EVALUATION AND DEVELOPMENT OF COST EFFECTIVE TIMBER PILE REPAIR TECHNIQUES

By

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LIST OF SYMBOLS

C_D	load duration factor
C_F	size factor for sawn lumber
C_P	column stability factor
C_b	bearing area factor
C_{cs}	critical section factor for round timber piles
C_{sp}	single pile factor for timber piles
C_t	temperature factor
C_u	untreated factor for timber piles
E	modulus of elasticity, psi
E'	allowable modulus of elasticity, psi
F_b	tabulated bending design value, psi
F_b'	allowable bending design value, psi
F_c	tabulated compression design value parallel to grain, psi
F_c'	allowable compression design value parallel to grain, psi
P_{eac}	compression strength of epoxy-aggregate core, lbs
P_{fiber}	compression strength of fiberglass, lbs
P_{wood}	compression strength of wood, lbs

CHAPTER 1

INTRODUCTION

1.1 Background

Thousands of state and county bridges in Oklahoma are supported by timber piles. Many of these timber piles are exposed to weathering over extended periods of time, thus they are subject to deterioration, caused by the attack of decay fungi. Fig. 1.1 shows typical decayed timber piles still in service. Many of these bridges are in need of restoration. Conventional repair methods involve supporting the bridges with falsework jacking and replacing the decayed timber piles. These processes are usually time consuming and costly. Therefore, the development of new timber pile repair techniques will be beneficial.

FIG. 1.1. Decayed Timber Piles in Service

1.2 Problems of Wood Deterioration

Wood deterioration adversely alters the material properties of the wood. Therefore, the wood must be protected to ensure adequate performance. The decay fungi degrade the wood and decrease its strength. In order for decay fungi to survive, it requires oxygen, free water, temperature ranging between 0°C and about 43°C, and an adequate food source, which is generally the wood itself. Each of the elements must be present for deterioration to occur. Moisture content is a major factor in determining the degree of deterioration and the decay rate of the wood. The continuous changing of the moisture conditions enhances the growth of decay fungi. When water enters the wood, the wood swells and collects water in its cell cavities. This provides a favorable environment for decay fungi to grow. Conversely, when the wood is dry, it has the tendency to shrink. Shrinkage causes splits to form. Splits provide a pathway for decay fungi to penetrate into the core of the timber. Once inside, decay fungi breakdown the wood's composition, this consequently results in losses in strength.

1.3 Objectives

The objective of this study was to develop and evaluate cost effective repair techniques for the existing decayed timber piles supporting thousands of bridges in Oklahoma. Previously, timber piles that suffered from significant deterioration were required to be extracted and replaced. The results of this research provides adequate information to determine if the developed timber pile repair techniques are feasible to restore the degraded mechanical properties and therefore substitute the conventional method of extracting and replacing the piles.

1.4 Scope of Experimental Work

i. Smaller pile sizes were used in the fabrication of the laboratory tested timber piles to offset the limitation on the capacity of the testing equipment available.

ii. Testing was done only on two specimens per repair technique.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Development of Epoxy Repair

The first reported study on epoxy use for timber repair was presented by Avent et al. (1976). The epoxy repair method on wood appeared to be very successful in terms of rehabilitating the bolted timber connections on timber trusses. Prototypes of the truss joint were fabricated for testing. Avent et al. (1978) later applied the epoxy repair method developed previously on full-scale timber trusses. Newly fabricated timber trusses were tested experimentally to provide relative comparisons to the epoxy-repaired trusses. The epoxy repair method was found feasible to restore decayed timber truss joints. It was proven to be more economical than the conventional procedures of member replacing, stitch bolting, clamping and banding. Avent (1986) classified the epoxy repair into six basic categories presented in Table 2.1, in which type A denoted structural repair, and type B denoted semi structural repair.

TABLE 2.1. Basic types of epoxy repairs (courtesy of: Avent 1986)

Repair Type	Description
A-1	Epoxy injection of cracked and split members at truss joints
A-2	Epoxy injection and reinforcement of decayed wood
A-3	Splicing and epoxy injection of broken members
A-4	Epoxy injection of delaminated beams
B-1	Epoxy injection of longitudinal cracks and splits in truss members away from joints
B-2	Repair of bearing surfaces using epoxy gel

Basic steps required for epoxy repair method consisted of member preparations, joint sealing, injection and finishing. Avent (1986) also demonstrated the factors that influenced the bond strength of epoxy-injected structures. Shear block tests according to the *ASTM Standard D905-98* (ASTM 1998) were performed to determine the bond strength provided after the repair. The tests indicated that the epoxy repair overcame the effects of aging and glue line stress on the timber. The repair method has successfully restored the strength and integrity of the timber structures. Avent (1986) claimed that the allowable stresses after repair depends on the wood species, grain orientation, allowable wood shear stress, and lap length to member thickness ratio. The most useful and practical approach to compute the strength of the repaired timber was based on the computation of the average shear stress ,which is the ratio of the axial tension or compression force of the member over the contacted surface area.

The epoxy repair method was not only able to restore severely decayed and weathered timber structures, but also capable of resisting the future effects of weathering. Avent (1985) exposed decay free epoxy-repaired structures to weathering. The epoxy repair method responded well mechanically and also resisted decay.

Avent (1986) only developed a rational design approach for epoxy-repaired timber structures instead of a model to estimate the strength of the structures. No specifications with design criteria or allowable stresses for epoxy repairs were developed. The review on the epoxy repair method only reveals little on the way of accurately determining the design values for the repaired structures. The repair techniques were being utilized without the benefit of in depth engineering analysis.

2.2 Fiber-reinforced Polymer (FRP)

Fiber-reinforced polymer, also known as FRP has been widely used in strengthening concrete structures in recent years. FRP sheets are used in rehabilitation of reinforced concrete structures because of their easy on site installation, great geometrical flexibility, high strength-to-weight ration, good durability, fatigue resistance, and low creep (Hollaway and Leeming 1999).

FRP replaced the functions of steel reinforcement in conventional reinforced concrete. Under uniaxial compression, concrete will expand normal to the loading direction due to the Poisson's effect and cracking. Mirmiran and Shahawy (1997) revealed that the steel transverse reinforcement only delayed the radial expansion of the concrete, instead of preventing it due to its yielding resulting from high radial strain. Alternatively, Davol et al. (2001) indicated that triaxial compression for the concrete core could be initiated by providing FRP shell as a confinement agent. The presence of triaxial pressure throughout the loading can prevent the radial expansion from occurring.

Testing has been carried out by Mirmiran and Shahawy (1997) and Davol et al. (2001) to extensively investigate and quantify the behavior and performance of the combination of concrete and FRP shells. Similar conclusions were drawn in which the application of FRP shells developed significant strength and ductility enhancement, and held back the dilation rate of the concrete core much effectively than transverse steel reinforcement. Transversely-oriented fiber reinforcement provided confinement and resisted the volume expansion of the concrete core. It led to a low Poisson's effect, and the concrete core was well confined. The dilation rate and tangent modulus could be determined by using an incremental elastic equation developed by Davol et al. (2001).

Samaan (1998) corroborated the contribution of FRP shells by integrating their applications to concrete columns. The presence of FRP shells significantly improved the strength and ductility of concrete columns as illustrated previously. Samaan et al. (1998) concluded that the composite did not provide much strength or ductility to the structure when the fiber oriented away from the hoop direction.

Full-scale experimental testing was performed by Davol et al. (2001) to establish the flexural strength of concrete-filled FRP shells. These tests indicated that the circular FRP shells experienced local buckling on the compression side of the shell. A similar study in evaluating the increase in flexural strength of reinforced concrete beams after wrapping them with fiber fabrics was presented by GangaRao and Vijay (1998). The FRP-modified beams were evaluated in terms of strength, stiffness, compositeness between wrap and concrete, and associated failure modes. GangaRao and Vijay (1998) concluded that the application of fiber fabric easily improved the structural performance of the concrete structures. The effect of various wrapping configurations, i.e. longitudinal and transverse oriented fiber fabric did not make a substantial difference in their capacities. However the longitudinal reinforcement definitely increased the moment capacity of the beams. Strength and stiffness properties of the fiber reinforcement resulted in improved performance of rehabilitated concrete members, but only when other failure modes, i.e. shear failure or bond failure do not interfere. Conversely, Davol et al. (2001) did not include any application of longitudinal fiber reinforcement in their experiments; the specimens used in flexural tests were reinforced exclusively in the hoop direction.

Models to predict the stresses and strains in both longitudinal and hoop directions for the FRP shells were developed by Davol et al. (2001). Based on the assumption of the linear elastic nature of the FRP shells, the pressure applied to the concrete core is directly proportional to the radial expansion of the confined core. Other related documents such as Hoppel et al. (1994) illustrated the concept of quantifying the hoop strain of the shell, the confining pressure, and the axial stress in the concrete by using a Hooke's law relation.

Mirmiran and Shahawy (1997) questioned the feasibility of the confinement model developed for unconventional reinforced FRP shells. Samaan et al. (1998) also agreed that the model may not be conservative, since it has underestimated the ultimate strains of the composite. These models failed to predict the behavior of FRP-confined concrete, mainly because of its stiffness under restrain condition. Samaan et al. (1998) indicated that behavior of these columns has not yet been captured with proper analytical tools.

2.3 Significance of Bond Strength in Failure

The capacity of beams strengthened with FRP plates normally depend heavily on the bonding between the plates and the structures. When delamination occurred, the FRP plate debonded from the structure and subsequently the load capacity was reduced tremendously and followed by brittle failure. Aprile et al. (2001) applied a numerical displacement model based fiber frame element with bond slip between beams and FRP plates. The model predicts the beam loading capacity and failure mode due to decomposition of materials. It was originally developed by Spacone and Limkatanyu

(2000) to establish the bond stresses that develop at the plate-to-beam interface. Fourteen reinforced concrete beams were built and loaded to failure. FRP plates were bonded at the tension and the compression face of the beams tested in four-point bending. The tests were performed to determine the maximum bond value at the interface. Sebastian (2001) also conducted testing on large-scale FRP-plated concrete beams in four-point bending. Delamination of the fiber-reinforced polymer plate from the cover concrete due to the debonding of the adhesive was observed. Large-scale specimens were chosen to eliminate the occurrence of premature shear failure. Aprile et al. (2001) concluded that the ultimate failure condition for the beams was initiated by the debonding of the FRP plates under the loading points. The maximum flexural capacity of the beam was unable to be determined due to premature bond failure. Meanwhile, the specimens for Sebastian (2001) all experienced debonding at midspan when loaded to failure.

Aprile et al. (2001) added that failure of strengthened concrete beams was initiated by plate delamination. The FRP-plated reinforced concrete beams showed a brittle response because the response was dominated by the elastic behavior of the plates. Sebastian (2001) discovered that elementary beam formula for the plate-to-beam shear bond stress and the elementary beam theory for bending are not applicable in the analysis of the FRP-plated beams, because the assumption of full strain compatibility between the plate and the beam does not stand. Therefore, the development of an advanced non-linear finite elements analysis of the debonding phenomenon is necessary. Brooks and Choudhury (2002) demonstrated that surface geometry such as roughness and friction is the key to increase interfacial strength of the composite. The better the mechanical interlock between the two constituents, the higher the bonding strength it provides.

CHAPTER 3

MATERIALS AND SPECIMEN FABRICATION

3.1 Materials

Throughout this research project, a variety of materials were used in the fabrication process of the laboratory repaired timber piles. The data sheets for all materials are presented in Appendix B. These materials include:

i. Sikadur® 30

Sikadur 30 is a two-component, high-strength, high modulus structural epoxy paste adhesive. It works as a binder for mortar patching the timber piles. It was applied to the timber pile outer shells to seal all cracks and voids. This prevented any leakage during core repairing.

ii. SikaWrap® Hex 100G

SikaWrap Hex 100G is a unidirectional glass fiber fabric. It was embedded in epoxy to produce fiberglass, which was used to strengthen structural elements and provide material confinement.

iii. Sikadur® Hex 300

Sikadur Hex 300 is a two-component, high strength, high modulus epoxy. It is an impregnating resin for SikaWrap structural strengthening system. It was used as a binding agent for SikaWrap Hex 100G in this research project.

iv. Unitex® PRO-POXY 100

Unitex Pro-Poxy 100 is a two-component, low viscosity, high strength injection resin. It was used to fill the hollow core of the timber piles.

v. No.6 Aggregate and Pea Gravel Mixture

The aggregate mixture used to fill the decayed cores was composed of equal volume of No.6 Aggregate and pea gravel. The No.6 Aggregate was required to meet subsection 703.02 in *AASHTO Standard Specification* (1996). The gradation of No.6 Aggregate and pea gravel is provided in Table 3.1. These graded aggregates were uniformly blended to create approximately 35 percent of void space to be filled by injection resin. The use of the aggregate mixture decreases the exothermal problem that occurs while the injection resin is curing within the wood cores.

TABLE 3.1. Gradation of No.6 Aggregate and Pea Gravel

	No. 6 Aggregate	Pea Gravel
Sieve Size	Percent Passing	
3/4 in.	100	--
1/2 in.	45-55	--
3/8 in.	0	100
No.4	--	81.1
No.8	--	1.9
No.10	--	0.8

3.2 Specimen Fabrication

Seven epoxy-aggregate cylinders and sixteen laboratory repaired timber piles were fabricated for testing and evaluation of the timber pile repair techniques. Specimens with different reinforcement configurations were prepared during the course of fabrication.

3.2.1 Laboratory Fabricated Cylinders

Aggregate and epoxy were used to fill the voids within the decayed timber piles. Therefore, it was necessary to understand the behavior and the strength of these materials performing as a composite under loading. 4-in. diameter by 8-in. long plastic cylindrical forms were used to replicate the core of the actual laboratory repaired timber pile. The plastic forms were filled with aggregate mixture, followed by the injection of low viscosity epoxy resin. The injection process is shown in Fig. 3.1. An injection pressure of 25 psi was used. The epoxy-aggregate cylinders as shown in Fig. 3.2 were cut and inspected. The 25 psi injection pressure was sufficient to fill the voids.

FIG. 3.1. Injection of Low Viscosity Epoxy Resin

A total of seven epoxy-aggregate cylinders were fabricated and tested experimentally in compression. Four cylinders were reinforced by fiberglass. Two of them were wrapped transversely to their length, and the other two were wrapped in both transverse and longitudinal directions. The remaining three cylinders were remained unreinforced as shown in Fig. 3.2.

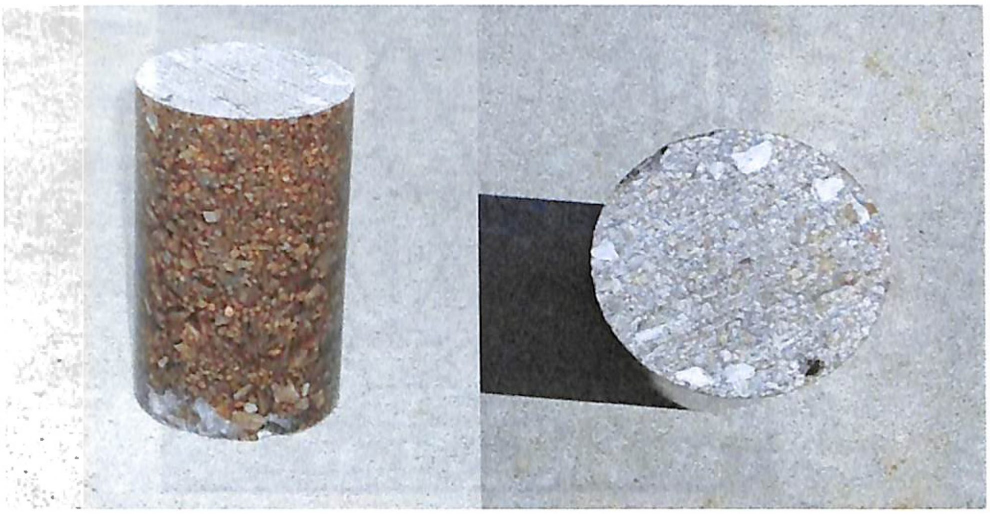


FIG. 3.2. Unreinforced Laboratory Fabricated Cylinder

3.2.2 Field Repaired Timber Piles

Eleven decayed timber piles supporting the bridge on SH-5 over tributary of Brush Creek in Cotton County, OK were repaired in place using a new timber pile repair technique. This repair technique consisted of filling the voids in the timber piles with aggregate and epoxy, and reinforcing the timber piles with fiberglass positioned transversely to the full exposed length of the pile with 6-in. of overlaps. The repair procedures of the field repaired timber piles were demonstrated by ODOT. The detailed repair specification is presented in Appendix A. One of the field repaired timber piles was extracted from the Cotton County Bridge. It was tested experimentally for compressive strength in the Civil Engineering Laboratory at Oklahoma State University, Stillwater as shown in Fig. 3.3.

FIG. 3.3. Field Repaired Timber Pile

3.2.3 Laboratory Repaired Timber Piles

Four highly deteriorated timber piles were extracted from a Payne County, OK Bridge and selected as the raw materials for the evaluation and development of repair techniques. Three basic repair techniques were formulated in this study:

i. The decayed areas of the timber piles were removed. The internal cavities of the timber piles were replaced by aggregate and epoxy.

ii. In addition to the repaired core, the timber piles were reinforced by transverse fiberglass reinforcement to withstand compression loading and provide material confinement.

iii. In addition to the repaired core and transverse fiberglass reinforcement, longitudinal fiberglass reinforcement was introduced into the fabrication of the specimens. Longitudinal fiberglass reinforcement was expected to improve flexural capacity of the laboratory repaired timber piles.

The orientations of fiberglass reinforcement used in the fabrication of test specimens are depicted schematically in Fig. 3.4.

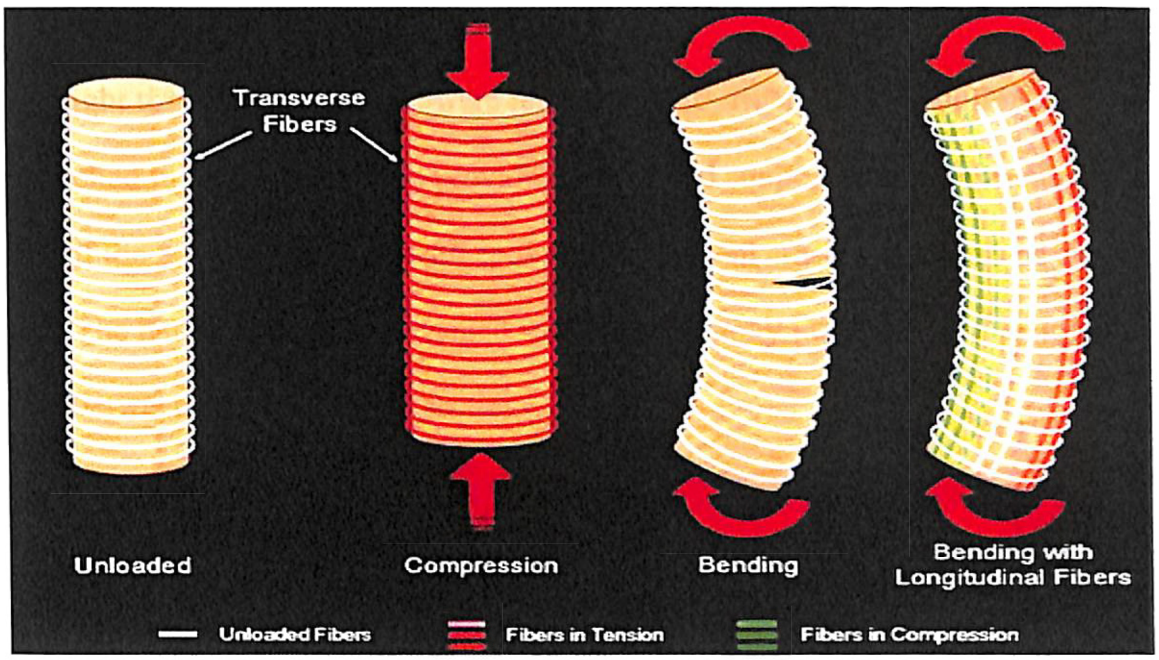


FIG. 3.4. Orientations of Fiberglass Reinforcement

The basic procedures to fabricate test specimens can be summarized in five major steps:

i. Pile preparation

The timber piles were then cut into eight 2-ft long segments for compression testing and eight 3-ft long segments for flexural testing. The pile segments were sandblasted to thoroughly remove all the dirt and debris from the surfaces to achieve an efficient bonding between the wood and the fiberglass.

ii. Wood core drilling

A 4-in. diameter hole was drilled along the center of every pile segment to replicate the decayed core of a timber pile.

iii. Fiberglass wrapping

Eight timber pile segments were reinforced with fiberglass. The pile segments were attached to plywood bases to provide stability and support during fabrication. The exterior of the piles were coated with epoxy mortar to seal cracks and voids as shown in Fig. 3.5. The hardened mortar prevented leaks during epoxy injection, and restored the bonding between separated wood sections.

