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# DETERIORATION AND RESTORATION OF CONCRETE BRIDGES ON THE STATE TRUNKLINE SYSTEM

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On September 29, 30 and October 1, 1947, Mr. Wooley of the Public Roads Administration, Mr. Shuttleworth, Bridge Maintenance Engineer, and the authors inspected 51 bridges on the state trunkline system in a survey extending through the central, eastern and southeastern regions of the lower peninsula. The itinerary of the survey is shown on the opposite page. This survey was part of a research program, recently undertaken by the Research Laboratory at the request of Chief Deputy Commissioner Harry T. Ward, dealing with the preservation and reconditioning of concrete bridges on the state trunkline system.

The immediate purpose of the survey was to determine the nature and extent of deterioration of the concrete in the bridges with the ultimate objective of finding the causes of such deterioration and of taking steps, not only to repair existing structures, but also to devise means of improving the durability of bridges to be constructed in the future.

In general, several types of deterioration were found. They include: (1) gradual or normal weathering; (2) cracking and spalling due to loads and shifting of walls and abutments on foundations; (3) characteristic scaling on decks, curbs, sidewalls and handrails due to chloride salts; (4) "D" lines or map cracking on the surfaces indicating accelerated weathering; and (5) cracking and spalling of thin handrail members accelerated by rusting of reinforcing steel.

The survey indicated, however, that all structures examined were still apparently fundamentally sound, even where the most advanced disintegration had taken place. The present problem is essentially one of maintaining the appearance of the structure and of preventing, if possible, further deterioration to the point where replacement of the structure, or major portions of it, may become necessary.

This report discloses the results of the condition survey, discusses possible causes and remedies and presents suggestions for reconditioning the structures for the purpose of restoration and preservation.

## RESULTS OF CONDITION SURVEY

The physical defects inherent in each structure encountered on the condition survey have been summarized in Table I. A detailed discussion of each type of deterioration follows.

### Normal Weathering

This is characterized by slight surface erosion and pitting, with no disfigurations commonly associated with disintegration of unsound concrete.

### Scaling Due to Chloride Salts

Characteristic scaling and subsequent disintegration due to salt action was observed on decks, curbs, sidewalls, and handrails where the salt solution, impounded in depressions on the bridge deck, had been splashed by traffic or carried in snow and ice to concrete members adjacent to the roadway. This action has been particularly prevalent on structures of the Detroit Industrial Expressway System and Willow Run Expressway. In some cases also the effect of chloride seepage through joints and vents of the deck was observed in the scaling and surface disintegration of supporting members. An outstanding example of heavy chloride damage was found in the Court Street Bridge in Saginaw, (B1 and X1 of 73-24-12) where serious disintegration had occurred in the piers and understructure by infiltration of sand-chloride through open joints in the deck system.

Typical examples of this type of disintegration are shown in Figure 1.

Structural Cracking and Faulting

Several structures showed cracks, breaks, and spalls resulting apparently from settlement or shifting of walls and abutments on foundations or from impact of vehicles.

Spalling and Cracking Accelerated by Rusting of Reinforcement

In quite a few cases the outer layers of thin members, such as newell posts and top sections of concrete handrails, had broken off or cracked apparently by the rusting of the reinforcing steel which was either too large or had inadequate depth of cover for the design and shape of the member. Examples of this type of disintegration are shown in Figure 2.

Temperature or Shrinkage Cracks

A few structures contained singular cracks running horizontally or in a diagonal pattern characteristic of temperature or shrinkage phenomena. This type of cracking is illustrated in Figure 3.

Deterioration Due to Water and Frost

Deterioration of this type is manifested by the appearance of "D" lines which is soon followed by cracking and general disintegration. "D" cracking was observed at localized areas on curbs, steps, handrails, end posts, and tops and sides of wing walls, abutments and piers. These cracks usually show up first on surfaces adjacent to joints, cracks, or other openings which permit infiltration of water. In certain cases water was observed to be seeping out of the cracks. Typical examples of this kind of deterioration are illustrated in Figure 4.

Disintegration is rapid after these "D" lines appear. Typical examples are shown in Figure 4. Experience and research have demonstrated that deterioration of this character is definitely associated with inferior concrete and, in some cases at least, is due to questionable construction practice. Evidence of this appears in the condition of concrete on opposite sides of the expansion joint in Figure 4E.

Cracking Due to Embedded Precast Units

Cracking has occurred where hollow precast structural members, such as hollow tile, were embedded in the structure to reduce weight. Examples of cracking resulting from this type of construction are illustrated in Figure 5.

