Effect of Salt on Reinforced Concrete Highway Bridges and Pavements

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(presented by P. E. Cunningham)

The deterioration of bridge deck concrete has caused serious concern among highway engineers for several years. Considerable research has been undertaken to determine the causes for this deterioration. It is generally agreed that surface spalling is the most serious and annoying type of distress found in bridge decks. Several recent research reports indicate that corrosion of reinforcing steel is often a factor in the occurrence of surface spalls. This paper focuses on this relationship and discusses the various factors that may contribute to corrosion of reinforcement.

Maintenance reports, research studies, and field inspections indicate that bridge deck durability is a serious problem in almost all states. Premature deck deterioration has been reported with sufficient frequency to warrant modifications that will prevent or minimize such problems in the future.

The Portland Cement Association, Highway Research Board, several state highway departments (Fig. 1), and other agencies have conducted research to identify the types

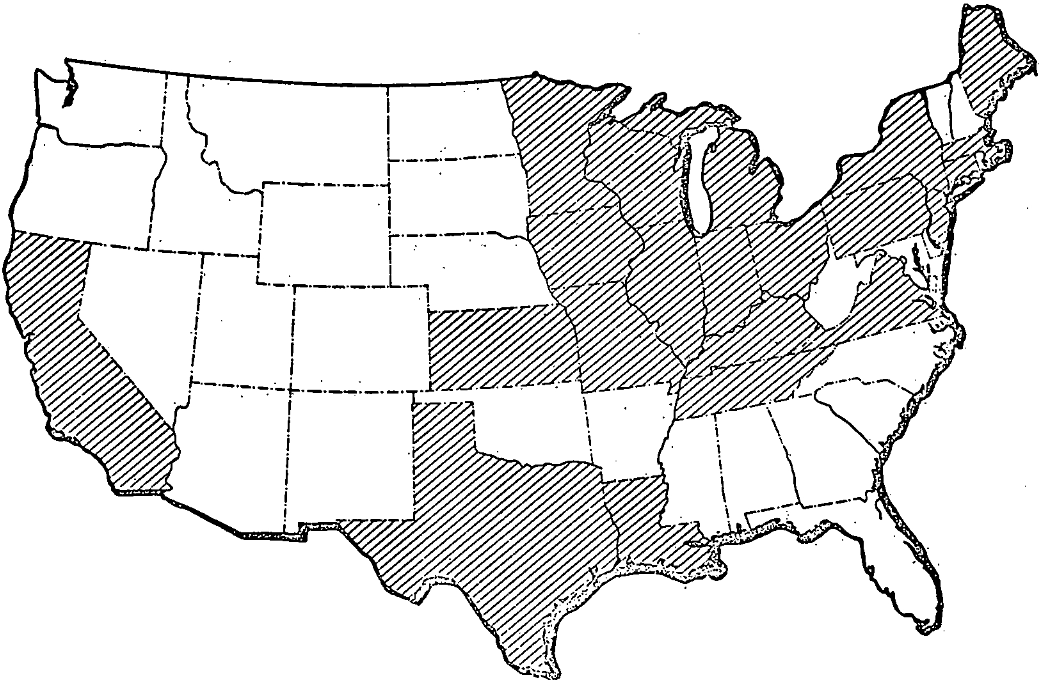

Figure 1. States that have conducted research on bridge deck durability.

and causes of deterioration. As a result, we are beginning to identify present problems and make changes that will provide structures with longer service lives.

For instance, concrete scaling has long been a recognized problem. Many states now report that scaling of bridge decks is not a serious problem although some surface scaling still occurs. This success has been attributed to the superior freeze-thaw resistance of air-entrained concrete. In addition, waterproofing systems have made a contribution, especially to poor quality of non air-entrained concrete.

Recently, several reports identified concrete spalling as the most serious form of deck deterioration because of the severe effect it has on riding surface, the reduction in structural capacity, and the difficulty in making a permanent repair. The use of deicing chemicals over the past several years has also significantly accelerated the spalling process.

This paper has been assembled from reports of many research and experimental projects and maintenance operations. It attempts to present an operational viewpoint of what can be done now to reduce deterioration of bridge decks and pavements. The many sources used are listed in the References. Reference numbers have been omitted in the text but can be furnished if requested.

