# DEEP IMPREGNATION OF CONCRETE BRIDGE DECKS WITH LINSEED OIL

Philip D. Cady, Donald E. Kline, Paul R. Blankenhorn,
The Pennsylvania State University

The overall objective of the research described in this paper was to evaluate the feasibility of deep ( > 5 cm) impregnation of concrete bridge decks with boiled linseed oil/diluent mixtures. Impregnation is one of the techniques that is currently receiving considerable attention as a means of improving the longevity of bridge decks by reducing or preventing spalling problems associated with corrosion of reinforcing steel. The choice of linseed oil was based on safety (low volatility and high flash point), cost considerations, and the elimination of the polymerization step required for other polymers. Also, many highway agencies are already familiar with linseed oil, since it is commonly sprayed on bridge deck surfaces periodically to retard surface scaling. The latter procedure results in penetration depths of less than 3 mm and has little or no effect on preventing spalling. Deep impregnation requires a drying step to remove water, followed by sufficient contact with the impregnant to permit penetration to the desired depth. Following a period of preliminary laboratory studies, demonstration impregnations were carried out on 5.6 $m^2$ areas on two bridge decks. One of the bridges had been subject to 3 winters of deicer salt application. The other had received no salt. Four days soaking time with a 50-50 mixture of boiled linseed oil/mineral spirits mixture was used in the impregnation step. Examination of cores subsequently removed from the test areas revealed that penetration depths ranging from about 5 to 10 cm were obtained.

## The Problem

Spalling of concrete bridge decks is currently one of the most serious problems facing highway agencies in the snow belt states. There has been a dramatic increase in the incidence and severity of bridge deck deterioration during the past twenty years. Two factors largely account for this. First, the increased volume of highway construction associated with the building of the interstate highway system produced a significant increase in the number of highway structures. Second, the "bare pavement" policy, stressing safe, all-weather driving conditions, was adopted by highway agencies in response to public pressure. The latter factor has involved the use of deicing chemicals which permeate concrete bridge decks causing corrosion of reinforcing steel and resultant spalling of the overlying concrete.

A formidable body of data exists to indict corrosion of the reinforcing steel, caused by presence of chloride deicer salts, as the major cause of bridge deck deterioration (1-4). There has been a phenomenal increase in the use of deicing salts in recent years. In 1947 less than one-half million metric tons were used in the entire country. By the winter of 1966-67, this figure had risen to about 6 million metric tons, and by the winter of 1975-76 it was estimated to be between 10 and 11 million metric tons (5). At the application rates currently in use, a typical bridge deck in a snow belt state receives about 1.2 Kg of salt per $M^2$ (about 1/4 pound per square foot) during an average winter season. The increased use of deicers is reflected in the accelerated pace of bridge deck deterioration observed. New bridges should last thirty years or more, but many now show signs of significant deterioration in five years or less (6). In 1973, the Federal Highway Administration estimated the annual cost for bridge deck repairs in the U.S. to be $70 million (7). By 1975, that figure had increased to $200 million per year (8). Even so, as a measure of damage being incurred, these figures are probably deceptively low since they likely represent the bounds of limited maintenance budgets. The Road Information Program (TRIP) estimates that during the winter of 1976-77 alone, 1626 bridges were rendered unusable due to record low temperatures and heavy salt applications (9). Most of the damage involved deck spalling, according to TRIP, and replacement or repair costs were estimated at $1 Billion.

## Bridge Deck Impregnation

Deep impregnation with sealants to immobilize chlorides present and to prevent the ingress of water, oxygen, and deicer salts is one of only two techniques that presently seem to offer promise for protection of existing chloride contaminated, but sound, concrete bridge decks.