## GENERAL DISCUSSION

It is believed that many of the factors responsible for the various types of concrete deterioration encountered in the survey have been eliminated through recent changes in design and construction practices. We have reference to the discontinuance of both precast hollow tile in the deck system to reduce weight and the massive concrete handrail system, the introduction of better joint sealers, and the adoption of air-entraining concrete which should result in a more uniform and durable concrete provided reasonable care is exercised in its manufacture and placement.

Perhaps the most outstanding cause of the sporadic weathering of concrete in various parts of the same structure is the non-uniformity of the concrete resulting from handling and placing in the forms. A review of the concrete mix design charts for structures covered in the survey which were built before 1940 indicates that in all except a very few cases the water-cement ratio was less than 6 gallons per sack, which is not excessive for this type of work. See Table II. Even though the designed water-cement ratio may be within the required limits, the actual water content will no doubt be much higher at certain critical points in the structure, such as tops of abutments and piers, handrail posts, and at joints, due to localized water gain. Moreover, there is the ever-present tendency of workmen to over-water the mix to gain added workability which, of course, aggravates the condition.

A possible method of increasing the durability of the top surfaces of deep structural members is to build up the concrete slightly higher than the finished dimension and strike off to the proper height when bleeding is over. This procedure would eliminate the weak top layer formed with excess water. Over-watering of the mix can be corrected only by more vigilant inspection and enforcement of specification requirements on the job. In addition to these measures, positive drainage of deck surfaces must be provided and joint design improved in order to eliminate seepage which accelerates weathering at vulnerable points by saturating the concrete with freezable water.

## RESTORATION OF CONCRETE BRIDGES

There are several different procedures for the repair of disintegrated concrete surfaces and the choice of method in any particular case will depend to a large extent on the condition of the concrete and its location in the structure. The repair methods described in the following text pertain primarily to that type of surface disintegration associated with chloride salts, water and frost action, and spalling due to impact. In general, the restoration process consists of completely removing the disintegrated concrete, properly preparing the exposed surface, and applying to it a new coat of concrete. The thickness, shape, and location of the concrete patch will determine the work method. The experiences of others in solving this problem are presented for reference and study.

Experience of the Oregon Highway Department (1)

The following is an outline of the procedure used by the Oregon State Highway Department in patching disintegrated concrete and waterproofing concrete surfaces for the prevention of disintegration.

"When disintegration of the commonly called "D-line" type has taken place, it usually affects the edges and corners of curbs, handrails, wing walls, and other exposed members. To prevent further progress, it is necessary to remove completely all disintegrated material, great care being taken to reach sound concrete beyond the extent of the disintegrated area. This can be accomplished by the use of hammers and chisels on small areas or by paving breakers or chipping hammers on larger areas. If the disintegration has reached an advanced stage, the complete removal and replacement of the affected portion of the structure may be necessary. The importance of the removal of all traces of disintegrated material cannot be overemphasized. Experience has shown that often the workman will remove all visible affected material, then place a patch on what was, in his judgment, sound concrete, only to discover later that the material adjacent to the patch continues to disintegrate.

"After the removal of the disintegrated concrete a patch is applied, the success of which depends upon securing a bond to the parent concrete, overcoming the tendency of the patch to shrink after placement, and proper curing. All places to be patched should be chipped out to secure not less than three-fourths-inch thickness for the patch. The edges of the patch should be square and not feathered. All surfaces should be clean and rough so as to secure a good bond and should be saturated thoroughly by several applications of water. The preshrinkage of mortar is required for all patches. This is done by mixing the mortar well ahead of use and letting it stand. The time required for preshrinkage of mortar varies with the different brands of cement and conditions of temperature and humidity, and is best determined by experiment on the job. In general the mortar thus preshrunk should be susceptible to use without the addition of water before reworking it for application. After the patch has been applied, proper care in curing must be taken by keeping the patch covered with wet burlap for six to ten hours, after which it can be covered with damp sand or burlap until the concrete has thoroughly hardened.

New concrete patches should be allowed at least two weeks to dry out before applying the waterproofing treatment. New concrete should be given a neutralizing wash before the application of the linseed oil used in the waterproofing treatment. A solution consisting of three pounds of zinc sulphate crystals to a gallon of water is brushed over the surface to be treated and allowed to dry for 48 hours. When thoroughly dry, all crystals on the surface are removed by wire brushing. This treatment is not necessary on old concrete.

