

# Low Porosity, High Strength Concrete for Bridge Decks

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## INTRODUCTION—THE PROBLEM

A few years ago a problem that previously had been a modest highway maintenance concern suddenly became a major source of difficulty and expense to highway departments in many areas of the country; including Indiana. In brief, concrete bridge decks, some new, started to spall, then delaminate, then come apart in relatively large chunks. The problem was quickly traced to steel corrosion, specifically to corrosion of the steel in the upper mat of concrete bridge decks; and more specifically to corrosion induced by chloride ions penetrating from the surface of the bridge deck. The chloride is derived from de-icing salt (usually sodium chloride but occasionally calcium chloride) applied to keep the bridge deck clear during winter snows.

Researchers established that chloride ions that penetrate to the vicinity of the steel interfere with the protective “passivating” layer of oxygen that ordinarily keeps steel embedded in concrete from rusting. The rate of corrosion of embedded steel depends on several factors, but most pertinently, in this connection, on the pH or alkalinity of the pore solution of the concrete and on the amount of dissolved chloride present. Generally speaking, high levels of alkali (high pH levels) protect the steel; however, if the concentration of chloride ions gets too high, the protective action tends to break down regardless of how high the alkalinity may be.

The concrete bridge deck corrosion problem is a bit different from most corrosion problems in that the damage is not due to loss of metal of the corroding steel but due rather to the buildup of the hydrated iron oxide corrosion product within the concrete. The hydrated iron oxide is bulky and as it builds up in the restricted pore spaces within the concrete it exerts expansive force that tends to lift up the concrete cover above the level of the steel. A layer of separation is thus produced; the loosened concrete above the layer then tends to spall and break up under the action of traffic.

There have been a variety of solutions to the problem suggested and worked on by the Federal Highway Administration and by researchers

in various state and university laboratories. One obvious key to the problem is the permeability of the concrete above the steel to water and to dissolved salt. This permeability is a function of the water: cement ratio of the concrete, and to some extent of how well the concrete is compacted and consolidated. This is difficult to do well in the restricted areas surrounding the reinforcing steel on bridge decks, and as a result most bridge deck concrete tends to be more permeable than it should be.

One proposed solution was to incorporate special wax beads into the bridge deck concrete mix, and then, after the concrete had hardened, to apply heat sufficient to melt the wax and thus plug up the internal pores and render the concrete less permeable. This solution was favored by FHWA in the recent past but generally has proven impractical.

The current favored approach seems to be a system of epoxy-coating the reinforcing steel by an electro-spray process developed at the National Bureau of Standards. This process keeps the chloride out of contact with the steel and seems to work reasonably well, but it is quite expensive.

#### LOW POROSITY, HIGH-STRENGTH CONCRETE AS A POTENTIAL SOLUTION

The research project on which this report is based rests on a completely different tack in terms of a solution to the bridge deck deterioration problem. The main idea is that ordinary portland cement concrete, normally specified for bridge decks, is not suited for that purpose in areas where salt is extensively applied. It is too porous; too prone to microcracking, which also lets the chloride through; and chemically it is not alkaline enough. There is a system for producing special low-porosity concrete from ordinary cement which is handled somewhat differently than usual.

The system, developed originally as an FHWA research contract by Prof. Stephen Brunauer of Clarkson College, New York, involves leaving the gypsum usually interground with portland cement clinker out of the cement, and instead controlling set and workability by adding a special admixture combination. In the current state of development the admixtures used are a specially-selected lignosulfonate and sodium bicarbonate, used on the order of about 1 percent of the former and 0.8 percent of the latter by weight of cement. These chemicals, added during concrete mixing also act in part like a superplasticizer and permit properly designed concrete mixes to flow with very little vibration at much lower than usual water contents. As a result, the final hardened concrete winds up with a much tighter structure, fewer pores, and

significantly lower permeability. It is also much stronger than conventional concrete and significantly more alkaline, the latter feature serving additionally to protect the steel against corrosion.