Methyl methacrylate monomer (MMA) has been the principal impregnant used in field studies prior to the research described here. Proper drying, impregnation, and polymerization procedures using methyl methacrylate will produce concrete with essentially zero permeability to water and will immobilize deleterious contaminants already contained in the concrete pore system (viz, chlorides). Also, the mechanical and durability properties of the concrete, per se, are significantly enhanced. However, the use of methyl methacrylate has serious drawbacks. The monomer is expensive, highly volatile, extremely flammable, and must be subjected to a separate polymerization step. Assuming that the improvement in mechanical and other properties afforded through the use of methyl methacrylate is not a necessary prerequisite, other materials may be used as impregnants whose function is merely that of blocking the pores and immobilizing salts contained therein. Furthermore, these impregnants could be selected to countermand the disadvantages of methyl methacrylate cited above.

A logical candidate as an impregnant is linseed oil. For years, highway agencies have been using mixtures of boiled linseed oil and diluents to seal the surfaces of concrete bridge decks to retard surface scaling. However, these applications penetrate the concrete surface to depths of only about 3 mm (1/8 inch) and have little or no effect in reducing spalling. Impregnation with linseed oil, or similar materials, to the level of the top reinforcing steel (5 to 10 cm or 2 to 4 in.) should, however, effectively block the continuous capillary system and immobilize chloride ions in the vicinity of the rebars.

## Purpose of the Research

The purpose of the research described in this paper was to develop in the laboratory and demonstrate in the field the methodology for deep penetration of concrete bridge decks with boiled linseed oil to prevent the ingress of deicer salts and water and to immobilize deleterious ions already present. This goal was pursued by addressing the following specific objectives:

1. Determination of the time, temperature, and impregnant conditions to optimally impregnate suitably dry concrete to a depth of about 6.4 cm (2 1/2 in.)
2. Evaluation of the protection against corrosion of the reinforcement by water and deicer salts afforded by the selected impregnant.
3. Demonstration of the feasibility of the technique involved on a chloride-contaminated and a non-contaminated bridge deck in the field.

## Laboratory Tests

### Impregnant

A series of laboratory experiments was conducted to examine boiled and raw linseed oil, straight and diluted with various amounts of mineral spirits, as candidate impregnants. In experiments where the ease of penetration of the impregnant was determined by the uptake of impregnant in dried concrete by capillary action, it was found that both raw and boiled linseed oil in various combinations with 25 percent by weight or more of mineral spirits gave penetrations of 5 cm (2 in.) or more. At high mineral spirits contents (50 to 70 percent), the raw linseed oil gave deeper penetrations than the boiled linseed oil, but not on a specimen weight gain basis. These tests also revealed that impregnant uptake is approximately 75 percent complete in four days at room temperature. In general, increasing temperatures, up to 60°C (140°F), slightly increased the percent completion of impregnant uptake at any specified time.

Loss of impregnant by evaporation from concrete specimens stored in the laboratory for six months, as measured by weight loss, was negligible. However, mortar specimens obtained from the impregnated concrete that were vacuum dried at 110°C (230°F) for 24 hours showed increases in porosity with increasing mineral spirits content in mercury porosimetry tests. This indicates that when the mineral spirits are removed, penetrable porosity may be obtained. However, this was under very severe conditions, and it is believed that the negligible losses observed on the specimens in laboratory air storage are indicative of good retention of the impregnant in the field.

On the basis of these tests, it was decided to use a 50-50 boiled linseed oil-mineral spirits mixture and a four-day soak impregnation period to obtain impregnation depths of at least 5 cm (2 in.).