RELATIONSHIP BETWEEN SPALLING AND CORROSION OF REINFORCEMENT

For over 50 years engineers have known that the products formed by the corrosion of reinforcement occupy over two times the volume of the original iron and can exert a mechanical pressure in excess of 4,000 psi. Under normal conditions, reinforcement is protected against corrosive attack when embedded in portland cement concrete. In recent years, however, both laboratory studies and statistical analysis of existing bridges have identified corrosion of reinforcement as a contributing factor in concrete spalling. Some of the more significant findings are as follows:

1. In Missouri, 87 percent of the cores taken through concrete with fracture planes exhibited corrosion of reinforcement; whereas, in areas without fracture planes, 16 percent of the cores showed evidence of corrosion. Similarly, a pending report by the Portland Cement Association states that the steel was corroded in all of the 29 cores taken through surface spalls. These data taken from existing highway structures show that most, but not all, spalls occur in locations where the steel is corroded. The data do not, however, show which occurs first.
2. A number of reinforced concrete slabs were constructed at the Portland Cement Association Laboratory in Skokie, Illinois, by using various water-cement (w-c) ratios and either ½- or 1½-in. concrete cover. These slabs were left outside and exposed to normal weather conditions except that a de-icer (flake calcium chloride) was applied after snow and ice storms. After 5 winters, all of the slabs with a ½-in. cover have rust stains on the surface. Interestingly, the slabs with high w-c ratios have a large number of rust stains but no spalls. The slabs with low w-c ratios have only a few rust stains but very pronounced spalls.
3. A test slab was constructed in Kansas to obtain an indication of the effect concrete cover has on bridge deck deterioration. The transverse reinforcement was placed at various depths from the concrete surface. A trowel point was drawn through the plastic concrete over each bar to create a vertical plane of weakness and accelerate deterioration. After 4 years, all types of spalling had occurred. During the testing period, they found that an increase in concrete cover increased the time required for both the appearance of rust stains in the concrete and appearance of spalls. After the test was completed, they removed several bars from the slab and concluded that an increase in concrete cover had reduced the corrosion of steel. From this test the following conclusion was drawn: "Repeated exposure of a reinforced concrete slab to moisture and salts appeared to create conditions of continuing corrosion of the steel and may have provided a pressure source sufficient to cause horizontal cracking and resultant spalls."
4. Engineers at the Portland Cement Association Laboratories at Skokie, Illinois, placed a prestressed wire (diameter of 0.612) in blocks 1 by 1 by 11, 2 by 2 by 11, and

3 by 3 by 11 to determine the effect of various thicknesses of cover on the corrosion of steel due to migration of chloride into the concrete. After 1 year, the wires were severely corroded in both the 1- and 2-in. blocks made from concrete with a w-c ratio of 7.8, and corrosion had started in the 1-in. blocks with a w-c ratio of 5.7.

5. Two hundred reinforced concrete test blocks ($4\frac{1}{2}$ by $2\frac{1}{2}$ by 15) were cast for testing by engineers from the California Transportation Agency. These specimens were partially immersed in a saturated solution of sodium chloride and periodically checked to monitor changes in electrical potential of the steel and appearance of rust stains or cracks in the concrete. A mathematical relationship was found between the time to an active potential and the time to cracking of the concrete due to corrosion of the reinforcement. The average time to concrete cracking due to corrosion of the reinforcement after exposure of the concrete to a salt solution averaged about 10 months.

Based on these data reviewed, it can definitely be stated that corrosion of reinforcement causes spalling.

EFFECT OF SALT ON CORROSION OF STEEL

Approximately 20 years after the original development of portland cement, a French engineer reported on the disintegration of concrete due to the action of seawater. Since that time, many research reports have been written on this subject. These reports have generally focused on the phenomenon known today as scaling. However, the effect of salt on corrosion of reinforcement in concrete has also been known for many years.

In a report published by the Bureau of Standards in 1913, E. B. Rosa wrote:

> The addition of a small amount of salt (a fraction of 1 percent) to concrete (as is frequently done to prevent freezing while setting) has a two-fold effect, viz., it greatly increases the initial conductivity of the wet concrete, thus allowing more current to flow, and it also destroys the passive condition of the iron at ordinary temperatures, thus multiplying by many hundreds of times the rate of corrosion and consequent tendency of the concrete to crack.