FIG. 3.5. Application of Epoxy Mortar Coating on Laboratory Repaired Timber Piles

The fiberglass was applied to the pile segments after the epoxy mortar coating cured. The reinforced pile segments were wrapped in two plies of fiberglass with a 6-in. overlay. The circumference was measured to determine the dimensions of the glass fiber fabric required for each pile segment. Impregnating resin was applied to the exterior of the pile segments before application of the glass fiber. The glass fiber fabric was fully saturated in resin before wrapping. Air voids trapped between the fiberglass and the piles were released by using a roller. Longitudinal oriented fiberglass was placed prior to the transverse oriented fiberglass when the pile segments were reinforced in both directions. The resin was allowed to cure before further handling. All pile segments were inspected for air voids after the resin hardened.

iv. Aggregate and epoxy injection

Mixture of No. 6 aggregate and pea gravel was placed into the hollow core and low viscosity injection resin was pressure injected into the remaining void space inside the core of the timber piles. The injection ports were placed at the plywood base and at the quarter points along the pile length. The typical setup for epoxy injection is shown in Fig. 3.6. Injection resin was injected starting from the bottom port proceeding upward. The same injection pressure of 25 psi as for the laboratory fabricated cylinders was used, assuming it was adequate to fill all the voids in the wood core. The injection ports were securely sealed after the injection.

FIG. 3.6. Typical Setup of Epoxy Injection for Laboratory Repaired Timber Piles

v. Finishing

The repaired timber piles were set aside for at least fourteen days to allow the epoxy to cure to its full strength. After curing, the injection ports and the plywood bases were removed from the piles. Both ends of the pile segments were machined parallel to each other and perpendicular to the pile length.

CHAPTER 4

LABORATORY TESTING PROCEDURES

The testing for the laboratory repaired timber piles, laboratory fabricated cylinders and field repaired timber piles was conducted to evaluate the effectiveness of the repair techniques. Table 4.1 and 4.2 list the laboratory testing performed.

TABLE 4.1. Summary of Compression Tests

Test	Specimen	Pile No.	Length (in.)	Dia. (in.)
Compression	Laboratory Repaired Timber Piles			
	Control Specimen	A5	24	9.85
		B1	24	9.10
	Repaired Core	A4	24	9.60
		B2	24	9.50
	Repaired Core with Transverse Fiberglass Reinforcement	A1	24	9.35
		A2	24	9.50
	Repaired Core with Transverse and Longitudinal Fiberglass Reinforcement	A3	24	9.50
		B3	24	9.40
	Laboratory Fabricated Cylinders			
	Unreinforced	1	8	4.00
		2	8	4.00
		3	8	4.00
	Transverse Fiberglass Reinforced	4	8	4.00
		5	8	4.00
	Transverse and Longitudinal Fiberglass Reinforced	6	8	4.00
		7	8	4.00
	Field Repaired Timber Piles			
	Repaired Core with Transverse Fiberglass Reinforcement	1	12	12.00
		2	12	12.00
	Repaired Core Only	3	12	12.00
	Solid Wood Core with Transverse Reinforcement	4	12	12.00

TABLE 4.2. Summary of Flexural Tests

Test	Specimen	Pile No.	Length (in.)	Dia. (in.)
Bending	Laboratory Repaired Timber Piles			
	Control Specimen	C3	36	9.25
		D3	36	8.60
	Repaired Core	C4	36	8.50
		D4	36	8.75
	Repaired Core with Transverse Fiberglass Reinforcement	C2	36	9.00
		D2	36	8.50
	Repaired Core with Transverse and Longitudinal Fiberglass Reinforcement	C1	36	9.75
		D1	36	8.50

4.1 Compression Tests for Laboratory Fabricated Cylinders

No. 6 aggregate, pea gravel and epoxy were used to fill the voids within the decayed timber piles. Therefore, it was necessary to understand the behavior and the strength of these materials performing as a composite under loading. The laboratory-fabricated cylinders were tested in a Tinius Olsen universal testing machine with a capacity of 300 kip. A digital dial gauge was used to measure the crosshead displacements while the cylinders were loaded to failure. The typical setup of the cylinder compression test is shown in Fig. 4.1. Stresses were determined from the load-displacement data with the assumption of elastic characteristics of the specimens.

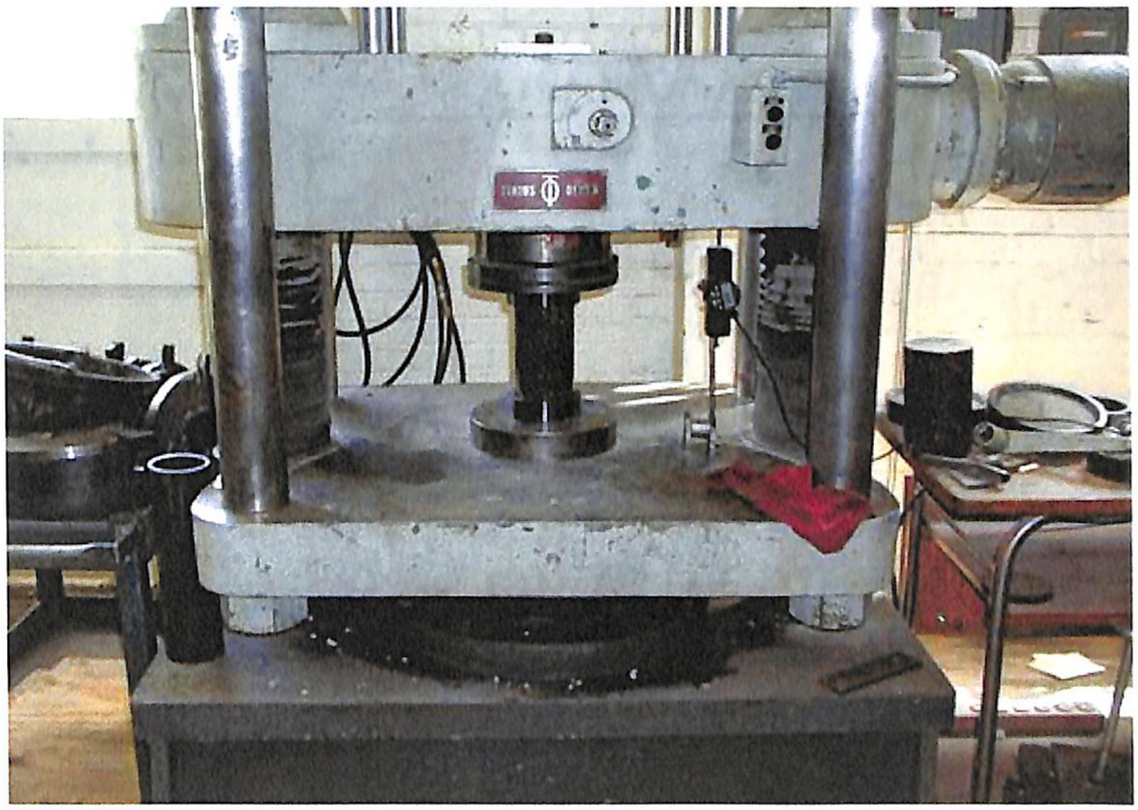


FIG. 4.1. Typical Setup for Compression Testing of Laboratory Fabricated Cylinders

4.2 Compression Tests for Laboratory and Field Repaired Timber Piles

Repaired timber piles were tested in compression to evaluate the effectiveness of their repair techniques. Field repaired timber piles were tested to determine their axial compression load capacity and predict in-field performance. Compression tests were performed using a 600 kip MTS hydraulic load frame. Fig. 4.2 shows a typical compression test setup. The specimens were placed in the load frame and centered to the bearing plates. The load frame was operated in stroke control with a testing rate of 0.10 in. per minute to achieve maximum load in approximately 10 minutes. Testing was performed until the specimen failed, or until the load frame reached its capacity of 600 kips.

FIG. 4.2. Typical Setup for Compression Testing of Laboratory Repaired Timber Piles

4.3 Flexural Tests for Laboratory Repaired Timber Piles

Timber piles can be subject to loading that causes bending. Therefore, it is necessary to perform flexural testing on the repaired timber piles. The flexural testing was performed on eight 3-ft specimens with a span to depth ratio of about 4:1 using a 300 kip Tinius Olsen universal testing machine. A typical bending test setup is shown in Fig. 4.3. Four-point bending was used on all bending specimens as depicted schematically in Fig. 4.4. A digital dial gauge was used to measure the crosshead displacements while the specimens were loaded to their ultimate capacities.

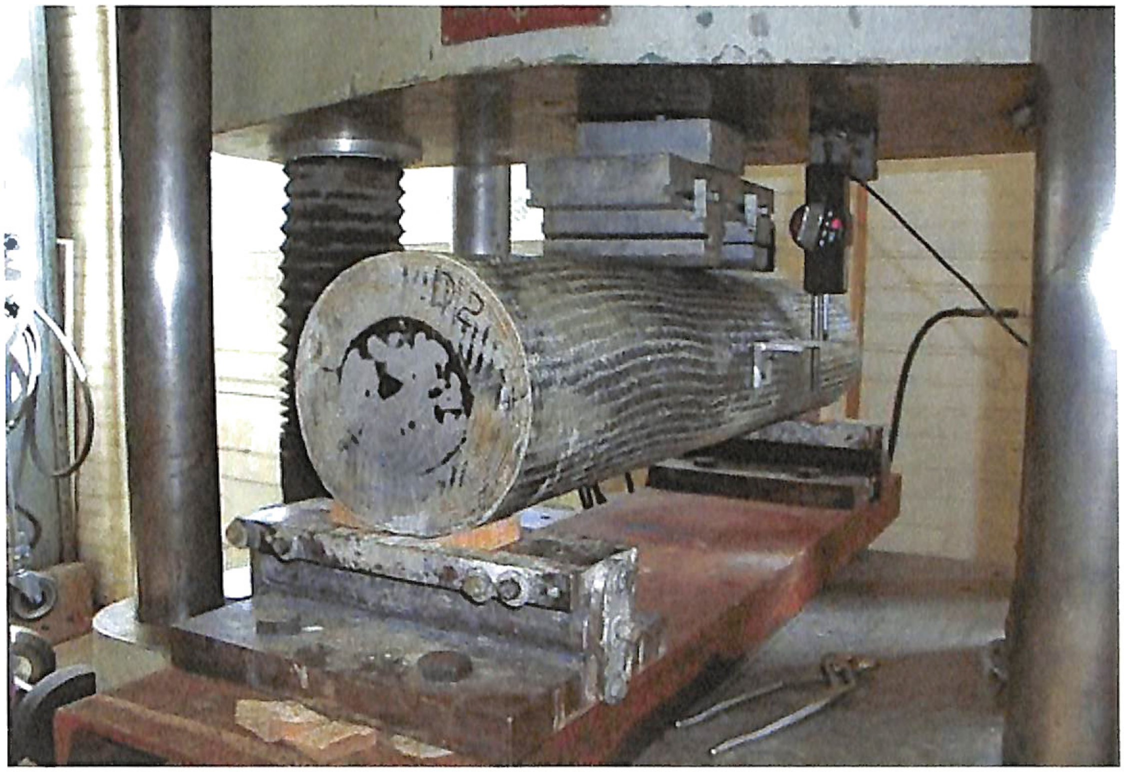


FIG. 4.3. Typical Setup for Flexural Testing of Laboratory Repaired Timber Piles

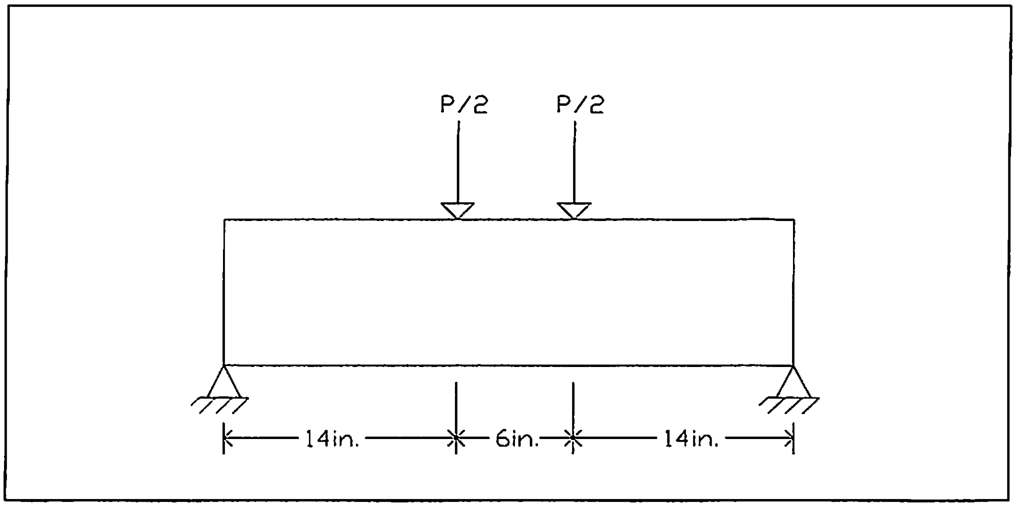


FIG. 4.4. Four-point Flexure for Bending Specimens

CHAPTER 5

TEST RESULTS

5.1 Compression Test Results for Laboratory Fabricated Cylinders

The test results of the cylinders tested in compression are presented in Table 5.1. These results provide a basic understanding of the behaviors and failure mechanisms of each repair technique.

TABLE 5.1. Summary of Compression Test Results for Epoxy-aggregate Cylinders

Specimen	No.	Max. Loading (kips)	Max. Compressive Stress (psi)	Avg. Compressive Stress (psi)	% Increase
Unreinforced	1	96	7,600	7,460	--
	2	90	7,142		
	3	96	7,639		
Transverse Fiberglass Reinforced	4	149	11,817	12,722	+70
	5	171	13,628		
Transverse and Longitudinal Fiberglass Reinforced	6	168	13,329	13,727	+84
	7	178	14,125		

5.1.1 Unreinforced

The unreinforced cylinders failed at an average maximum compressive stress of 7460 psi. Fig. 5.1 shows the load versus displacement diagram for the unreinforced cylinders. All three cylinders underwent post-yielding displacement and experienced excessive spalling and splitting as shown in Fig. 5.2. Under axial compression, they expanded normal to the loading direction due to the Poisson's effect and splitting.

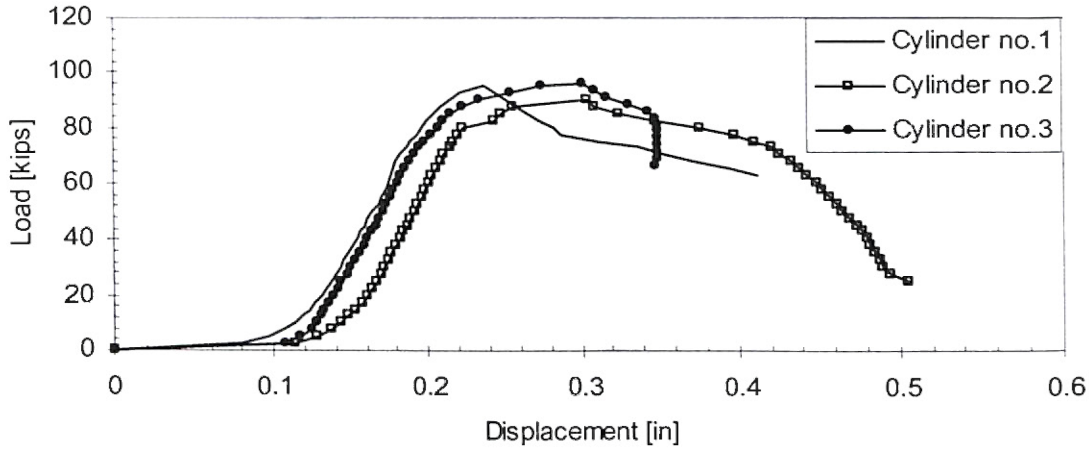


FIG. 5.1. Load-displacement Diagram for Unreinforced Laboratory Fabricated Cylinders

FIG. 5.2. Compression Failure of Unreinforced Laboratory Fabricated Cylinders

5.1.2. Transverse Fiberglass Reinforced

The presence of fiberglass reinforcement increased the compressive strength of the unreinforced cylinders by 70 percent. The load-displacement diagram for transversely reinforced cylinders is shown in Fig. 5.3. The stiffness of the specimens increased with the loading. The transverse reinforcement effectively controlled the radial expansion of the cylinders. The spalling of the unreinforced cylinders was replaced by the breaking of glass fibers as shown in Fig. 5.4. It was caused by the hoop stress acting on the fiberglass under compression loading.

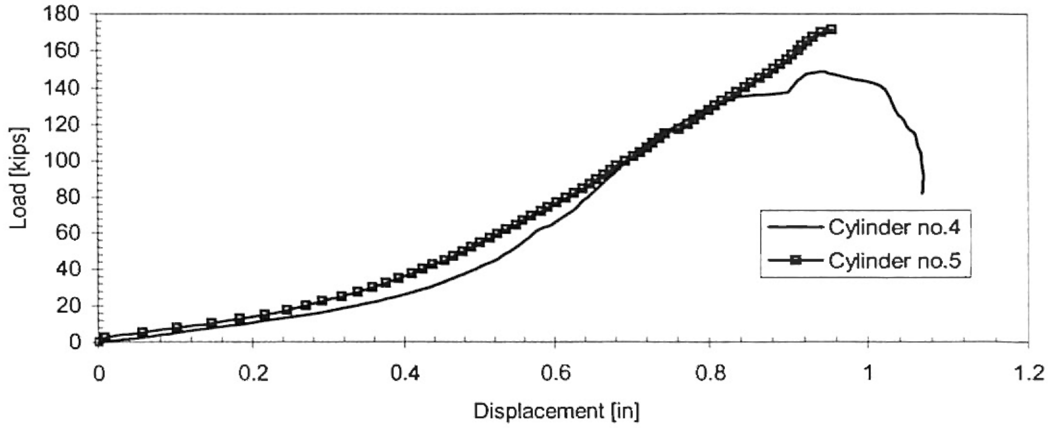


FIG. 5.3. Load-displacement Diagram for Laboratory Fabricated Cylinders with Transverse Fiberglass Reinforcement

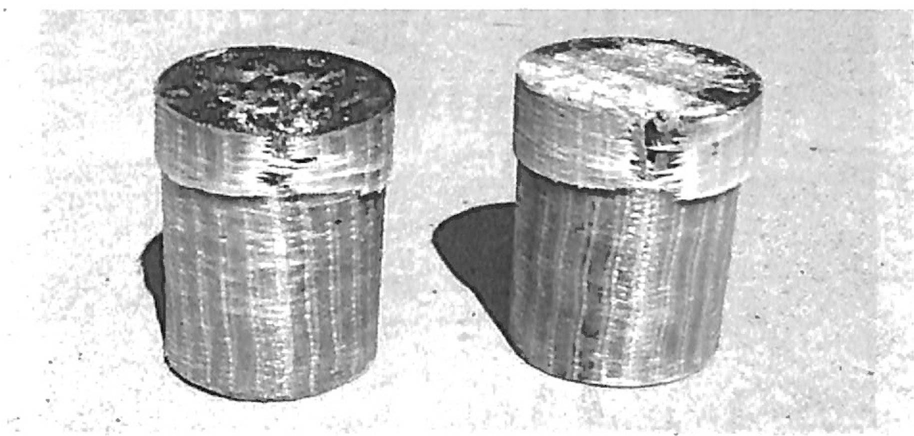


FIG. 5.4. Compression Failure of Laboratory Fabricated Cylinders with Transverse Fiberglass Reinforcement

5.1.3 Transverse and Longitudinal Fiberglass Reinforced

An 84 percent increase in compressive stress over unreinforced specimens was found when both transverse and longitudinal fiberglass reinforcement were used. Fig. 5.5 shows the load vs. displacement diagram for cylinders with transverse and longitudinal reinforcement. The same failure phenomenon as the cylinders with only transverse fiberglass reinforcement was observed as shown in Fig. 5.3. Figure 5.6 shows the cylinders with transverse and longitudinal fiberglass reinforcement after they reached ultimate load.

