>	mm <sup>2</sup>	millimeters squared	0.0016	square inches	in <sup>2</sup>
ft <sup>2</sup>	square feet	0.093	meters squared	m <sup>2</sup>	m <sup>2</sup>	meters squared	10.764	square feet	ft <sup>2</sup>
yd <sup>2</sup>	square yards	0.836	meters squared	m <sup>2</sup>	m <sup>2</sup>	meters squared	1.196	square yards	yd <sup>2</sup>
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi <sup>2</sup>	square miles	2.59	kilometers squared	km <sup>2</sup>	km <sup>2</sup>	kilometers squared	0.386	square miles	mi <sup>2</sup>
<b><u>VOLUME</u></b>					<b><u>VOLUME</u></b>				
fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft <sup>3</sup>	cubic feet	0.028	meters cubed	m <sup>3</sup>	m <sup>3</sup>	meters cubed	35.315	cubic feet	ft <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.765	meters cubed	m <sup>3</sup>	m <sup>3</sup>	meters cubed	1.308	cubic yards	yd <sup>3</sup>
NOTE: Volumes greater than 1000 L shall be shown in m <sup>3</sup> .									
<b><u>MASS</u></b>					<b><u>MASS</u></b>				
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.102	short tons (2000 lb)	T
<b><u>TEMPERATURE (exact)</u></b>					<b><u>TEMPERATURE (exact)</u></b>				
°F	Fahrenheit	(F-32)/1.8	Celsius	°C	°C	Celsius	1.8C+32	Fahrenheit	°F

\*SI is the symbol for the International System of Measurement



## **ACKNOWLEDGEMENTS**

The author would like to thank Travis Kinney from the Major Bridge Maintenance Program for his guidance and support. The author would also like to thank the members of the ODOT Research Section for their advice and assistance in the preparation of this report.

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## EXECUTIVE SUMMARY

Timber piles support several bridges across Oregon. Although these piles are treated with preservative before installation, many piles experience significant deterioration due to biological activity. One such activity is fungal decay. Several methods have been used in the past to repair decayed timber piles and attempt to restore the capacity of the piles. Most of them are mechanical repairs that include mechanical fasteners, steel members, concrete elements, and additional treated wood. The splice design used in Oregon was introduced in 1983 and was very cumbersome to carry out in the field.

The ODOT Major Bridge Maintenance Engineer has proposed an alternative design that is easier to implement. The new repair scheme includes removing decayed area within the pile leaving a 2" outer shell, filling it up with rapid strength concrete and then placing a steel splice post with a ½" plate welded on the bottom. The design has not been validated by test results. The overall goal of the project was to characterize the new timber pile repair design. More specifically, the objectives of the study were to (a) characterize flexural and compressional properties of the timber splice repair design and (b) discern any influence of concrete plug length on the performance of the piles. The objective was achieved by conducting two destructive tests on pile splices – compression (3) and flexure (3).

Overall, the repair design performed well during testing. In compression, the piles did not fail and the testing had to be stopped as the capacity of the actuator was exceeded. The loads achieved in compression were higher than the nominal capacity of wood. In flexure the piles performed adequately albeit with a reduced moment capacity. Failure mode in flexure was consistent across all three tests. The dependence of compressional performance of the plies on concrete plug length was not discernable from the current data set. With the increase in concrete plug depth, a decrease in ultimate bending load was observed. These results cannot be statistically validated because of limited sample size. The pile splice repair design reinforces the pile in the axial direction but expectedly reduces the moment capacity. The results suggest that the design can be used in practice after accounting for the reduction in moment capacity. However, further testing is required to achieve statistical confidence in the results. The piles selected for this study, except one, has never been in contact with degraded wood. As a verification of test results the next logical step will be to test piles removed from service due to rot. Another line of research should investigate the nominal expected capacities of the repair.



## 1.0 INTRODUCTION AND OBJECTIVE

Wood is a natural, biological, and renewable material that can be used as a construction material for a myriad of applications. One such application is timber piles. Timber piles support several bridges across Oregon. Although these piles are treated with preservative prior to installation, many piles experience significant deterioration due to biological activity such as fungal decay. Preservative treatment methods only penetrate into the outer shell of large timber members. In service, when these timber members start to dry, wood tends to shrink. The shrinkage in wood causes cracks and checks in the member. These defects are superficial and do not impede the structural performance of the member. However, these defects allow a pathway for biological agents such as decay fungi to reach the untreated core. Consequently, when a pile decays, it is the inner core where maximum decay is observed while the treated outer shell is intact.

