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BRIDGE DECKS: WHERE A LITTLE WATER MAY BE TOO MUCH!

Motorists cannot help but become aware of the problems with bridge decks if they drive the highways of states where winter snows necessitate the use of deicing chemicals. Many of MDOT's 4,500 trunkline bridges share those problems and numerous and costly repairs continue to be required to restore or maintain the strength and riding quality of our decks.

Why a Problem With Carefully Constructed Decks?

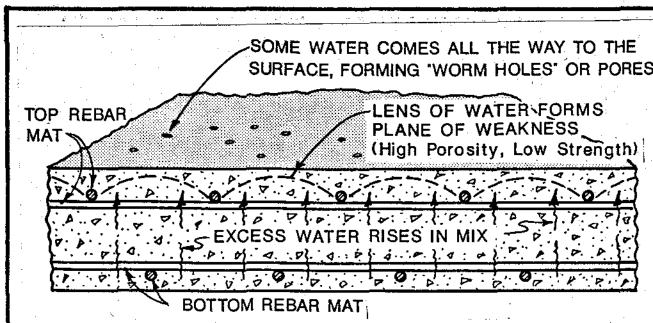
A study of bridge deck delamination in the mid-1960s by the Missouri Highway Department led them to conclude that a plane-of-weakness has developed in some bridge decks slightly below the surface. It results from excess water in the mix, some of which rises and forms a high water content lens at or near the top rebar mat, resulting in a thin layer of very porous and weak concrete at that location. Some water also rises all the way to the surface, forming small paths ('worm holes' or pores) that later allow brine to reach the top mat rebars.

The expansion of rebar diameter due to formation of rust then causes delamination of the deck concrete along the weakened plane. The Missouri investigators called this "fracture plane deterioration," and it was later found to occur throughout the country—including the State of Michigan.

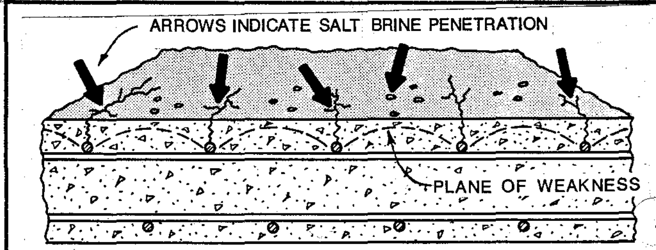
Decks that contain extensive and severe planes-of-weakness fail by delamination and spalling (removal of the loose pieces) at a relatively early age; while other decks of similar design and concrete cover over the bars, may perform adequately for many years. Many have questioned why this occurs. Investigations have shown the primary cause to be excess water in the mix. It also appears that structural vibrations during and after placement of deck concrete may aggravate the situation by concentrating the excess mix water in a most unfortunate location, forming the so-called plane-of-weakness slightly below the deck surface. Although the average water content and porosity of the deck as a whole may be only slightly higher than normal, the concentration of much of the excess water in a thin lens below the surface, results in extremely high water/cement ratios along a selected layer. Porosity is extremely high along that layer, and strength is nil.

I-94 in Berrien County

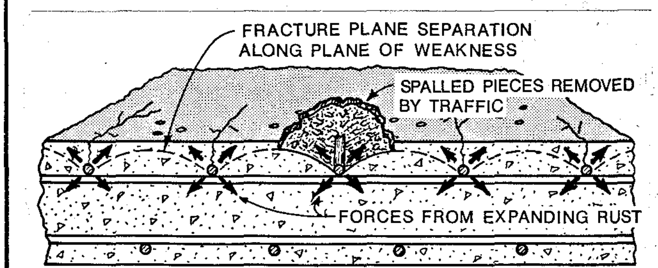
During the widening of bridges, under traffic on I 94 in Berrien County in 1965 (110 spans of 34 structures), the eruption of tiny fountains of clear water through the top surface of the deck was repeatedly observed just prior to the initial set of the concrete. These decks were being subjected to severe vibrations from truck traffic on the old portion of the deck a few feet away. Rippling of the decks was observed after finishing, with troughs occurring over the top transverse reinforcing bars and crests between the bars. The vertical distance from crest to trough was about 1/8 in. This rippling, caused by the traffic-induced vibration, occurred after final finishing of the deck. It was observed also that float finishing of the surfaces where rebars were quite close to the surface caused displacement of coarse aggregate from above the reinforcement, resulting in an increased mortar content along with a localized high water/cement ratio. This in turn caused increased shrinkage and led to cracking above the bars. Cracks were visible over each bar in some areas of several decks shortly after construction. Such cracking causes significant increases in the amount of salt solution reaching the rebars.



First: Fresh concrete under structural vibration.



Later: Shrinkage cracking, wormholes (pores), and plane-of-weakness in cured concrete allow salt solution to penetrate to the rebars.



Finally: Failure caused by expanding rust.

Testing Laboratory U of M 1913 — Research Laboratory MSU 1939

Investigation and Research Division 1924 ✶ Testing and Research Division 1933 ✶ Materials and Technology Division 1985

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The net effect of the traffic-induced vibrations was an accumulation of water within the deck just beneath the surface. Obviously, if a small fountain of clear water breaks through the surface crust on occasion, there has to be a reservior or small 'pond' somewhere beneath that surface. Subsequent removal of an uncracked 'hollow area' on one of the decks revealed a surface layer (about 1 in. thick) of sound concrete, underlain by about 1/8 in. of sandy rubble which separated the surface layer from the sound concrete underneath. This appears to be evidence of a water reservoir that did not surface. These factors, coupled with the examination of numerous decks under repair, show the repeated occurrence of spreading delamination and spalling away of relatively sound surface layers, separating along a built in plane-of-weakness and porosity.