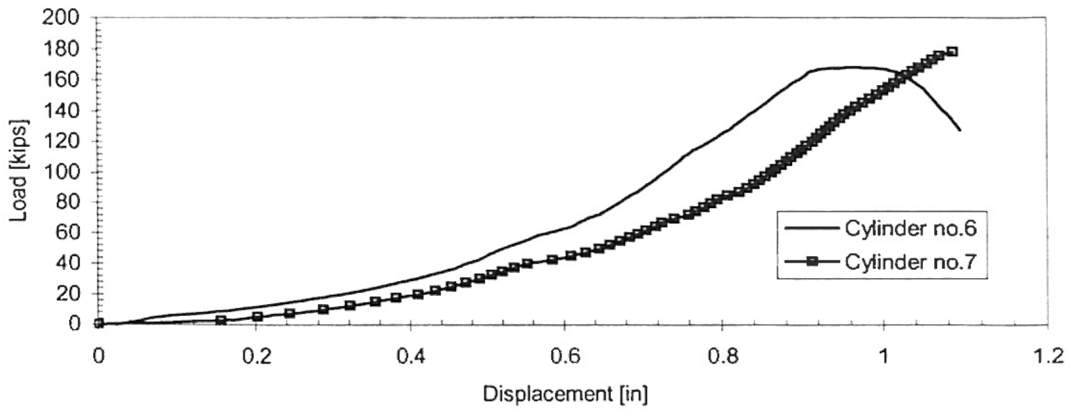


FIG. 5.5. Load-displacement Diagram for Laboratory Fabricated Cylinders with Transverse and Longitudinal Fiberglass Reinforcement

FIG. 5.6. Compression Failure of Laboratory Fabricated Cylinders with Transverse and Longitudinal Fiberglass Reinforcement

5.2 Compression Test Results for Laboratory Repaired Timber Piles

Compression failure varied within every different repair pile types. Table 5.2 is the summary of the test results for the laboratory repaired timber piles tested in compression. The specimens within the same repair pile type failed in the same manner and their maximum compressive stresses were mostly identical.

TABLE 5.2. Summary of Compression Test Results for Laboratory Repaired Piles

Specimen	Pile No.	Max. Loading (kips)	Max. Compressive Stress (psi)	Avg. Compressive Stress (psi)	% Increase
Control Specimen	A5	101	1,326	1,507	--
	B1	110	1,687		
Repaired Core	A4	206	2,850	3,416	+127
	B2	282	3,981		
Repaired Core with Transverse Fiberglass Reinforcement	A1	425	6,191	6,256	+317
	A2	448	6,320		
Repaired Core with Transverse and Longitudinal Fiberglass Reinforcement	A3	478	6,748	6,969	+365
	B3	499	7,190		

5.2.1 Control Specimen

The control specimens failed at an average maximum compressive stress of 1507 psi. The load versus displacement diagram for the control specimens is shown in Fig. 5.7. Both specimens failed as the wood shell crushed as shown in Fig. 5.8.

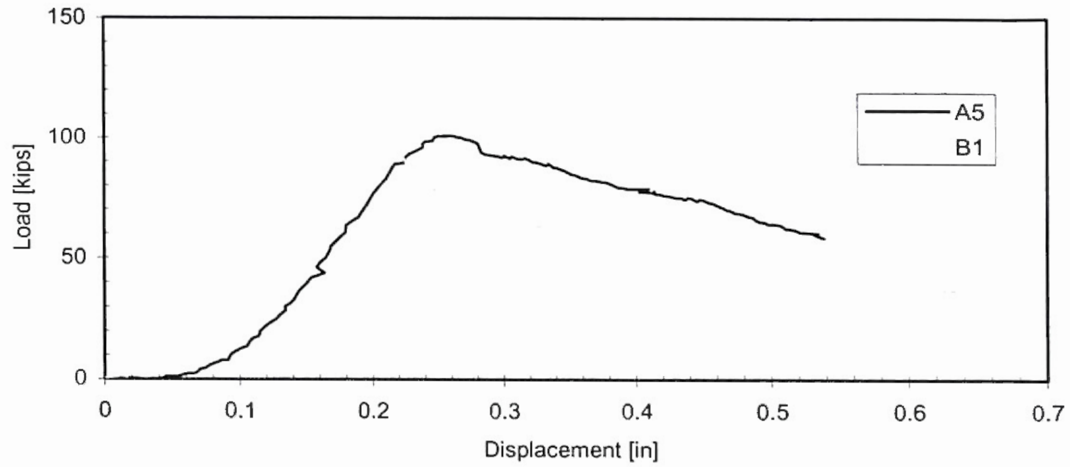


FIG. 5.7. Load-displacement Diagram for Control Specimen

FIG. 5.8. Failure of Control Specimen under Compression

5.2.2 Repaired Core

The repaired core provided a 127 percent increase in compression strength over the control specimens. They failed at an average maximum compressive stress of 3416 psi. The load versus displacement diagram is shown in Fig. 5.9. Both specimens experienced a similar failure as the control specimens. The wood shell spalled under loading. It caused the wood shell to separate from the core, followed by excessive splitting of the wood shell as shown in Fig. 5.10.

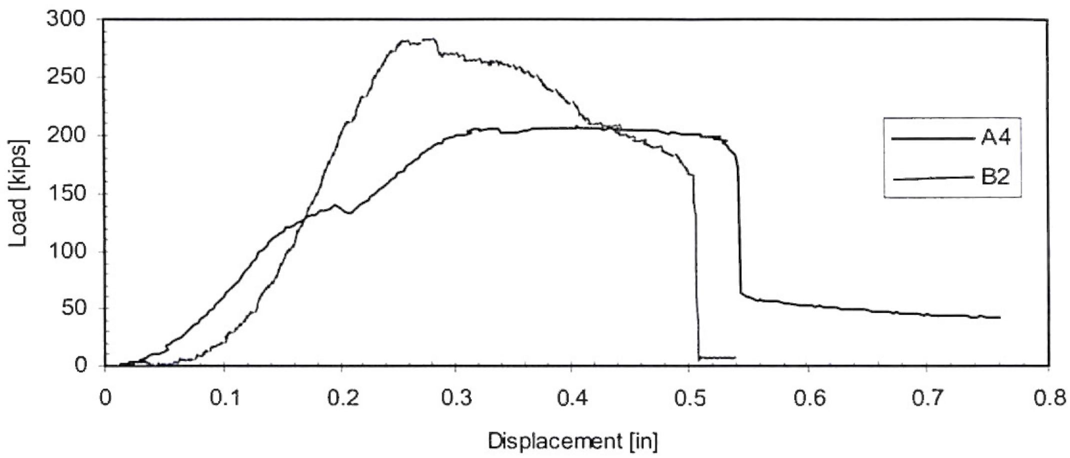


FIG. 5.9. Load-displacement Diagram for Core-repaired Timber Piles

FIG. 5.10. Compression Failure of Core-repaired Timber Piles

5.2.3 Repaired Core with Transverse Fiberglass Reinforcement

The specimens with repaired core and transverse reinforcement failed at an average compressive stress of 6256 psi. The transverse reinforcement improved the compressive strength of the unreinforced specimens by 317 percent. There was no sign of debonding between the wood shell and the repaired core. The load-displacement diagram shows in Fig. 5.11 indicated a ductile failure while the specimens experienced post-yielding displacement. Rupture of the fiberglass reinforcement is shown in Fig. 5.12.

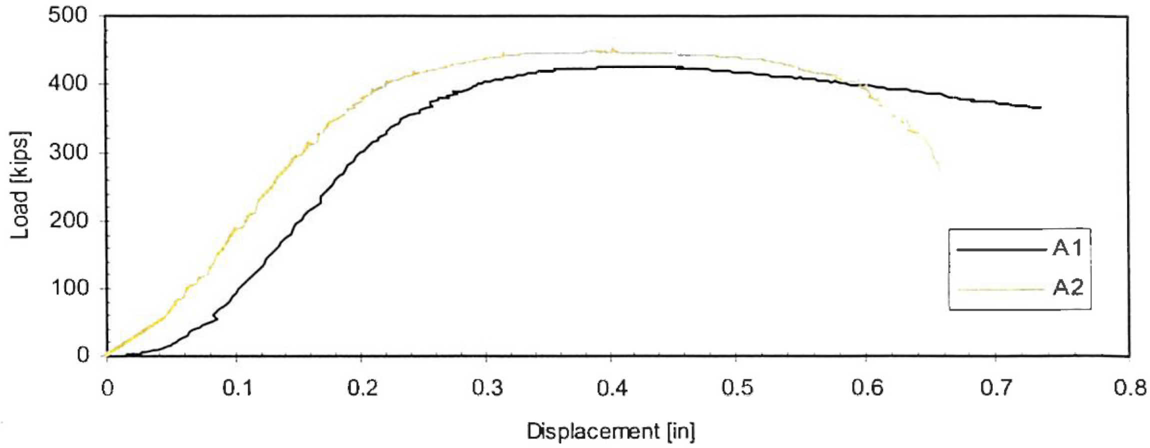


FIG. 5.11. Load-displacement Diagram for Core-repaired Timber Piles with Transverse Reinforcement

FIG. 5.12. Compression Failure of Core-repaired Timber Piles with Transverse Reinforcement

5.2.4 Repaired Core with Transverse and Longitudinal Fiberglass Reinforcement

The piles with repaired core, and transverse and longitudinal fiberglass reinforcement displayed a behavior similar to the specimens with only transverse fiberglass reinforcement. The addition of the longitudinal fiberglass reinforcement provided a strength enhancement of 11 percent to the pre-existing transverse reinforcement. Fig. 5.13 shows the load versus displacement for the specimens. The hoop stress acting against the fiberglass caused peeling of the fiber all around the pile perimeter as shown in Fig. 5.14.

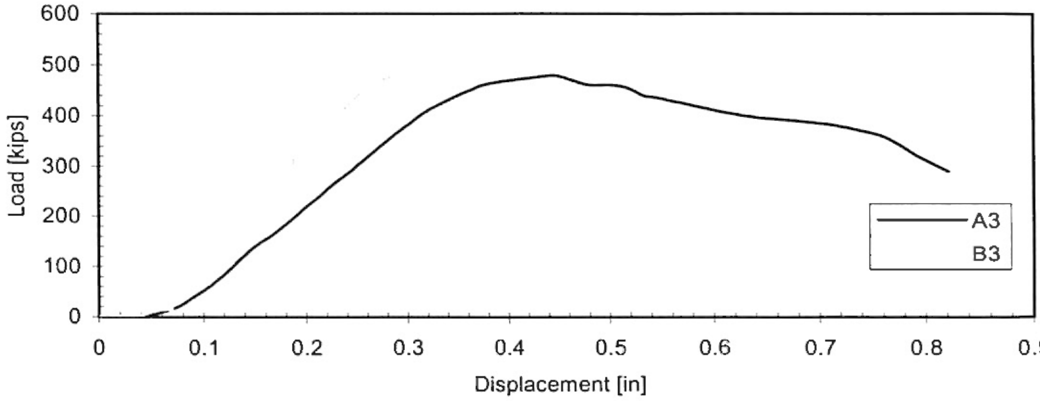


FIG. 5.13. Load-displacement Diagram for Core-repaired Piles with Transverse and Longitudinal Reinforcement

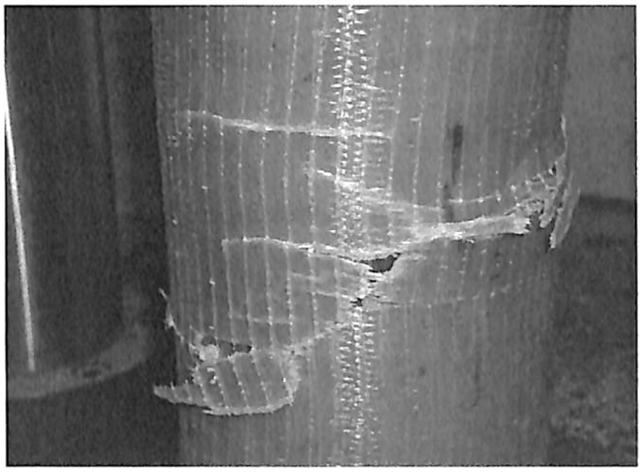


FIG. 5.14. Fiber Rupture of Core-repaired Timber Piles with Transverse and Longitudinal Reinforcement

5.3 Compression Test Results for Field Repaired Timber Piles

The compression performance of the field repaired piles depends heavily on the repair techniques. Table 5.3 gives the summary of the test results for the field repaired timber piles tested in compression.

TABLE 5.3. Summary of Compression Test Results for Field Repaired Timber Piles

Specimen	Pile No.	Max. Loading (kips)	Max. Compressive Stress (psi)
Repaired Core with Transverse Fiberglass Reinforcement	1	626	5,532
	2	614	5,430
Repaired Core without Fiberglass Reinforcement	3	279	2,468
Solid Wood Core with Transverse Fiberglass Reinforcement	4	356	3,148

5.3.1 Repaired Core with Transverse Fiberglass Reinforcement

Field repaired timber pile No. 1 with transverse fiberglass reinforcement and a repaired core exceeded the capacity of the MTS load frame at 626 kips. It is equivalent to 5532 psi of compressive stress. However, pile No. 2 with the identical repair technique failed at a maximum compressive stress of 5430 psi. There was no visible fracture or debonding between the wood shell and repaired core. The failure was resulted from the rupture of the transverse fiberglass reinforcement.

5.3.2 Repaired Core without Fiberglass Reinforcement

The core-repaired timber pile without any fiberglass reinforcement failed at a compressive stress of 2468 psi when the wood shell buckled under loading and debonded from the epoxy-aggregate core. The specimen crushed and split excessively. It only achieved about 45 percent of the capacity of the repaired timber piles with fiberglass reinforcement. This demonstrated the significance of the fiberglass reinforcement in the development of the repair techniques.

5.3.3 Solid Wood Core with Transverse Fiberglass Reinforcement

The repaired pile with a solid wood core and transverse fiberglass reinforcement failed at a maximum compressive stress of 3148 psi, which is approximately 60 percent of pile with the combination of repaired core and fiberglass reinforcement. Fiber pullout was observed while the wood core remained unharmed. The fiberglass reinforcement successfully provided material confinement to avoid crushing of the wood core.

The load and displacement diagrams for the field repaired timber piles are shown in Fig. 5.15. Fig. 5.16 shows the various failure modes of field repaired timber piles.

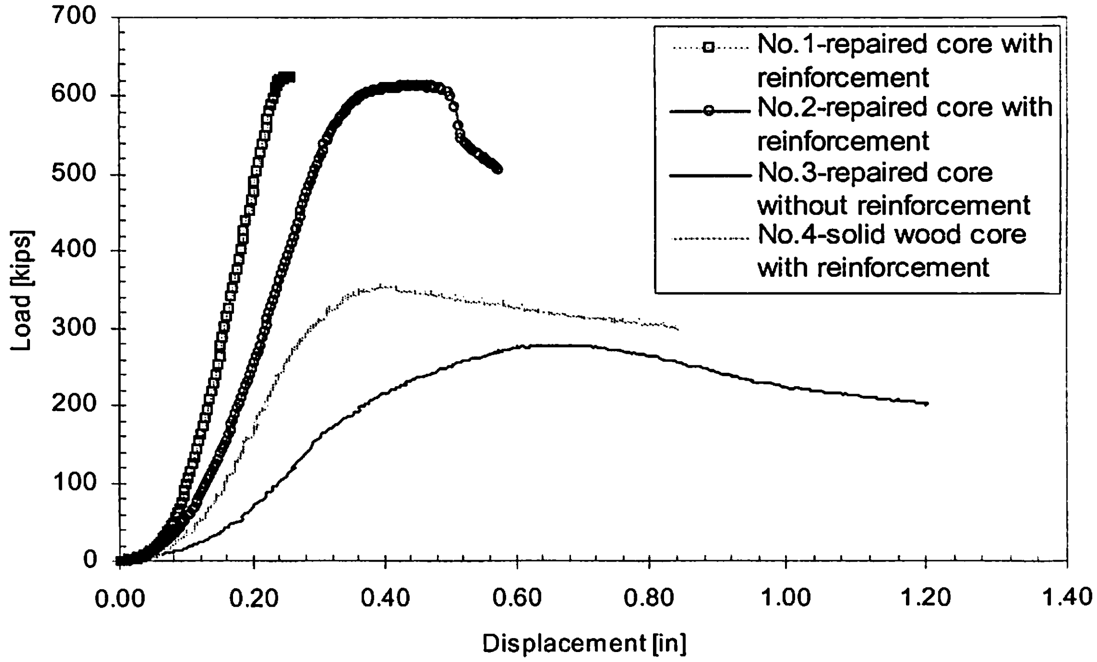


FIG. 5.15. Load-displacement Diagram for Field Repaired Timber Piles

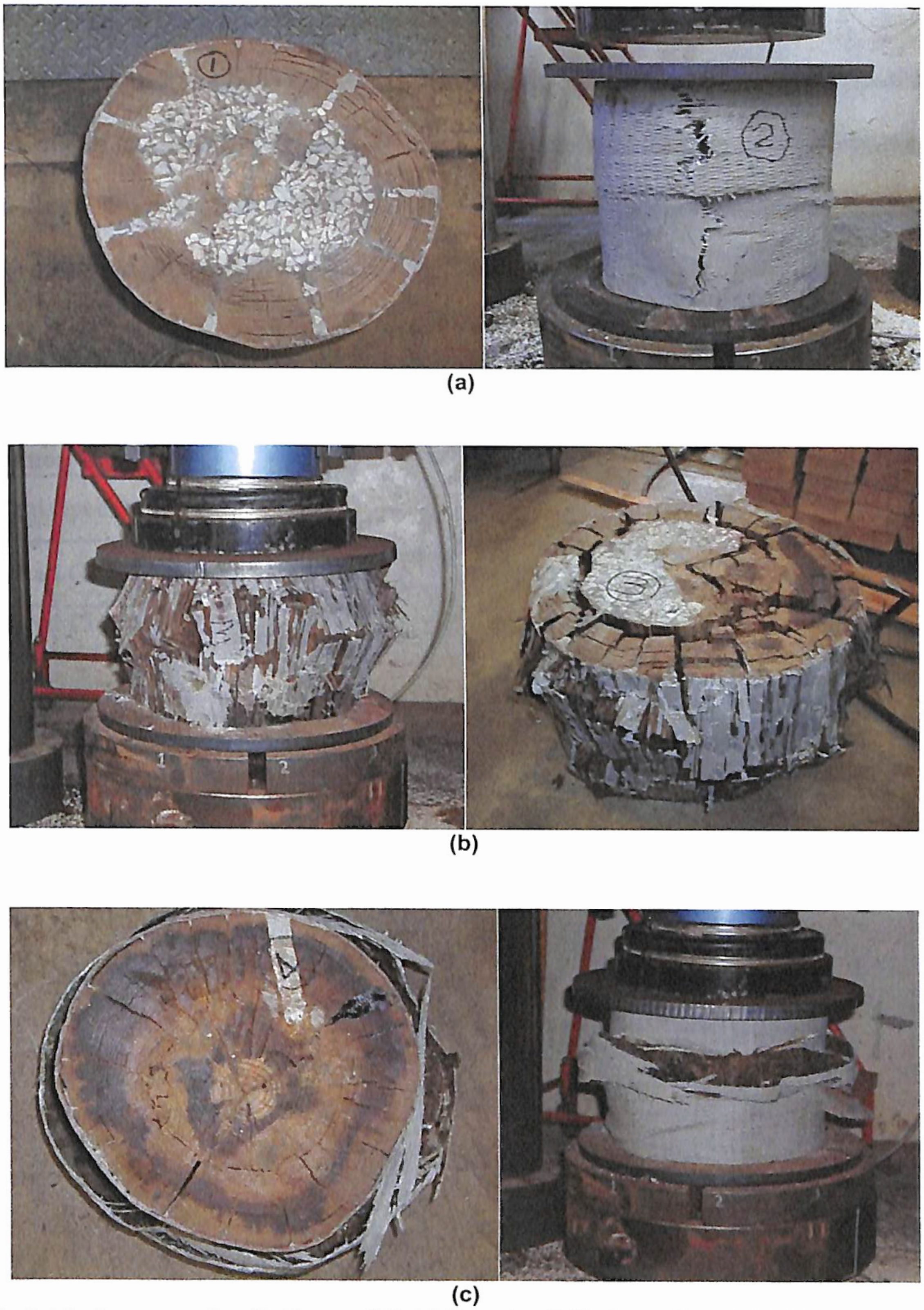


FIG. 5.16. Compression Failure of Field Repaired Timber piles: (a) Fiber Rupture of the Transverse Reinforcement; (b) Debonding of Wood Shell and Repaired Core; (c)Fiber pullout and rupture

5.4 Flexural Test Results for Laboratory Repaired Timber Piles

Most of the specimens tested in flexure did not failed in bending due to their low span to depth ratio. Table 5.4 gives the summary of the stresses that caused failure for these specimens regardless of their failure mechanisms. Localized crushing at loading points was visibly observed on bending specimens as shown in Fig. 5.17.