Several methods have been used in the past to repair decayed timber piles and attempt to restore the capacity of the piles. Most of them are mechanical repairs that include mechanical fasteners, steel members, concrete elements and additional treated wood. Some examples of mechanical repairs that are used by Department of Transportation in other states are member augmentation, clamping and stitching, stress laminating (*Minnesota DOT 2011*), fiber reinforced polymer coating (*Lopez-Anido et al. 2005*), epoxy injections, epoxy injections coupled with fiber reinforcement (*Emerson 2003, Oklahoma DOT*), and two C-channels to form a jacket around the damaged area (*Enchayan 2010*). Pile splicing is a form of mechanical repair. A variety of different way exists to splice the piles and most of these solutions have proven to be effective in the field.

The splice design used in Oregon was introduced in 1983 and was very cumbersome to carry out in the field. The ODOT Major Bridge Maintenance Engineer has proposed an alternative design that is easier to implement. A pictorial description of the steps involved along with a schematic of the piles is provided in Appendix A. Briefly, the new design involves:

- Verifying whether pile has at least 2” thick outer shell
- Cutting the pile off at desired splice location
- Removing the rotted core by mechanical means
- Filling the void with rapid strength concrete to restore pile cross sectional capacity
- Placing an oversized steel pipe pile on top of the filled pile
- Filling the void space between oversized steel pipe pile and filled timber pile with rapid strength concrete to create a moment connection
- Placing on top of the steel pipe pile a square steel tube with a 0.5” plate welded on the bottom to achieve splicing of the wooden and steel pile.

The overall goal of the project was to characterize the effectiveness of the proposed pile repair on piles with varying levels of rot. More specifically, the objectives of the study were to:

1. Characterize flexural and compressional properties of the timber splice repair design.
2. Discern any influence of concrete plug length (mimicking levels of rot) on the performance of the piles.

The objective was achieved by conducting two tests on pile splices – compression and bending. Compression tests assessed whether the repair had realized adequate axial strength of the pile. Bending tests are required to characterize the moment carrying capacity of the pile repair design. This is an important consideration as piles will be expected to provide lateral support.

## 2.0 MATERIALS AND METHODS

### 2.1 MATERIALS

Six timber piles were removed from service by an ODOT Bridge Maintenance crew and brought to an ODOT maintenance yard where a pile splice procedure was conducted. Only one of the six specimens had actual rot present within the core of the pile. To mimic rot, the piles were augur drilled to desired length and then filled with concrete. Subsequently, splicing was performed following the steps outlined in the previous section. The spliced pile sections were then delivered to the Department of Wood Science and Engineering on May 1, 2015. A schematic of the piles is presented in Appendix A1. Out of the 6 piles, three were for compression tests and the other three were for flexural tests. The variable examined for both compression and flexural tests was concrete plug depth. A summary of all six pile types and a typical concrete fill depth are presented in Table 2.1. The compression piles had a square 10x10x.38 tube of length 24" followed with a sleeve that was 20" long, and the wooden pile of 14" nominal diameter was 32" long. On the other hand the flexural piles were 96" long 16" nominal diameter piles, followed by a 20" long steel sleeve that facilitated the connection to a square 10x10x0.38 pipe.

