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16. ABSTRACT

Problem

Salting to prevent icing in the mountains or frost in the valleys is causing premature bridge deck deterioration in California. When de-icing salts reach the deck reinforcing steel, an electrolytic action begins which causes some of the steel to corrode. As the corrosive particles build up they expand against
the concrete covering the steel. As the process continues the tensile strength of the concrete is exceeded and intermittent horizontal cracks develop along the upper plane of the steel forming what is commonly referred to as an undersurface fracture. Traffic impact causes the concrete above the undersurface fracture to eventually ravel out leaving a pothole in the deck surface and exposed reinforcing steel, see figure 1.

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DETERIORATION IN DE-ICING SALTED BRIDGE DECKS

by C. F. STEWART

August, 1970

PROBLEM

Salting to prevent icing in the mountains or frost in the valleys is causing premature bridge deck deterioration in California. When de-icing salts reach the deck reinforcing steel, an electrolytic action begins which causes some of the steel to corrode. As the corrosive particles build up they expand against the concrete covering the steel. As the process continues the tensile strength of the concrete is exceeded and intermittent horizontal cracks develop along the upper plane of the steel forming what is commonly referred to as an undersurface fracture. Traffic impact causes the concrete above the undersurface fracture to eventually ravel out leaving a pothole in the deck surface and exposed reinforcing steel, see figure 1.

SOLUTION

The only way that steel corrosion, and attendant potholing, can be prevented in decks subjected to salt is to prevent contact of salt and steel. Increasing cover and improving concrete quality appear to be means of protecting the steel from salt intrusion. But, since all concrete is

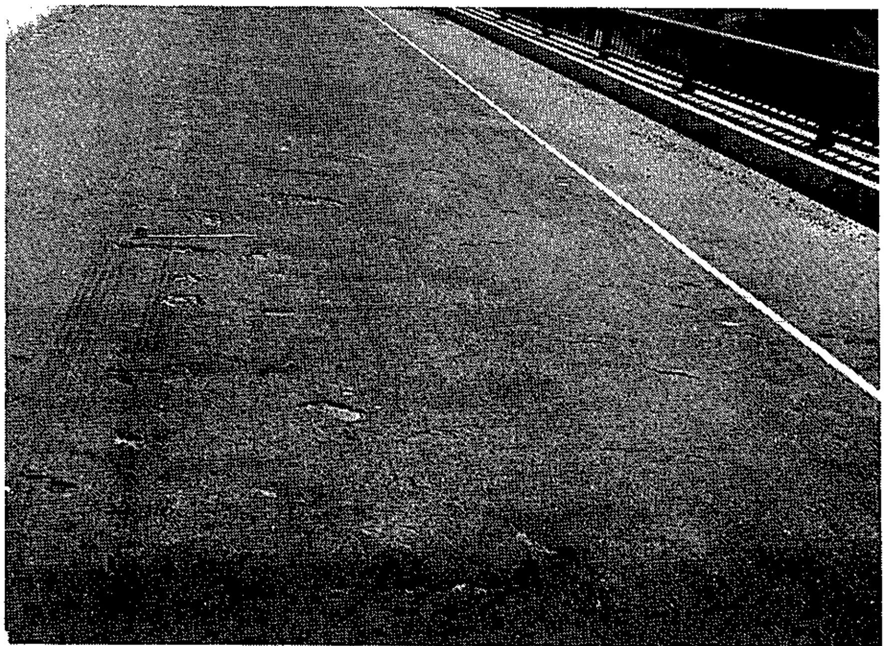

Fig. 1

Beginning stage of deck surface pot-holing.

porous to some degree and is usually cracked, especially bridge deck concrete, these means merely delay passage of salt. These improvements in concrete quality should not be de-emphasized due to their value in providing more durable decks in non-salting or limited salting areas, but it must be realized that the only positive way to prevent salt intrusion on a concrete deck is to seal the deck with an impervious membrane.

There are several materials available which are practically impervious, such as rubber and plastic sheeting, but unfortunately, either they cannot be bonded to the deck or the necessary protective overlay cannot be bonded to them. At present there are only two known materials available for use as an impervious deck membrane: A relatively thin layer of epoxy, usually coal tar extended epoxy, and a multi-layer sandwich of coal tar and glass fabric. Most bridges now being built in California's mountain area are sealed with one or the other of these materials as are all bridges in both the mountain and valley areas which have had decks restored.

