Repair of Timber Bridge Piling by Posting and Epoxy Grouting

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ABSTRACT

Evaluated in this paper is the repair of timber bridge piles by posting and epoxy grouting. The repair procedure consists of cutting out the damaged pile section and replacing it with a new section. After spiking the new section in place, the joints are epoxy-injected to form a permanent bond. The first phase of the study consisted of laboratory testing of repaired pile sections in both compression and bending. Full axial compression strength could be restored through the repair process; however, the ultimate bending strength could only be restored to typical allowable stress values. Flexural stiffness could also be restored to expected values for undamaged piles. To study the durability and long-term effects of the repair procedure, a field repair was also initiated. On a low-volume bridge located in a Louisiana national forest, three piles were repaired and instrumented. After 2 years, no significant movement or deterioration has been observed.

One of the most common types of bridge support is the timber pile. Piles are found extensively on short span, low-volume bridges and have been widely used over the last 40 years. Nationwide, many of these older bridges have piles that have been seriously weakened by decay or insect attack. Typically, decay occurs at or above the average waterline and is associated with cyclic wetting and drying, while insect attack usually occurs below the waterline. Many of these bridges are in good condition and still functional except for significant damage to a relatively small number of the pile supports. A method of repair for such piles that is both structurally sound and cost effective would significantly extend the life of these bridges.

The purpose of this paper is to evaluate the effectiveness of posting and epoxy grouting for replacing damaged pile sections. A two-phase program of laboratory tests and field repairs was utilized in this investigation.

LITERATURE REVIEW

A survey of the literature reveals relatively little information on the repair and rehabilitation of timber piles. One area of attention relates to defining and quantifying the nature of pile deterioration. Williams and Norton (1) have analyzed the rate of pile deterioration and found it to be exponential in nature. They developed a mathematical model to predict the rate of pile decay. Various authors (2-4) have described the nature of pile attributed to both decay and insect attack. Recommendations on controlling pile deterioration generally relate to chemical treatments of protective coverings (5,6).

The rehabilitation of damaged piles falls into five categories: replacement, augmentation, grouting, jackets, and cutting and posting as summarized in Table 1. Replacement is probably the most widely used procedure. However, it can be quite expensive. Augmentation (7) involves the addition of material and connectors. Such procedures typically consist of bolting splices of steel or wood, attaching a new section of pile to an existing one, or the addition of bracing. One serious drawback is that the connectors used are subject to future deterioration. A less severe approach is to grout the damaged area. Large voids have been successfully grouted with cement (8), while lesser damage can be grouted with epoxy (9). However, little published information is available on strength after repair or on methods for deciding when the damage can be repaired by grouting. A more popular procedure is to reinforce a damaged pile with a jacket (10-12). As shown in Figure 1, the procedure is to pour a reinforced concrete jacket around the damaged pile. The form consists of fiber-reinforced plastic or fabric that can be fitted around the pile in the form of a sleeve. The process can be used to increase the strength of the pile and will prevent further deterioration. However, the pile size is increased and specialized equipment and personnel are required.

The procedure of cutting and posting, which is the object of this investigation, consists of cutting out the damaged section and replacing it with a new piece. Typically, the piece is spiked or bolted to the existing pile and a relatively weak connection is formed. However, the use of epoxy offers the potential for increasing the pile capacity associated with this approach. In order to evaluate the effects of using epoxy injection for bonding the new piece into the existing pile, both a laboratory study and a field pilot project were conducted.

DESCRIPTION OF THE REPAIR PROCEDURE

The basic repair procedure is outlined as follows:

1. Determine the limits of damage by taking borings. Drill bit borings are recommended in which an electric drill is used. The chips are visually examined for soundness. A hand auger or incremental borer can also be used, although such methods are much slower than drilling.
2. Provide temporary shoring if necessary. Repairs can often be made during dry periods when stream beds are low or dry. In such cases, temporary

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TABLE 1 Repair and Rehabilitation Procedures for Timber Piles

Procedure	Applicable Type of Damage	Advantages	Disadvantages	Strength after Repair: Test Results Available	Strength after Repair: Analytical Procedures for Predicting Repair Strength	Reference
Replacement	Any type where piles can be redriven	Complete restoration May increase capacity	Expensive May require superstructure removal	None reported	Standard procedures for pile capacity	–
Grouting						
Cement	Internal decay primarily above water	Inexpensive Ease of application	No criteria for deciding applicability Variability of results	Some conducted but not reported	None	8
Epoxy	Internal decay and exterior splits above water	Inexpensive	Skilled workmen required No criteria for deciding applicability	Reported on wood but not piles	None	9
Pile Augmentation	Decay, splits, and breaks	Inexpensive Applicable under water	Subject to deterioration Increases pile size	None reported	None	7
Jackets	Decay, splits, and breaks	Protect against deterioration May increase capacity Applicable under water	Increases pile size Specialized equipment and personnel required	Some conducted but not reported	None	10-12
Cutting and Posting	Decay, splits, and breaks above water	Ease of application Inexpensive	Flexural strength reduced	Axial and flexural	Criteria given	Author