**Table 2.1: Description of the 6 piles tested.**

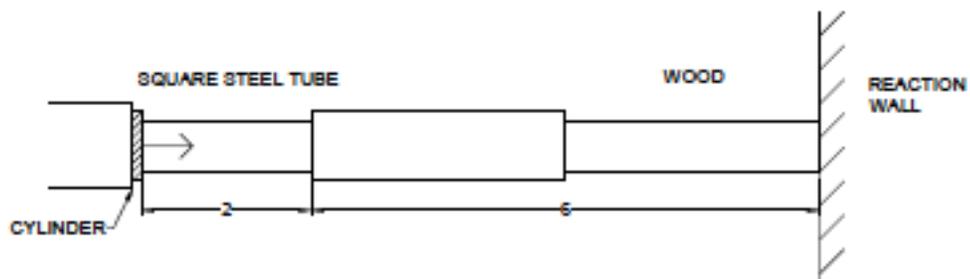
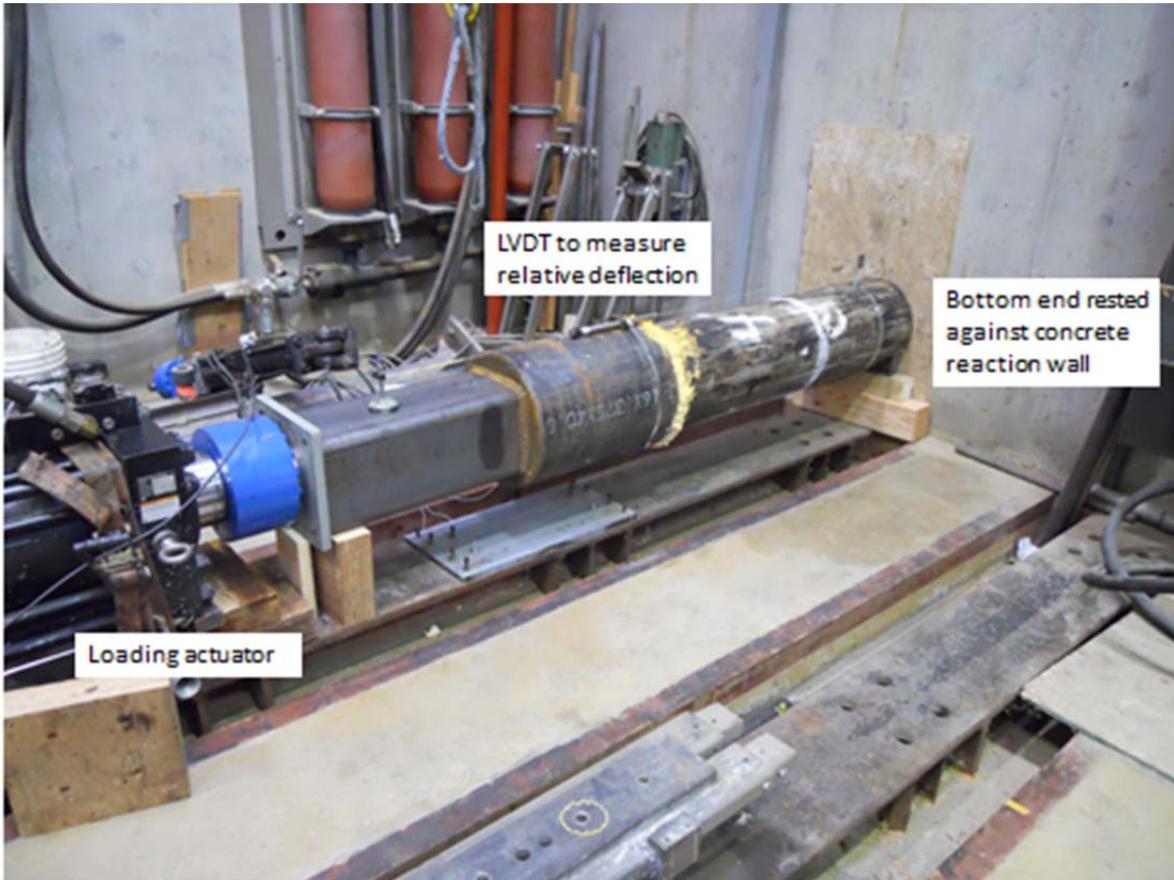
File No.	Type	Depth of Concrete (in)
1	Compression	21
2	Compression	35
3	Compression	49
4	Flexure	21
5	Flexure	35
6	Flexure	49

### 2.2 METHODS

#### 2.2.1 Compression Tests

The test setup for compression test is shown in Figure 2.1. There are no ASTM standards for testing of full size timber piles (Timber Piling Council 2002). Current design values for timber piles are developed after testing of small clear specimen as per ASTM D 143 (*ASTM D 143 2014*) and adjusting for defects and grade as per ASTM D2555 (*ASTM D2555 2011*) guidelines (*Timber Piling Council 2002*). Therefore, a set up based on ASTM D198 (*ASTM 2014*) which stipulates testing procedure for wood in structural sizes was used for this study. The compression tests were performed horizontally to ease the material handling process as well as for safety reasons. The pile was rested against a three feet deep concrete reaction wall designed to withstand a moment of 3000 kip feet (1 kip = 1000 lbs) with allowable deflection of 0.01". The pile was loaded axially using a 300,000 lbs (300 kip) actuator with a 20" cylinder travel. The cylinder was held with tie downs to prevent uplift of the cylinder that would in turn produce out

of plane loads. A linear variable displacement transducer (LVDT) was used to measure relative deflection between the steel casing and wood pile and had a gauge length of 40". The test was controlled by a constant rate of displacement of the hydraulic actuator. The rate of displacement of the actuator was 0.2" per minute and tested until failure or till the capacity of the actuator was reached (300 kip). Load, deflection of the load head, and LVDT deflection were continually monitored and logged using an automated data acquisition system. Using the monitored load and deflection data, load-deflection curves were generated for further analysis.