Table 5.4. Summary of Flexural Test Results for Laboratory Repaired Timber Piles

Specimen	Pile No.	Diameter (in.)	Max. Loading (lbs)	Max. Stress (psi)	Avg. Stress (psi)	Failure
Control Specimen	C3	9.25	5,600	504	607	Crushing
	D3	8.60	6,300	710		
Repaired Core	C4	8.50	37,200	4,319	4,980	Flexure
	D4	8.75	53,000	5,641		Shear
Repaired Core with Transverse Fiberglass Reinforcement	C2	9.00	67,500	6,602	6,581	Shear
	D2	8.50	56,500	6,560		
Repaired Core with Transverse and Longitudinal Reinforcement	C1	9.75	79,500	6,116	7,064	Shear
	D1	8.50	69,000	8,011		Flexure

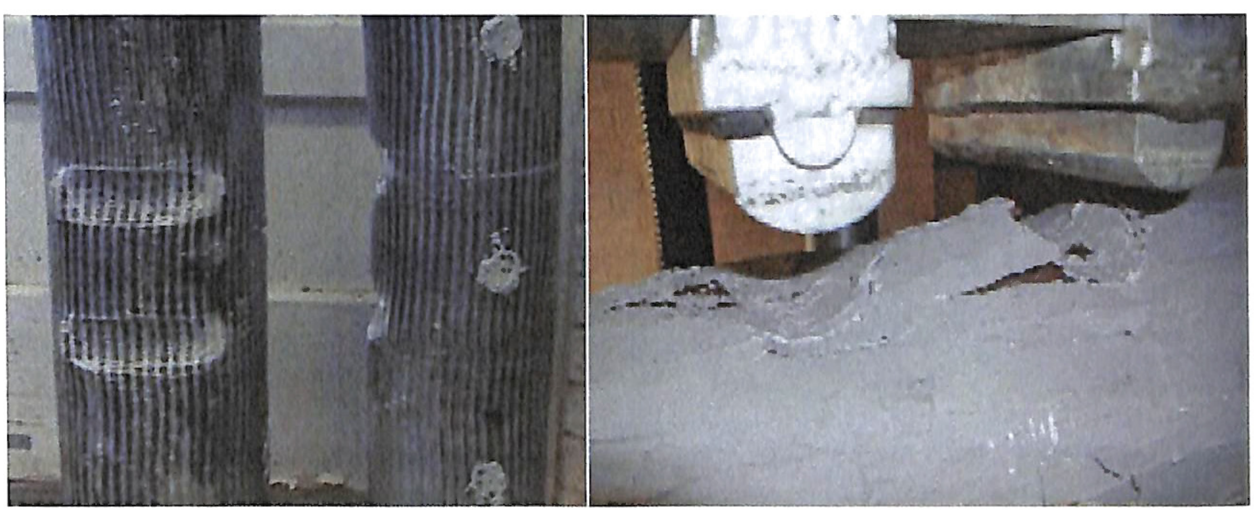


FIG. 5.17. Localized Crushing at Loading Points on Flexural Specimens

5.4.1 Control Specimen

Specimen C3 and D3 crushed at a low average stress of 607 psi. The load versus displacement diagram for the control specimens is shown in Fig. 5.18. Splitting of the wood along its length as shown in Fig. 5.19 was caused by tension acting perpendicular to the grain. The real flexural strengths of specimens C3 and D3 are undetermined.

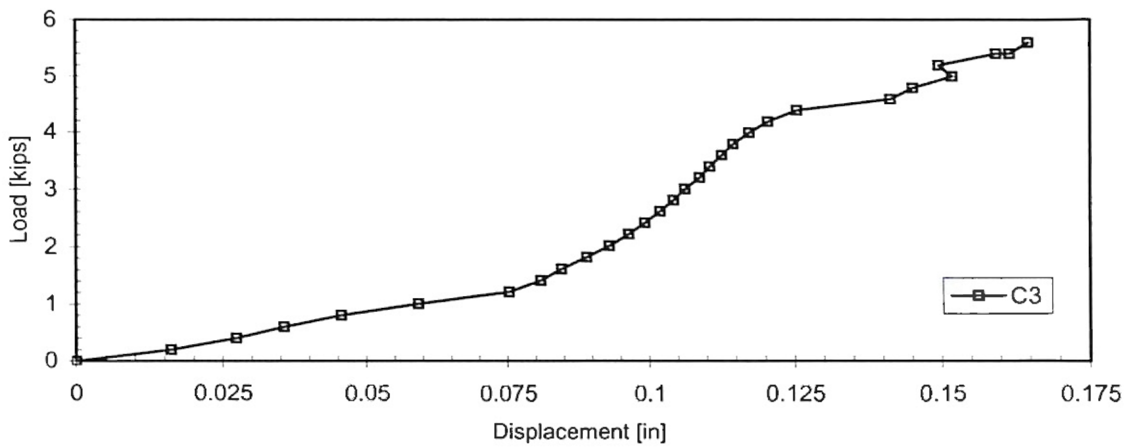


FIG. 5.18. Load-displacement Diagram of Control Specimen

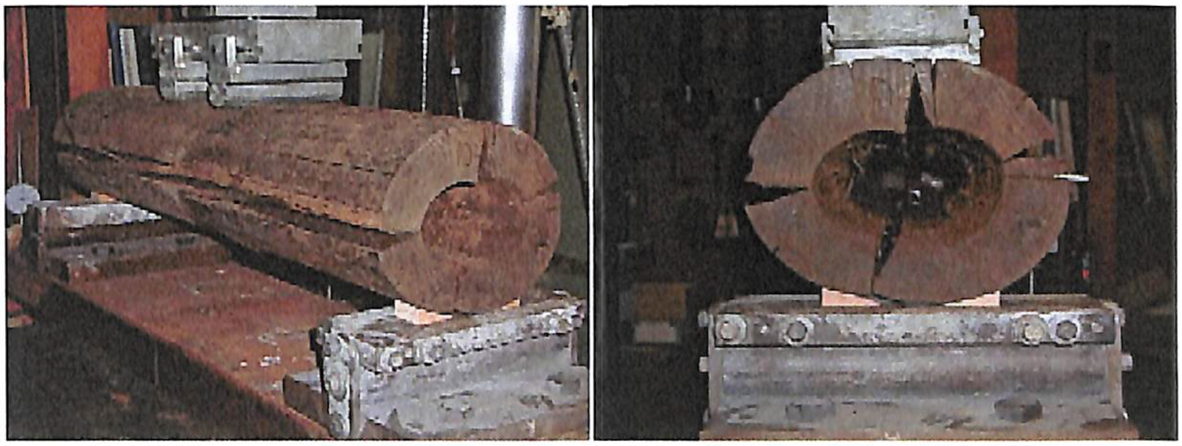


FIG. 5.19. Splitting of Control Specimen under Four Point Bending

5.4.2 Repaired Core

The core-repaired timber piles failed at an average stress of 4980 psi. The load versus displacement diagram is shown in Fig. 5.20. There is no evidence to identify which specimen represented the actual behavior of the core-repaired timber piles. These specimens experienced different failure as shown in Fig. 5.21. Flexural failure occurred on specimen C4, while cracks propagated at its midspan along with the loading. Conversely, specimen D4 failed in shear that caused the wood shell to split. There is no indication of interfacial debonding between the core and the wood shell in either specimen. The bonding for the composite was considered sufficient.

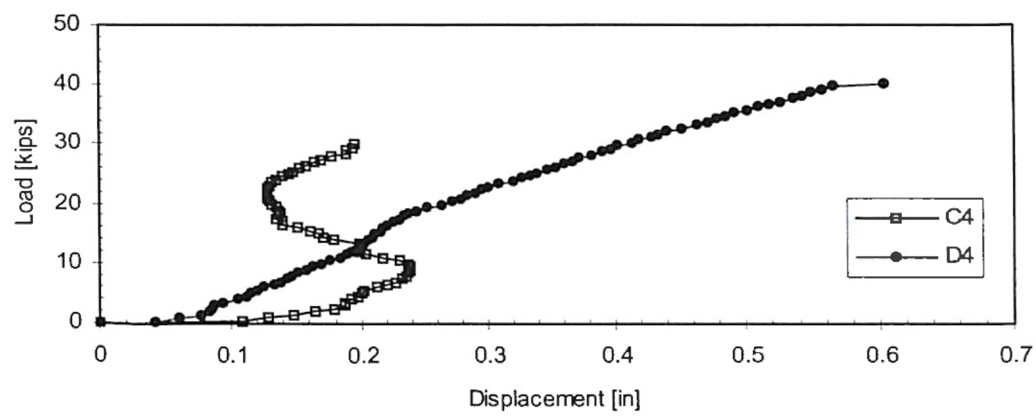
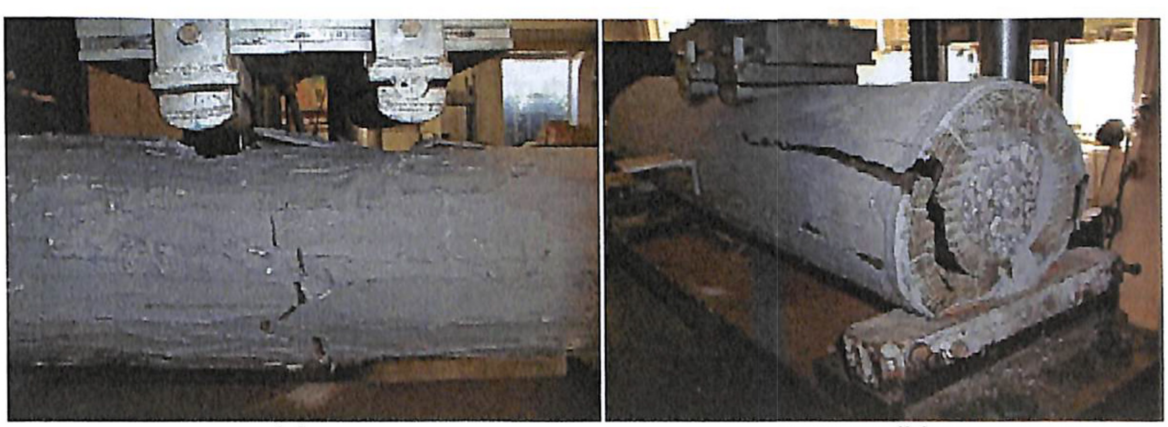


FIG. 5.20. Load-displacement Diagram for Timber Piles with Repaired Core



(a) (b)

FIG. 5.21. Failures of Timber Piles with Repaired Core: (a) Flexural Failure on Specimen C4; (b) Shear Failure on Specimen D4

5.4.3 Repaired Core with Transverse Fiberglass Reinforcement

The addition of transverse fiberglass reinforcement enhanced the strength of specimens C2 and D2 compared to the specimens with a repaired core but no fiberglass reinforcement. The load-displacement diagram shows that the specimens underwent post-yielding displacement as shown in Fig. 5.22. Failure occurred at an average stress of 6580 psi and both specimens failed in a similar fashion, i.e. bond failure between fiberglass reinforcement and wood shell as shown in Fig. 5.23. Bond slip at the interface of the repaired core and wood shell occurred in these specimens, thus affecting their performance. There was no significant fiber rupture in either specimen.

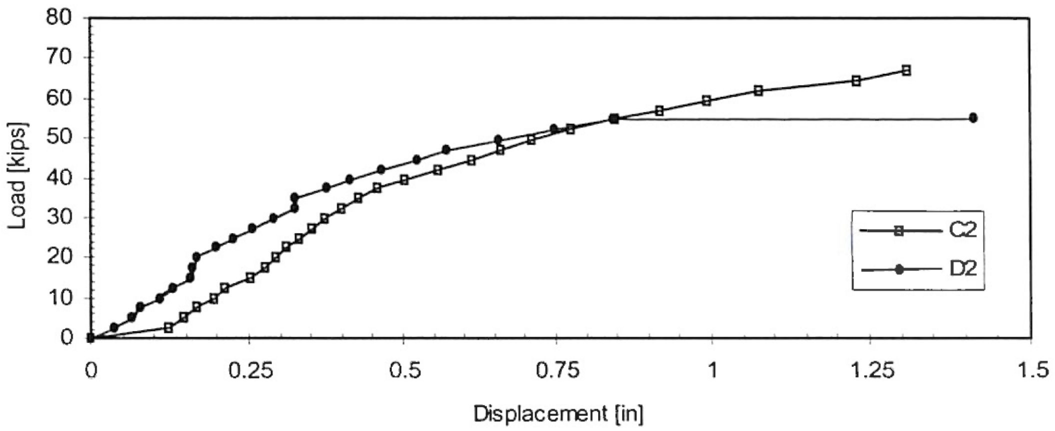


FIG. 5.22. Load-displacement Diagram for Core-repaired Timber Piles with Transverse Reinforcement

FIG. 5.23. Delamination of Fiberglass Reinforcement

5.4.4 Repaired Core with Transverse and Longitudinal Fiberglass Reinforcement

The contribution of longitudinal fiberglass reinforcement in specimen C1 cannot be identified, because specimen C1 failed in shear. Conversely, specimen D1, which was failed by true bending, achieved a maximum bending stress of 8011 psi. This is a 22 percent increase over the pile type with only transverse fiberglass reinforcement, and 42 percent increase over the pile type with only the core-repaired. However, the longitudinal fiberglass reinforcement did not improve their ductility. Fig. 5.24 presents the load versus displacement diagram for specimen C1 and D1.

Tearing of the longitudinal fiber at midspan only occurred on specimen D1 due to true bending as shown in Fig. 5.25. The remaining continuous fibers still provided some strength and ductility until the specimen reached maximum loading. In specimen C1, there was no severe fiber rupture and the failure was caused by bond failure.

Localized slippage of the repaired core within the wood shell was observed in both specimens. It led to visible protrusion of the core. Interfacial bond failure between fiberglass reinforcement and wood shell was found in both specimens. Fig. 5.26 shows the bond failure for specimen C1 and D1. The separation of all the interfaces led to the conclusion that shear was critical and the bonding between the core and surrounding wood needed to be improved.

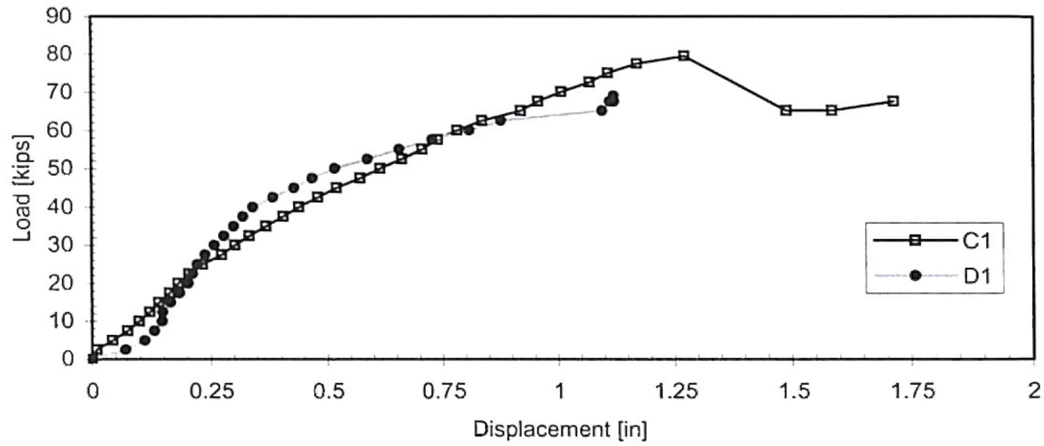


FIG. 5.24. Load-displacement Diagram for Core-repaired Timber Piles with Transverse and Longitudinal Reinforcement

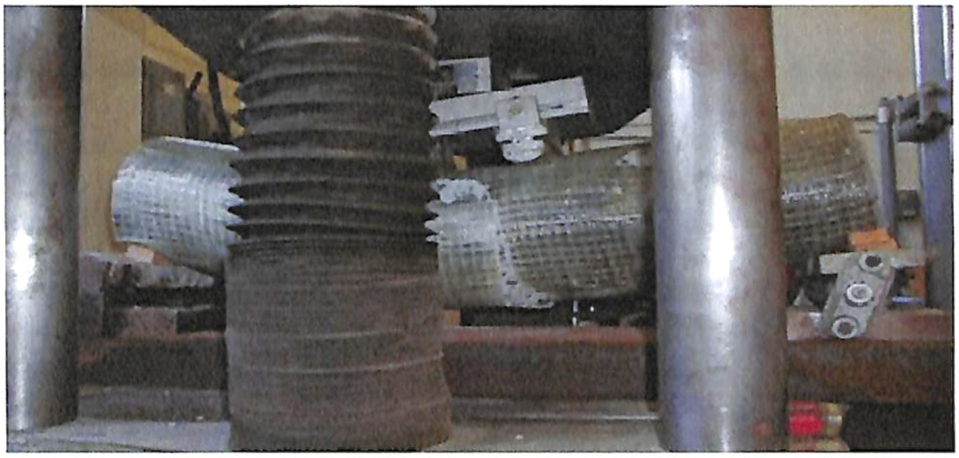


FIG. 5.25. Fiber Rupture at Midspan of Specimen D1

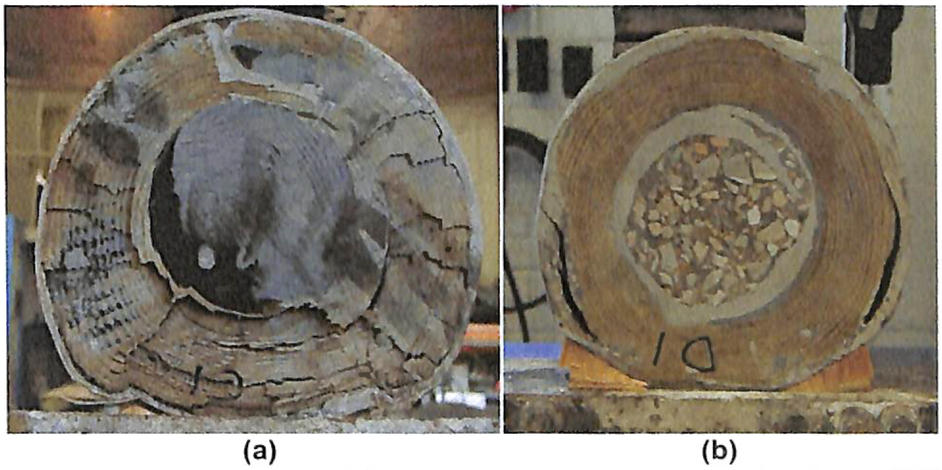


FIG. 5.26. Bond Failure: (a) Bond Slip of the Core; (b) Delamination of Fiberglass Reinforcement

5.5 Comparison of Laboratory Test Results with Published Compressive Strengths

The criterion for the newly developed repair is that it must meet or even exceed the performance of the sound timber piles. Therefore, the test results of the repaired timber piles have been compared to the established design values. Nominal bending strength, compressive strength parallel to the grain, shear strength and modulus of elasticity values of several species of wood possibly used for piles were taken from the *National Design Specification for Wood construction* (American Forest & Paper Association 1997). These values are based on tests of small-clear material values and adjusted by various strength-reduction factors. The process of adjusting the small-clear material values to design values, together with the various strength-reduction factors are presented in *ASTM standard D25-98* (ASTM 1999). Summary information regarding the small-clear material data is provided in the *Wood Handbook: Wood as an Engineering Material* (Forest Products Laboratory 1987) as shown in Table 5.5. Values from both sources are used for comparisons with the test results of laboratory repaired timber piles.

