Abridgment

Application: Deep Grooving—A Method for Impregnating Concrete Bridge Decks

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ABSTRACT

Polymer impregnation of concrete is a long-term protection method for chloride-contaminated concrete bridge decks. The deep-grooving impregnation method significantly reduces impregnation time, simplifies equipment needs, mitigates potential fire hazards, and may provide a long-lasting and more skid-resistant surface. The procedures for impregnating a concrete bridge deck using the deep-grooving method are presented. Included are methods used to calculate the optimum groove spacing, width, and depth. An optimum drying criterion using a propane-fired infrared heater is presented. A method for determining the impregnation time and polymerization times and methods for a methyl methacrylate (MMA) monomer system are also presented. In addition, methods for filling the grooves, an estimated total time to impregnate an average bridge, and cost data are presented.

The polymer impregnation of steel-reinforced concrete bridge decks is a process that may provide long-term rehabilitation of salt-contaminated bridge decks where the corrosion of the reinforcing steel is imminent or in its initial stage. Therefore, an investigation into the cause(s) of any observed deterioration and the extent of the chloride contamination should be performed on every candidate deck. The purpose of the investigation is to determine if polymer impregnation is the proper solution to the observed deterioration problem. The investigation should include a topographic survey, half-cell potentials, level of chloride contamination, detection of delamination planes, and depth of concrete cover. In addition, cores need to be taken for petrographic examinations and for determination of the mean surface pond impregnation rate. The application of the deep-grooving impregnation method is based on laboratory results and thus necessitates the need for a full-scale field trial. The field trial procedures for the deep-grooving impregnation method are presented in this paper.

DEEP-GROOVING IMPREGNATION METHOD

The deep-grooving method of the polymer impregnation of concrete bridge decks consists of the following phases:

1. Cutting grooves on lines of equal elevation to a depth of 0.5 in. above the upper steel reinforcing bars,
2. Drying the concrete to a depth of 0.5 in. below the upper steel reinforcing mat,
3. Soak-impregnating the dried concrete by filling the grooves with the monomer, and
4. Filling the grooves with dry sand, impregnating the dry sand with the monomer, and polymerizing the impregnated mass, or filling the grooves after the polymerization of the impregnated concrete.

The optimum spacing of the grooves (distance from edge of groove to edge of groove) is to be equal to the distance from 0.5 in. above the upper steel reinforcing bars to 0.5 in. below the upper steel reinforcing mat (1). Figure 1 shows an example of spacing, where No. 5 steel reinforcing bars are used in both directions; therefore, the spacing of the grooves is equal to 2.25 in. (0.5 in. + 2 x 0.625 in. + 0.5 in.). This value is the required depth of impregnation from the bottom of the grooves. The width of the grooves is determined by dividing 10 percent of the vertical cross-sectional area of the deck to be serviced by one groove by the groove depth. The area to be serviced by the area of one groove is the depth of impregnation required (D - 0.5 + S) times the width (W + S) minus the groove area [(W) (D - 0.5)]. Groove depth will be equal to cover depth minus 0.5 in. (D - 0.5). Therefore,

$$W = \{(0.10)\,[(W + S)(D - 0.5 + S) - (W)(D - 0.5)]\}/(D - 0.5) \qquad (1)$$

where

W = groove width (in.),
S = edge-to-edge distance between grooves (in.), and
D = cover depth (in.).

Continuing the previous example and assuming a cover depth of 2 in., the groove depth will be 1.5 in. (2 in. - 0.5 in.), and the groove width can be determined from the preceding equation:

$$W = \{(0.10)\,[(W + 2.25)(2 - 0.5 + 2.25) - (W)(2 - 0.5)]\}/(2 - 0.5) \qquad (2)$$

from which W = 0.66 in., and the groove spacing, center-to-center, is W + S = 0.66 + 2.25 = 2.91 in.

The calculation is based on a monomer loading of 10 percent by volume (2). An estimated cost of a grooving machine to cut grooves 0.75 in. wide, 1.5 in. deep, and spaced at 3 in. center-to-center is $480,000. The machine would have a cutting width of 6 ft and would cut the grooves at a rate of about 300 yd^2/hr. The entire deck is to be grooved before the drying phase is started.

The grooved-concrete deck is to be dried with a propane-fired infrared (IR) heater with an optimum constant surface temperature of approximately 600°F (1). The concrete is to be considered dry when the temperature at a depth of 0.5 in. below the upper steel reinforcing mat is equal to 230°F (2). A 24-in.-wide area around the perimeter of the shielded drying area should be covered with insulation that has an insulating value of R-19 (1). An area of 20 x 12 ft can be dried at one time. An estimated cost of a 20 x 12-ft heater is $48,000. R-19 insulation is to be placed over the dried area during the cooling cycle. Thermocouples (two per drying area) are to be placed at a depth of 0.5 in. below