(All dimensions in feet)

Figure 2.1: Compression pile test set up.

## 2.2.2 Flexural Tests

Similar to compression test, there is no ASTM standard for testing full-size timber piles in flexure (*Timber Piling Council 2002*). The design values for timber piles are based on adjusted small clear specimen strength values as per ASTM D 143 (*ASTM D 143 2014*) and ASTM D2555 (*ASTM D2555 2011*). The test set up used in this study therefore, was based on the standard for wooden poles, i.e., ASTM D1036 (*ASTM 2012*). The set up was similar for all the piles tested in flexure regardless of the concrete plug depth. The flexure test set up is shown in Figure 2.2. The test set up was configured to test the flexural capacity of the interface between steel, wood, and concrete. The loading set up was a modified cantilever, with end of the steel square tube resting on an 8” wide high density rubber pad, which was against the edge of the concrete reaction wall. A hydraulic actuator connected to a 12x12” steel pad restrained the deflection at 92” from the end of the steel square tube. Another hydraulic actuator was connected to the tip end (wooden) of the pile with a steel cable. The test was controlled by a constant rate of displacement of the hydraulic actuator at the tip end. The rate of displacement of the actuator at the tip end of the pile was 0.2” per minute and tested until failure. A LVDT was placed at the tip end of the piles (Figure 2.2 inset) to measure the tip deflection. Load-deflection curves were generated for further analysis.

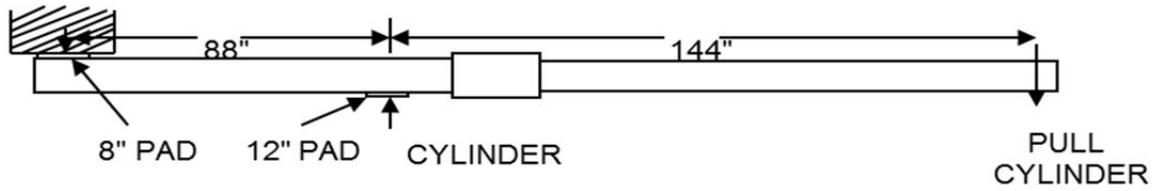
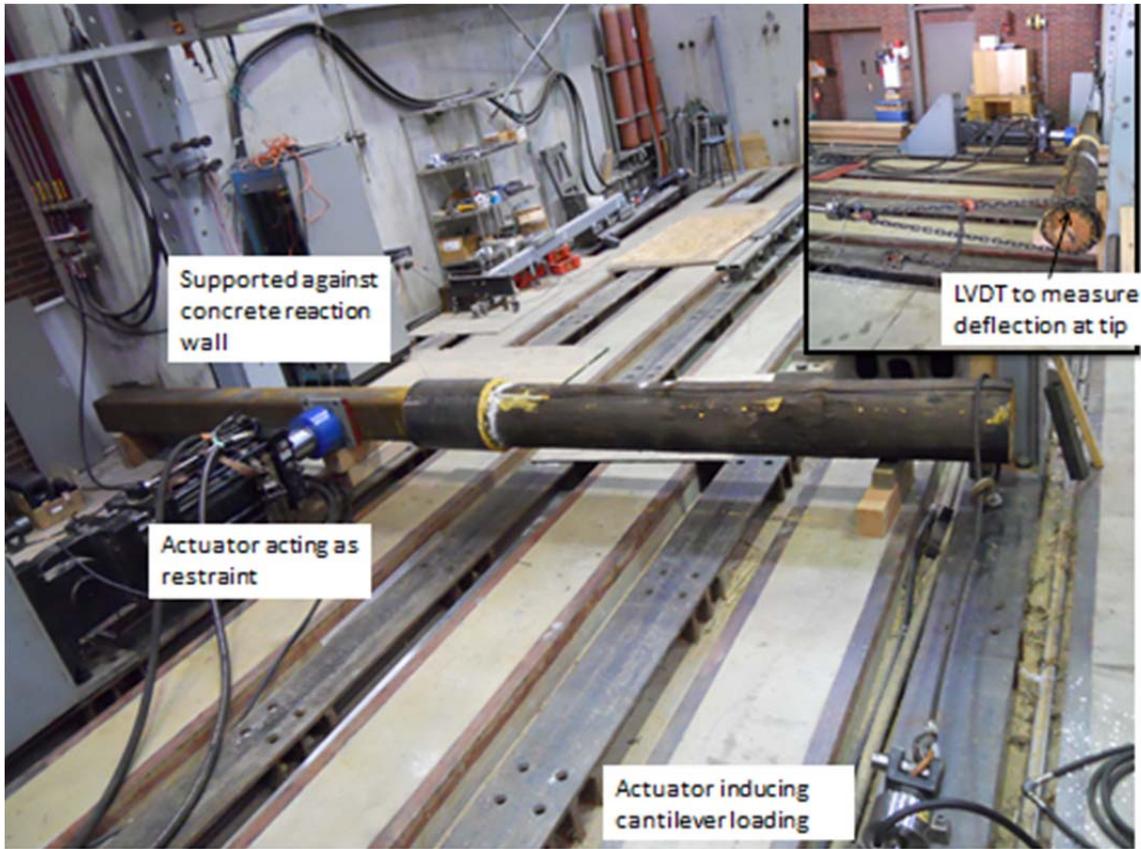