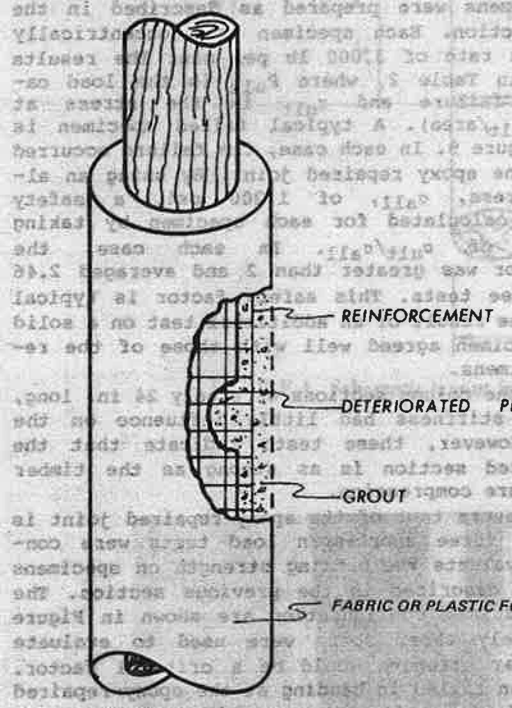

FIGURE 1 Reinforced concrete jacket for pile repair.

supports can be used. Otherwise, the pile cap must be relied on to transmit the dead load to adjacent piles. An obviously deteriorated pile is shown with a jack supporting the cap in Figure 2.

3. Cut the deteriorated section out of the pile. Cuts should be made perpendicular to the longitudinal axis of the pile. If deterioration extends to the pile cap, then the entire upper section should be removed. An example of a pile with a removed section is shown in Figure 3.

4. Prepare the replacement section by cutting a similar diameter section to fit with 1/8- to 1/4-in. clearance at top and bottom. To maintain the spacing, add washers secured by roofing nails to both ends as shown in Figure 4. To prevent epoxy from migrating parallel to the grain in surface checks during injection, cut an epoxy trench around the circumference of the pile approximately 9 in. to either side of the joint (Figure 4). For short replacement sections, the trench can be omitted in the replacement section. The trench should be 1/4-in. wide and 3/4- to 1-in. deep. Inspect the base of the trench for deeper checks. If any are found, drill a 1/4-in. hole to the bottom of the check. During the sealing stage, this trench will be filled with epoxy gel to prevent

FIGURE 2 Seriously deteriorated pile with jack supporting pile cap.

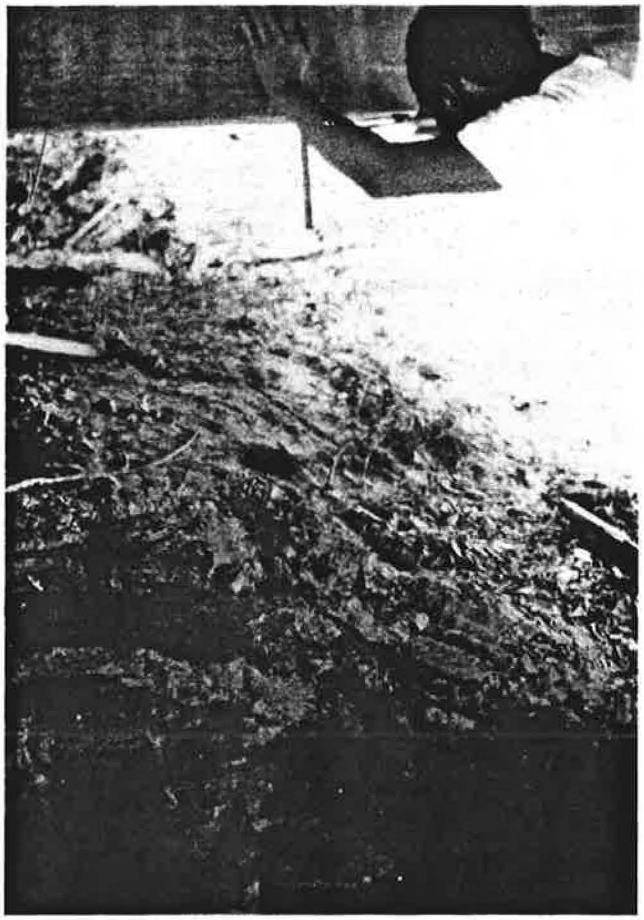

FIGURE 3 Pile stub remaining after removal of section below pile cap.

longitudinal injection epoxy migration much as a slurry trench prevents fluid migration through soil.

5. The replacement section is placed in position and wedged tight with wooden wedges (Figure 4). The wedges maintain a constant opening during the curing process. A section in place is shown in Figure 5.

6. Tie pins are placed at each cut location. Four holes are drilled at approximately 6 in. above each joint with a 14-in. long, 9/16-in. drill bit. The holes are spaced at 90 degrees around the pile and drilled at a 60-degree or larger angle with the horizontal as shown in Figure 4. The steel pins are 3/8-in. square bars twisted to form a spiral of one revolution for each 6 in. of length. The pins are lightly driven until flush with the surface (Figure 6).

7. Set injection and venting ports and seal the joint between epoxy trenches. Sealing in progress is shown in Figure 7. The epoxy trenches and holes in the base of the trenches are filled completely with an epoxy gel of putty-like consistency such as Sika Dur Hi-Mod Gel. Injection and venting ports of 1/4-in. copper tubing are placed at the joint (two minimum) and at the opening for each pin and sealed in place with gel (see Figure 4). Then the entire section between trenches is coated with gel.

8. Leak test the sealed joint by temporarily capping all ports and pressurizing the injection port with air or gas. A soap film brushed over the joint can be used to detect leaks. Repair all leaks before the final step.