### Large Scale Slabs

The drying and impregnation procedures developed in the bench-scale laboratory experiments were tested on full-scale depth, reinforced concrete slab specimens in the laboratory to perfect techniques before going into the field. Two 1.83 m by 1.83 m by 20.3 cm thick (6 ft. x 6 ft. by 8 in.) slabs were constructed. Reinforcement consisted of two layers of reinforcing bars with 5 cm (2 in.) of clear concrete cover from the top and bottom faces of the slab. Each layer of reinforcement consisted of 1.59 cm diameter (no. 5) bars on 20.3 cm (8 in.) centers in one direction over 1.27 cm diameter (no. 4) bars on 15.2 cm (6 in.) centers in the other direction. The concrete used in these slabs was produced in one batch having a cement factor of 350 kg/m$^3$ (590 lb/yd$^3$), water/cement ratio of 0.53 by weight, 11.4 cm (4.5 in.) slump, 7.5 percent air content, and had a 28-day compressive strength of 25.304 mPa (3670 lbf/in.$^2$).

The temperature attained at a depth in the concrete during drying can be used as the criterion to gage the sufficiency of drying relative to securing a selected depth of impregnation. Therefore, it is important to know to what extent the manner of obtaining temperatures within the concrete affects the temperature readings. It was suspected by the researchers that temperature measurements obtained from thermocouples inserted in holes drilled in the top surface of the slabs would be falsely high due to conduction of heat through the thermocouple wires and to direct exposure of the hot junction to IR radiation. To evaluate this problem, temperature measurements were made at depths of 1.3, 2.5, 6.4, and 10.2 cm (1/2, 1, 2 1/2, and 4 in.) from the top surface of the slab using type T (copper-constantan) thermocouples inserted in 0.64 cm (1/4 in.) diameter holes drilled in the slab from both the top side and the bottom side. Temperature measurements for all eight thermocouples, plus one located on the top surface, were continuously recorded while drying was carried out using a propane fired, infrared heater. It was found that thermocouples inserted through the top surface give readings that may be falsely high by as much as 111°C (200°F) at the surface to 28°C (50°F) at

10.2 cm (4 in.) deep. However, it was determined that a 100 MJ/hr/$m^2$ (9000 BTU/hr/sq ft) propane-fired catalytic IR heater set about 28 cm (11 in), from the concrete surface will produce sufficient drying in three to four hours to provide 5 cm (2 in.) or more penetration of 50-50 by weight boiled linseed oil-mineral spirits after four days of soaking.

One of the large slab specimens was salt contaminated by ponding brine solution for 90 days. Sixteen corrosion potential determinations (10) gave an average of -0.53 volts relative to the copper-copper sulfate half-cell, well in excess of the -0.35 volts considered to be indicative of active corrosion. Impregnation of this slab with 50-50 boiled linseed oil-mineral spirits by weight resulted in a reduction of the corrosion potential by 40 percent (-0.32 volts CSE), putting it in the "uncertain" range. It is concluded from this that deep impregnation by linseed oil will significantly reduce the probability of active rebar corrosion in chloride-contaminated concrete. The question may arise as to whether the reduction in corrosion potential resulted from drying or the presence of the linseed oil. It should be pointed out that the area of the slab that was dried and impregnated was only 0.30 m x 0.61 m (1 ft. x 2 ft.) of the 1.83 m x 1.83 m (6 ft. x 6 ft.) slab. Furthermore, drying was carried out to a depth of only 10.2 cm (4 in.) maximum of the 20.3 cm (8 in.) slab thickness. Therefore, the slab was by no means totally dried and by the time that impregnation was completed (4 days) moisture equilibrium was undoubtedly re-established in the slab.

Long-term corrosion potentials after salt contamination and impregnation with linseed oil mixtures were not investigated. However, Clear and Hay (11) found that a surface treatment of linseed oil retarded the ingress of chlorides into their test slabs. Deep impregnations would not be worn off by traffic as surface treatments would.