Figure 2.2: Bending test set up and schematic

### 3.0 RESULTS AND DISCUSSION

A summary of results is presented in Table 3.1, which lists the stiffness and the load at non-linear region. In compression, none of the test specimen indicated any failure up to the limit of 300 kip available with the hydraulic test equipment. This performance exceeded the nominal capacity of Douglas-fir wood, which is 220 kip calculated following AASHTO LRFD Bridge design specifications (AASHTO 2014). Therefore, the splice repair design, in addition to restoring the axial load capacity of the piles, strengthens the piles. This observed result was similar to Emerson et al. (Emerson et al. 2013), where repaired pile section with Epoxy coating and reinforcement axially strengthened the pile. In addition, some of the repaired piles in Emerson et al. (Emerson et al. 2013) exceeded the test set up capacity similar to the trends observed in this study.

**Table 3.1: Compression test summary**

Test Specimen #	Length of concrete plug (in)	Stiffness (Kip/in/in)	load at non-linear (Kip)
1	21	450	N/A
2	35	90	250
3	49	93	240

Deflections were recorded at two locations during the compression tests – (1) the cylinder or the load head displacement providing the total displacement of the system, and (2) LVDT displacement over a 40” gauge length. The LVDT was placed to measure the relative displacement of the wood to concrete/steel interface. It was assumed due to the difference in the stiffness between wood and concrete that the concrete and steel were fixed, and wood embedded onto the fixed support when load was applied. Both these measurements provide insight on the behavior of the pile during the test. Total displacement represents the system better and provides insights on all the contact points and the onset of non-linearity in the system. The LVDT displacements helps to better characterize the contact between wood and concrete. Moreover, stiffness calculations were conducted over a 40” gauge length using deflections from LVDT.

Theoretical stiffness values over a 40” gauge length calculated using AASHTO designated E value of Douglas-fir pile was 79 Kips/in/in. The values listed in Table 3.1 for all the tests regardless of concrete plug length are greater than the calculated E value of Douglas-fir. As the core is being reinforced with a stronger and stiffer material, an increase in stiffness of the pile was expected. The pile with 21” of concrete plug depth has an unusually high observed stiffness (Table 3.1). The axial stiffness of a member is proportional to the cross sectional area (A), modulus of elasticity (E) and inversely proportion to the length of the member (L).