TABLE 5.5. Wood Handbook Average Mechanical Properties

	Compression F_c (psi)		Bending F_b (psi)		Shear F_v (psi)	
Species	green	dry	green	dry	green	dry
Pacific Coast Douglas Fir	3,780	7,230	7,700	12,400	900	1,130
Red Oak	3,680	6,820	8,300	14,000	1,290	2,080
Red Pine	2,730	6,070	5,800	11,000	690	1,210
Southern Pine	3,530	7,270	7,400	13,100	910	1,390

The bending strength, compression strength, and shear strength values from the nominal *NDS* design values are based on a 10-year load duration, while the strength values from the *Wood Handbook* are based on a 10-minute load duration. Therefore, the nominal design values must be adjusted to 10-minute load duration by applying load duration factor (C_D) of 1.6. Load duration factor adjustment for the modulus of elasticity was not necessary, since all published values were based on short-term loading. Nominal design values were also reduced by the single pile factor (C_{sp}) of 0.8. A temperature factor (C_t) of 1.0 was used due to normal temperature condition occurring during testing. Due to constant weathering of the timber piles, it is reasonable to assume wet service condition. The adjustment for moisture content was eliminated. The untreated factor (C_u) was taken as 1.0 for treated timber piles; column stability factor (C_P) and critical section factor (C_{cs}) were taken as 1.0, assuming adequately braced members. For timber piles with circumference less than 43 in., the size factor (C_F) is not applicable. The allowable design values for round timber piles are presented in Table 5.6.

TABLE 5.6. NDS Design Values for Round Timber Piles

	Compression		Bending		Shear	
Species	F_c (psi)	F_c' [a] (psi)	F_b (psi)	F_b' [b] (psi)	F_v (psi)	F_v' [c] (psi)
Pacific Coast Douglas Fir	1,250	1,600	2,450	3,136	115	184
Red Oak	1,100	1,408	2,450	3,136	135	216
Red Pine	900	1,152	1,900	2,432	85	136
Southern Pine	1,200	1,536	2,400	3,072	110	176

[a] $F'_c = F_c\ (C_D\ C_t\ C_u\ C_{sp}\ C_P\ C_{cs})$
[b] $F'_b = F_b\ (C_D\ C_t\ C_u\ C_F\ C_{sp})$
[c] $F'_c = F_c\ (C_D\ C_t\ C_u)$

Through the use of the design values published in NDS and data from Wood Handbook, it is not difficult to see that epoxy and fiberglass reinforcement effectively recovered the original strength of the decayed timber piles. Relative comparisons for bending and compressive strengths are presented in Table 5.7 and 5.8.

TABLE 5.7. Comparison of Laboratory Test Results with Published Flexural Strengths

		Wood Handbook	NDS
Published Mechanical Properties			
Wood Handbook Average Mechanical Properties	8,300 psi	--	165%
NDS Design Values	3,136 psi	-62%	--
Laboratory Repaired Piles			
Control Specimen	607 psi	-93%	-81%
Epoxy and Aggregate Repair	4,980 psi	-40%	59%
Repaired Core with Transverse Reinforcement	6,581 psi	-21%	110%
Repaired Core with Longitudinal and Transverse Reinforcement	7,064 psi	-15%	125%

TABLE 5.8. Comparison of Laboratory Test Results with Published Compressive Strengths

		Wood Handbook	NDS
Published Mechanical Properties			
Wood Handbook Average Mechanical Properties	3,780 psi	--	136%
NDS Design Values	1,600 psi	-58%	--
Laboratory Repaired Piles			
Control Specimen	1,507 psi	-60%	-6%
Epoxy and Aggregate Repair	3,416 psi	-10%	114%
Repaired Core with Transverse Reinforcement	6,256 psi	66%	291%
Repaired Core with Longitudinal and Transverse Reinforcement	6,969 psi	84%	336%
Field Repaired Piles			
Repaired Core without Reinforcement	2,468 psi	-35%	54%
Transverse Reinforcement with Wood Core	3,148 psi	-17%	97%
Transverse Reinforcement with Repaired Core	5,430 psi	44%	239%

The laboratory repaired timber piles with epoxy-aggregate repaired cores and transverse fiberglass reinforcement exceeded both Wood Handbook average compressive strengths and NDS design values. Similar results were obtained for the field repaired timber piles. Conversely, the laboratory repaired timber piles were only able to develop 80 percent of the average published bending strength from Wood Handbook, yet all the repaired piles exceeded the NDS design values for bending.

CHAPTER 6

ANALYSIS

The compression specimens were fabricated of two or more constituent materials and every material has their own specific material properties. While these materials are assumed to be firmly bonded, the specimen cannot be modeled as a single member, because each material behaves differently during loading. A limit state analysis was used to replace the complexity of the dynamic model. Instead of failing as a fully composite member, the materials failed successively under loading, until the specimen reached its maximum capacity.

The following assumptions were made to allow Hooke's law to be valid for this analysis.

i. The materials are linearly elastic.

ii. The materials are homogeneous within themselves.

iii. The nature of the boundary conditions remains unchanged during the entire deformation process.

The equation of equilibrium is not sufficient to determine the load acting on each material, because the specimens are statically indeterminate as shown in Fig. 6.1. There is only one equation of equilibrium and it contains three unknowns. Therefore, the unknowns cannot be determined by static equilibrium alone.

$$P_{total} = P_{eac} + P_{wood} + P_{fiber}$$

where, P_{total} = maximum capacity of specimen, lbs

P_{eac} = compression strength of epoxy-aggregate core, lbs

P_{wood} = compression strength of wood, lbs

P_{fiber} = compression strength of fiberglass, lbs

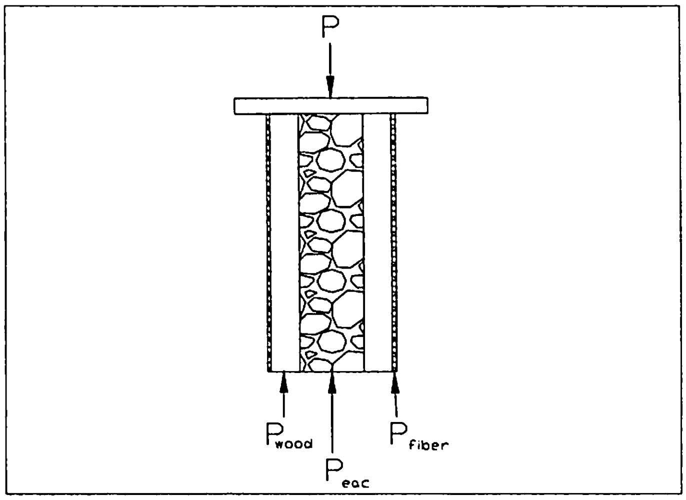


FIG. 6.1. Compression Specimen under loading

The equation of compatibility was applied to predict the maximum capacity of the specimens. When the specimen was axially loaded, it underwent three stages until the failure occurred:

i. Stage 1

Wood, epoxy-aggregate core, and fiberglass were compressed, all three materials deformed equally until wood reached its capacity and failed.

$$P_{stage\#1} = (AE|_{wood} + AE|_{eac} + AE|_{fiber}) \cdot \varepsilon|_{wood}$$

ii. Stage 2

Wood failed and was unable to carry the additional load. Epoxy-aggregate core and fiberglass provided the compression strength until the epoxy-aggregate core crushed.

$$P_{stage\#2} = (AE|_{eac} + AE|_{fiber}) \cdot \Delta\varepsilon|_{stage\#2}$$

iii. Stage 3

Only the fiberglass was carrying the additional load, until exceeding its compression strength. The specimen failure was considered at this point.

$$P_{stage\#3} = (AE|_{fiber}) \cdot \Delta\varepsilon|_{stage\#3}$$

where, $P_{stage\#1}$ = failure load for first material, lbs

$P_{stage\#2}$ = additional load for second material to reach failure, lbs

$P_{stage\#3}$ = additional load for third material to reach failure, lbs

A = cross sectional area, in^2

E = modulus of elasticity, psi

ε = strain

6.1 Control Specimen

The material properties of the wood used in the limit state analysis are the average mechanical values taken from *Wood Handbook: Wood as an Engineering Material* (Forest Products Laboratory 1987), as previously presented in Table 5.5.

Material Properties

$E|_{wood} = 1500000$ psi
$\sigma_c|_{wood} = 3780$ psi

$$\varepsilon|_{wood} = \frac{\sigma_c}{E} = \frac{3780}{1500000} = 0.00252$$

A5

$d = 9.85in^2$
$A = \pi(9.85^2 - 4^2) = 63.6in^2$

$P = \sigma_c \times A = 3780 \times 63.6 =$ **240.4 kips**

B1

$d = 9.10in^2$
$A = \pi(9.10^2 - 4^2) = 52.5in^2$

$P = \sigma_c \times A = 3780 \times 52.5 =$ **198.5 kips**

6.2 Repaired Core

Since the epoxy-aggregate core does not have an obvious yield point, the offset method was used to determine an arbitrary yield stress. A line was drawn parallel to the initial linear elastic portion of the stress-strain diagram, with a 0.002 strain offset. The offset method is shown in Fig. 6.2. The slope of the linear portion of the stress-strain curve equals the modulus of elasticity of the epoxy-aggregate cylinders. Table 6.1 is the summary of the material properties of epoxy-aggregate cylinders.

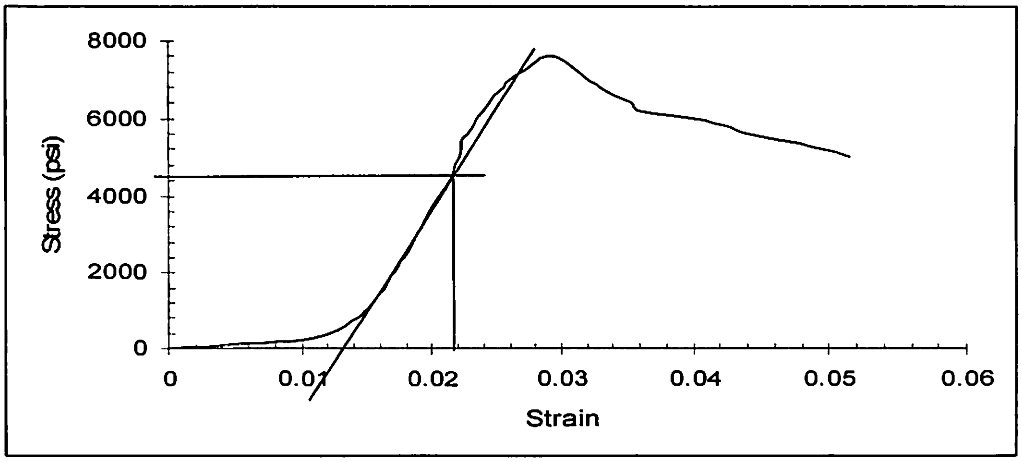


FIG. 6.2. Use of the Offset Method on Stress-Strain Diagram

TABLE 6.1. Summary of the Material Properties of Epoxy-Aggregate Cylinders

Cylinder No.	Displacement (in)	E (psi)	Yield Stress (psi)	Strain
1	0.065	585000	4780	0.00813
2	0.07	600000	5250	0.00875
3	0.07	618000	5410	0.00875

Material Properties

$E|_{wood} = 1500000$ psi
$\sigma_c|_{wood} = 3780$ psi
$\varepsilon|_{wood} = 0.00252$

$E|_{eac} = 600000$ psi
$\sigma_c|_{eac} = 5250$ psi
$\varepsilon|_{eac} = 0.00875$

A4

$d = 9.60in^2$

$A|_{wood} = \pi(9.60^2 - 4.0^2) = 59.8in^2$

$A|_{eac} = \frac{\pi}{4}(4.0)^2 = 12.57in^2$

<u>Stage 1</u>

$P_{stage\#1} = (AE|_{wood} + AE|_{eac}) \cdot \varepsilon|_{wood}$

$= [(59.8 \times 1500000) + (12.57 \times 600000)] \times 0.00252$

$= \boxed{245.0 \text{ kips}}$

<u>Stage 2</u>

$\Delta\varepsilon|_{stage\#2} = \varepsilon|_{eac} - \varepsilon|_{wood} = 0.00875 - 0.00252 = 0.00623$

$P_{stage\#2} = AE|_{eac} \cdot \Delta\varepsilon|_{stage\#2}$

$= 12.57 \times 600000 \times 0.00623$

$= \boxed{47.0 \text{ kips}}$

$P_{total} = P_{stage\#1} + P_{stage\#2} = 245 + 47 = \boxed{292.0 \text{ kips}}$

B2

$d = 9.50in^2$

$A|_{wood} = \pi(9.50^2 - 4.0^2) = 58.3in^2$

$A|_{eac} = \frac{\pi}{4}(4.0)^2 = 12.57in^2$

<u>Stage 1</u>

$P_{stage\#1} = (AE|_{wood} + AE|_{eac}) \cdot \varepsilon|_{wood}$

$= [(58.3 \times 1500000) + (12.57 \times 600000)] \times 0.00252$

$= \boxed{239.0 \text{ kips}}$

<u>Stage 2</u>

$\Delta\varepsilon|_{stage\#2} = \varepsilon|_{eac} - \varepsilon|_{wood} = 0.00875 - 0.00252 = 0.00623$

$P_{stage\#2} = AE|_{eac} \cdot \Delta\varepsilon|_{stage\#2}$

$= 12.57 \times 600000 \times 0.00623$

$= \boxed{47.0 \text{ kips}}$

$P_{total} = P_{stage\#1} + P_{stage\#2} = 239 + 47 = \boxed{286.0 \text{ kips}}$

6.3 Repaired Core with Transverse Fiberglass Reinforcement

Material Properties

$E|_{wood} = 1500000$ psi
$\sigma_c|_{wood} = 3780$ psi
$\varepsilon|_{wood} = 0.00252$

$E|_{eac} = 600000$ psi
$\sigma_c|_{eac} = 5250$ psi
$\varepsilon|_{eac} = 0.00875$

A1

$d = 9.35in^2$
$A|_{wood} = \pi(9.35^2 - 4.0^2) = 56.1in^2$
$A|_{eac} = \frac{\pi}{4}(4.0)^2 = 12.57in^2$

Stage 1

$P_{stage\#1} = (AE|_{wood} + AE|_{eac}) \cdot \varepsilon|_{wood}$

$= [(56.1 \times 1500000) + (12.57 \times 600000)] \times 0.00252$
$= \boxed{231.0 \text{ kips}}$

Stage 2

$\Delta\varepsilon|_{stage\#2} = \varepsilon|_{eac} - \varepsilon|_{wood} = 0.00875 - 0.00252 = 0.00623$
$P_{stage\#2} = AE|_{eac} \cdot \Delta\varepsilon|_{stage\#2}$
$= 12.57 \times 600000 \times 0.00623$
$= \boxed{47.0 \text{ kips}}$

$P_{total} = P_{stage\#1} + P_{stage\#2} = 231 + 47 = \boxed{278.0 \text{ kips}}$

A2

$d = 9.50in^2$
$A|_{wood} = \pi(9.50^2 - 4.0^2) = 58.3in^2$
$A|_{eac} = \frac{\pi}{4}(4.0)^2 = 12.57in^2$

Stage 1

$$P_{stage\#1} = (AE|_{wood} + AE|_{eac}) \cdot \varepsilon|_{wood}$$
$$= [(58.3 \times 1500000) + (12.57 \times 600000)] \times 0.00252$$
$$= \boxed{239.4 \text{ kips}}$$

Stage 2

$$\Delta\varepsilon|_{stage\#2} = \varepsilon|_{eac} - \varepsilon|_{wood} = 0.00875 - 0.00252 = 0.00623$$
$$P_{stage\#2} = AE|_{eac} \cdot \Delta\varepsilon|_{stage\#2}$$
$$= 12.57 \times 600000 \times 0.00623$$
$$= \boxed{47.0 \text{ kips}}$$

$$P_{total} = P_{stage\#1} + P_{stage\#2} = 239.4 + 47.0 = \boxed{286.4 \text{ kips}}$$

Although the fiberglass with transverse orientation did not provide compression strength directly, its presence increased the compression strength of the repaired timber piles by 80 percent over the timber piles with only repaired core. Therefore, it is rational to believe that the increase in compression strength was due to the confinement provided by the transverse fiberglass reinforcement. As the specimen was compressed longitudinally, it expanded laterally due to the Poisson's effect. In order for the Poisson's effect to be valid, the material must be homogeneous, and the elastic properties must be the same in all directions perpendicular to the longitudinal axis. Since the fiberglass is an orthotropic material, the elastic properties are the same throughout its transverse direction. The transverse fiberglass reinforcement resisted lateral expansion of the wood and epoxy-aggregate core. The loading caused the transverse fiberglass reinforcement to expand radially, and become loaded in tension until it reached its maximum tensile strength. The contribution of the transverse fiberglass reinforcement was not included in this analysis. The Poisson's effect on the repaired timber piles will be studied thoroughly in future research.

6.4 Repaired Core with Transverse and Longitudinal Fiberglass Reinforcement

The elastic properties of the longitudinal fiberglass reinforcement are obtained from the material safety data sheets provided in Appendix B.