## Test Sites

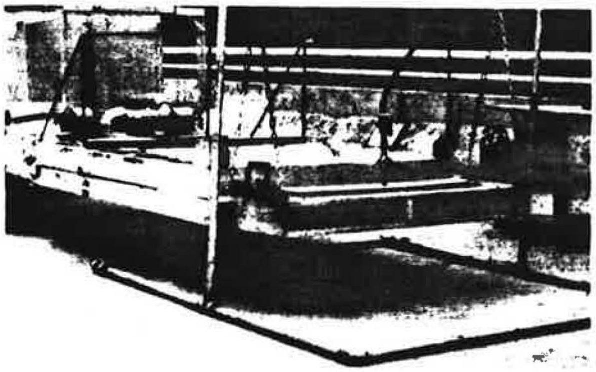
Evaluation of the selected impregnant and methodology that resulted from the laboratory work was carried out in the field on two selected bridge decks. One of the bridge decks had been subjected to deicer salt application and the other had not. The bridge that had received deicer applications was constructed in 1972. It is a four-span, steel I-beam and multigirder structure on the eastbound lanes of traffic route 322 at the Oak Hall interchange in central Pennsylvania. Steel stay-in-place forms had been used for deck placement. The bridge was placed in service in November 1973, and therefore, it had been subjected to three winter seasons of deicer salt applications at the time of test. The 1.52 m x 3.66 m (5 ft. x 12 ft.) test area was selected in the acceleration lane of the west end span, the lowest area of the deck. This area of the deck was selected because it was felt that the deck drainage would tend to concentrate the deicer salts in this area. Chloride determinations (using the Berman titration technique) (12) gave values that ranged from 2.43 kg $Cl^-/m^3$ (4.1 lb $Cl^-$/cu yd) at the surface to 0.18 kg $Cl^-/m^3$ (0.3 lb $Cl^-$/cu yd) at a depth of 3.8 to 5.1 cm (1 1/2 to 2 in.) adjacent to the test site and 1.42 to 0.95 kg $Cl^-/m^3$ (2.4 to 1.6 lb $Cl^-$/cu yd) at 1.3 to 3.8 cm (1/2 to 1 1/2 in.) in the water table area at the actual low point of the deck.

Although the second bridge was constructed in 1971, it had not yet been placed in service (as of impregnation) and had received no deicer applications. It is a three-span, prestressed spread box beam structure on the eastbound lanes of traffic route U.S. 322 over the Bellefonte Central Railroad right-of-way near Toftrees, Pennsylvania. Conventional wood forms had been used for deck placement. The 1.52 x 3.66 m (5 ft x 12 ft) test area was selected in the traffic lane of the west end span.

## Procedure

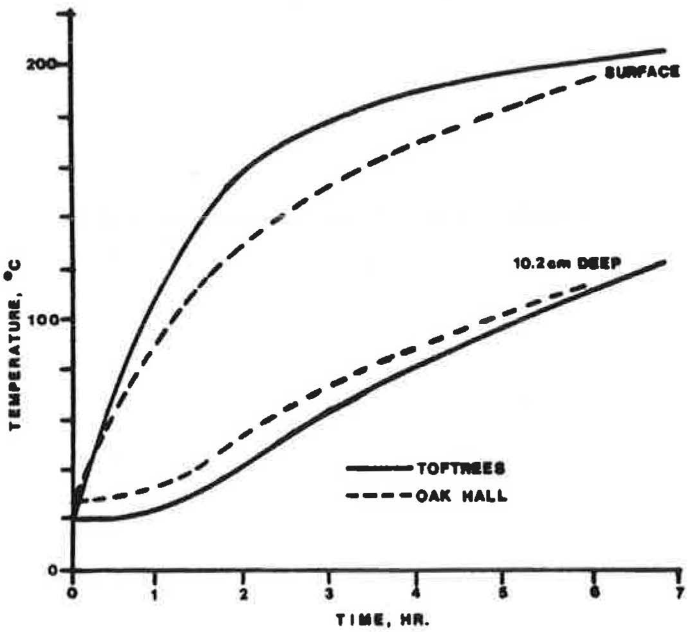
In order to permit impregnation depths of at least 5.1 to 6.4 cm (2 to 2 1/2 in.), the drying criterion adopted for the field tests was the attainment of a temperature of 110°C at 10.2 cm (230°F at 4 in.). This was accomplished using propane-fired, catalytic infrared heaters in much the same manner as drying was carried out on the large test slabs in the laboratory. Drying of each of the two 1.52 m x 3.66 m (5 ft x 12 ft) test areas was done in two 1.52 m x 1.83 m (5 ft x 6 ft) sections using a trailer mounted unit in combination with a smaller portable unit. The drying operation is illustrated in Figure 1.