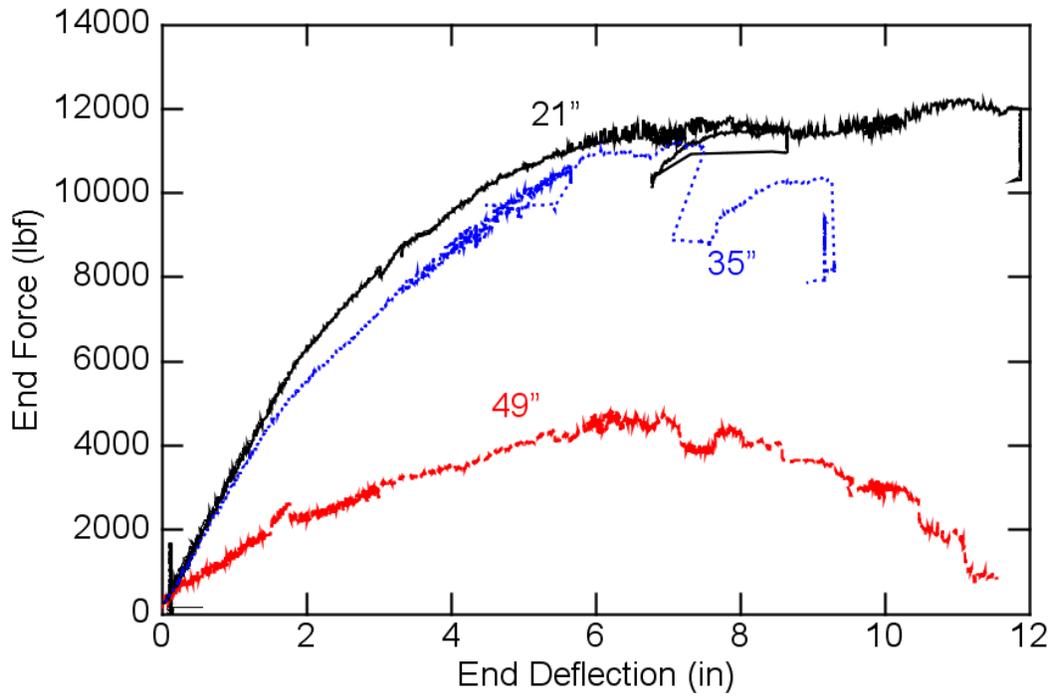
$$k = \frac{AE}{L} \quad (3-1)$$

For the pile with 21” plug length, the stiffness is extremely high. This is one data point and there could possibly be multiple reasons for the high value. A possibility of this observation being a testing artifact is very likely. In other words, this observation is likely to be a testing anomaly. With a shorter concrete plug length, a high effective stiffness is observed. Another reason could be the length of concrete plug providing a unique interface of steel, concrete, wood, and grout. This material combination might have provided the extreme stiffness to the splice. More tests are needed to gain an insight on whether the observed high stiffness was caused by a unique specimen material combination or a testing artifact.

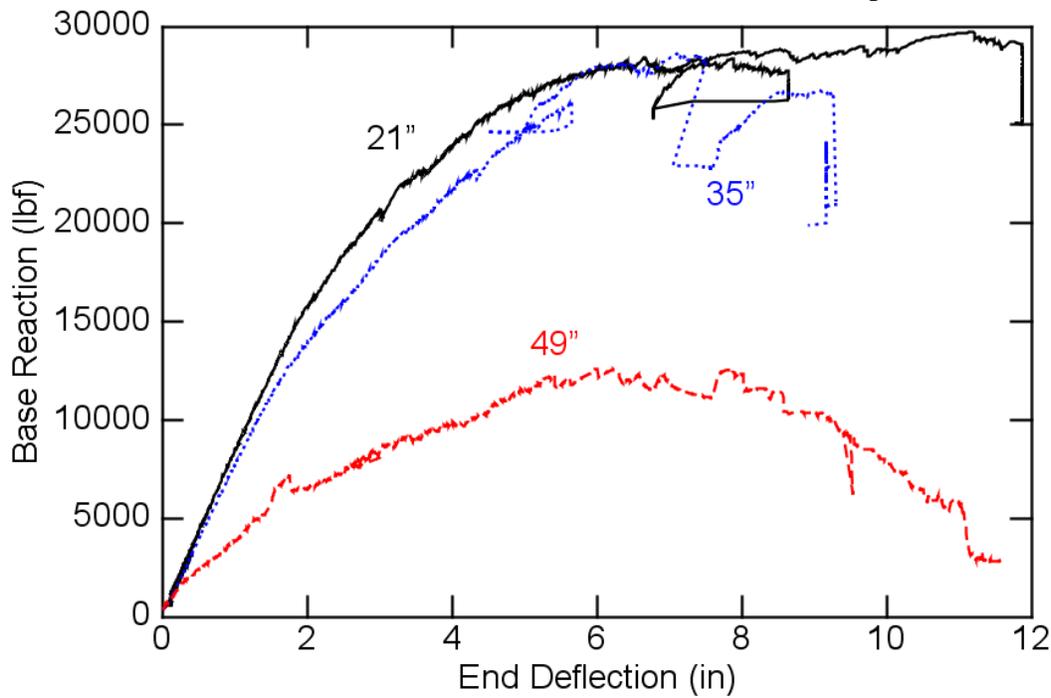
Radial mushrooming of wood right below the edge of concrete plug, was the expected mode of failure but was not observed. Additionally, longitudinal splitting of piles was not observed. Assumption of the compressional failure at interface between concrete and wood could not be validated as the ultimate load in compression exceeded the nominal capacity. For the pile with shortest concrete plug length, the non-linearity in the load-deflection diagram wasn't observed. Excluding the stiffness result for the 21” concrete plug length, the other stiffness observations was similar. Due to lack of replication in the experimental design any inference on the effect of concrete plug length on stiffness of the pile cannot be made. The load at which the behavior deviates from linearity is important. While this was not observed in the shortest concrete plug depth, at 35” and 49” of plug depth the loads were fairly similar, with a difference of 10 kip. Again, the results do not have any statistical significance. These results suggest that the pile splice repair strengthens the axial capacity of the piles regardless of the concrete plug depth. The effect of plug length on the axial stiffness capacity cannot be discerned using current data set and more tests are needed to fully understand the effect of concrete plug length on compressional properties of the pile.