9. Pressure inject a low viscosity epoxy such as Sika Dur Hi-Mod LV into one port while using the others as venting ports. (A nozzle pressure of 40 psi is recommended.) As venting ports leak epoxy, they are capped and the injection continues. When all ports are capped, injection should be continued until approximately 20 psi pressure is maintained for at least 5 sec. The procedure is completed by capping off the injection port.

LABORATORY EXPERIMENTAL STUDY

To evaluate the effectiveness of the posting and epoxy grouting repair procedure, two series of tests were conducted. In both test series, cut and posted pile sections were repaired and tested. The epoxy used was Sika Dur Hi-Mod LV, which has been found to be effective in the repair of timber structures (13). The first was a set of axial load tests on a pile segment with a single joint. The pile configuration is shown in Figure 8a. The pile segments were taken from Southern pine telephone poles obtained from South Central Bell. Although smaller than typical bridge piles (8 in. versus 12 in.), the piles are large enough to model typical bridge pile behavior. Three specimens were prepared as described in the previous section. Each specimen was concentrically loaded at a rate of 3,000 lb per min. The results are shown in Table 2, where P_{ult} is the load capacity at failure and σ_{ult} is the stress at failure (P_{ult}/area). A typical failed specimen is shown in Figure 9. In each case, the failure occurred away from the epoxy repaired joint. By using an allowable stress, σ_{all}, of 1,200 psi, a safety factor was calculated for each specimen by taking the ratio of $\sigma_{ult}/\sigma_{all}$. In each case, the safety factor was greater than 2 and averaged 2.46 for the three tests. This safety factor is typical for wood. The result of an additional test on a solid control specimen agreed well with those of the repaired specimens.

Because the column sections were only 24 in. long, the member stiffness had little influence on the strength. However, these tests indicate that the epoxy-repaired section is as strong as the timber itself in pure compression.

A more severe test of the epoxy-repaired joint is in bending. Three short-span load tests were conducted to evaluate the bending strength on specimens repaired as described in the previous section. The specimen and load configuration are shown in Figure 8b. Relatively short spans were used to evaluate whether shear strength would be a critical factor. Each specimen failed in bending at the epoxy-repaired joint. The test results are shown in Table 3, where P_{ult} is the load capacity at failure; σ_{ult} is the extreme fiber bending stress at failure; and M_{ult} is the bending moment at failure. The safety factor based on an allowable extreme fiber bending stress, σ_{all}, of 1,850 psi averaged 0.94 for the three tests and was obtained by taking the ratio of $\sigma_{ult}/\sigma_{all}$ at the centerline. The deviation of each failure stress from the mean was small. This characteristic was expected because the quality control of the epoxy formulation is quite high. A safety factor of at least 1.7 would be desirable for such a material. Based on these tests, the ultimate bending strength of the repaired joints approximately equals the allowable strength of an undamaged pile. The properties of the wood itself are significantly more variable and a normal wood safety factor would be much higher--approximately 2.25.

A failed section is shown in Figure 10. An examination of each of these sections indicated that the extreme fiber tension section failed initially. The