Before the waterproofing treatment is applied, it is necessary that the concrete surface be clean and dry. Dust and loose material can be removed with a wire brush. Road oil or grease can be removed by scrubbing with gasoline or a solvent. Efflorescence can be removed by scrubbing with a ten per cent solution of hydrochloric acid. When water is used in cleaning, ample time must be allowed to permit thorough drying of the concrete surfaces before applying the waterproofing.

After the surface has been properly prepared and is clean and dry, two coats of hot linseed oil are to be applied. The first coat consists of a mixture of 50 per cent raw linseed oil and 50 per cent turpentine heated to 175°F. and applied with an ordinary paint brush. Better results will be obtained if the air temperature is above 65°F. The first coat is allowed to set 24 hours before applying the second coat. After the first coat of the linseed oil-turpentine mixture has set, spots will usually be noticed where the concrete is more porous than the remainder of the surface treated. These spots should be spot treated with the hot mixture and allowed to set before the second coat of linseed oil is applied.

The second coat consists of undiluted raw linseed oil heated to 175°F. and applied in the same manner as the first coat. When this coat is thoroughly dry, the surface is ready for a paint coat.

The entire surface treated with oil is given two coats of white lead and oil paint, tinted to the desired shade. A concrete color can be obtained by the addition of lampblack and raw sienna ground in oil. The white paint used in Oregon has the following formula:

| Paint Composition | Per Cent |
|---|---|
| Pigment not less than | 70 |
| Vehicle not more than | 30 |

| Pigment Composition | Per Cent |
|---|---|
| White lead carbonate | 40.0 to 45.0 |
| Titanium barium pigment | 35.0 to 40.0 |
| Zinc Oxide | 15.0 to 20.0 |
| Tinting pigments, if required | 0.0 to 5.0 |

The first coat is thinned by the addition of two quarts of turpentine and two quarts of boiled linseed oil to the gallon of paint. The second coat is thinned with about one quart of boiled linseed oil to the gallon of paint, so as not to give a heavy pigment coat that will be susceptible to scaling, but which is still heavy enough to brush out uniformly and evenly.

This waterproofing treatment is not a cure for the basic weakness of the concrete which makes it susceptible to disintegration. If properly applied and maintained, it promises to postpone serious disintegration for many years."

Experiences of the New Jersey Highway Department (2)

The method employed by New Jersey to patch concrete pavement surfaces is described as follows. The technique is applicable to bridge decks, curbs, side walls, and other horizontal surfaces.

"We have done some considerable quantity of this type of work. The thickness of the patches placed has varied from an appreciable depth down to almost a feather edge. In making these thin patches the surface is first thoroughly cleaned and all unsound concrete removed either by hand or power tools. It is highly desirable that the outside perimeter of the patch be trimmed down to provide a vertical edge. Immediately after cleaning off the surface to be patched the same is thoroughly cleaned with a high pressure air jet. It is then thoroughly sprinkled with clean water and dusted uniformly and carefully with neat cement. This is done immediately prior to placing the concrete mixture and before the cement has had a chance to dehydrate. Should anything occur which would prevent placing the concrete before the cement has dehydrated, the patch should again be wet and neat cement again dusted over the same. The concrete mixture is then applied; the same being mixed with a very low water cement ratio, so that it is, as a matter of fact, harsh and dry. The mixture is then thoroughly tamped into place, struck off high and allowed to stand until initial set has taken place. The concrete is again tamped, screeded off to the proper elevation and finished in a manner to conform to the balance of the surface, after which it is cured with the use of wet burlap, at least originally. Other standard curing methods are also used later during the period.

The cement used has, in some cases, been special high early strength cement but, more frequently, however, we have used the standard Portland cement and have, in many cases, included a two and one-half per cent calcium chloride solution in the mixing water used. Generally speaking, the water cement ratio should not exceed four gallons.

In connection with the matter of the aggregates and proportions of concrete mixtures, we would advise as follows:

For patches up to an inch and a half in depth we have used a 1-1-2 mixture, using as aggregates sand and broken stone or gravel up to one-quarter inch maximum. Over an inch and a half in depth and up to four inches we have used two different proportions; the first being 1 - 1-1/2 - 2-1/2 and the other 1 - 1-3/4 - 3. In such cases the maximum size of the coarse aggregate has been three-quarter inch broken stone or gravel. Where a patch is over four inches in depth we use a 1 - 1-3/4 - 3 mixture, together with a coarse aggregate having a maximum size of one and one-half inches. The standard coarse aggregate used in our concrete pavement mixture is what is known as either inch and a quarter size or three-quarter inch size. The inch and a quarter size is prepared from a mixture of roughly fifty per cent inch and a half and either three-quarter or five-eighth inch stone. The three-quarter inch size is made by a combination of practically equal proportions of inch and five-eighth inch sizes.