The load deflection diagram from the three flexural tests is presented in Figure 3.1. Two separate load deflection behavior is presented - tip load vs. tip deflection (Figure 3.1a) and end force or base reaction vs. tip deflection (Figure 3.1b). The base reaction is the force measured at the actuator restraint (Figure 2.2). Each curve has a characteristic linear portion, followed by a shift point beyond which the load-deflection relationship is non-linear. This represents the point that the repaired piles could be deflected to without compromising elasticity. Apparent lateral stiffness as indicated by the slope of the linear portion of the curve is presented in Table 3.2. Qualitatively a decrease in the slope of load deflection diagrams is observed as the concrete plug depth increases. This is validated by calculated values (presented in Table 3.2) of the slope of the initial straight line portion of the load-deflection plots. With the increase in concrete plug depth, a decrease in ultimate bending load was observed. Similar to compression tests, this behavior cannot be statistically validated due to lack of replication. The predominant failure mode for all three piles was through localized crushing of wood near the perimeter fill of the steel casing followed by tensile wood failure in the pile. This was more prominent in the 49” concrete plug depth pile, i.e., tensile bending of the wooden pile and exaggerated localized crushing of wood at the fulcrum point between the steel casing and the pile. The ultimate load observed would induce a lower moment (as listed in Table 3.2) on wood concrete interface than the calculated design capacity of 137 kip feet. Therefore, the splice repair did not restore the original design moment

capacity of the piles. In all three piles the failure occurred at the base of the splice and the failure modes were consistent, with no sign of buckling.



(a) End force vs. deflection at the tip



(b) Base reaction vs. deflection at the tip

Figure 3.1: Load-deflection plots for three bending tests.

**Table 3.2: Summary of bending test results**

<b>File No.</b>	<b>Depth of concrete (in)</b>	<b>Maximum load (lbf)</b>	<b>Apparent Stiffness (lbf/in)</b>	<b>Moment induced at the failure section (kip.ft)</b>
4	21	12233	3077	122
5	35	11217	2863	112
6	49	4843	1060	49

### **3.1 GENERAL DISCUSSION**

Overall, the repair design developed by ODOT performed well during testing. In compression, the piles did not fail and the testing had to be stopped as the capacity of the actuator was exceeded. The loads achieved in compression were higher than the nominal capacity of wood. There were no significant indications of decrease in point of non-linearity during compression loading with increasing concrete plug length. This however, needs to be statistically validated by conducting more tests. As the piles performed exceedingly well and the ultimate load capacity of the restored piles was not realized within the current test set up, the size of the concrete plug length was not an influencing factor in compression. Irrespective of the concrete plug length, indication of buckling as a failure mode was not observed.

In flexure the piles performed adequately albeit with a reduced moment capacity. Failure mode was consistent across all three tests. Unlike compression results, a distinct decrease in point of non-linearity as well as apparent stiffness was observed with increasing concrete plug length in flexure tests. The moment induced at the failure section was also reduced as a result of increasing concrete plug length. The greatest reduction in moment capacity 64% was observed in the repaired pile with 49” concrete plug length.

The splice repair design reinforces the pile in the axial direction but expectedly, reduces the moment capacity. This gives confidence that the design can be used in practice after accounting for the reduction in moment capacity. However, further testing is required to achieve statistical confidence in the results. The piles tested were removed from service due to checking where rot was mimicked by augur drilling a wooden shell and remediation was performed by filling concrete in the augured hole. Although this process is the closest to mimicking an actual rot in the field, rot being a biological activity can leave the wood vulnerable in many other ways. Only one pile out of six had rot present when removed. It was then augured to desired dimension. The 2” shell that is left intact in the piles tested has never been in contact with degraded wood. As a verification of test results the next logical step will be to test piles removed from service due to rot.