A search of the literature reveals that salt has the following effects leading to corrosion of reinforcement:

1. The normal passive condition of the steel is destroyed. This is generally attributed to a reduction in pH of the concrete and a subsequent loss of protective film around the reinforcement.
2. Variations in salt content, oxygen supply, or stress along the length of the reinforcement can produce an electric cell.
3. A small amount of salt greatly increases the electrical conductivity of wet concrete.
4. The corrosive products do not provide a protective coating over the reinforcement because the anode and cathode can be separated a considerable distance because of the increase in electrical conductivity.

ACCESS BY CHLORIDES TO THE REINFORCEMENT

Salt may be added to the mix, enter cracks in the deck, or penetrate the sound concrete. It is necessary to understand each of these procedures if we are to prevent corrosion of reinforcement.

Calcium Chloride Additive

Laboratory tests have shown that approximately 2 lb of salt per cu yd (6-bag mix) of concrete is sufficient to almost completely destroy the passivity of iron. The standard specifications, however, in approximately 8 states still permit calcium chloride to be added to structural concrete. This practice is potentially hazardous and should be prohibited.

Effect of Cracks

There is ample evidence of cracking that has not led to further distress. However, the importance of cracking should not be overlooked. Certainly, wide cracks permit moisture containing dissolved de-icing chemicals, oxygen, and other aggressive elements direct access to the reinforcement. In addition, cracks are subjected to mechanical pressures from particulate intrusions, formation of ice, and pounding of traffic. These forces lead to further distress of the concrete.

Salt Penetration Into Sound Concrete

As previously mentioned, numerous measurements of chloride content have been made that document the fact that chlorides can and do penetrate sound concrete to appreciable depths. Several studies have been made that show that the time required for corrosion of reinforcement and subsequent spalling of the reinforced concrete is decreased by the following factors: increase in chloride content in the environment, increase in w-c ratio, and decrease in concrete cover.

FACTORS AFFECTING THE TIME REQUIRED FOR CORROSION OF REINFORCEMENT

These study findings will be related to practical applications by examining separately each of the factors listed in the previous section.

Chloride Content in the Environment

Nationally, the increase in use of salt for snow and ice control is phenomenal. Data provided by the Salt Institute (Fig. 2) indicate that the use of salts on pavements and structures has increased approximately 4½ times since 1962. Obviously, many highways are now being subjected to a much harsher environment than that existing

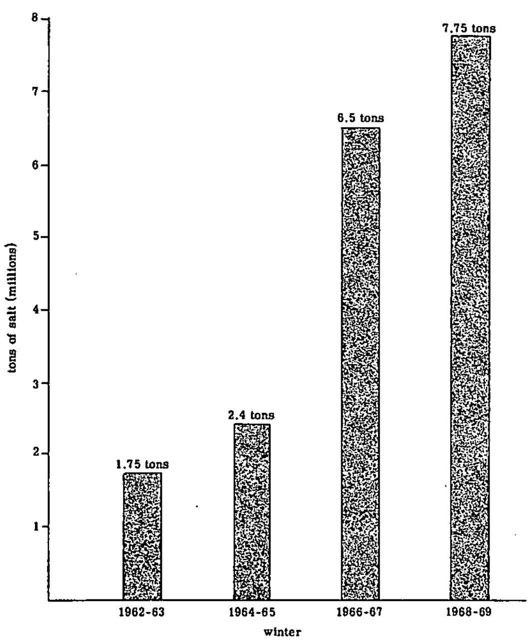

Figure 2. Use of salt for snow and ice control on highways and streets.

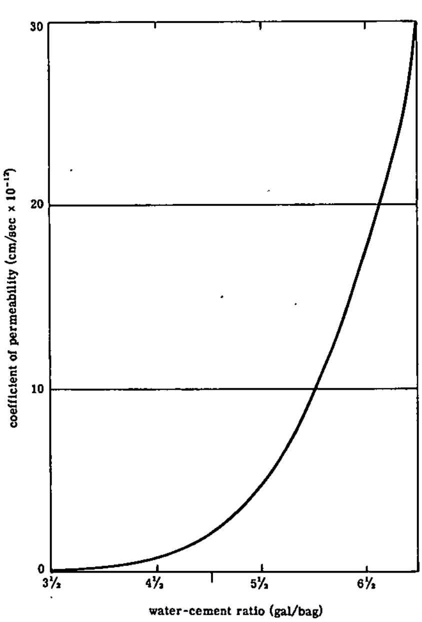

Figure 3. Relationship between the permeability of cement paste and w-c ratio.

only a few years ago. Although various noncorrosive de-icing agents have been studied, we are unaware of any such system that is both effective and economical. Because no decrease in public demand for bare pavements is anticipated, we recommend that structures and pavements containing reinforcement be designed to resist these harsh environments.