RESTORATION

The deck sealant material is the key to an effective preventive system on new bridges as well as to most systems for restored or rehabilitated decks. Hence, these two materials will be discussed in greater detail later. First, however, it might be best to discuss the complete deterioration picture with attention directed toward restoration because it is this subject which has the greatest immediate need.

The subject of restoration is much more interesting and complex than is the one of deterioration prevention. The only problem associated with prevention is in selecting an effective sealant membrane. On the other hand, problems associated with restoration are numerous. Some of the questions which need answering before restoration is done are: Is the deck reparable or should it be replaced instead; should there be total or partial restoration (the difference will be discussed later); how long can traffic lanes be closed for repair; what type of patching materials should be used; what type of sealant should be used; should the sealant be protected with an asphalt concrete (AC) overlay. In addition to these general questions there are numerous questions on each category concerning such things as application methods, AC thickness, weather condition restrictions during application, method of measuring and paying, etc.

This paper will not attempt to cover all the problems of deterioration restoration, but will cover the more basic ones. It is more correctly a report on the state of the art of the bridge deck restoration in California. It discusses potholing deterioration only with no mention of scaling deterioration because it is the author's belief that a solution to deck potholing will also be a solution to deck scaling. The reverse is not true, however.

There are several vital facts to be remembered in assembling an effective restoration package. They are: The restoration will not prevent continued deterioration if it does not include the removal of all concrete containing more than a certain value of chloride ions (at present this value is believed to be 500 ppm); the amount of corrosion necessary to spall concrete occurs with little loss of steel cross section; the sealant material should be flexible; the sealant has to either be sufficiently tough to bear traffic, including chain abrasion in the mountains, or be protected by an overlay.

Electrolysis

Before accepting the premise that deterioration will continue after partial restoration, it is necessary to have knowledge of the electrolysis process. Even though the salt content in de-iced decks is usually fairly uniform at a given depth throughout the deck, the corrosion affected area at the time of needed repairs usually represents only about 10 percent of the total deck surface area. The reason for this is that in the electrolysis process anode and cathode areas are established on a bar or on adjacent connected bars. With the damp, salt impregnated concrete acting as an electrolyte, an electrical current flows from the anode to the cathode area. By the chemistry of the process corrosion occurs at the anode but not at the cathode area. Most often the noncorrosive cathode area is considerably greater in size than is the corroded anode area.

If the salt impregnated concrete is removed from the affected anode area the current flow from that area is stopped. Since, however, the adjacent cathode areas usually contain sufficient salt to cause steel corrosion there is no reason why some of these areas will not change polarity and become anodic. The degree to which anode areas develop and the intensity of their activity is dependent on the salt and moisture levels of the concrete.

Total vs. Partial Restoration

One might ask that if continued deterioration in the deck is expected when only that portion of the concrete in the corroded area is removed (partial restoration, figure 2) why limit the removal, why not remove all salt laden concrete (total restoration, figure 3)? The primary

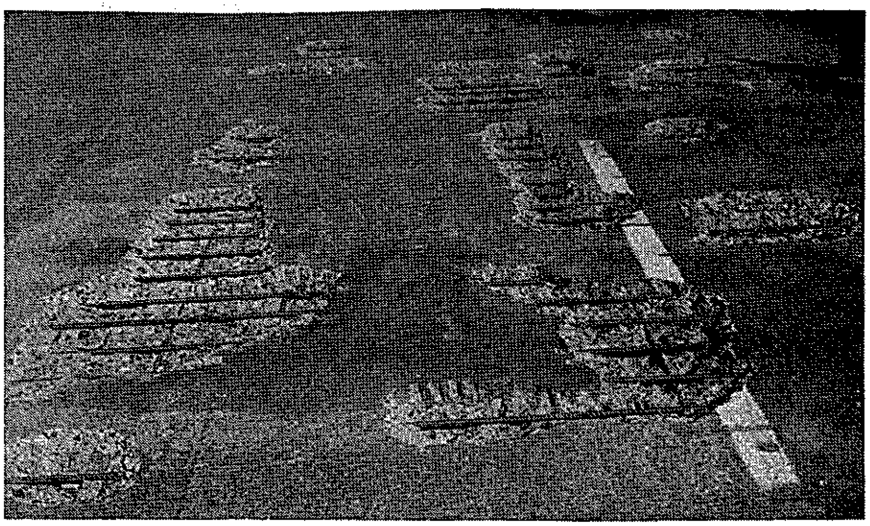

Fig. 2

Partial restoration - Concrete removed in anode areas only.