Material Properties
$E\,|_{wood} = 1500000$ psi $\sigma_c\,|_{wood} = 3780$ psi $\varepsilon\,|_{wood} = 0.00252$
$E\,|_{eac} = 600000$ psi $\sigma_c\,|_{eac} = 5250$ psi $\varepsilon\,|_{eac} = 0.00875$
$E\,|_{long\cdot fiber} = 3600000$ psi $\sigma_c\,|_{long\cdot fiber} = 78500$ psi $\varepsilon\,|_{long.fiber} = \frac{\sigma_c}{E} = \frac{78500}{3600000} = 0.0218$

A3

$$d = 9.50 in^2$$

$$A\,|_{wood} = \pi\left(9.50^2 - 4.0^2\right) = 58.3 in^2$$

$$A\,|_{eac} = \frac{\pi}{4}(4.0)^2 = 12.57 in^2$$

$$A\,|_{long.fiber} = 2\pi r t = 2\pi\left(\frac{9.50}{2} + 0.04\right)(0.08) = 2.40 in^2$$

Stage 1

$$\begin{aligned} P_{stage\#1} &= (AE\,|_{wood} + AE\,|_{eac} + AE\,|_{long.fiber}) \cdot \varepsilon\,|_{wood} \\ &= [(58.3 \times 1500000) + (12.57 \times 600000) + (2.40 \times 3600000)] \times 0.00252 \\ &= \boxed{261.0 \text{ kips}} \end{aligned}$$

Stage 2

$$\Delta\varepsilon\,|_{stage\#2} = \varepsilon\,|_{eac} - \varepsilon\,|_{wood} = 0.00875 - 0.00252 = 0.00623$$

$$\begin{aligned} P_{stage\#2} &= (AE\,|_{eac} + AE\,|_{long.fiber}) \cdot \Delta\varepsilon\,|_{stage\#2} \\ &= [(12.57 \times 600000) + (2.40 \times 3600000)] \times 0.00623 \\ &= \boxed{100.8 \text{ kips}} \end{aligned}$$

Stage 3

$$\Delta\varepsilon|_{stage\#3} = \varepsilon|_{long.fiber} - \varepsilon|_{eac} = 0.0218 - 0.00875 = 0.01305$$

$$\begin{aligned} P_{stage\#3} &= AE|_{long.fiber} \cdot \Delta\varepsilon|_{stage\#3} \\ &= 2.40 \times 3600000 \times 0.01305 \\ &= \boxed{112.8 \text{ kips}} \end{aligned}$$

$$P_{total} = P_{stage\#1} + P_{stage\#2} + P_{stage\#3} = 261.0 + 100.8 + 112.8 = \boxed{474.6 \text{ kips}}$$

B3

$$d = 9.40 in^2$$

$$A|_{wood} = \pi(9.40^2 - 4.0^2) = 56.8 in^2$$

$$A|_{eac} = \frac{\pi}{4}(4.0)^2 = 12.57 in^2$$

$$A|_{long.fiber} = 2\pi r t = 2\pi\left(\frac{9.40}{2} + 0.04\right)(0.08) = 2.38 in^2$$

Stage 1

$$\begin{aligned} P_{stage\#1} &= (AE|_{wood} + AE|_{eac} + AE|_{long.fiber}) \cdot \varepsilon|_{wood} \\ &= [(56.8 \times 1500000) + (12.57 \times 600000) + (2.38 \times 3600000)] \times 0.00252 \\ &= \boxed{255.3 \text{ kips}} \end{aligned}$$

Stage 2

$$\Delta\varepsilon|_{stage\#2} = \varepsilon|_{eac} - \varepsilon|_{wood} = 0.00875 - 0.00252 = 0.00623$$

$$\begin{aligned} P_{stage\#2} &= (AE|_{eac} + AE|_{long.fiber}) \cdot \Delta\varepsilon|_{stage\#2} \\ &= [(12.57 \times 600000) + (2.38 \times 3600000)] \times 0.00623 \\ &= \boxed{100.4 \text{ kips}} \end{aligned}$$

Stage 3

$$\Delta\varepsilon|_{stage\#3} = \varepsilon|_{long.fiber} - \varepsilon|_{eac} = 0.0218 - 0.00875 = 0.01305$$

$$\begin{aligned} P_{stage\#3} &= AE|_{long.fiber} \cdot \Delta\varepsilon|_{stage\#3} \\ &= 2.38 \times 3600000 \times 0.01305 \\ &= \boxed{111.8 \text{ kips}} \end{aligned}$$

$$P_{total} = P_{stage\#1} + P_{stage\#2} + P_{stage\#3} = 255.3 + 100.4 + 111.8 = \boxed{467.5 \text{ kips}}$$

TABLE 6.2. Comparison of Theoretical Result and Experimental Data for Compression Test

Specimen	Pile No.	Theoretical (kips)	Experimental (kips)	% difference
Control Specimen	A5	240.4	101	-138
	B1	198.5	110	-81
Repaired Core	A4	292	206	-42
	B2	286	282	-1.4
Repaired Core with Transverse Fiberglass Reinforcement	A1	278	425	+53
	A2	286.4	448	+57
Repaired Core with Transverse and Longitudinal Fiberglass Reinforcement	A3	474.6	478	+0.6
	B3	467.5	499	+7

The theoretical and experimental comparisons for each of the correlated specimens are shown in Table 6.2. to verify the theoretical model used. It is expected that variability in the wood produced much of the error in the control specimens. A portion of the error in the analysis of the specimens with the repaired core and transverse and longitudinal reinforcement stems from neglecting the Poisson's effect and material confinement provided by the transverse fiberglass reinforcement.

CHAPTER 7

RECOMMENDATIONS AND CONCLUSIONS

7.1 Summary

Due to the deterioration of the existing timber piles in the bridges, restoration and rehabilitation are in demand. New timber pile repair techniques were developed and evaluated. Therefore, testing has been performed to establish the performance of the repaired timber piles. A series of bending and compression testing was carried out to evaluate the effectiveness of an epoxy-aggregate repair with fiberglass reinforcement. Aggregate and epoxy filled cylinders were tested to provide knowledge of the behavior and interaction between the epoxy resin and aggregate mixture, as well as the fiberglass reinforcement. Compression tests for field repaired timber piles were conducted to determine their load bearing capacity and in-field performance. Laboratory repaired specimens displayed similar behavior to field repaired specimens.

7.2 Recommendations

As results of this study, several recommendations are made:

i. Epoxy-aggregate repair is capable of developing compressive strength up to 7500 psi. It greatly enhances the performance of the original timber piles. Therefore, epoxy and aggregate has been proven sufficient to replace the decayed core of timber piles, and provide adequate strength to a structure.

ii. The presence of transverse fiberglass reinforcement provides material confinement and is expected to decrease the effects of continuous weathering on the timber piles. Therefore, transverse fiberglass reinforcement is necessary for the repair techniques to be effective.

iii. Among the timber pile repair techniques developed, the combination of core repair and transverse fiberglass reinforcement provides significant enhancement in performance and was proven to be most effective.

7.3 Conclusions

A new cost-effective timber pile repair technique has been developed. The epoxy-aggregate repair with the addition of transverse fiberglass reinforcement significantly enhanced the performance of the decayed timber piles. The repair significantly improved the compression behavior of the decayed timber piles. The combination of the epoxy injection and transverse fiberglass reinforcement restored the decayed timber piles to a state stronger in compression parallel to the grain than the original timber. However, due to the various failure modes in the bending specimens, a firm conclusion cannot be drawn towards the repair's ability to improve bending strength. Also, longitudinal fiberglass reinforcement did little to enhance pile performance. The timber pile repair techniques were concluded to be structurally sufficient, more cost effective, and therefore a viable alternative to the conventional method of replacing decayed timber piles.

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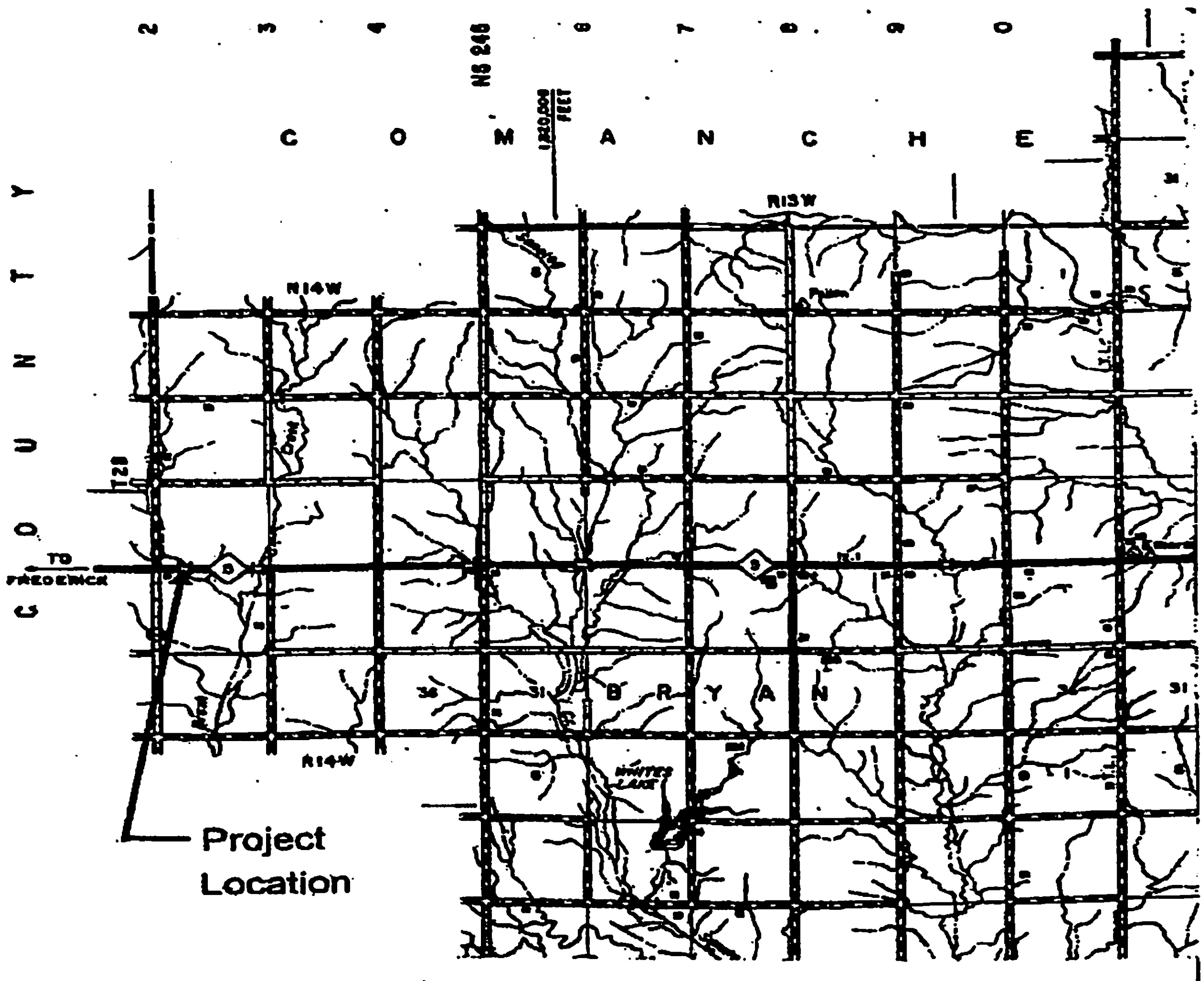
APPENDIXES

APPENDIX A

OKLAHOMA DEPARTMENT OF TRANSPORTATION

BRIDGE REPAIR TECHNIQUE

STATE OF OKLAHOMA
DEPARTMENT OF TRANSPORTATION
PLAN OF PROPOSAL
TIMBER PILE REPAIR PROJECT
SH-5 OVER TRIBUTARY OF BRUSH CREEK
PROJECT NO.: MC -
STATE JOB NO.: (04)
COTTON COUNTY
Location. 1710-0025X NBI No.: 04201



TOTAL PROJECT LENGTH: 0.0 MILES

CONSTRUCTION NOTES:

C-1 1999 OKLAHOMA STANDARD SPECIFICATIONS FOR HIGHWAY CONSTRUCTION - ENGLISH GOVERN, APPROVED BY THE FEDERAL HIGHWAY ADMINISTRATION, SEPTEMBER 21, 1999.

C-2 Wages paid on this project shall comply with Wage Rate shown in the proposal.

TRAFFIC CONTROL:

Project shall consist of maintaining at least one full lane of traffic on the bridge at all times during the project as follows:

(TO-25) Construction signing will be installed in a manner approved by the Engineer, in accordance with Chapter VI of the Manual for Uniform Traffic Control Devices, current edition, and applicable O.D.O.T. standard drawings. The contractor shall provide a proposed traffic control plan for approval by the Engineer prior to beginning work. Price bid on this Item shall be payment in full for the installation, maintenance and subsequent removal of all necessary construction traffic control required for completion of the project.

(SP-1) Traffic Control Standards need for this project:

TCS1-1-00E	TCS2-1-00E	TCS3-1-00E
TCS4-1-00E	TCS5-1-00E	TCS6-1-00E
TCS7-1-00E	TCS8-1-00E	TCS9-1-00E
TCS10-1-00E	TCS36-1-00E	

Traffic may only be restricted during daylight hours. All regular traffic lanes shall be open when no work is taking place.

(1) **FALSEWORK AND JACKING:**

Item "Falsework and Jacking" consists of all Falsework and Jacking required to complete the repair in accordance with Section 502 of the Specifications and in a manner approved by the Engineer. **Falsework shall be required only if an exterior piling is chosen for testing. The Engineer shall designate which pile will be tested after repairs are completed**

The Contractor shall be fully responsible for the adequacy of the falsework and the safety of the bridge and traveling public during the work. Damage to the structure, due to any settlement or failure of falsework, shall be repaired to serviceable condition by the Contractor at his expense, to the satisfaction of the Engineer. Structural repairs shall be complete before removing any falsework or jacking.

The Contractor shall submit detail drawings and calculations of falsework design to the Bridge Engineer for approval within one week after issuance of the work order. The falsework shall be designed and sealed by a Professional Engineer who is currently registered with the Oklahoma State Board of Registration for Professional Engineers and Land Surveyors.

(2) **REPAIR BRIDGE PILING**

Item "REPAIR BRIDGE PILING" shall consists of the following repairs to each of the pile designated as "Hollow" and "Deteriorating" in Figure 1 and performed in a manner approved by the Engineer.

a) Excavate below ground-line a minimum of 2' to expose a minimum of 2' of sound piling.

b) Contractor will be allowed to drill a maximum of 3" diameter holes through the outer shell of the hollow or damaged timber pile only on the north and south faces of each pile. These holes shall be spaced to allow for proper cleaning and placement of fill material.

c) Clean adjacent surfaces of deteriorated timber and other surface debris minimizing damage caused to sound timber fibers. Where feasible, clean the interior surfaces of the void to enhance adhesive bond and ultimate compression of the member. Clean by vacuuming, flushing, sawing or other approved means.

d) Allow timber to drain and dry.

e) Four (4) holes will be drilled outside of damaged section. These will consist of two (2) 13/16"x9" holes from opposite side and offset 4" from each other (see figure 2). Two (2) will be located 2 inches above the damaged portion and two will be located 2 inches below the damaged portion (see figure 3).

f) Apply a Borate fungicide as recommended by manufacture to surfaces of cavities and drilled holes to kill decay fungi and poison the timber as a future food source. Allow a minimum of one hour for the Borate solution to soak into the wood. If voids fill with water, it will render the treatment ineffective and will have to be re-applied.

g) Install one 3/4" x 3" Borate Rod into each of the drilled holes.

h) Plug drilled holes with treated timber dowel.

i) Fill voids in timber pile with aggregate meeting subsection 703.02 for No. 3 Aggregate in the Standard Specification.

j) Place two wraps of material equivalent to Sika Wrap Hex 100 G (see sheet 12 for required specifications) for the full exposed length of the pile with 6" overlaps. The resin for the glass fiber fabric impregnation will be equivalent to Sikadur Hex 300 (see sheet 13 for required specifications).

k) Space injection ports for the Epoxy Resin Mortar so that travel of material between ports is assured. Begin injection at the lower port and continue until the resin rises to the entry port above the port being pumped. When material travel is indicated move the nozzle to the port showing resin and seal the previously pumped port. Continue this procedure until the void is completely filled. On wide cracks, where travel of the resin between port will be rapid, two or more ports may be pumped simultaneously. Epoxy Resin Mortar shall meet standard specification AASHTO M 235-91 (1996) for "Epoxy Resin Adhesives", Type IV, Grade 1, and appropriate Class for temperature at the time of application.

l) When the Epoxy Resin Mortar has cured, the ports are to be removed to a smooth finish.

Work for the above activities will be limited to the following at one time:

1) **two (2) piles per bent at one time**
2) **only on non-adjacent piling**
3) **one (1) pile per half (north/south) bent**

(This limitation will not apply if contractor chooses to install falsework at his/her own expense and follows the procedure for the "Falsework and Jacking" pay item.)

m) A ultra-violet resistant coating equivalent to Sikagard 670W (see sheet 14 and 13 for required specifications) is to be applied to the exposed composite surface. The ultra-violet resistant coating shall be light gray in color. This coating is to cure for 24 hours prior to being in contact with backfill soil.

n) Backfill excavated areas and reattach cross-bracing.

The cost for the above work, materials, equipment, and incidentals necessary to complete this activity as shown in the plans shall be included in the price bid for "Repair Bridge Piling"

(3) **Repair Bridge Piling**

This activity is intended to replace one of the piles repaired by "Repair Bridge Piling" and used the removed portion for testing. **The Engineer shall designate which pile will be tested after repairs are completed**

a) Excavate below ground-line a minimum of 2.5' to expose a minimum of 1.5' of sound piling.

b) Remove the top portion of timber pile designated by the Engineer. The removed portion of Pile Repair (Timber) Type 'B' is intended for test purposes and shall remain the property of the State of Oklahoma for testing. Contractor shall make arrangements with the ODOT Cotton County Superintendent, (580)875-3295, for loading on a state vehicle. Efforts will be made to minimize damage to removed portion.

c) Splice new timber pile as shown in figure 4 using Class AA specified by **pay item note (4)** and reinforcing steel.

d) Compressive Strength. Design concrete mix to attain at least 2,800 psi before opening the supported portion of the bridge to traffic, and at least 4,000 psi in 28 days.

e) Backfill excavated areas and reattach cross-bracing.

Contractor shall confirm timber pile dimension.
Item "Falsework and Jacking" shall be required only if an exterior piling is chosen for testing.
The cost for the above work, materials, equipment, and incidentals necessary to complete this activity as shown in the plans shall be included in the price bid for "Repair Bridge Piling"

(4) **CLASS AA CONCRETE:**

The new concrete must meet all requirements of Class AA concrete as specified in Subsection 701.01 of the Standard Specification with the following exceptions:

a) Cement. Use Type III cement only in the concrete mix design. Do not use flyash or other pozzolans without prior approval. Do not use more than 700 pounds of cement per cubic yard.

b) Aggregate. Use no. 67 aggregate.

c) Chemical Admixtures. Use approved AASHTO M194 Type F, high range water reducing admixture and a Type C, calcium nitrite based accelerating admixture in the concrete mix design. Do not use admixtures containing calcium chloride. Use admixtures that are compatible with each other and in accordance with the manufacture's recommendations.

d) Polypropyleen Fibers. Use fibermesh or other approved polypropylene fibers having the specified characteristics, at the rate of 3.0 pounds per cubic yard of concrete. Use fibers with the following characteristics:

Fiber Material Type	100% polypropylene collated, fibrillated fibers (No olefin materials)
Specific Gravity	0.91
Modulus of Elasticity	500,000 to 700,000 psi
Tensile Strength	70,000 to 110,000 psi
Length	Graded, Min 0.25 inches, Max 1.0 inches

e) Compressive Strength. Design concrete mix to attain at least 2,800 psi before opening the supported portion of the bridge to traffic, and at least 4,000 psi in 28 days. Verify mix design strength gain, at 70^0 F initial concrete temperature, with laboratory testing.

f) Air Entrainment and Slump. Use concrete having entrained are ranging from 5 to 7 percent and slump ranging from 5 to 7 inches, **after the**

admixtures are added and concrete is pumped. Measure air and slump immediately before placement.

g) Concrete Temperature. When the ambient temperature is below 70° F maintain concrete temperature at the time of placement from 70° F to 100° F.