Effect of Water-Cement Ratio

Figure 3, which contains data provided by the Portland Cement Association, shows that the w-c ratio has a very pronounced effect on the porosity of cement paste. The coefficient of permeability increases rapidly with an increase in w-c ratio in excess of 5 gal per sack. Various tests have shown that the chloride content inside an uncracked concrete specimen does, in fact, increase with an increase in w-c ratio. Obviously, concrete should be as impermeable as possible. As a practical matter, a maximum w-c ratio of 5 to $5\frac{1}{2}$ gal per sack appears to be the optimum balance between the requirements for workability of the mix and permeability of the paste.

Effect of Concrete Cover Over Reinforcement

A detailed study was made on the Blue Rapids Bridge in Kansas to determine the relationship between the concrete cover and the occurrence of surface spalls, hollow areas, and potholes. Figure 4 shows the general relationship of the average bar depth to the percentage of surface deterioration.

Figure 5 shows the relationship between chloride content and depth of cover for bridge decks in Kansas. Similar curves have been developed in other states. These curves and laboratory studies reveal that chloride content at the level of the reinforcement is approximately halved for each additional inch of concrete cover.

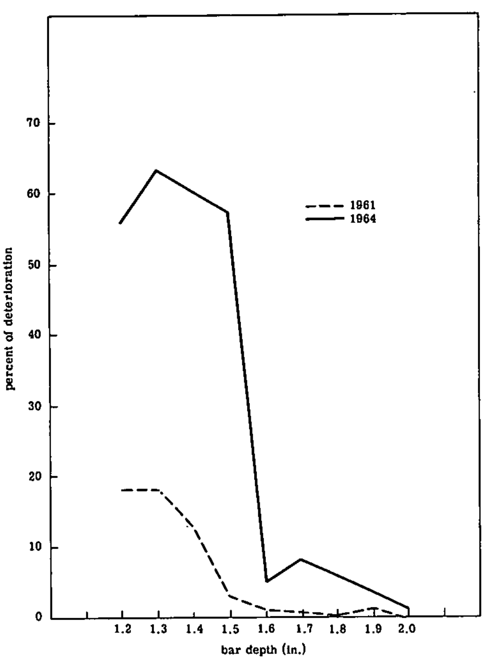

Figure 4. Average bar depth per 5-ft increment versus percentage deterioration in the same area—Blue Rapids Bridge, Kansas.

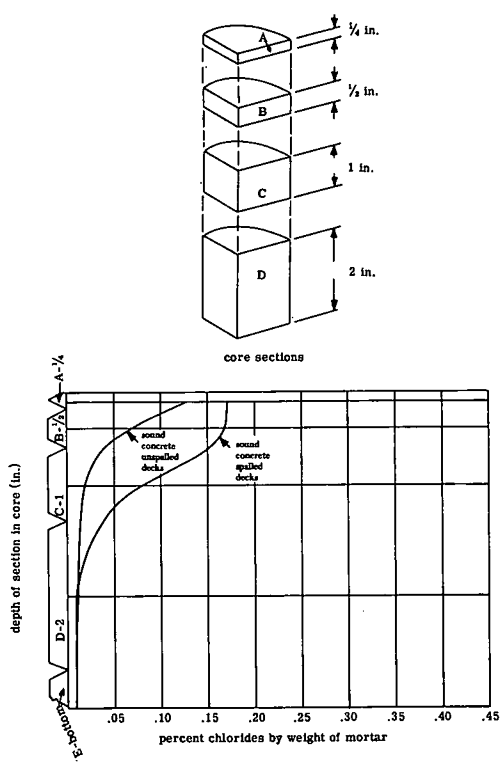

Figure 5. Relationship of chloride content and depth of cover—Kansas bridge decks.