I-75 Rouge River Bridge

About a year later, during deck placement on the high level bridge carrying I 75 over the Rouge River, its very large deck was found to develop ripples in the surface within 20 to 30 minutes after finishing. Low level structural vibrations were noted, which were caused by adjacent construction activities and railroad traffic below the bridge. Similarities in the appearance of the deck of this bridge to those previously widened under traffic, along with inspections of other newly constructed bridges that exhibited deck rippling, led to the conclusion that perhaps sufficient structural vibration exists on many new bridges to cause separation and collection of water within the deck and thereby a plane-of-weakness. Subsequently, the Rouge bridge did delaminate at a relatively early age. Similar though less severe rippling exists on numerous decks throughout the state. Since vibrational forces and gravity are the main sources of force on the newly finished deck, the evidence suggests that sufficient vibration existed on many decks during concrete placement that selective collection of excess water from the mix occurred.

MDOT Research Investigation

A laboratory experiment was conducted in the Research Laboratory's Structures Unit, which involved casting 3 ft square by 8 in. thick concrete slabs to simulate a bridge deck. Selected specimens were subjected to vibration during cure, at frequencies typical of bridge deck vibration, while matching "control" specimens were cured without vibration. Varying amounts of water were placed in the concrete. Rebar shaped cylindrical voids were formed in the specimens. After curing, hydraulic pressure was applied within the voids, simulating the pressure caused by expansion of the rebar due to corrosion. One pair of blocks used a good quality, 3-in. slump, bridge deck concrete mix. Another set was cast using more mix water (4-in. slump) in both vibrated and unvibrated states. Applying the internal hydraulic pressure to the first set caused the unvibrated block to fracture vertically at about 1800 psi; while the vibrated block fractured, again vertically, at about 1600 psi. In the second set, with more mix water, the control block fractured vertically at about 1500 psi; while the vibrated block broke horizontally at about 800 psi. A third set was cast with still more water, and it was found that bleed-water channels like worm holes from rebar void location to the surface, formed paths through which deicing salts readily could penetrate to the rebar. Fluids leaked readily through these holes when the voids were pressurized. This illustrates the effect of excess water on deck porosity.

The laboratory work was quite limited, but is significant because of the possibilities it suggests. The first case indicates that good quality low water/cement ratio concrete is somewhat tolerant of structural vibrations. Comparison of the first with the second case suggests quite strongly that excess water can be collected by structural vibration in such a way as to cause a horizontal plane-of-weakness. Failure along this plane is relatively easy to initiate, and pressure due to expansion while rust is forming is known to be very high.

Information and concepts derived from this experiment were checked out in the field, and similar evidence was found on many bridge decks over several years. Modes of failure of sound concrete purposely overloaded in tests, lend additional credence to the plane-of-weakness hypothesis, since fractures in such concrete approach the surface in a different way than do the failures or delaminations of bridge decks. Also, bridges of identical design and with similar concrete cover over the reinforcement, sometimes show remarkable differences in deck performance, depending on whether the concrete has excess water.

Several studies have shown that high quality (low water/cement ratio) concrete can be subjected to significant vibration levels during cure without developing problems. (If interested in additional information in this regard see National Cooperative Highway Research Report 86, "Effects of Traffic Induced Vibrations on Bridge-Deck Repairs" by David G. Manning, Dec. 1981, for a nationwide perspective on the subject.)

Quality Control is Critical

Thus, it appears that efforts to prevent the addition of excess water in bridge deck concrete should pay dividends in improved performance. Indeed, the improved, water-reduced mixtures of recent years appear to be performing far better than the relatively wet mixed concrete used in the early days of the Interstate construction program. Concrete cover over the bars has been increased, and rebars now are epoxy coated to increase corrosion resistance. However, careful control of deck concrete quality still is required, as the evidence shows strongly that it doesn't take much additional water in the mix to be 'excess,' and that planes-of-weakness in a bridge deck can be expected to reduce its useful service life. Therefore, maintaining high quality (low water/cement ratio) concretes is of considerable importance to the durability of our decks.

This article has explained how some bridge decks were built in such a way as to have surface spalls at a relatively early age. However, all decks with uncoated steel, are subject to attack by chloride-induced corrosion of the reinforcement, followed by the concrete failures that result from corrosion-induced expansion of the reinforcement. Increased amounts of concrete cover over the bars; and improved concrete quality that reduces shrinkage cracking, porosity or permeability; both act to retard the rate of deterioration. Since a very large number of Michigan's older bridges, and others throughout the Country, were built with relatively small concrete cover and uncoated rebars, corrosion-induced spalling will continue to be troublesome. A future article will deal more extensively with the mechanisms of corrosion and long-term deck deterioration. At the present time, only cathodic protection (a relatively new development for bridge decks, using applied electrical voltage to suppress corrosive currents) is capable of stopping corrosion in an existing chloride contaminated deck. Future MATES articles will discuss cathodic protection and a new salt-substitute deicing chemical called calcium-magnesium acetate (CMA).

-Chuck Arnold

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