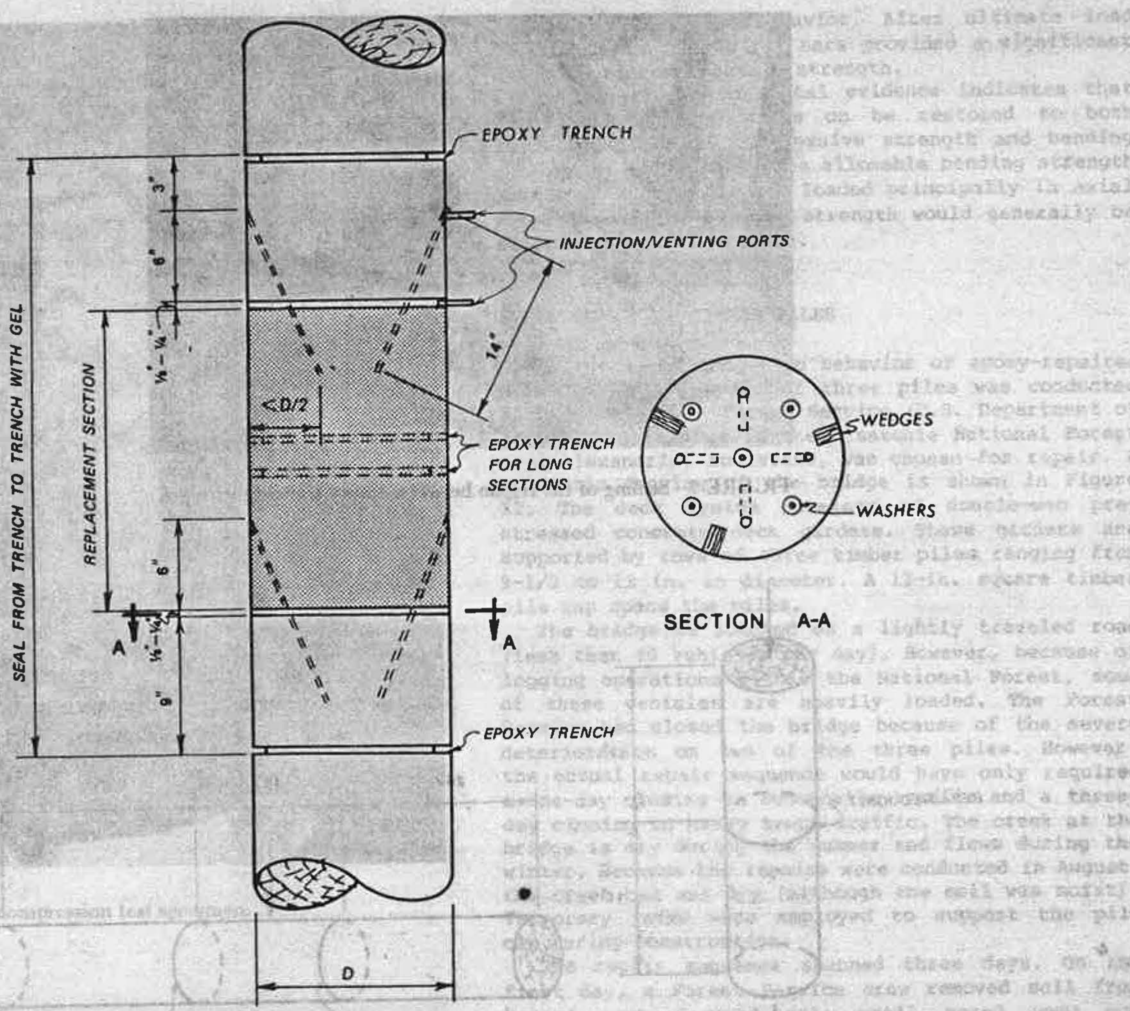

FIGURE 4 Schematic layout for epoxy repair of timber piles.

FIGURE 5 Pile with replacement section in place.

FIGURE 6 Spiral steel rod being placed at joint.

FIGURE 7 Sealing of the region between epoxy trenches with gel.

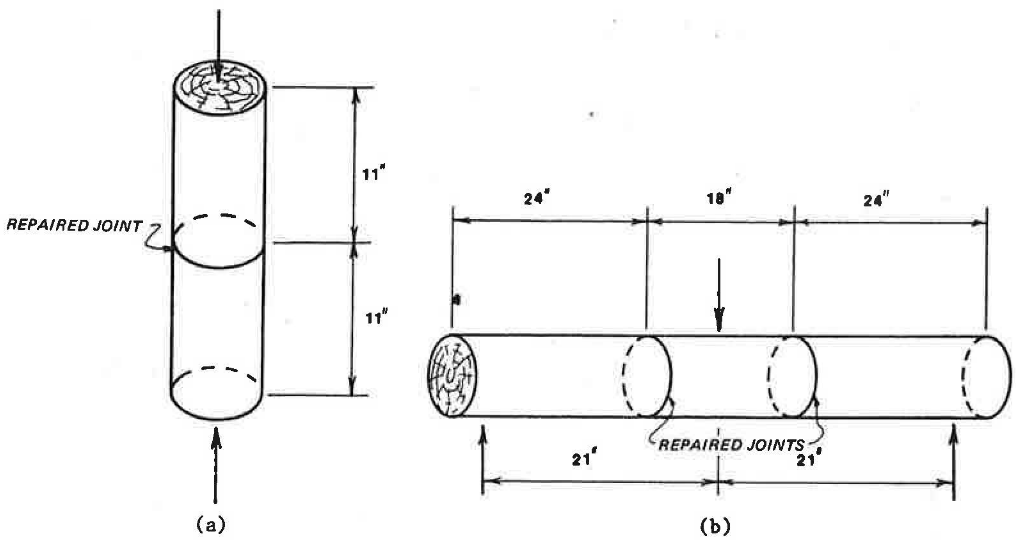

FIGURE 8 Typical test specimens for axial and flexural load tests.

TABLE 2 Axial Load Tests of Timber Piles

Specimen No.	Diameter (in.)	Area (in.)	P_{ult} (kips)	σ_{ult} (kips/in.^{2})	σ_{all} (kips/in.^{2})	Safety Factor
10	6.93	37.7	98.5	2.61	1.2	2.18
11	8.03	50.7	147.5	2.91	1.2	2.43
12	8.31	54.2	180.0	3.32	1.2	2.77
Average				2.95		2.46
Undamaged control specimen		41.3	120.5	2.92	1.2	2.43

TABLE 3 Flexural Load Tests of Timber Piles

				At Centerline		At Repaired Section			
Specimen No.	Diameter (in.)	Section Modulus (in.^{3})	P_{ult} (kips)	σ_{ult} (kips/in.^{2})	M_{ult} (ft-k)	σ_{ult} (kips/in.^{2})	σ_{all} (kips/in.^{2})	Safety Factor	M_{ult} (ft-k)
1	8.49	56.6	15.6	2.89	13.7	1.65	1.85	0.89	7.8
2	7.62	45.7	13.8	3.18	12.1	1.82	1.85	0.98	6.9
3	7.41	43.1	12.4	3.02	10.9	1.73	1.85	0.94	6.2
Average				3.03		1.73		0.94	
Undamaged control specimen	9.41	69.5	38.3	5.78	33.5	5.78	1.3	4.44	33.5