These data indicate that the service life of the concrete deck is largely dependent on the depth of concrete cover over the reinforcement. They also indicate that a 2-in. cover should be sufficient to virtually eliminate deterioration due to corrosion of the reinforcement. There are, however, ample reasons to believe that additional cover should be specified, including the following:

1. Because the use of de-icing salts in recent years has substantially increased, past experience may be a poor indicator for use in designing for protection against future applications of these chemicals.
2. Laboratory studies by the Portland Cement Association have shown that de-icing chemicals can penetrate 2 in. of good quality concrete (5 gal per bag) in only 1 year.
3. Various agencies have recommended a 3-in. cover over the steel for reinforced concrete in a marine environment.
4. Whatever the minimum cover desired, some additional cover should be specified to provide for construction tolerances.

Certainly, a 2-in. cover is the minimum that can be expected to provide a reasonable level of protection against de-icing chemicals. An increase in cover within practical limits should result in an increase in the service life of the deck.

ACTION THAT CAN BE TAKEN NOW

The following actions can be taken now to reduce bridge deck and pavement spalling where de-icing chemicals are used:

1. Increase the depth of concrete cover over the reinforcement. We strongly recommend a minimum cover of 2 in. and would prefer 3 in.
2. Hold mixing water to a minimum. We support the recommendation of the Portland Cement Association that the w-c ratio should not exceed 5 gal per bag.
3. Use high cement contents. Cement content should be a minimum of 7.0 bags per cu yd for ¾-in. maximum size aggregate as recommended by the Portland Cement Association.
4. Keep cracking to a minimum. Suggestions to accomplish this are as follows: (a) keep heavy construction equipment off the new decks and pavements for as long as reasonably practicable, (b) do not add water or grout to the surface of the plastic concrete and fill low areas with additional concrete and rescreed, (c) schedule deck pours to avoid adverse weather conditions, including high temperature, low humidity, and high winds, which have more effect on cracking than do construction practices, (d) keep mix temperature as low as practicable, (e) begin curing when surface moisture disappears, and (f) have size and spacing of transverse reinforcing as large as design will permit in order to reduce horizontal cracking.

FUTURE ACTION

Will the reinforcement in future bridge decks be protected by additives to concrete, coatings on the reinforcement, cathodic protection, or waterproofing treatments? Waterproofing treatments have gained in popularity and appear to be the best approach for future construction because an effective system would protect the deck against both spalling and scaling.

Information is needed on the cost-effectiveness of these waterproofing treatments. We also need to identify the corrective treatment for spalls that provides the best service life. In addition, bridge piers and reinforced concrete pavements should be reviewed to determine if the chlorides are acting on the reinforcement. We believe work in these areas will provide answers that will reduce future maintenance costs.

Solutions to these problems should be easier to attain as a result of efforts by the California Division of Highways. It has developed a nondestructive device that can measure the electrical potential between the reinforcement and surrounding concrete. As corrosion begins, this electrical potential increases and continues to increase as the corrosion process advances. With this device engineers will be able to determine if the reinforcement is corroding in either prestressed or conventional concrete structures. In addition to its other uses, this device will reduce the time required to evaluate the effectiveness of corrective and protective treatments. We believe this to be a major breakthrough and that further development and field evaluation in other states are warranted. Therefore, a project has been set up within the Bureau of Public Roads to demonstrate this device on bridge decks and pavements at no cost to any agency desiring a demonstration.

The use and performance of protective treatments is currently being evaluated in the field. A status report is tentatively scheduled for publication by August. Corrective treatments are also being studied.

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Formal Discussion

J. D. Shackelford

This paper does an excellent job of bringing together the many different and varied sources of research on the subject of the effects of salts on bridge and pavement deterioration. However, in the monumental task the authors had of searching through the available information, they overlooked several references relating to the use of calcium chloride as an additive to structural concrete and the effect of such an additive on the corrosion of reinforcing steel. These references have a very significant bearing on the conclusions that were presented in this paper.