## 4.0 CONCLUSIONS

The results of three compression and three bending pile tests with varying concrete plug depth indicated that the repair design exceeds nominal capacities in compression and can be used in service. The repair reinforced the piles in axial direction but did not restore the design moment capacity in bending. The moment capacity of the piles decreased with increasing concrete plug depth. These results are only indications and have not been statistically verified. The results of this study and the observed failure modes were not suggestive of an effect of concrete plug length on the overall performance of the piles. Overall, the splice repair design is adequate as it reinforces the pile in the axial direction but expectedly, reduces the moment capacity of the pile.



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## **APPENDIX A**

### **SCHEMATIC DETAILS OF TEST SPECIMEN**



# APPENDIX A – SCHEMATIC DETAILS OF TEST SPECIMEN

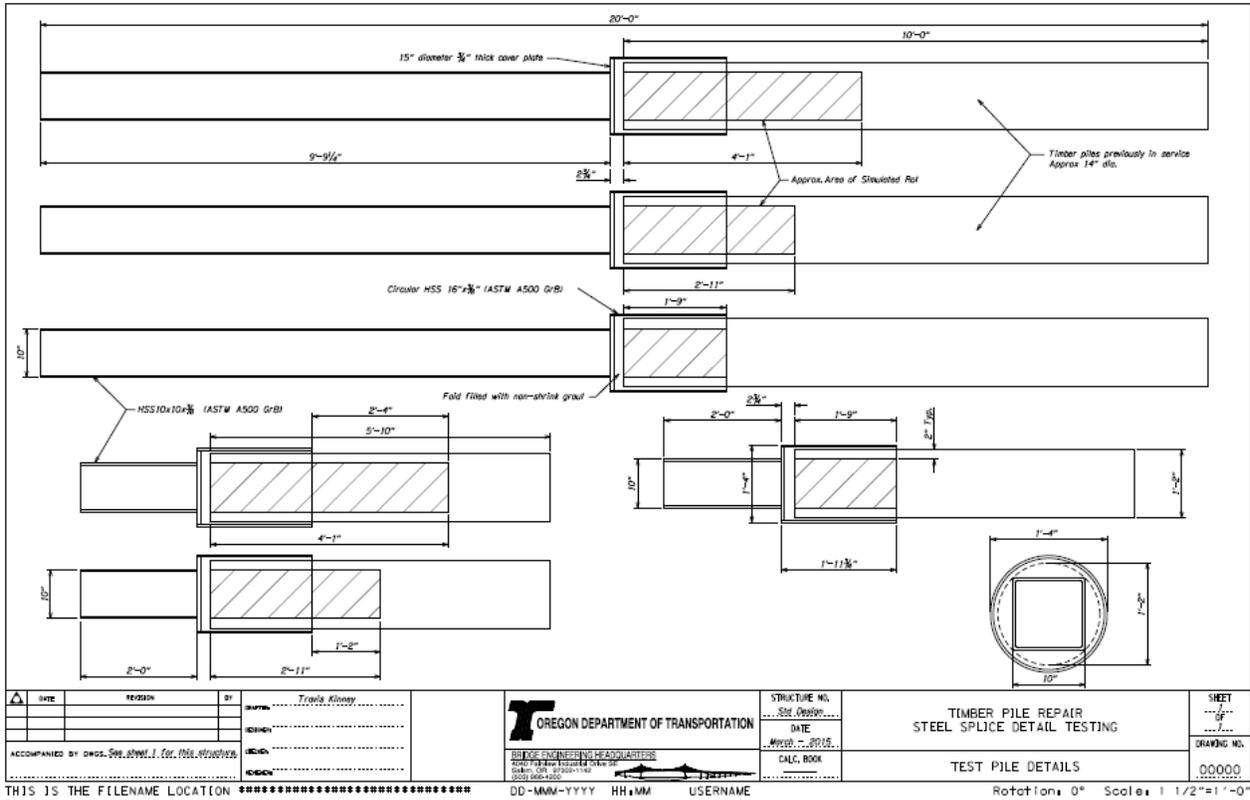


Figure A.1.1 : Timber pile repair splice test specimen detail



(a) Identifying piles



(b) Augur drilling to simulate rot



(c) Innovative ways to remove materials



(f) Prepared compression samples



(e) Mortar mix and steel casing



(d) Simulated rot

Figure A.1.2 : Pictorial overview of the manufacturing process of the test specimen.