Figure 1. Drying the test area with gas fired IR heaters.



In order to monitor the heating process relative to the drying criteria presented above, copper-constantan (Type T) thermocouples were installed at the surface and at a depth of 10.2 cm (4 in.) in 0.64 cm (1/4 in.) diameter holes drilled from the top surface. The thermocouple outputs were continuously recorded. Spot temperature checks were also made with a handheld thermocouple indicator. The time-temperature curves for the two test sections are shown in Figure 2. In both cases, these are the data for the first of the two equipment set-ups needed to cover the designated test areas, and the temperatures have been corrected for top insertion. The second set-ups in each case produced similar results. It is noteworthy that the drying process on the non-contaminated (Toftrees) deck was carried out during a light, but steady, rain. To prevent rewetting of the dried areas, timber dams sealed with caulking were placed around the periphery to divert surface drainage, and the areas were covered with galvanized sheet metal.

Figure 2. Typical temperature vs. time during drying on bridge decks.




As shown in Figure 2, the time required to meet the stated drying criterion, 110°C at 10.2 cm (230°F at 4 in.), was about six hours in both instances. This is somewhat longer than encountered in the laboratory, but not unexpected in view of the effects of wind and heat conductivity. Since the propane consumption rate was approximately 2.44 $kg/m^2$/hr (0.5 lb/sq ft/hour) with the heating devices employed, the unit fuel consumption for drying to 4 in. was about 12.2 $kg/m^2$ (2 1/2 lb/sq/ft). Larger unit heaters required for practical full-scale field application (units up to 3.66 m x 12.19 m (12 ft x 40 ft) have been built) would undoubtedly have lower fuel consumption because of reduced heat loss due to the smaller perimeter to heating area ratio. Also, shallower depths of drying will require less fuel, the quantity required being approximately proportional to the depth of drying in the range of 2.5-10.2 cm (1-4 in.).

After the test areas had cooled for about two hours, impoundment dams for containing the impregnant were constructed with building brick and mortar, sealed with epoxy resin. For practical, full-scale bridge work, it is envisioned that portable, reusable dam sections might be used in conjunction with a suitable sealing or gasket material. For the purpose of this study, however, the brick and mortar technique was quick, efficient, and provided reliable impoundment.

After the surface temperature dropped into the range 45°-50°C (113-122°F), the impregnant, a 50-50 mixture by weight of boiled linseed oil and mineral spirits, was introduced into the impoundment. The temperature range cited above optimizes the opposing effects of temperature and evaporation of diluent (mineral spirits) on the viscosity, and hence, the penetration rate, of the impregnant. After ponding the area with the impregnant, it was covered with plywood sheathing and a tarpaulin for weather protection.

Based on the results of the laboratory studies, reported earlier, the ponding process at each site was carried on for four days in an effort to obtain at least 6.4 cm (2 1/2 in.) of penetration.

After completion of the required period of ponding, 10.2 cm (4 in.) diameter cores were removed from the two test areas to ascertain the depth of penetration. In all, three cores were removed from the Oak Hall and two from the Toftrees deck. The appearance of the cores shortly after removal are shown in Figures 3 and 4. The depth of heavy penetration of the impregnant is clearly evident in these photographs. However, as will be shown below, the depth of sealing extends considerably deeper than this zone.

Figure 3. Cores removed from Oak Hall deck.