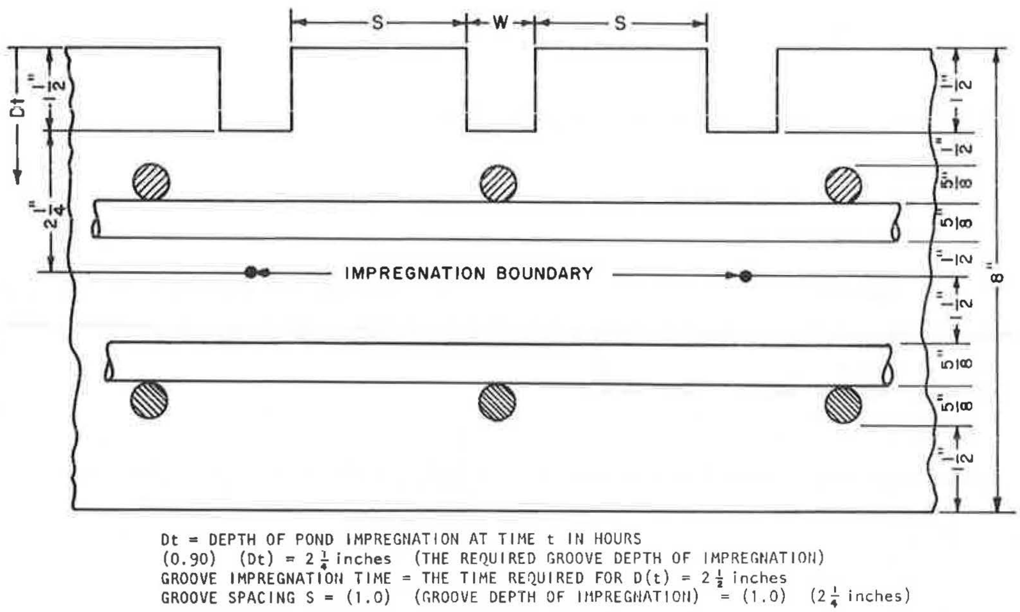

FIGURE 1 Method for determining the groove impregnation time and groove spacing.

the upper steel reinforcing mat in order to determine when the concrete is dry and when the monomer has polymerized. The propane requirements for drying are expected to average approximately 0.331 gal/ft^2. Typically, 3 hr is the required heating time needed to achieve drying by using a 600°F constant surface temperature (1).

The time of soak impregnating by grooving is to be determined from the mean surface pond impregnation rate (1). As an example (Figure 1), with a required depth of impregnation of 2.25 in. below the base of the groove, the surface pond impregnation depth (D_t) would be equal to 2.25 in. ÷ 0.90 = 2.50 in. The time of impregnation would then be equal to the time required to impregnate to a depth of 2.5 in. by surface ponding, which is typically 16 hr. Approximately 3 lb of monomer is required per square foot of bridge deck [100 parts methyl methacrylate (MMA) to 10 parts trimethylopropane trimethacrylate (TMPTMA) to 0.5 parts 2,2'- azobisisobuyronitrile (AZO), by weight]. During the impregnation phase, the deck is to be covered with a 4-milthick sheet of polyethylene to reduce the evaporation rate of the monomer and the fire hazard.

After the impregnation phase, the grooves are to be filled with dry, compact, well-graded sand with 100 percent passing the No. 8 sieve and less than 2.0 percent passing the No. 200 sieve. About 4 lb of dry sand are required per square foot of deck. The sand is to be saturated with monomer and the impregnated mass polymerized by placing a polymerization vessel over the impregnated area. The vessel is to be filled with several inches of water, and the water temperature increased to about 205°F with steam. The 205°F water temperature is to be maintained with steam until the monomer is polymerized. The monomer is to be considered polymerized when the thermocouples indicate that a temperature of 122°F has been maintained for 5 hr or 130°F for 2 hr (as shown in Figure 2) at the depth of impregnation.

It is envisioned that the sides and top of the compartmentalized vessel is to be constructed of nonspark metal. The steam pipes would run through the vessel, and the bottom of the vessel would be lined with a nylon-metal laminate. The top, sides, and a 24-in.-wide area encompassing the vessel should be insulated with an insulation material with a value of R-30. Typically, it takes 16 hr to obtain a temperature of 122°F at a depth of 4 in. below the surface with hot water being maintained at about 205°F. Therefore, a conservative estimate of the time to polymerize is about 21 hr.

The total time required to impregnate a bridge deck by the grooving method is going to be dependent on site conditions. However, as an estimate, an average bridge deck that is about 40 ft wide and 216 ft long can be completed in about 10 days by using the grooving method. The estimate assumes one 20-ft lane to be completed at one time by using 1 IR heater (20 x 12 ft) and the following time requirements: 8 hr grooving, 72 hr drying, 16 hr impregnating, and 21 hr polymerizing.