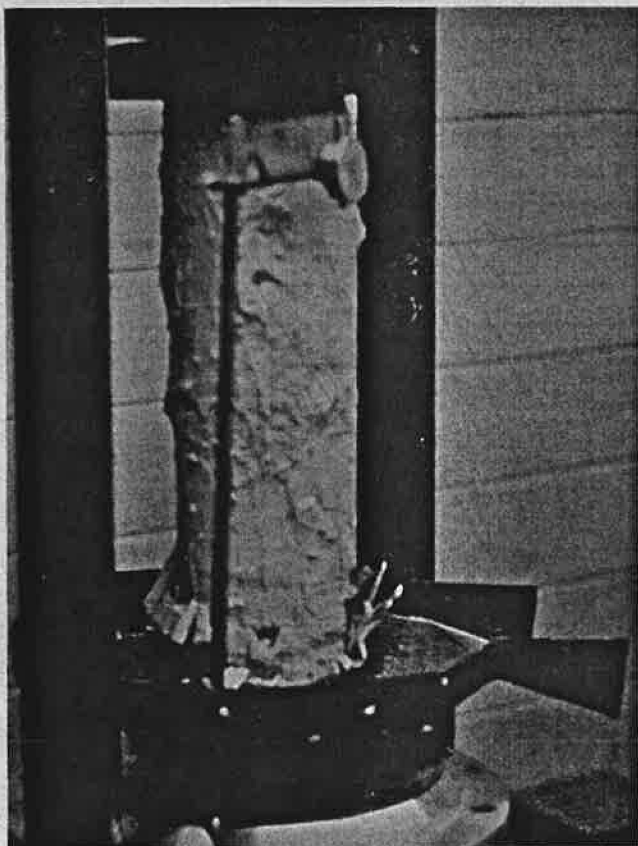

FIGURE 9 Failed compression test specimen.

FIGURE 10 Failed joint of a typical flexural test specimen.

failure did not occur at the epoxy-to-wood bond, but rather in the epoxy itself. This failure type indicates the effectiveness of the pressure-injected epoxy at the bond line because the epoxy failed before the bond.

A load-deformation curve was plotted for each specimen. These plots are shown in Figure 11. It can be seen that the stiffnesses of the epoxy-repaired sections are similar to that of the control specimen, which was a solid section of the same stock. Although not measured, it should be noted that the failures represented ductile behavior. After ultimate load was obtained, the spiral bars provided a significant level of reserve ductile strength.

In summary, experimental evidence indicates that the epoxy-repaired piles cn be restored to both satisfactory axial compressive strength and bending stiffness, but only to the allowable bending strength level. Because piles are loaded principally in axial compression, the bending strength would generally be a secondary consideration.

FIELD REPAIR OF TIMBER PILES

To evaluate the long-term behavior of epoxy-repaired piles, a field repair of three piles was conducted in August 1983. A Forest Service (U.S. Department of Agriculture) bridge in the Kisatchie National Forest near Alexandria, Louisiana, was chosen for repair. A schematic drawing of the bridge is shown in Figure 12. The deck system consists of double-web prestressed concrete deck girders. These girders are supported by rows of three timber piles ranging from 9-1/2 to 12 in. in diameter. A 12-in. square timber pile cap spans the piles.

The bridge is located on a lightly traveled road (less than 20 vehicles per day). However, because of logging operations within the National Forest, some of these vehicles are heavily loaded. The Forest Service had closed the bridge because of the severe deterioration on two of the three piles. However, the actual repair sequence would have only required a one-day closing to automobile traffic and a three-day closing to heavy truck traffic. The creek at the bridge is dry during the summer and flows during the winter. Because the repairs were conducted in August, the creek bed was dry (although the soil was moist). Temporary jacks were employed to support the pile cap during construction.

The repair sequence spanned three days. On the first day, a Forest Service crew removed soil from around each damaged pile until sound wood was reached. A backhoe was used with from 2 to 4 ft of soil being removed from around the piles. This operation required about 2 hr. The extent of damage was determined on each pile by drilling and examining the chips. The three replacement sections were selected from a local plant and brought to the site during the first day.

The actual repairs began on the second day with a four-man crew. The jacking, cutting, posting, sealing with epoxy gel, and leak testing was completed for all piles. On the third day, the epoxy injection was completed and the deformation gauges were set.

The damaged piles are shown in Figures 13 and 14. Piles 1 and 2 were damaged from the pile cap to a depth of 5 ft and were 10 1/2 and 11 1/2 in. in diameter, respectively. These 5-ft sections were replaced with new treated sections obtained from a local lumber yard. Pile Number 1 with the damaged section removed is shown in Figure 3, and the new section in place at Pile Number 1 is shown in Figure 6. Pile Number 3 was repaired by replacing a 3 ft section beginning at 2 ft below the pile cap and having a 9 1/2-in. diameter. The new section in place is shown in Figure 5. All piles were repaired using the procedure described previously. After the replacement sections were placed and wedged, the jacking forces were released. Figure 7 illustrates the sealing phase of the repair on Piles 1 and 2. The repaired Piles 1 and 2 are shown 1 year after repair in Figure 15 and 2 years after repair in Figure 16.