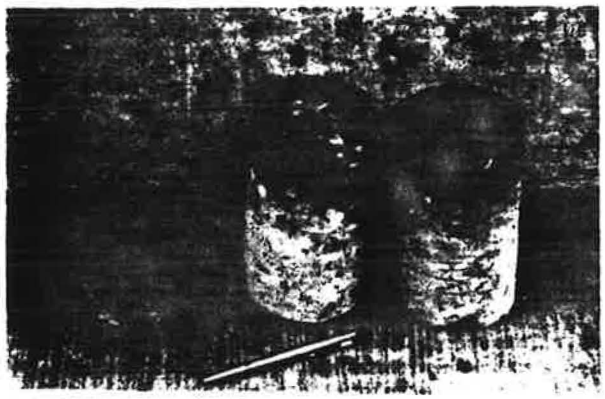
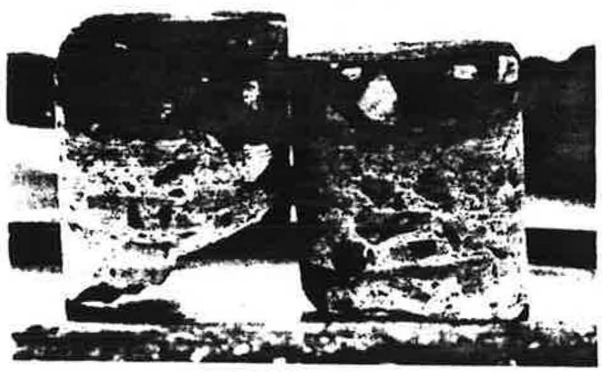


Figure 4. Cores removed from Toftrees deck.



Each of the cores was sectioned longitudinally with a diamond saw. One half-section of each core was then polished in successive grinding steps on a lap to 1900 fineness. The other half of each core was etched with concentrated hydrochloric acid for about 10 minutes. The results are shown in Figures 5 through 8. The polished sections clearly show depths of penetration of 5.7 to 6.4 cm (2.25 to 2.5 in.) for the Oak Hall Cores and 2.5 to 5.1 cm (1 to 2 in.) for the Toftrees cores. However, acid etching reveals that the actual depth of sealing ranges up to 10.8 cm (4.25 in.) and 7.0 cm (2.75 in.), respectively. The rather significant difference in penetration between the two decks is believed to be due to the fact that the drying and initiation of the impregnation step were carried out on the Toftrees deck during a steady rain storm. It would definitely not appear to be related to the presence of deicer salts because the Toftrees deck, the deck with the lesser penetration, was the deck which had not been subjected to deicer application. In any event, it is clear that the goal of sealing the concrete to a depth of approximately 6.4 cm (2 1/2 in.) was attained.

Figure 5. Oak Hall core specimens (polished).

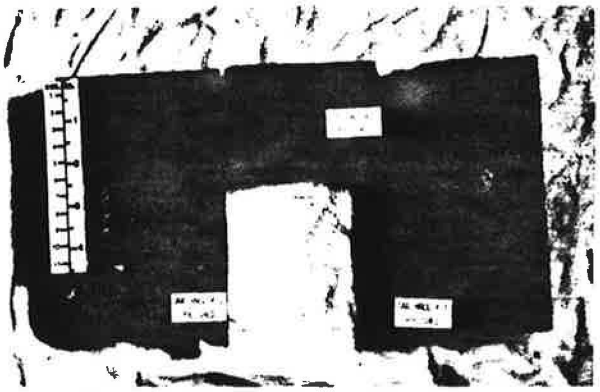


Figure 6. Oak Hall core specimens (acid etched).