In our opinion, the most important factors to be observed in any work of this character are as follows:

1. <u>The thorough cleaning and removal of all unsound materials.</u>

2. <u>The use of an extremely dry mixture and extremely thorough tamping.</u>

3. <u>Delay of final finishing until after initial set has taken place and the greater part of shrinkage has taken place.</u>

4. <u>Careful and complete curing.</u>

It is not always entirely feasible to use exactly the same ingredients in making the patch that were originally used in constructing the pavement. Particularly if the pavement is old and somewhat discolored, there may be a considerable color contrast between the patch and the surrounding pavement. This is not entirely desirable, although, in my opinion, it is a minor factor; the integrity of the patch being of far greater importance than the spotty appearance. If, however, appearance is of importance, admixtures of either ferrous oxide or lamp-black may be employed.

A great deal of the work which we have done has been the patching of isolated spalled or deteriorated areas. There have on one or two occasions, however, been fairly sizeable areas patched, particularly where pavements have been damaged by the burning of vehicles carrying inflammable materials. Particularly in the case of the isolated patch proposition, one operation in particular, done within the last two years, has indicated the probability that if a surface is, in general, basically unsound, it is probably not worthwhile to do thin patching, by reason of the fact that while the patch may stand up, the remainder of the surface surrounding the patch will, in the course of a comparatively short time, disintegrate around the patch. In such cases, it is probably better to completely resurface the pavement, performing only such patching as may be essential to provide a reasonably sound base for the resurfacing."

The Bridge Maintenance organization should perhaps supplement the experience of Oregon, New Jersey and others repairing concrete by experimenting with the use of air-entraining concrete, membrane curing materials, proprietary bonding agents and non-shrinking cements in connection with their present techniques of patching in order that the Department may benefit by obtaining a wider field of knowledge and experience in this important work.

The Gunite Method

Gunite is the trade name of a sand-cement mixture placed with the "Cement Gun" and possesses properties that make it particularly adaptable for repairing masonry or concrete structures. The cement gun may be purchased outright for repair purposes or the work may be done by regular Gunite contractors under contract. The method is generally too well known to warrant further discussion here.

The Intrusion Method (3)

The Intrusion Method has been used successfully in stabilizing old cut-stone structures and foundations. Briefly, the intrusion process consists of drilling holes at intervals and injecting an intrusion mixture which consists of Portland cement, a powdered mineral filler and water, and in some cases a fine sand. The intrusion mixture is injected by pumping under pressure sufficient to secure thorough penetration of the structure without displacement of structural parts. The intrusion mixture fills the cavities with a dense, strong paste highly bonded to the walls.

Prepacking Method (3)

Prepacking is concrete made by packing the forms with coarse aggregate and then pumping in a cement base intrusion mixture to fill the voids under pressure. Defective concrete of the structure is chipped out, a form applied, and the space behind the form is packed lightly with coarse aggregate. Intrusion mixture is pumped in and, under pressure, not only fills the spaces within the prepacked aggregate, but also penetrates into the pores of the underlying surfaces and into corroding cracks and void spaces. The cementing to and stabilizing of the underlying mass is a distinctive feature of this method of repair.

The work of restoration by either method discussed above is conducted by the Intrusion-Prepakt Co. with offices in Chicago, Cleveland and Toronto.

## SUMMARY

The investigation has served a useful purpose in focusing attention on several pertinent factors associated with bridge design, construction and maintenance which should not be overlooked if we wish to construct more pleasing and enduring structures.

1. All plans for future concrete bridges should be carefully scrutinized for design weaknesses which will permit water to accumulate and remain at localized areas where it will eventually seep into joints and onto tops of abutments, piers and wing walls.

2. All joints in the roadway or at abutments should be carefully designed and constructed to insure no leakage into the structure or through joints onto members of the substructure.

3. Durable concrete should be striven for by employing a low water cement ratio, sound aggregates, sufficient cement, proper construction practices and workmanship, and firm enforcement of specifications through vigilant inspection.

4. The use of air-entraining concrete should eliminate many of the weaknesses now showing up in the older structures constructed with standard Portland cement.

5. Many of the structures now showing deterioration can be successfully and economically repaired with available maintenance equipment and personnel by following well-established procedures.

6. Structures in advanced stages of deterioration can be successfully repaired by methods requiring more specialized equipment such as the Gunite process.

7. Every bridge to be repaired will constitute an individual problem which will require good judgment and ingenuity, but experience indicates that it can be done. From the present condition of many structures, this work should start now.

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