The authors refer to a 1913 report by E. B. Rosa relative to the effect on the passive condition of iron at ordinary temperatures when adding calcium chloride to the concrete. Following this train of thought a little further, I find a later report that states (38):

> It has been established that calcium chloride incorporated in concrete does not contribute to corrosion of steel in concrete. It has been shown by Wells (50) that the calcium chloride combines with the chemical constitutents of the cement very early and no longer exists in the concrete in the form of a salt. Actually, a very dilute salt solution exists only during the plastic stage of the concrete.

In addition, the following are statements from only a sample of reports relative to this subject:

1. In 1923, Cottringer and Kendall (26) found after one year no corrosion of ¾-in. bars in 6- by 6- by 24-in. long concrete specimens mixed with 0 to 10 percent calcium chloride. Also another report in 1923 (38) stated that "steel in 1:2:4 concrete and 1:3 mortar specimens (was) examined by the U.S. Bureau of Standards (23) after outdoor storage for 5 or 6 years. Tests (were) also made using metal lath in slabs. Corrosion of metal due to calcium chloride was not serious nor of progressive nature when metal was completely embedded. Pockets near reinforcing should be avoided."

2. Mattimore (24) reported as follows: "The plain concrete slabs were cured by being kept wet for eight days and were not opened to traffic for twenty-one days, while the calcium chloride concrete was kept wet for only two days, from that time during the remainder of the seven-day period it was not covered, while at seven days it was open to a normal traffic on one of our main routes. Attention is also called to the fact that the concrete with a 2 percent solution of calcium chloride shows higher compressive strength than does the concrete to which a 4 percent solution has been added. Recent data on calcium chloride check this result. These concrete slabs were reinforced with cold-drawn wire mesh, and an examination of the steel showed no detrimental action of the calcium chloride.

3. Pearson (25) reported the following: "The majority of people would pass upon them (steel rods) as being entirely satisfactory. Corrosion is absent over the greater portion of the surfaces of the rods, what rust occurred being localized apparently where

voids occurred on the surface of the steel. Comparison of the one year and five year specimens indicates that corrosion is not progressive."

4. A report by Swallow (31) states: "It may be remarked that the only places where rusting of steel in concrete has been observed experimentally are in positions where rusting would have occurred in any case, and that lack of proper contact between concrete and reinforcement should be regarded as a serious defect, and it is only under such conditions that rust has been observed. There is no evidence to show that rusting is worse in calcium chloride concrete or that the rusting is progressive. By increasing the fluidity of a concrete mix, the calcium chloride addition should assist placing and help to assure good contact with the reinforcement. To this extent it may be said to assist in preventing corrosion."

5. Libberton (27) in a written discussion stated: "In construction work generally there have been many cases where the rusting of reinforcing has menaced either the appearance or the strength of a building and with that in mind we have endeavored for some years to determine any cases of rusting where calcium chloride was used in the concrete. While calcium chloride or compounds depending largely upon it for their efficiency have been used in very large quantities during the past ten or fifteen years, we have yet to find a case of rusting in actual construction where calcium chloride was incorporated in the concrete."

It appears from these sources (and others listed in the References) that the conclusion reached by the authors is not valid.

The conclusion as stated in the paper suggests that calcium chloride should be prohibited from use as an additive to structural concrete. I believe that this conclusion is in error when viewed in terms of the overwhelming amount of evidence that shows that the corrosion of steel in concrete with calcium chloride admixture is not different from that in concrete containing no admixture, and has been proven many times to be nonprogressive.

Certainly calcium chloride is a material that has to be used with engineering judgment. As a supplier of calcium chloride, we do not recommend its use in all applications, such as when the temperature is too high (40), when prestressed concrete (39) is being cast, or when aluminum (42) or other di-metal systems are present. However, when justifiable conditions prevail, there should be no hesitancy on the part of an engineer or architect to specify the use of calcium chloride as an additive for structural concrete.

These comments are directed only toward the use of calcium chloride as an additive to concrete. The problem associated with de-icing salts (much more sodium chloride used than calcium chloride) penetrating concrete and causing or accelerating corrosion is another subject. No doubt this is a major problem facing the industry today, and the authors have done a good job summarizing the various factors contributing to this situation.