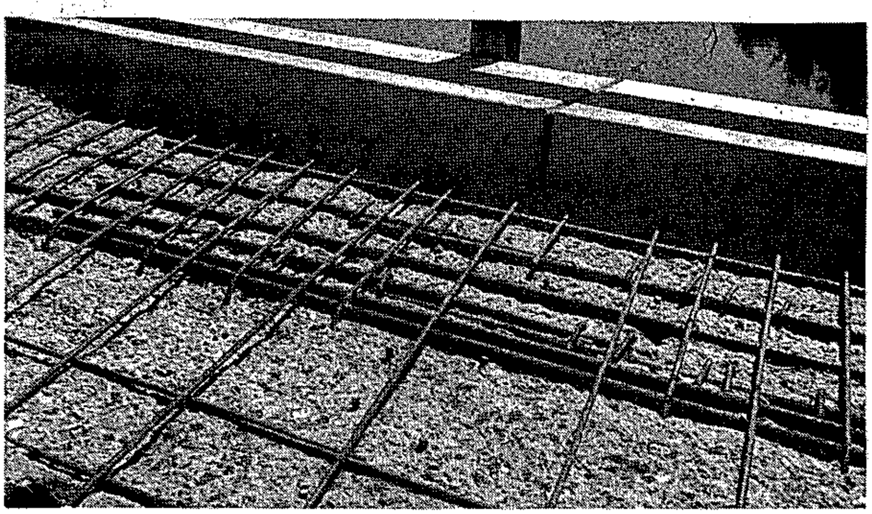

Fig. 3

Total restoration - All salt laden concrete removed.

answer is economy. On the average, total restoration costs from 3 to 5 times more than partial restoration (including a seal and overlay for each). This first cost difference is not, however, the only factor to be considered. Equally important is the life expectancy of the two systems. In addition, construction problems and allowable lane closure time must be considered.

It is reasonable to assume that a total restoration, with a protective sealant, would have a normal expected life of 50 years since the finished product would closely approximate that of a new deck. The expected life of a partial repair, due to the continued corrosion potential, is much more difficult to predict. There have been similar partial repairs made to decks in California that were constructed with calcium chloride and these decks are still performing with little or no maintenance after 11 to 20 years. Based on this performance history and the effectiveness of present sealants it is reasonable to expect a minimum of 15 years additional life from a partially repaired de-icing salt damaged deck. It is therefore, estimated that a total restoration will have at least 3 times the life expectancy of a partial restoration. However, since total restoration costs up to 5 times partial restoration, in the long run partial restoration would generally be more economical.

There are four other factors which favor partial restoration over total restoration: (1) During total restoration of a continuous reinforced concrete structure the concrete would normally be removed to the level of the longitudinal negative moment steel. This would require supporting the structure, which under some conditions would not be practical; (2) Partial repair work can normally be scheduled so that there will be no weekend lane closures. This is practically impossible with total restoration work; (3) It is unrealistic to make a 50-year additional life comparison of structures which are already 10 years old or older because, due to highway realignment, additional clearance or width requirements, or other reasons, a structure seldom remains in the highway system for 50 years; (4) Before additional repairs are required to a partial restoration, improvements will have been made in restoration methods and materials which should further enhance partial restoration.

One question which is often asked when a minimum life expectancy of 15 years is designated for a partial repair job is, why is it since the deck being repaired is often only 10 years old an additional 15 years can be expected from the partial repair. The answer lies in the reason the repairs are being made. The primary purpose for making the repair is to fill potholes in the deck, to maintain a safe, smooth riding surface. The actual loss of reinforcing steel due to the corrosion process up to that time in most cases, has been small, see figure 4. If the concrete over the steel could have taken the tensile stress exerted by the corrosive action, repairs would not have been required in 10 years. The equivalent tensile force on the concrete is expected due to continued corrosion after a partial repair, but the difference in performance is afforded by the AC