When necessary to produce concrete of the specified temperature range, heat the mix water, the aggregates or both, before batching. Use approved methods of heating that uniformly heat the materials. Do not use methods of heating that prevent the entrainment of the required amount of air. Do not directly heat the aggregates by gas or oil flame, or on sheet metal over fire. Do not heat either water or aggregate above 150° F. Mix materials if any material is heated over 100° F, in a way that the cement does not contact any materials hotter than 100° F.

When the ambient air temperature is 70° F or higher, maintain concrete temperature 70° F to 90° F. Cool mix water, if necessary to maintain the specified temperature.

Place concrete with 20 minutes of batching and before initial set. Do not retemper mix.

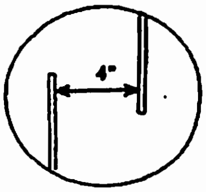
The Contractor shall make trial mixes (Batches) with passing test results prior to use.

(Figure 1)

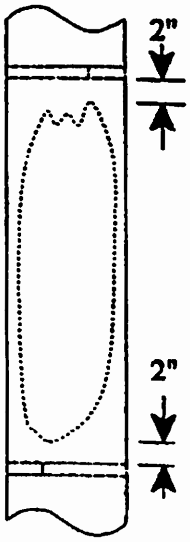
	West Bent	East Bent
North	X	X
	θ	θ
	X	X
	O	X
	X	θ
South	X	θ

X = Hollow
θ = Deteriorating
O = Adequate

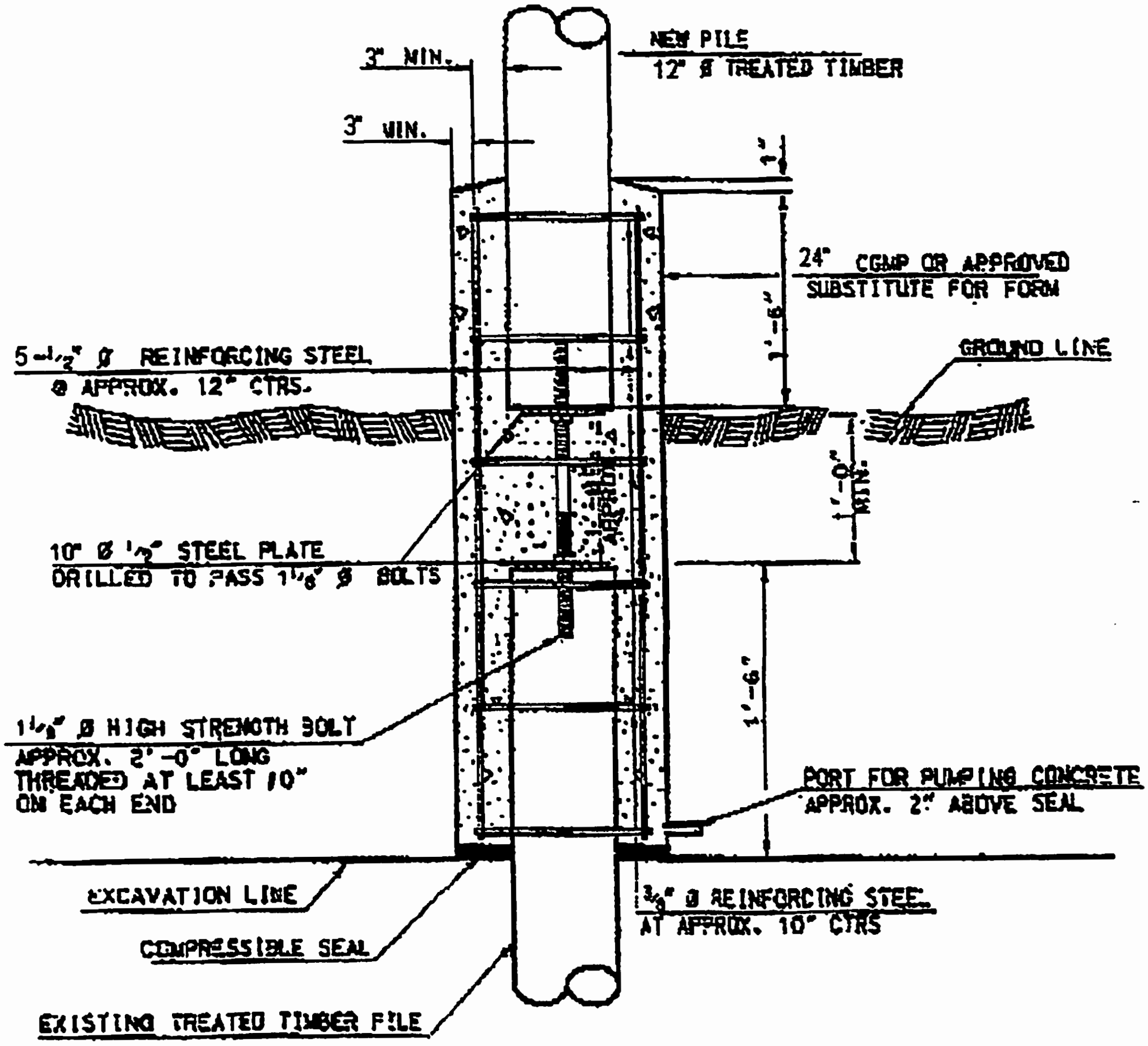
(Figure 2)



(Figure 3)



(Figure 4)



TIMBER PILE REPAIR

APPENDIX B

MATERIAL SAFETY DATA SHEETS

SikaWrap® Hex 100G

Glass fiber fabric for structural strengthening

Description

SikaWrap Hex 100G is a unidirectional E-glass fiber fabric. Material is field laminated using Sikadur Hex 300 or Sikadur Hex 306 epoxy to form a glass fiber reinforced polymer (GFRP) used to strengthen structural elements.

Where to use

- Loading increases
- Seismic strengthening
- Columns
- Masonry walls
- Damage to structural parts
- Temporary strengthening
- Change in structural system
- Design or construction defects

Advantages

- Used for shear, confinement or flexural strengthening.
- Flexible, can be wrapped around complex shapes.
- Light weight
- Good resistance to impact
- Non-corrosive
- Acid resistant
- Low aesthetic impact
- Economical

How to use

SURFACE PREPARATION

Surface must be clean and sound. It may be dry or damp, but free of standing water and frost. Remove dust, laitance, grease, curing compounds, impregnations, waxes, foreign particles, disintegrated materials, and other bond inhibiting materials from the surface. Existing uneven surfaces must be filled with an appropriate repair mortar. The concrete adhesive strength must be verified following surface preparation by random pull-off testing (ACI 503R) at the engineer's discretion. Minimum tensile strength 1.5 MPa with concrete substrate failure.

Preparation work

Concrete - Blast clean, shotblast or use other approved mechanical means to provide an open roughened texture. In certain applications and at the engineer's discretion, the intimate contact between the substrate and the fabric may be determined to be non-critical. In these cases, a thorough cleaning of the substrate using low pressure sand or water blasting is sufficient.

MIXING

Consult Sikadur Hex 300/306 data sheet for information on epoxy resin.

TECHNICAL DATA

Packaging	Rolls 127 cm x 46 m or 127 cm x 9 m
Colour	White
Storage Conditions	Store dry at 5° -32°C

PROPERTIES

FIBER PROPERTIES

Primary Fiber Direction	0° (unidirectional)
Tensile Strength	2.3 GPa
Tensile Modulus	72 GPa
Elongation	4%
Density	2.55 g/cm^3
Area Weight	915 g/m^2

CURED LAMINATE PROPERTIES with Sikadur Hex 300 Epoxy

(21° - 24°C/5 days and 48 h post cure at 60°C)

Property	Average value[1] MPa	Design value[2] MPa	ASTM Test Method
Tensile Strength*	612	558	D3039
Tensile Modulus*	26 119	24 444	D3039
Tensile % Elongation*	2.45	2.23	D3039
60°C - Tensile Strength	551	531	D3039
60°C - Tensile Modulus	25 690	23 361	D3039
60°C - % Elongation	2.28	2.14	D3039
Compressive Strength	597	542	D695
Compressive Modulus	29 715	25 494	D695
32°C - Tensile Strength	30	24	D3039
32°C - Tensile Modulus	6 649	6 317	D3039
32°C - % Tensile Elongation	0.46	0.34	D3039
Shear Strength ± 45° in plane	40	34	D3518
Shear Modulus ± 45° in plane	2 314	2 110	D3518
Ply Thickness (mm)	1.016	-	-

TECHNICAL DATA (continued)

CURED LAMINATE PROPERTIES with Sikadur Hex 306 Epoxy

(21° - 24°C/5 days and 48 h post cure at 60°C)

Property	Average value[1] MPa	Design value[2] MPa	ASTM Test Method
Tensile Strength*	575	514	D3039
Tensile Modulus*	25 300	21 796	D3039
Tensile % Elongation*	2.31	2.03	D3039
60°C - Tensile Strength	477	446	D3039
60°C - Tensile Modulus	22 781	21 239	D3039
60°C - % Elongation	2.19	2.01	D3039
Compressive Strength	517	470	D695
Compressive Modulus	29 270	24 466	D695
32°C - Tensile Strength	34	26	D3039
32°C - Tensile Modulus	5 648	5 145	D3039
32°C - % Tensile Elongation	0.66	0.52	D3039
Shear Strength ± 45° in plane	42	39	D3518
Shear Modulus ± 45° in plane	2 323	2 141	D3518
Ply Thickness (mm)	1.016	-	-

* 24 Sample coupons per test series; all other values based on 6 coupon test series
[1] Average value of test series
[2] Average value minus 2 standard deviations

APPLICATION

Prior to placing the fabric, the concrete surface is sealed using Sikadur Hex 300 epoxy. Product may be spray, brush or roller-applied. SikaWrap 100G can be impregnated using either the Sikadur Hex 300 (vertical and horizontal surfaces) or Sikadur Hex 306 epoxy (vertical surfaces and over head). For best results on larger projects, the impregnation process should be accomplished using an AMI Custom Fabric Impregnator (saturator) or similar device. In special cases where the size of the project does not justify the use of a saturator, the fabric may be saturated by hand using a roller or a spatula prior to placement. In either case, this system installation should be performed only by a specially trained, approved contractor.

Cutting SikaWrap

Fabric can be cut to appropriate length by using a commercial quality heavy duty scissors. Since dull or worn cutting implements can damage, weaken or fray the fiber their use should be avoided.

LIMITATIONS

Design calculations must be made and certified by an independent licensed professional engineer.
System is a vapour barrier.
System must be protected from UV with Sikagard 550W.

Caution

SikaWrap fabric is non-reactive. However, caution must be used when handling since a fine "glass" may be present on the surface. Gloves must therefore be worn to protect against skin irritation. Caution must also be used when cutting SikaWrap fabric to protect against airborne glass dust generated by the cutting procedure. Use of an appropriate, properly fitted NIOSH/MSHA approved respirator is recommended. Consult product label for more information.

First aid

In case of skin contact, wash with soap and water. For eye contact flush immediately with plenty of water for at least 15 minutes. Contact a physician. For respiratory problems transport victim to fresh air. Remove contaminated clothing and wash before re-use.

KEEP OUT OF REACH OF CHILDREN
FOR INDUSTRIAL USE ONLY

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Sikadur® 30

High-Modulus, High-Strength, Structural Epoxy Paste Adhesive for use with Sika CarboDur Reinforcement System

Description

Sikadur 30 is a two-component, 100% solids moisture-tolerant, high modulus, high strength, structural epoxy paste adhesive. Meets ASTM C881 and AASHTO M-235 requirements.

Where to use

- Adhesive for bonding external reinforcement to concrete, masonry, steel, wood, stone, etc.
- Structural bonding of composite laminates (Sika CarboDur CFRP) to concrete.
- Structural bonding of steel plates to concrete.
- Suitable for use in vertical and overhead configurations.
- Multi-purpose, high strength, structural epoxy paste adhesive.
- As a binder for epoxy mortar repairs.

Advantages

- Long pot life and open time
- Moisture tolerant before, during and after cure.
- High-modulus, high-strength, structural paste adhesive.
- Excellent adhesion to concrete, masonry, metals, wood and most structural materials.
- Fully compatible and excellent adhesion to Sika CarboDur CFRP composite laminates.
- Paste consistency ideal for vertical and overhead applications.
- High temperature resistance
- High creep resistance under permanent loads.
- High abrasion and shock resistances.
- Convenient easy mix ratio A:B = 3:1 by weight.

TECHNICAL DATA

Packaging	10 kg unit	
Colour	Component A	White
	Component B	Black
	Components A+B	Light Grey
Yield		
Type of Laminate	**Sikadur 30 kg / Linear metre**	
S512/H514	0.30	
S612/S614/M614	0.36	
S812	0.48	
S914/M914	0.54	
S1012	0.60	
S1212/S1214/M1214	0.72	
S1512	0.90	

Yield is based on a 3 mm nominal thickness and does not take into consideration the plane, roughness of substrate as well as laminate crossings. Actual consumption of adhesive will then be higher.

Shelf Life	2 years in original, unopened packaging. Store dry at 5° - 32°C. Condition product to 15° - 24°C before using.
Mixing Ratio	A:B = 3:1 by weight and by volume

PROPERTIES (23°C AND 50% R.H.)

Density	2 kg/L (A+B)	
Pot Life	Approx. 70 min	
Tensile Properties ASTM D638		
7 days	Tensile strength	24.8 MPa
	Elongation at break	1%
	Modulus of elasticity	4.5 GPa
Flexural Properties ASTM D790		
14 days	Modulus of rupture	46.8 MPa
	Tangent modulus of elasticity in bending	11.7 GPa
Shear Strength ASTM D732		
14 days		24.8 MPa
Bond Strength ASTM C882		
Hardened concrete to hardened concrete		
2 days	Moist cure	18.6 MPa
2 days	Dry cure	22 MPa
14 days	Moist cure	21.3 MPa
Hardened concrete to steel		
2 days	Moist cure	17.9 MPa
2 days	Dry cure	20.6 MPa
14 days	Moist cure	17.9 MPa

Sika®

TECHNICAL DATA (continued)			
Deflection Temperature ASTM D648			
7 days	Fiber stress loading = 1.8 MPa 47°C		
Water Absorption ASTM D570			
24 h	0.03%		
Compressive Strength, MPa ASTM D695			
	5°C*	**23°C***	**32°C***
4 h	-	-	37.9
8 h	-	24.1	46.2
16 h	-	46.2	51
1 day	5.1	53.7	53.7
3 days	46.8	57.2	57.2
7 days	55.1	59.3	59.3
14 days	58.6	59.3	61.3
28 days	58.6	59.3	62
*Product cured and tested at temperatures indicated.			
Modulus of Elasticity ASTM D695			
7 days	2.69 GPa		

- Solvent-free
- Colour coded components to ensure proper mixing control.
- M.T.Q. acceptance

How to use

SURFACE PREPARATION

Surface must be clean and sound. It may be dry or damp, but free of standing water and frost. Remove dust, laitance, grease, curing compounds, impregnations, waxes, foreign particles, disintegrated materials, and other bond inhibiting materials from the surface. Existing uneven surfaces must be filled with an appropriate repair mortar (i.e. Sikadur 30 with the addition of 1 part sand). The concrete adhesive strength must be verified after surface preparation by random pull-off testing (ACI 503R) at the engineer's discretion. Minimum tensile strength: 1.5 MPa with concrete substrate failure.

Planeness of substrate to be checked with a metal batten. Tolerance for 2 m length max. 10 mm, or 2.5 mm for 50 cm length respectively.

Concrete - Blast clean, shotblast or use other approved mechanical means to provide an open roughened texture. (CSP 5)

Steel - Sandblast to white metal finish.

Timber - Blast clean or grind. After cleaning, remove all dust from the surface with an industrial vacuum cleaner.

CarboDur - Surface should be wiped clean using an appropriate cleaner. Using a clean white cloth wipe down the side receiving adhesive (this side is not labeled) with acetone until all residual carbon dust is removed (i.e. the white cloth remains white after wiping the laminate). In the case where the design requires "stacking" of the strips, the bottom surface of the strip (labeled) should be lightly sanded (emery paper type 180) prior to the application of the second strip.

MIXING

Pre-mix each component. Empty component B into component A pail or add component B in the correct mix ratio to component A. Mix for 3 min using a low-speed drill (300-450 rpm) to minimize air entrapment. Use a Exomixer type mixing paddle (recommended model). During the mixing operation, scrape down the sides and bottom of the pail with a flat or straight edge trowel at least once to ensure thorough mixing. Upon completion of mixing, Sikadur 30 should be uniform in colour. Mix only that quantity you can use within its pot life.

APPLICATION

For bonded, external reinforcement - Apply the neat mixed Sikadur 30 onto the concrete with a trowel or spatula to a nominal thickness of 1.5 mm. Apply mixed Sikadur 30 onto the CarboDur laminate with a "roof-shaped" spatula to a nominal thickness of 1.5 mm. Within the epoxy open time and depending on the temperature, place CarboDur laminate onto the concrete surface. Using a hard rubber roller, press the laminate into the epoxy resin until the adhesive is forced out on both sides. Remove excess adhesive. Glue line should not exceed 3 mm. The laminate must not be disturbed for a

minimum of 24 h. The epoxy will reach its design strength after 7 days.
For vertical and overhead patching - Work Sikadur 30 with the addition of 1 part sand into the prepared substrate, filling the cavity. Strike off level. Lifts should not exceed 25 mm.

CLEAN UP

Clean all tools and equipment immediately with Sika Equipment Cleaner. Wash soiled hands and skin thoroughly in hot, soapy water. Once hardened, product can only be removed mechanically.

LIMITATIONS

Minimum substrate and ambient temperature: 5°C.
Maximum substrate and ambient temperature: 35°C.
Do not thin: Solvents will prevent proper cure.
Use oven-dried aggregate only.
Maximum glue line of neat epoxy: 3 mm.
Maximum epoxy mortar thickness: 25 mm per lift.
Material is a vapour barrier after cure.
Minimum adhesive strength of concrete substrate: 1.5 MPa.

Caution

Component A - Irritant - Contains epoxy resins. Prolonged contact with skin may cause irritation. Avoid eye contact.
Component B - Irritant - Contains amines. Contact with skin may cause severe burns. Avoid eye contact. Avoid breathing vapours. Product is a strong sensitizer. Use of safety goggles, chemical-resistant gloves and NIOSH/MSHA organic vapour respirator is recommended. Avoid breathing vapours. Use adequate ventilation. Remove contaminated clothing. Consult product label for additional information.

First Aid

In case of skin contact, wash with soap and water. For eye contact flush immediately with plenty of water for at least 15 minutes. Contact a physician. For respiratory problems, transport victim to fresh air. Remove contaminated clothing and wash before re-use.

For more information, consult Sika Material Safety Data Sheet.

WEAR PROTECTIVE CLOTHING, GOGGLES, GLOVES AND/OR BARRIER CREAMS
KEEP OUT OF REACH OF CHILDREN
FOR INDUSTRIAL USE ONLY

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ISO 9001-94
ISO 14001-96
MONTREAL

ISO 9002-94
EDMONTON

Sikadur® Hex 300/306

High-Modulus, High-Strength, Impregnating Resin for the SikaWrap System

Descrition
Sikadur Hex 300 and Sikadur Hex 306 are two-component 100% solids, moisture-tolerant, high strength, high modulus epoxies.

Where to use
- For use as an impregnating resin with SikaWrap structural strengthening system.
- Sikadur Hex 300 is used as a seal coat and impregnating resin for horizontal and vertical applications.
- Sikadur Hex 306 is a thixotropic version of Sikadur Hex 300 used as an impregnating resin on overhead applications.