I was pleased to see the authors continue with suggested remedies and methods in which a more durable structure could be obtained, specifically relative to bridge decks. It was somewhat disappointing that no reference was made to the use of latex-modified portland cement compositions as a possible solution to providing more durable, resistant wearing surfaces for bridge decks. This modified system allows the placement of relatively thin sections (as little as ¾ in.) of modified portland cement compositions to either existing or new structures. This material has the capability of bonding to a clean, sound substrate with a strength equal to or greater than the strength of the substrate itself. The material has demonstrated by experience over a 10- to 13-year period in field applications as well as laboratory studies to be greatly more resistant to freeze-thaw damage in the presence of salt brines.

One thing that is stressed in the comments and references mentioned (both in the paper and this discussion) is controlling the w-c ratio of the composition. One of the highlights of the latex-modified portland cement composition is the fact that the water used in this particular system is less than 4 gal per sack of cement (w-c ratio of 0.34 to 0.37). Also, this system does not sacrifice workability at that low w-c ratio as this material still has a slump of 5 to 7 in.

By the nature of this system (formation of plastic films as well as higher density because of lower w-c ratio), this material is less permeable than unmodified portland cement compositions. Tests are currently being made to measure the migration of sodium and calcium chloride de-icing salts into this system from both laboratory specimens and field cores.

Other factors that contribute to the success of this approach are that the modulus of elasticity is approximately half that of unmodified compositions at the same time the flexural strength is considerably higher. On a "living" bridge deck, these properties are very important. Because the bulk of the modified system consists of portland cement, sand, aggregate, and water, the composition has essentially the same coefficient of thermal expansion as unmodified compositions. Also, the modified system has the same color appearance, and the surface can be texturized to any degree of roughness desired. Several reports on the use and performance of this system are available (43, 44, 45, 46, 47, 48, 49).

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Hall and LaHue

The 2 points raised by Mr. Shackelford pertain to the discussion of calcium chloride additives to concrete and the omission of a reference to Dow Chemical's latex-modified portland cement bridge deck overlays. The lack of reference to the latex overlay was not intentional. Reports on this method of repairing bridge decks have been distributed nationally by the Bureau of Public Roads in the construction and maintenance bulletins. We believe this type of overlay shows promise, but, because field evaluations are still under way in many states, an official position by the Bureau of Public Roads at this time would appear premature.

Concerning the discussion of chloride additives to concrete, we stated in our paper: "Laboratory tests have shown that approximately 2 lb of salt per cu yd (6-bag mix) of concrete is sufficient to almost completely destroy the passivity of iron. The standard specifications, however, in approximately 8 states still permit calcium chloride to be added to structural concrete. This practice is potentially hazardous and should be prohibited."

We refer here specifically to chloride additives used in bridge deck concrete. We have studied the quotes in Mr. Shackelford's discussion. We have also reexamined our reference sources on this subject. Considering all the data available, we retain our position on this matter. Future editions of this paper will include an additional recommendation as follows: Prohibit the addition of calcium chloride as an accelerator in concrete that is to be placed in bridge decks.

We can agree with Mr. Shackelford on one point in his discussion, and that is "... calcium chloride is a material that has to be used with engineering judgment."

It is discussions such as these that assist all highway engineers in achieving the best possible product. We appreciate the time taken by Mr. Shackelford to respond to our paper.

Informal Discussion

Lorne W. Gold

Investigations have been made on the possible effect of salt, and considerable scaling or spalling is found with specimens that do not contain steel. Do you care to comment on that?

Cunningham

I am not familiar with any area of the country where this is occurring. Our review was mainly confined to bridge decks containing steel.

Samuel Nitzberg

Have you had any experience with concrete construction in which vibrations and extreme cold together cause the concrete to disintegrate?

Cunningham

No, But I can see that this type of disintegration could occur under the given circumstances.

Nitzberg

Have you noticed that in the cold weather areas there are always potholes and large disintegrated areas that occur within a year or two on all bridges always at the apex?

Cunningham

Our office has not received any reports of this type of concrete disintegration.

Nitzberg

In our study we find that the longer the bridge is, the greater the vibration, and that the colder the weather is, the worse the disintegration of the concrete. It just breaks up and crumbles into potholes.

Cunningham

In what state?

Nitzberg

I have noticed it in New Jersey and New York. In fact I found this condition throughout the country in a study I made of it. Yet, in the South, in Florida, South Carolina, and Georgia, I have not seen this condition.

Cunningham

We found that disintegration of concrete on bridge decks was confined mainly to the northern states where there is freezing and thawing and where chemicals are used. In the southern states, we have found very little concrete bridge deck disintegration.