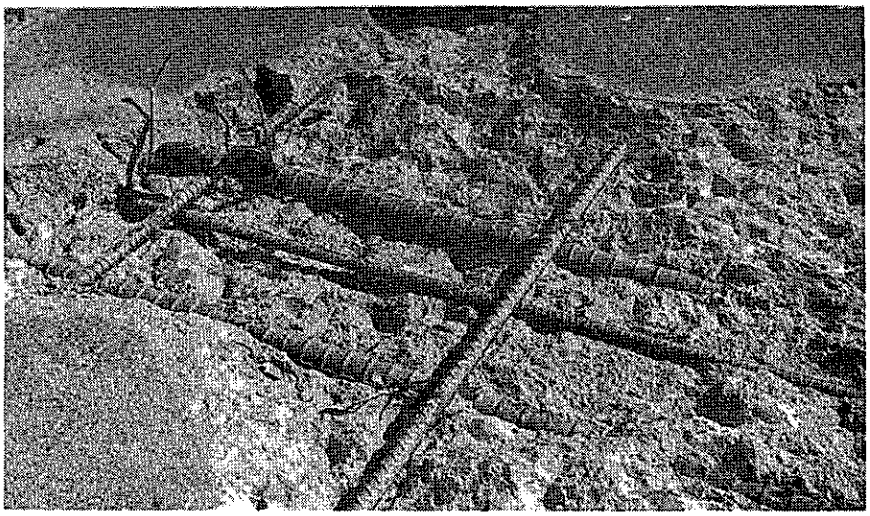

Fig. 4

Corrosion sandblasted from steel. Note minor pitting.

overlay. As the concrete is pushed upward and undersurface fractures develop in it, the AC overlay will give with the pressure, remain intact and prevent traffic from ravelling the concrete. This is not an assumption, there are several examples on California bridges. Therefore, by preventing potholing in the concrete the life of the partial repair becomes dependent on the time required to reduce the total steel cross section in a given area to an unacceptable level. Again, from experience this time is estimated to be a minimum of 15 years.

Continuous Patching Vs. Restoration

It has been advocated that rather than patch, seal and overlay by costly contracts when the decks start potholing, have regular maintenance forces patch potholes as they occur. Experience has shown that without the protective overlay, a large number of patches made in a heavy freeze-thaw environment, no matter how well made, fail in less than 1 year. Furthermore, a large number of potholes form during the winter months, a time when patching is very difficult and potholing is hazardous to the motorist. Maintenance patching, therefore, appears to be less expensive and more desirable at first glance, but in the long run, due to adverse factors mentioned, it would probably end up more expensive, more hazardous and definitely more unsightly.

Patching Materials

After a decision on the type of restoration is made, partial or total, the type of patching material to be used must be decided. There is only one economical choice for total restoration: Portland cement mortar. In partial restoration there are two: Cement mortar or epoxy mortar. Important differences between the two which must be considered when choosing between them are: Epoxy mortar is more expensive, has a greater tendency to flow under a sustained load, is more sensitive to the weather during placing, but requires less lane closing time than does cement mortar. Due to the large difference in thermal coefficient of expansion of epoxy and PCC, a vital requirement of the epoxy in an epoxy mortar patch is that it be flexible enough to "give" during low temperature changes. Figure 5 shows an epoxy mortar patch being placed.

Fig. 5

Placing epoxy mortar patch.

Concrete Removal

The concrete removal and reinforcing steel cleaning problems are the same regardless of the patching materials selected to fill the void. The main problem in concrete removal is to prevent fracture of the concrete under that which is to be removed. Limiting the weight of the chipping gun to about 30 pounds appears to minimize this problem

Not all damaged concrete areas are visible on the surface; frequently, incipient potholes exist in the form of undersurface fractures, see figure 6. These areas should be located and treated the same way as the potholed areas. Sounding the concrete by striking it or dragging an object over it is the best way to locate undersurface fractures. A low pitched "hollow sound" results when there is an