The research project, now nearing completion, involves a series of side-by-side comparisons of low porosity concrete properties relevant to the problem with corresponding properties of concrete made according to the general specifications for concrete for use in bridge decks in Indiana. The comparisons also include concretes prepared according to the so-called Iowa dense mix specifications, which have had some success there especially in repair work, and low porosity concrete incorporating flyash, which somewhat modifies the properties, mostly favorably. The work is being carried out by S. E. Coleman as his research toward a Ph. D. degree and is sponsored by the Indiana State Highway Commission and the Federal Highway Administration.

#### CURRENT TRENDS OF THE RESULTS OF THE RESEARCH PROGRAM

Clearly, low porosity concrete as formulated in this program is substantially stronger than ordinary bridge deck concretes. Compressive strength values of about 8 to 10 thousand psi are readily attained. Furthermore, the rate of strength gain in the first two or three days is remarkably superior for the low porosity system.

We have had great difficulty making reproducible measurements of the permeabilities of our concretes, since they are all quite impermeable as prepared under ideal laboratory conditions. The water transmission rate is so slow, even under high applied pressure, that small temperature fluctuations or other such effects interfere markedly.

Shrinkage measurements of mortar specimens have been carried out for more than one year, and it is reasonably well established that the shrinkage of the low porosity materials is significantly less than shrinkage of ordinary portland cement mortars. This is not surprising in view of the low water:cement ratio that can be employed. This tendency would be reflected with significantly less microcracking in the field concrete.

Freeze-thaw durability measurements carried out by standard ASTM methods indicate almost perfect freezing resistance of the low porosity concrete, with some deterioration evident in the ordinary portland cement concrete.

Scaling tests, involving repeated freezing—thawing cycles of specimens exposed to calcium chloride solutions, seem to show very significant resistance to scaling effects induced by freezing in the

presence of dissolved chloride salts on the part of the low porosity concretes.

An extensive series of measurements of chloride diffusion in the different concretes has been carried out and the results are being evaluated critically. So far, it appears that chloride penetration through low porosity concrete systems is significantly less than through ordinary bridge deck concrete as usually specified.

Tests of carbonation rates reveal that, presumably because of their tight structure, low porosity concretes carbonate hardly at all, even in atmospheres of high CO<sub>2</sub> contents; in contrast, the ordinary concretes become carbonated for substantial distances into the section. This carbonation results in a serious reduction of the alkalinity of the concrete, thus promoting corrosion.

Within the last year or two it has become increasingly evident that one of the major limiting factors on the rate of corrosion of steel in concrete, even in exposed bridge decks, is the rate of oxygen diffusion to the level of the steel. While we do not have specific measurements of this, it seems self-evident that the very much tighter microstructure of the low porosity concrete should result in a much lower oxygen diffusion rate, hence much slower corrosion should corrosion start.

However, we have carried out a variety of electrochemical measurements and visual measurements of corrosion on exposed steel in concrete set out in the atmosphere, some with chloride already present within the concrete (mixed in the concrete batching operation), others with salt solutions ponded on the surface of the test slabs. So far it appears that, in the low porosity concrete tests, the concrete has succeeded in maintaining a completely passivated condition of the embedded steel; in contrast, the conventional bridge deck concrete and to a lesser extent the Iowa dense concrete mixes have not done so, and active corrosion is taking place at a high rate.

## CONCLUDING REMARKS

The project described is still underway, and evaluation of the results of many of the tests remains to be done. Nevertheless, it is clear at this stage that low porosity concrete indeed offers highly superior resistance to corrosion and the effects of corrosion in concrete for highway bridge decks, and substitution of such concrete for conventional portland cement concrete may turn out to be the least expensive and perhaps most prudent solution to future highway bridge deck construction in areas where deicing salts are necessarily applied each winter.

The possible use of such formulations in repair work for existing bridges remains an open question, but one that perhaps deserves investigation.

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