All piles were successfully injected with little leaking. In Piles 1 and 2, the epoxy migrated upward to the pile cap in spite of the epoxy trench. Pile

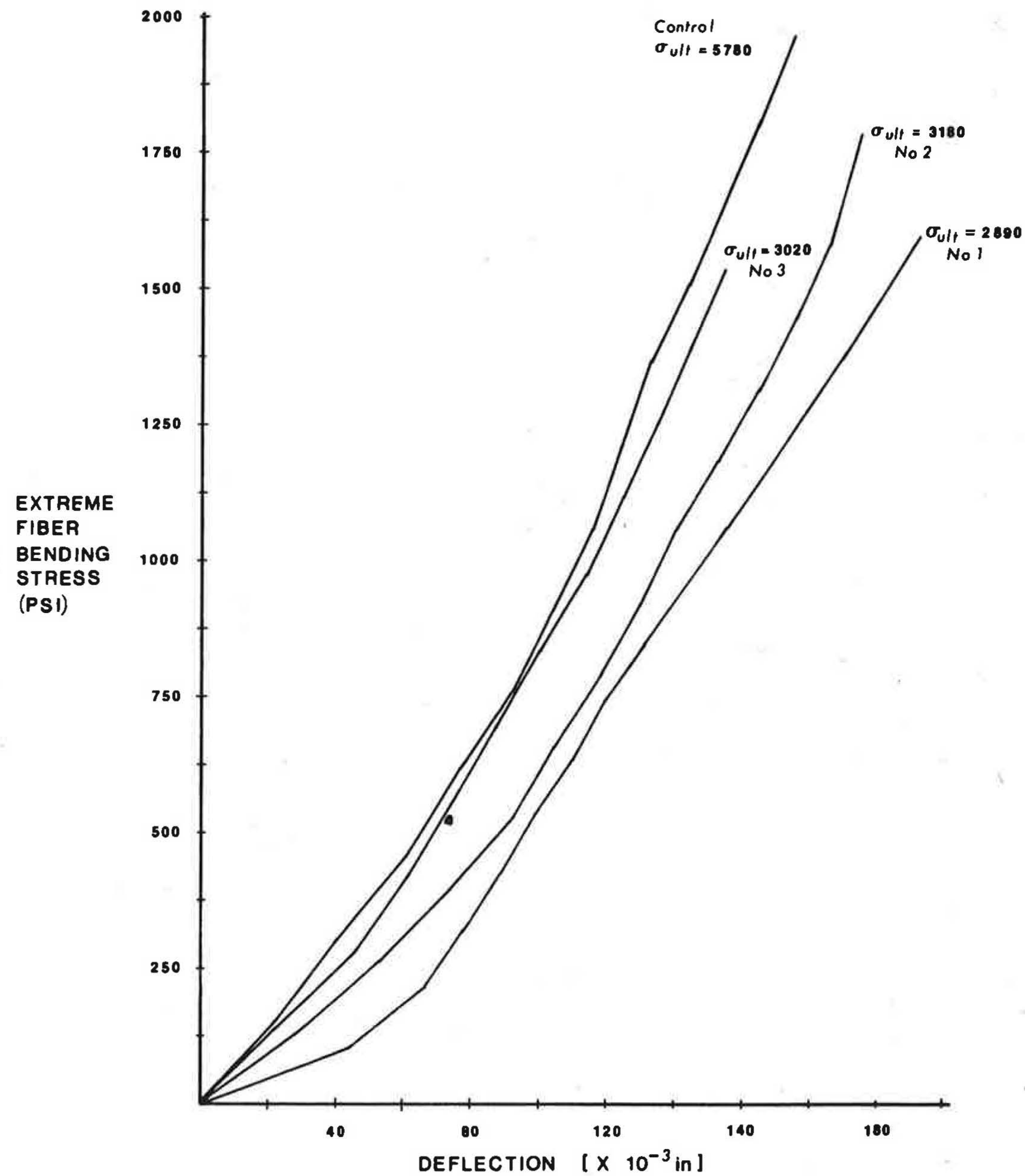

FIGURE 11 Load-deflection curves for flexural tests.

Number 3 showed no migration problems. For each case, a nozzle back-pressure of approximately 20 psi was obtained. A set of permanent deflection measuring devices was placed on each repaired joint as shown schematically in Figure 17. These devices are being monitored over a multi-year period to evaluate long-range behavior of the epoxy-repaired piles. The results from the gauge readings over the first 2 years are given in Table 4 and indicate that practically no relative movement has occurred at any of the epoxy bond lines.

SUMMARY AND CONCLUSIONS

A method for posting and epoxy grouting timber piles is detailed and a laboratory investigation has been conducted to evaluate the strength and behavior of epoxy-repaired timber piles. In addition, three piles were field-repaired at a bridge in the Kisatchie National Forest near Alexandria, Louisiana. These piles are being monitored for long-term behavior.

Although the study sample was small, some tentative conclusions can be drawn from the research, for example, (a) posting and epoxy grouting will provide a predictable level of structural restoration, (b) the axial compressive strength can be restored to the original design capacity, and (c) the flexural strength can be restored to a level of approximately one-half the original design capacity. It is therefore recommended that design computations on strength after repair be based on: (a) the full design allowable stress of the existing pile in compression; and (b) 45 percent of the allowable stress of the existing pile in flexure.