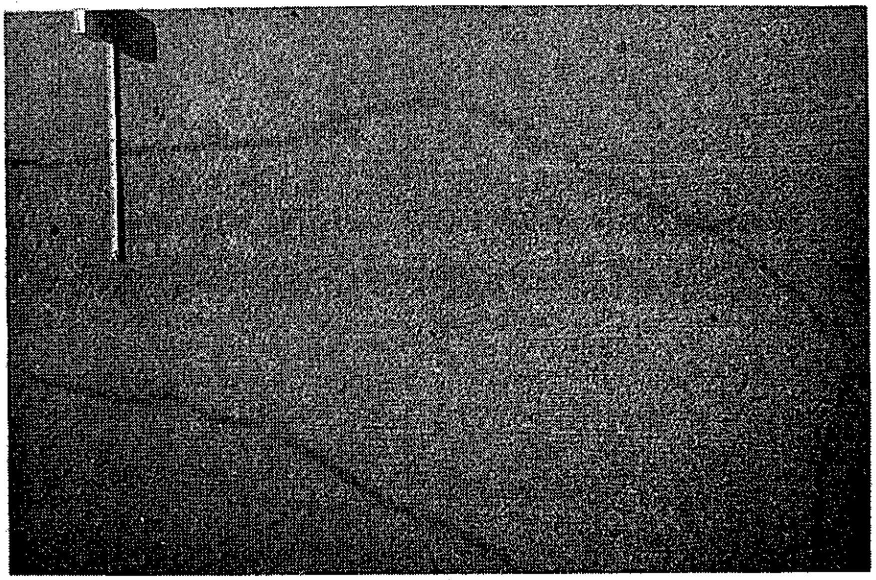

Fig. 6

Outline of a horizontally oriented undersurface fracture plane.

undersurface fracture. The chain "broom" shown in Figure 7 has proven to be a very effective device for finding undersurface fractures in concrete bridge decks.

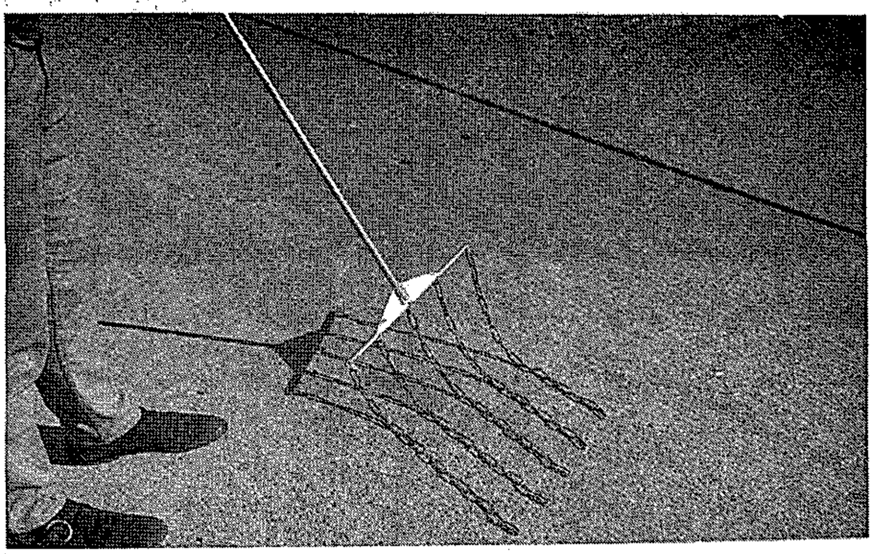

Fig. 7

A chain "broom" for locating undersurface fracture planes.

It would be advisable to locate all anodic areas, at least the ones in advance stage, and remove the salt laden concrete from the steel. It has not been fully explored, but the electrical potential method of measuring the voltage over a systematic grid of the deck and connecting points of equal potential to form contours shows promise of being effective in locating anodic areas.

Deck Seal

When the patching is completed, the entire deck area is sealed. As previously stated, epoxy and coal tar-glass fabric are the two commonly used sealant systems.

The coal tar-glass fabric system figure 8, has for several years proven its effectiveness in sealing industrial building roofs. Massachusetts highway engineers report that the coal-tar system has also been an effective deck sealant in their state for several years. The ability

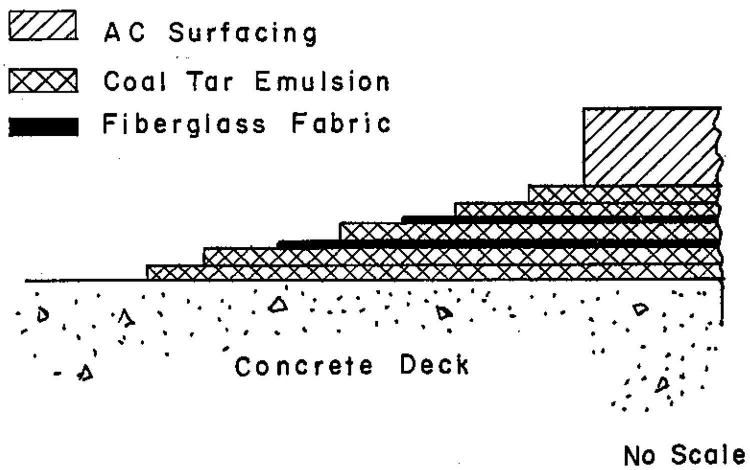

Fig. 8

Coal tar-glass fabric deck seal.