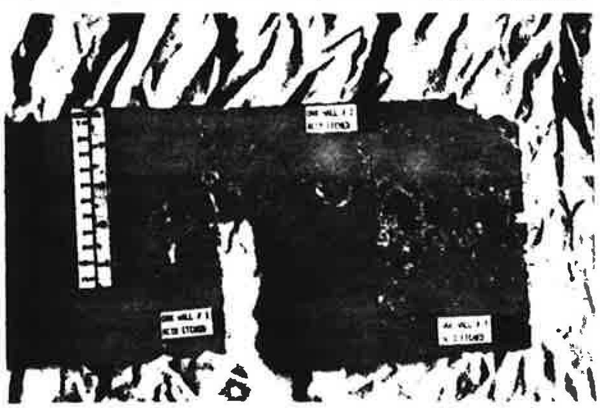


Figure 7. Toftrees core specimens (polished).

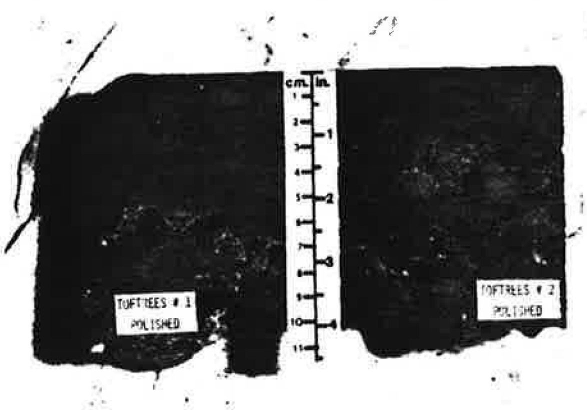
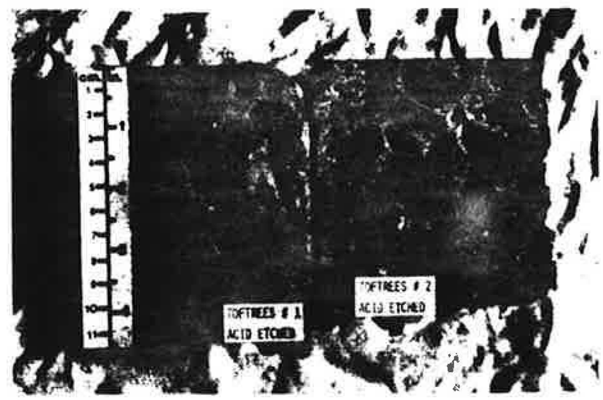


Figure 8. Toftrees core specimens (acid etched)



## Applicability of Results

While the equipment used in this research is not of sufficient size to be practical for commercial application, it is readily amenable to scale-up. Based on the work reported here, it is estimated that with equipment of appropriate size, a 12 m wide by 60 m long (40 ft x 200 ft) bridge deck could be impregnated in less than two weeks. If it is assumed that 15 bridge decks of this size were done per year and the capital equipment is amortized at 6 percent, has zero salvage value, and a 10-year life, it is estimated that the unit cost, excluding contractors' profit, for commercial impregnation will be about $23.35/m$^2$ ($2.17 per sq ft). This is based on summer 1976 costs. Of this estimated cost, 41 percent is for the impregnant, 29 percent for labor, 18 percent for fuel, and 12 percent for capital recovery and maintenance of equipment.

## Conclusions

The following conclusions appear to be warranted relative to the research described in this paper:

1. Concrete that has been suitably dried to temperatures of at least 110°C (230°F) can be impregnated to depths of 5 to 10 cm (2 to 4 in.) by ponding a mixture consisting of equal parts by weight of boiled linseed oil and mineral spirits for a period of 4 days.
2. Corrosion potentials of actively corroding reinforcing steel in salt contaminated concrete slabs are significantly reduced by impregnation with 50-50 boiled linseed oil-mineral spirits mixtures.
3. The techniques developed were demonstrated to be applicable in the field and, with appropriate scale-up, should be commercially feasible.

However, the long-term benefits of deep impregnation with linseed oil in the field remain to be demonstrated.

## Acknowledgments and Disclaimer

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facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Pennsylvania Department of Transportation or the Federal Highway Administration.

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