As an alternative, electric blankets similar to those used for curing wax bead concrete may be used

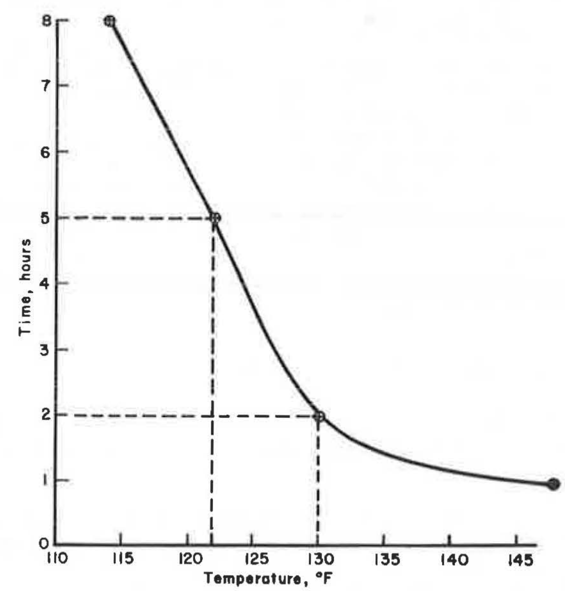

FIGURE 2 Impregnated in situ concrete polymerization time of an MMA system as a function of activation temperature.

to polymerize the MMA monomer system (3). A conservative polymerization time would be about 6 hr [4.25 hr to obtain a temperature of 130°F at a depth of 4 in., see Figure 3 (3), plus 1.75 hr]. The estimated total time required to impregnate an average bridge deck would be reduced to 8.5 days. In either approach, the grooves can either be filled with an ambient cure polymer concrete or latex-modified mortar after the polymerization process has been completed.

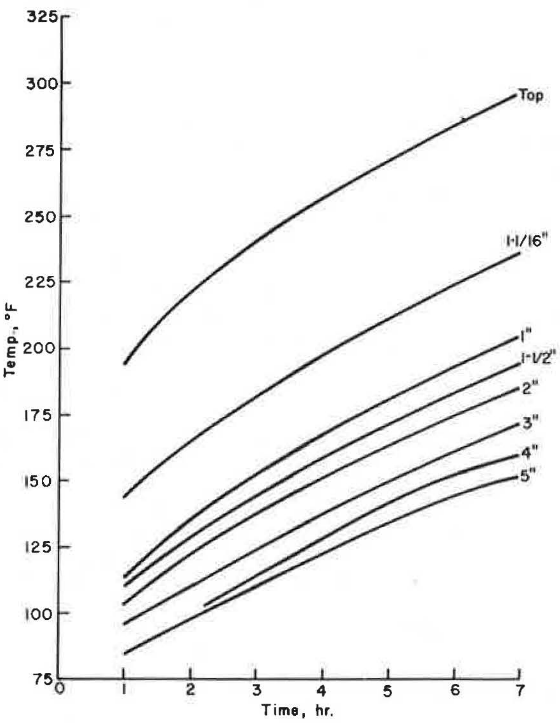

FIGURE 3 Temperature versus time at various depths by using electric heating blankets at 100 to 89 w/ft^2 *(3)*.

COST

The cost data presented are for average 1981 values (4). Road user and traffic maintenance and protection costs were not included. Although these are real and important costs, it is difficult to arrive at representative average values because these costs vary so widely, primarily in response to traffic volume. The data in Table 1 present the average 1981 costs for the deep-grooving impregnation system, present method of deck rehabilitation, deck replacement, and maintenance.

However, decisions based on initial costs or individual events will generally not result in a least-cost solution. Least-cost solutions account for all of the costs incurred over the service life of a structure, considering the time value of money. Least-cost solutions may be realized by comparing equivalent uniform annual cost for perpetual service, in the case of bridge decks, or capitalized cost (present worth of perpetual service). By using engineering economic evaluation methods with a true

TABLE 1 Summary of Cost Data

Item, Material, or Activity	1981 Estimated Cost (\$/ft^2)
Deep-grooving impregnation system	
Deep grooving (0.75 in. x 1.5 in. deep, 3 in. center-to-center	1.00
Drying	1.06
Impregnation	0.98
Polymerization	2.29
Impregnant (MMA)	2.49
Present method of deck rehabilitation	
Scarification of sound areas of deck (0.25 in.)	0.59
Removal of deteriorated concrete and PCC[a] patch	12.89
Deck modifications (raising expansion dams, scuppers, and back walls)	0.96
Latex-modified mortar or concrete (1.5 in. thick)	3.64
Deck replacement	
Complete deck removal	11.11
New deck with epoxy-coated rebars in top mat only	13.73
Maintenance: hot-mix bituminous patching	1.18

[a]PCC = portland cement concrete.

cost of long-term borrowing (6 percent interest factor), the capitalized cost of the current method of concrete bridge deck rehabilitation is about \$12.80/ft^2 compared with \$7.96/ft^2 for the deep-grooving impregnation method. Therefore, the deep-grooving method of impregnation offers a cost-effective solution to significant problems, and thus efforts should be extended to further develop the method through the application of full-scale field trials.

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The authors are responsible for the accuracy of the data and the conclusions and opinions.

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