of the material when properly formulated to reseal itself at temperatures normally found in bridge decks during the summer months probably is its greatest asset. This resealing property minimizes permanent damage (loss of integrity) to the system by reflection cracks over cracks caused by concrete shrinkage on new decks and by corrosion expansion on restored decks. The occurrence of reflection cracks can be reduced by increasing the coal-tars' flexibility at low temperatures by extending it with proper flexiblizers. Another point in favor of the coal-tar system is that it requires much less surface preparation and is generally less expensive than the epoxy system. It does, however, normally require a longer lane closure time than does an epoxy seal, and this fact alone could preclude its use under certain traffic conditions.

The coal-tar extended epoxy system has some flexibility and if properly compounded and placed, is not too severely damaged by minor cracking. However, its flexibility is much less than the coal tar-glass fabric system and it would undoubtedly be permanently damaged by large or extensive cracking. This would severely reduce its sealing effectiveness as it has no resealing capability. The biggest problem with the epoxy sealant though occurs during placing as it is a very sophisticated material. Its adverse properties are: Very sensitive to low temperature, mixing practices and moisture; has a tendency to blister while still semi-fluid under certain deck and ambient temperature conditions;

suffers from capillary action, manifested by pinhole voids in the hardened material, when certain size and shape of aggregate is broadcast into it.

The most economical and effective surface preparation for an epoxy sealant is by sandblasting. The coal tar-glass fabric sealant requires little surface preparation. The epoxy membrane cannot endure more than about three years of tire chain wear; so, it must be protected where tire chains are used. (When placed on new decks in the valley, the epoxy membrane also becomes the decks' wearing surface and as such must bear tire traffic.) The coal tar-glass fabric system requires a protective overlay regardless of whether tire chains are used or not.

Aggregate is always broadcast into the epoxy membrane while it is still fluid. The sole purpose of the aggregate is to provide texturing when the epoxy membrane is also to be the wearing surface and to provide mechanical connectors when it is to be protected with an overlay. The coal tar-glass fabric system does not require mechanical connection as an emulsion tack coat bonds the asphalt concrete overlay to it.

Asphalt Concrete Overlay

The best protective material found to date for either sealant is an asphalt concrete overlay. Thickness of the required overlay depends on the abuse it will be subjected to. Normally the thickness varies from 2 to 3 inches.

Asbestos has been added to some AC overlays to enable use of higher percent of asphalt for greater durability. The actual effectiveness of the asbestos has not been determined. If AC has not been down long enough to be kneaded by regular traffic during warm weather it will normally ravel under traffic during cold or wet weather.

Most deck seals are not totally impermeable and could become ineffective if water were allowed to pond above them. AC surfacing is usually fairly permeable and water does pond in it. This ponding, however, can be markedly reduced, if not eliminated, by placing two-inch diameter plastic "bleeder" pipes through the deck along the gutter line at about 20 foot spacing.

NONCORROSIVE DE-ICERS

The costly and complex problem of salt deterioration could be eliminated by the development and use of a noncorrosive de-icing material. Unfortunately, this panacea has not yet been found. Materials have been found which under certain conditions are effective de-icers and are noncorrosive to steel. But, they are either corrosive to the concrete, have too high a freezing point, or become corrosive to steel when concentrated (as could occur in deck cracks over the steel). Work is now underway to combine some of the more promising materials with an effective inhibitor.

CONCLUSION

There are still many unanswered questions on the subjects of deterioration prevention and restoration of de-icing salted bridge decks. This paper has attempted to open some areas of the subjects to stimulate thought and discussion in an attempt to hasten some of the answers. Several of the answers will be found only through research and experience. Both are time consuming. In the meantime, immediate action is needed to reduce the deterioration problem; this action must be directed by engineering judgement, taking into account the vital factors of function, safety, economy and effectiveness. Bare pavements through the use of salt, like it or not, will probably continue for many years.