Jerrold L. Colten

Do you have any correlations on the effective life of prestressed portable spans now being used?

Cunningham

No.

Don L. Spellman

I would like to say amen to all of Mr. Cunningham's recommendations. I am a pessimist, however, because I feel that even if we follow all these recommendations, which are really just good concreting practices, we are still not going to stop bridge deck deterioration. We may be able to slow it down, and, if we can stop it for 20 years, we still are better off. But sooner or later the salt is going to penetrate, and when it reaches the steel we will have trouble.

John Pendleton

Do you have any comment on what I guess you would call the malpractice of using rusted steel reinforcement fresh concrete? Do you get any effect from this?

Spellman

I think we would because of differential conditions from one part of the steel to another, and this tends to create electrolytic cells responsible for corrosion. At least our studies of potential measurements of steel and concrete show we already have a cell condition set up.

Kaare Flaate

We have problems with concrete bridge decks in the heavily populated areas where salt is used to melt ice and snow. We get spalling and, it seems to us that this spalling occurs primarily because of the reduced quality of the concrete and that the spalling is increased by the heavy traffic of studded tires. I am not quite sure that the reinforcement is so important. In some instances, the concrete deteriorates all the way down to the reinforcement and even further. It just happens that the reinforcement is there and tends to add something to the deterioration of the whole bridge deck. But the main reason for the deterioration seems to be the salt, frost, and dynamic effects, and I believe it can go much deeper than to the reinforcing steel. Even in very cold weather with light traffic and no salt, we have no problems. We thought we were doing something good by putting an asphalt cover on top, but this is probably worse than anything else if it is not really waterproof. So what we are trying to do now is get a waterproof deck that can move with respect to the underlying concrete.

Lawerence H. Chenault

Some years ago we did a snow-melting heating installation in a carwash where spalling was a real problem. I realize this is not a bridge, but it is an example of a heating system installation over a very badly spalled concrete deck. We placed 3 in. of concrete and used an acid etch and then a detergent solution to clean the concrete prior to the bonding of the new overlay. This has been in use for 4 years, and there has been no detachment or failure of this bonded overlay.

John Sayward

I do not know whether this is an explanation of the spalling, but it may have some similarity to what is known as salt weathering, which again is something related to frost action. In salt climates salt gets into porous rocks and then evaporates. The moisture gets out, but the salt starts to crystallize and keeps growing inside, unable to migrate through the small passages. This is much the same mechanism that exists with frost action. It creates a pressure just as the corrosion of the iron causes pressure, as stated by Mr. Cunningham. Why would this not be possible, granted there is a permeability of some degree to the concrete.

Gold

I think it is quite true that there are a number of things we still do not understand about this particular problem.

James A. Murchie

I wonder if anyone would care to comment on continuously reinforced concrete pavements inasmuch as their defects seem to compare with those in bridge decks. We are getting a problem now, and it sounds like this one being discussed. Although the mechanism is slightly different, we are getting the same ultimate effect; that is, we are actually losing steel.

Glenn G. Balmer

One of the fundamental principles in making good concrete, as has already been stated by Mr. Cunningham, is to keep the water content low. To make good concrete requires that as small an amount of water as practical be used. Of course, an adequate amount of cement is essential. Scaling is a surface phenomenon and may occur on concrete without steel. Too much water in concrete causes bleeding. The surface of the concrete is weakened from overworking or from too much water coming to the top. Strength-producing components of the concrete settle, leaving the surface weak. Another important factor in making good concrete is to use an air-entraining agent. Concrete should have on the order of 5 to 7 percent air. This is a means of mechanically resisting freeze-thaw cycles. The microscopic air bubbles in the concrete permit expansion and contraction to take place without causing failure of the concrete, or at least they decrease the failure. Spalling is a problem somewhat separate from scaling. Spalling is often caused by variation in stress. The stress may be from differential expansion or contraction or from external loads.

William F. Limpert

Has any work been done on coating reinforcing rods? If so, have there been cost effectiveness comparisons made between coating the rods to prevent the corrosion and laying another 2 in. of concrete on top of it?

Spellman

I believe galvanized reinforcing bars were put in some bridge decks in Michigan, but I have not seen any results.