The repair procedure restores the flexural stiffness to approximately that of the original pile. In addition, the flexural failure mode is ductile. When the epoxy bond line fails in tension, there is a reduction in load-carrying capacity. However, the

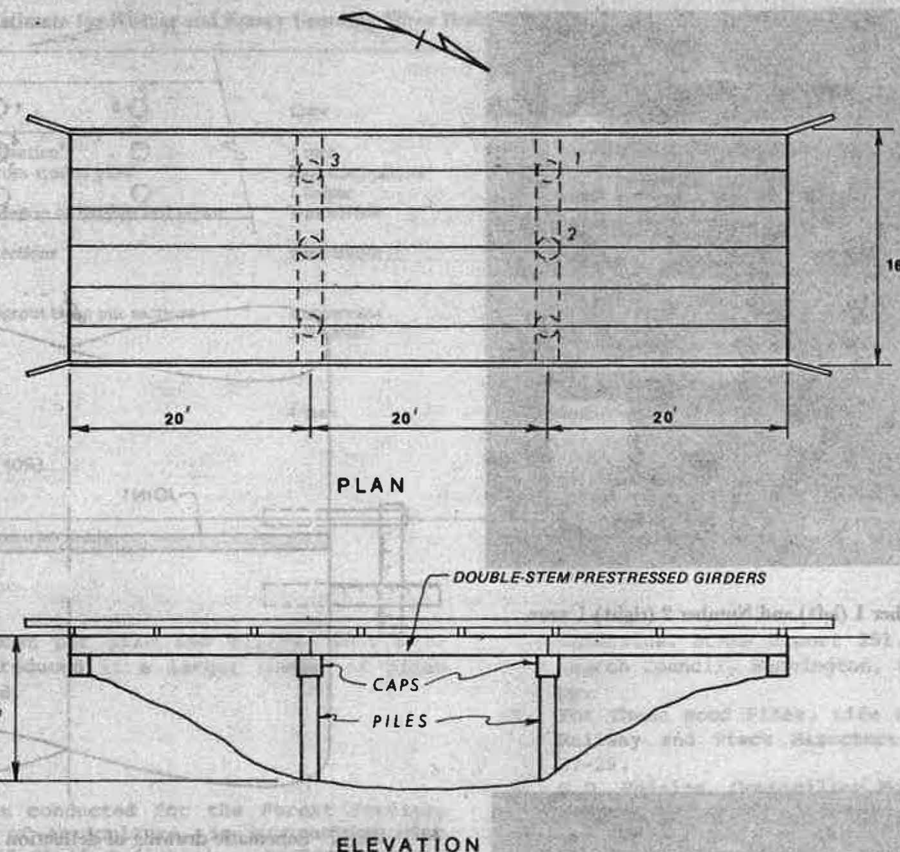

FIGURE 12 Schematic diagram of bridge to be repaired.

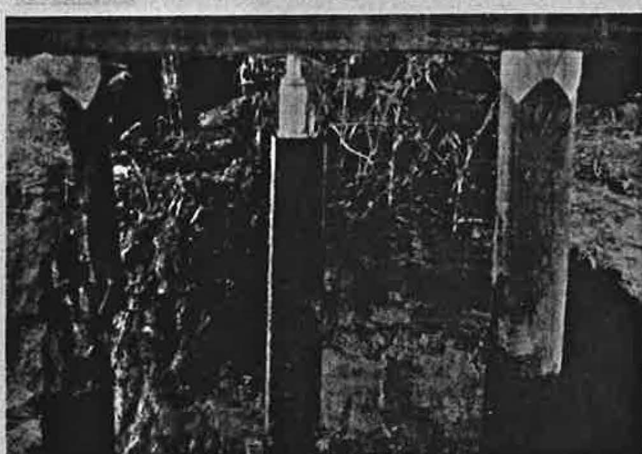

FIGURE 13 Damaged piles Number 1 (left) and Number 2 (right) with jack in place.

FIGURE 14 Damaged pile Number 3.

twisted steel pins remain bonded and provide a significant ductile range in the load-deformation curve.

An important aspect of forming a strong epoxy bond line is the pressure injection. The use of pressure ensures that the epoxy is forced into the wood fibers to produce a strong bond. It provides a level of quality control on the bonding process that cannot be obtained by simply pouring epoxy into the joint as is sometimes recommended by contractors.

Because the epoxy gains strength very rapidly,

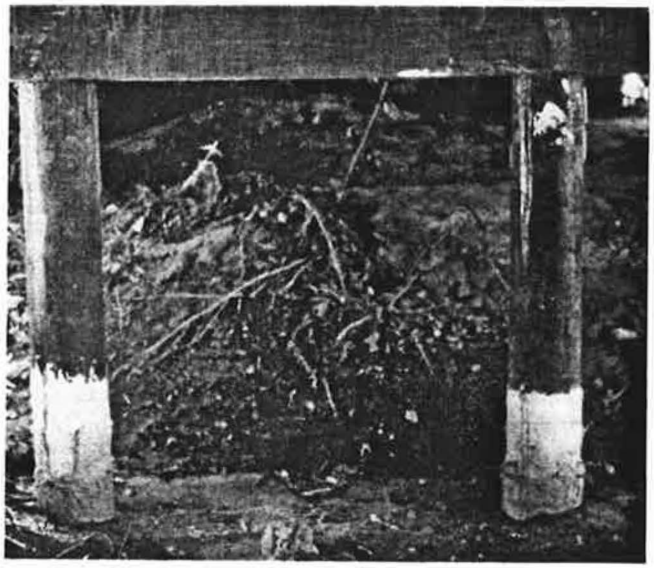

FIGURE 15 Piles Number 1 (left) and Number 2 (right) 1 year after repair.