Advantages
- Long pot life and open time
- Easy to mix
- Tolerant of moisture before, during and after cure.
- High-strength, high-modulus adhesive.
- Excellent adhesion to concrete, masonry, metals, wood and most structural materials.
- Fully compatible and developed specifically for the SikaWrap System.
- High creep resistance under permanent load.
- High abrasion and shock resistance
- Solvent-free, VOC compliant

TECHNICAL DATA		
Packaging	15 L unit (4 US gal.)	
Colour	Clear, amber	
Yield	As a primer: 3-5 m^2/L, depending on substrate porosity As an impregnating resin: 1.5 m^2/L	
Shelf Life	2 years in original, unopened packaging. Store dry at 5° - 32°C. Condition product to 18° - 24°C before using.	
Mixing Ratio (A:B)	**Hex 300**	**Hex 306**
By volume	2.36:1	2.77:1
By weight	2.90:1	3.28:1

PROPERTIES (23°C AND 50% R.H.)	
Viscosity	
Hex 300	550 cps
Hex 306	7000 cps
Pot Life	4 h
Tack Free	20 h
Tg	79°C after 48 h/60°C post cure 46°C after 120 h/21°C post cure
HDT ASTM D648	77°C
Service Temperature Range	-40°C to 60°C
Tensile Strength ASTM D638	72.4 MPa
Tensile Modulus ASTM D638	3.2 GPa
Elongation at Break	4.8%
Flexural Strength ASTM D790	123.4 MPa
Flexural Modulus ASTM D790	3.1 GPa

How to use

SURFACE PREPARATION
Substrate must be clean, sound, and free of surface moisture. Remove dust, laitance, grease, oils, curing compound, waxes, impregnations, foreign particles, coatings and disintegrated materials by mechanical means, i.e. sandblasting. For best results, substrate should be dry.

MIXING
Pre-mix each component. Mix entire unit, do not batch. Pour contents of part B to part A. Mix thoroughly for 5 min on low using a paddle style mixer on low-speed drill (400-600 rpm) until uniformly blended.

APPLICATION
As a primer - Apply mixed Sikadur Hex 300 epoxy at a rate of 3-5 m^2/L to properly prepared substrate using a brush, roller or airless sprayer.
As an impregnating resin - Use Sikadur Hex 300 for vertical and horizontal applications and Sikadur Hex 306 for overhead applications. Resins may be applied to fabric by either manual or mechanical means.

Sika®

CLEAN UP
Ventilate area. Confine spill. Collect with absorbent material. Dispose of in accordance with current, applicable local, state, and federal regulations. Uncured material can be removed with approved solvent. Cured material can only be removed mechanically.

LIMITATIONS
Minimum and maximum substrate and ambient temperature: 10° - 38°C.
Do not thin with solvents.
Material is a vapour barrier after cure.
Minimum age of concrete must be 21-28 days depending on curing and drying conditions.

Caution

Component A - Irritant - Sensitizer. Contains epoxy resin. Can cause sensitization after prolonged or repeated contact. Skin and eye irritant. High concentrations of vapour may cause respiratory irritation. Avoid skin contact. Use only with adequate ventilation. Use of safety goggles and chemical resistant gloves is recommended. In case of exceedance of PELs, use an appropriate, properly fitted NIOSH/MSHA approved respirator. Remove contaminated clothing. Consult MSDS for more detailed information.

Component B - Corrosive - Sensitizer. Contains amines. Contact with eyes or skin may cause severe burns. Can cause sensitization after prolonged or repeated contact. Skin and eye irritant.
High concentrations of vapour may cause respiratory irritation. Avoid skin contact. Use only with adequate ventilation. Use of safety goggles and chemical resistant gloves is recommended.
In case of exceedance of PELs, use an appropriate NIOSH/MSHA approved respirator.
Remove contaminated clothing.
Consult product label for more information.

First aid

In case of skin contact, wash with soap and water. For eye contact flush immediately with plenty of water for at least 15 minutes. Contact a physician. For respiratory problems, transport victim to fresh air. Remove contaminated clothing and wash before re-use.

For more information, consult Sika Safety Material Data Sheet.

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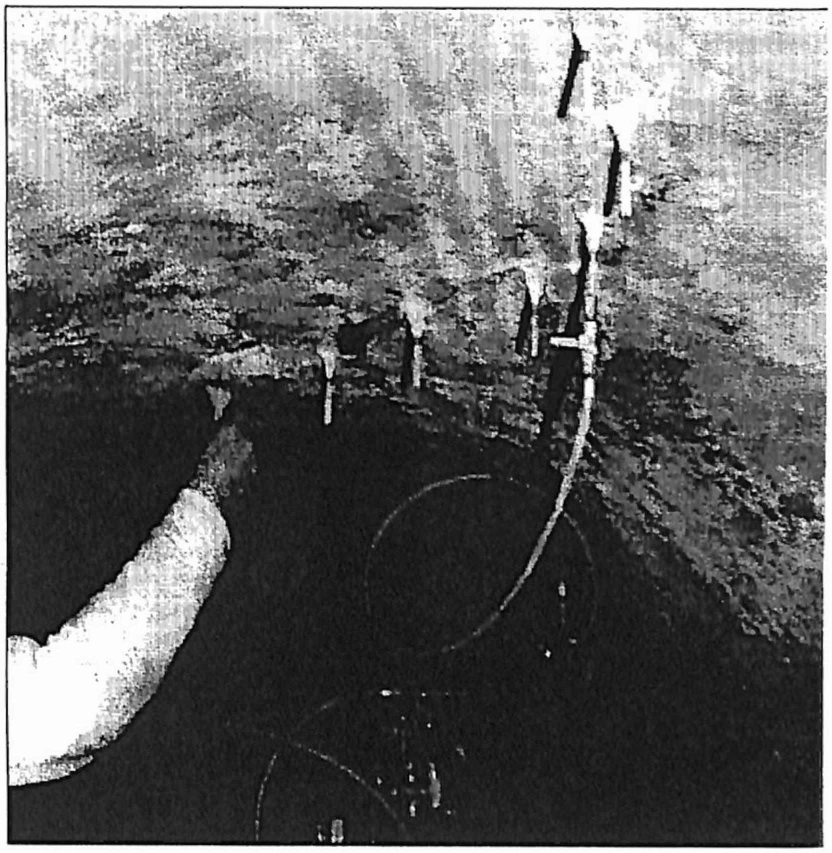
UNITEX® PRO-POXY 100

LOW VISCOSITY INJECTION RESIN & MORTAR BINDER

BENEFITS:

- Structurally Restores Integrity of Concrete
- Low Viscosity
- Moisture Insensitive



Adverse conditions?
Depend on PRO-POXY 100 *to perform when and where you need it.*

PRO-POXY 100

LOW VISCOSITY INJECTION RESIN

DESCRIPTION

A solvent-free, moisture insensitive, low viscosity, high strength, two component injection resin. It meets ASTM-C-881 Types I, II, IV & V, Grade 1, Classes B & C. It also meets USDA specifications for use in food processing areas. An excellent epoxy adhesive for use in crack grouting by pressure injection or gravity-feed and for making epoxy mortars and grouts.

USAGE

- Pressure-injection of cracks in structural concrete, masonry, wood, etc.
- Gravity feed of cracks in horizontal concrete and masonry.
- Epoxy resin binder for epoxy mortar patching and overlay of interior, horizontal surfaces.

Appearance: Component A - clear
Component B - amber

Shelf Life: 1 year in original unopened container

Storage Conditions: Store at 40 - 95°F (5 - 35°C). Condition material to 65 - 85°F (18 - 29°C) before using.

Gel Time (60 g mass): 30 min at 73 ± 2°F (23°C)

APPLICATION

TO PRESSURE INJECT CRACKS: Flushing cracks is detrimental and should not usually be done. Use automatic injection equipment for 2:1 ratio epoxy that will absolutely stay on ratio while under pressure. Carefully set surface or counter sink ports on face of crack. Be sure the crack is open where ports are placed and not impacted with debris. Set the ports with PRO-POXY 300, 300 FAST, or 300 PASTE, being careful not to obstruct the crack with epoxy. If feasible, also seal the back side of crack with PRO-POXY 300, 300 FAST, or 300 PASTE. PRO-POXY 300, 300 FAST, or 300 PASTE is a cap sealing compound when used in this application. A successful and profitable injection job depends largely on carefully placing the cap seal and ports allowing the injection to proceed smoothly with no leaks. Allow the cap seal to fully cure. Cure time will depend on temperature and whether PRO-POXY 300, 300 FAST, or 300 PASTE was used. Inject PRO-POXY 100, always starting at the lowest port. If the back side of the crack has been sealed, stay on a port as long as it is accepting epoxy. Cap adjoining ports as epoxy extrudes out of them staying on the original port until the pump stalls out or the crack is completely filled.

TO BIND MORTAR AND GROUT FOR PATCHING: Premix entire unit of A and B or exact portions, 2 parts A to 1 part B by volume with low speed Jiffy mixer for 3 minutes. Hold back some neat resin for priming patch. Paint concrete to be patched with just enough neat resin to wet out the surface. Slowly add oven-dried aggregate (typically 4-5 parts of aggregate to 1 part epoxy) to the mixed epoxy while mixing with a slow speed Jiffy mixer being careful not to mix in air. Prepared mortar must be placed before primer becomes tack free. Epoxy mortar may be placed and leveled with trowels. Do not disturb patch until it is fully cured. Ultraviolet light will darken epoxy. Oven-dried aggregate may be sprinkled to refusal on top of mortar to protect from UV. Brush off excess after epoxy has cured.

TO GRAVITY FEED CRACKS: Seal underside of slab prior to filling if cracks reflect through. Pour neat PRO-POXY 100 into vee-notched crack. Continue placement until completely filled.

PACKAGING

150 ml x 300 ml cartridge
1 gal (3.8 L) units
3 gal (11.4 L) units
15 gal (56.8 L) units
165 gal (624.6 L) units

COVERAGE

1 gal/3.8 L of mixed epoxy yields 231 cu in .0037 cu m of epoxy

1 gal/3.8 L of mixed epoxy combined with 5 gal 18.9L of aggregate yields 808.5 cu in .013 cu m of mortar.

COMPLIANCES

ASTM-C-881, Types I, II, IV & V
Grade 1
Class A, B, C

LIMITATIONS

- Minimum substrate temperature is 40°F (5°C).
- Do not thin. Solvents will prevent proper cure.
- Use oven-dried aggregate only.
- Minimum age of concrete must be 21-28 days, depending on curing and drying conditions, for mortar.
- Do not seal slabs on grade with product. PRO-POXY 100 is a vapor barrier.
- Maximum epoxy mortar thickness is 1.5" (3.8 cm) per lift.

CAUTION

- Component A - Irritant
- Component B - Corrosive
- Product is a strong sensitizer. Use of safety goggles and chemical resistant gloves are recommended.
- Use of a NIOSH/MSHA organic vapor respirator is recommended if ventilation is inadequate.
- Avoid breathing vapors.
- Avoid skin contact.

FIRST AID

EYE CONTACT: Flush immediately with water for at least 15 minutes. Contact physician immediately.

RESPIRATORY CONTACT: Remove person to fresh air.

SKIN CONTACT: Remove any contaminated clothing. Remove epoxy immediately with a dry cloth or paper towel. Solvents should not be used as they carry the irritant into the skin. Wash skin thoroughly with soap and water.

CURED EPOXY RESINS ARE INNOCUOUS.

CLEANUP

Collect with absorbent material. Flush area with water. Dispose of in accordance with local, state, and federal disposal regulations. Uncured material can be removed with Unitex CITRI-CLEAN or other approved solvent. Cured material can only be removed mechanically.

Contact UNITEX Technical Services for further information or installation instructions.

PRO-POXY 100 LV
ASTM C-881
TYPES I, II, IV & V
GRADE 1, CLASSES B & C

LABORATORY TESTS	RESULTS	SPECIFICATIONS	
C-881 Brookfield Visc.	500 cps	2000 cps	Maximum
C-881 Gel Time	30 Minutes	30 Minutes$_{1,2,4,5}$	Minimum
C-882 Bond Strength (2 day cure)	2,380 PSI	1,000 PSI$_{1,4}$	Minimum
C-882 Bond Strength (14 day cure)	3,035 PSI	1,500 PSI$_{1,2,4,5}$	Minimum
D-570 Absorption	0.84%	1.0%$_{1,2,4,5}$	Maximum
D-648 Heat Deflection Temperature	50°C	49°C$_{4,5}$	Minimum
D-2566 Linear Coefficient of Shrinkage	0.0043	0.005$_{1,2,4,5}$	Maximum
D-695 Compressive Strength	12,385 PSI	5,000 PSI$_{2}$ 8,000 PSI$_{1,5}$ 10,000 PSI$_{4}$	Minimum
D-695 Compressive Modulus	267,586 PSI	90,000 PSI$_{2}$ 150,000 PSI$_{1,5}$ 200,000 PSI$_{4}$	Minimum
D-638 Tensile Strength	7,168 PSI	2,000 PSI$_{2}$ 5,000 PSI$_{1}$ 6,000 PSI$_{5}$ 7,000 PSI$_{4}$	Minimum
D-638 % Elongation at Break	2.3%	1.0%$_{1,2,4,5}$	Minimum
C-881 Filler Content	0.0%	None	
C-883 Shrinkage	Pass	None	
D-732 Shear Strength	8,500 PSI	None	
D-790 Flexural Strength	8,700 PSI	None	
C-884 Thermal Compatibility	Pass	None	

$_{1}$ - ASTM C-881 Type I
$_{2}$ - ASTM C-881 Type II
$_{4}$ - ASTM C-881 Type IV
$_{5}$ - ASTM C-881 Type V

06/20/97

UNITEX 3101 GARDNER, KANSAS CITY, MISSOURI 64120 816-231-7700

MATERIAL SAFETY DATA SHEET

Complies with OSHA's Hazard Communication Standard, 29 CFR 1910,1200

IDENTITY As Used on Label and List: **PRO-POXY 100 LV**

SECTION I

Manufacturer's Name:	UNITEX 3101 Gardner Kansas City, MO 64120	Emergency Telephone No.: Telephone No.: Date Prepared:	800-424-9300 816-231-7700 01/30/02

PREPARED BY: Technical Services

Section II-Hazardous Ingredients/Identity Information:

PRODUCT CLASS: Epoxy

Hazardous Components (Specific Chemical Identity: Common Name(s)

	OSHA PEL	...	ACGIH TLV	...	Approx %
COMPONENT A:					
Modified Bisphenol A/Epichlorohydrin Base Epoxy Resin CAS #25068-38-6	NE	...	NA	...	>83%
Aliphatic Glycidyl Ether CAS #2461-15-6	NE	...	NE	...	<17%

This product contains detectable amounts of the following chemical known to the State of California to cause birth defects/cancer or other reproductive harm: Epichlorohydrin.

	OSHA PEL	...	ACGIH TLV	...	Approx %
COMPONENT B:					
Trade Secret Amine Blend containing one or more of the following:					
CAS #694-83-7	NE	...	NE	...	>90%
CAS #68411-90-5	NE	...	NE	...	
CAS #140-31-8	NE	...	NE	...	
CAS #84852-15-3	NE	...	NE	...	
CAS #NE	NE	...	NE	...	
2,4,6- Tri(dimethylaminomethyl)phenol CAS #90-72-2	NE	...	NE	...	<5%

None of the remaining components are considered a Hazardous Material or carcinogen (1910.1200 Hazard Communication (d) 4).

Transportation Information:

DOT Classification: Amines, Liquid, Corrosive, n.o.s. (aminopropyldiethanolamine)

UN2735, Hazard Class 8, PG III

SECTION III - Physical/Chemical Characteristics:

Boiling Point:	N/E	Specific Gravity:	A: 1.12 B: 0.96
Vapor Pressure (mm Hg):	N/E	Melting Point:	N/E
Vapor Density (Air = 1):	> 1	Evaporation Rate (ETHER = 1)	> 1
Solubility in Water:	Insoluble		
Appearance and Odor:	A: Clear Liquid, mild odor. B: Amber liquid, strong odor.		

SECTION IV - Fire and Explosion Hazard Data:

Flash Point (Method Used):	>200°F.
Flammable Limits:	LEL: N/A UEL: N/A
Extinguishing Media:	Foam, CO2, Water Fog
Special Fire Fighting Procedures:	None
Unusual Fire and Explosion Hazards:	None. Avoid breathing Smoke.

SECTION V - Reactivity Data:

Stability: Stable Conditions to Avoid: None

PRO-POXY 100 LV

Incompatibility (Materials to Avoid):	Strong Oxidizers, strong Bases		
Hazardous Decomposition or Byproducts:	CO, CO2, NOX		
Hazardous Polymerization:	None	Conditions to Avoid:	Fires when curing.

SECTION VI - HEALTH HAZARD DATA:

Carcinogenicity: Unrelated NTP? No IARC? No OSHA Regulated? No

Effects and Hazards of Overexposure (Acute and Chronic):

Eyes:	May produce irritation, sensitization.
Skin:	May produce irritation, sensitization.
Inhalation: (breathing)	May produce irritation, sensitization.
Ingestion: (swallowing)	May produce irritation, sensitization.

Emergency and First Aid Procedures:

Remove any contaminated clothing.

Eyes:	Flush immediately with large amounts of water for at least 15 minutes; contact physician immediately.
Skin:	Remove epoxy from skin immediately with a dry cloth or paper towel. Wash area of contact thoroughly with soap and water. SOLVENTS SHOULD NOT BE USED because they carry the irritant into the skin.
Inhalation:	If respiratory irritation occurs, go to fresh air. Flood work area with fresh air. If irritation continues, seek medical attention.
Ingestion:	Not Expected. Contact medical help immediately. Untrained first aid personnel should not attempt to administer first aid.

Contaminated clothing should be washed prior to re-use.

SECTION VII - Spill or Leak Procedures:

Steps to be taken in case material is leaked or spilled:	Bind with absorbent material.
Waste Disposal Method: Small Spill:	Per local, state and federal regulations.

SECTION VIII - Safe Handling and Use Information:

Respiratory Protection:	Respiratory protection is required when ventilation is inadequate. NIOSH/MSHA approved respirators should be provided and worn. All workers required to use respiratory protection should be trained in their proper selection, use and care. A written respirator program is outlined in 29 CFR 1910.134, and is required by OSHA.
Ventilation (Local Exhaust):	Recommended
Ventilation (Mechanical-General)	Recommended
Ventilation (Special):	Recommended; when local and mechanical ventilation is not adequate.
Ventilation (Other):	N/E
Protective Gloves:	Recommended
Eye Protection:	Recommended
Other Protective Equipment:	Recommended; splash bib with protective clothing.
Work/Hygienic Practices:	Remove and wash contaminated clothing. As with all commercial and industrial products, always wash hands before eating or smoking.

SECTION IX - Special Precautions:

Precautions to be taken in handling:	Store in a cool, dry location. Do not allow the material to freeze, as product may be damaged. Store away from sparks and open flame.
Other Precautions:	None

N/A: Not Available N/E: Not Established

VITA (1)

Victor Yung Lung Wong

Candidate for the Degree of

Master of Science

Thesis: EVALUATION AND DEVELOPMENT OF COST EFFECTIVE TIMBER PILE REPAIR TECHNIQUES

Major Field: Civil Engineering

Biographical:

Personal Data: Born in Sibu, Sarawak, Malaysia, on November 12, 1979, the son of Mee Kwong Wong and Yiew Tieh Ting.

Education: Graduated from Catholic High School, Sibu, Sarawak, Malaysia in December 1996; received Bachelor of Science in Civil Engineering from Oklahoma State University, Stillwater, Oklahoma in December, 2001. Completed the requirements for the Master of Science degree with a major in Civil Engineering at Oklahoma State University in May, 2004.

Experience: Employed by Oklahoma State University, Department of Civil Engineering as a graduate teaching assistant, January, 2002 to May, 2003; worked as a graduate research assistant, May, 2002 to August, 2003.

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