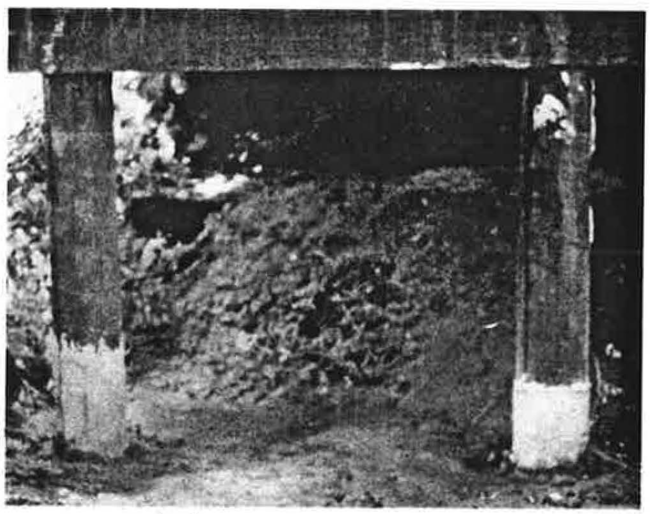

FIGURE 16 Piles Number 1 (left) and Number 2 (right) 2 years after repair.

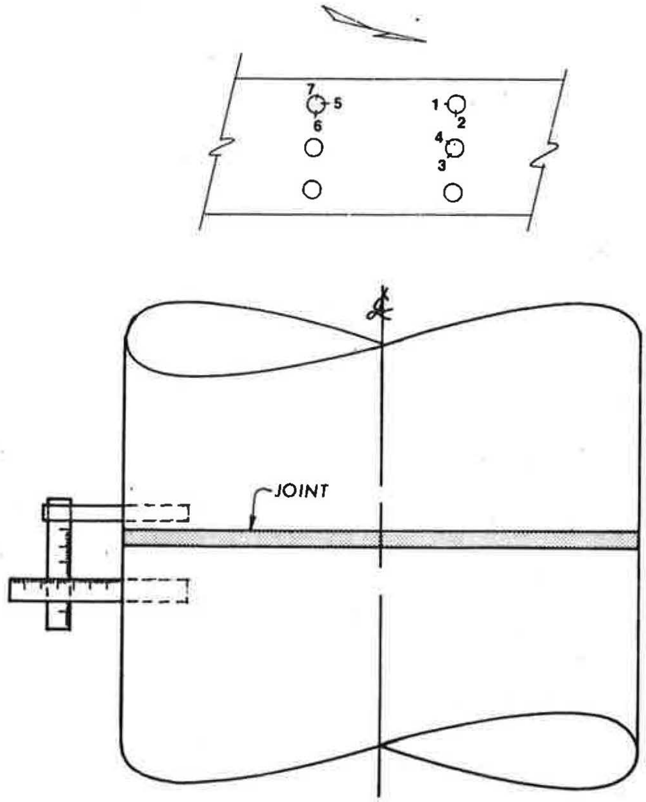

FIGURE 17 Schematic drawing of deflection gauges at a repaired pile joint.

the bridge can be quickly reopened to traffic. For both the epoxy used here and similar types used in wood repair, the initial cure time varies with temperature, but is typically about 4 hr. At initial cure, the epoxy has 50 percent of its ultimate compressive strength. The final cure time to obtain full compressive strength ranges from 24 hr at 90°F to 72 hr at 50°F. Thus, a bridge can be opened to full traffic within one to three days, depending on the temperature.

A final area of interest is the cost of the repair. Because unit costs vary considerably in different localities, only an approximate estimate can be given. A cost breakdown for the three pile repairs near Alexandria, Louisiana, is given in Table 5. For

TABLE 4 Results of Long-Term Bridge Monitoring

Gauge No.	Change in Deflection from Initial Reading on Aug. 11, 1983 (in.)					
	11 Days		1 Year		2 Years	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
1	1/64	0	1/64	1/64	1/64	0
2	1/64	0	0	0	1/64	0
3	1/64	1/64	0	0	0	0
4	0	0	0	1/64	0	1/64
5	0	1/64	0	1/64	0	1/64
6	0	0	0	1/64	Gauge Damaged	Gauge Damaged
7	0	0	0	0	0	0

TABLE 5 Cost Estimate for Posting and Epoxy Grouting Three Bridge Piles near Alexandria, Louisiana (1983)

Task	Crew	Material/Equipment	Unit Cost ($)	Units	Total Cost ($)
Mobilization/demobilization[a]	4 men	Truck transportation to site	0.50/mi	360 mi	180
Remove soil/debris from around piles[a]	Backhoe operator	Backhoe	100/hr	4 hr	400
	1 helper		10/hr	4 hr	40
Inspect and evaluate degree of damage and repair procedure	1 supervisor		40/hr	2 hr	80
Obtain replacement sections	1 supervisor		40/hr	4 hr	160
		Three 12-in. diameter replacement sections x 10 ft long	3/ft		90
Cut, post, and epoxy-grout three pile sections	1 supervisor		40/hr	12 hr	480
	3 laborers		10/hr/man	36 hr	360
		Epoxy	40/gal	6 gal	240
		Generator	10/hr	12 hr	120
		Miscellaneous supplies	200	Job	200
Crew living expenses	4 men	Motel/meals	200/day/crew	2 days	400
Subtotal					2,750
Overhead and profit (40%)					1,000
Total					3,750

[a]May vary considerably from job to job.

this job, the cost per pile was $1,250. This unit price would be reduced if a larger number of piles had been repaired.

ACKNOWLEDGMENTS

This project was conducted for the Forest Service, U.S. Department of Agriculture, in conjunction with the Department of Civil Engineering, Louisiana State University. Appreciation is extended to both organizations for their cooperation throughout the project.

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