Bridge Deck Repair Techniques on the New Jersey Turnpike

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• NOWHERE have bridge deck repair problems been more vividly demonstrated, as to both variety and severity, than on the Passaic River Bridge of the New Jersey Turnpike.

Over 1 mi long and six lanes wide, the Passaic River Bridge stands in the Jersey meadows just outside of Newark. The $6\frac{1}{2}$-in. reinforced concrete deck on the bridge was placed during the winter of 1951. Since that time, the bridge has shown a steadily increasing volume of traffic now exceeding 80,000 vehicles per day, 19 percent of them trucks.

In 1957 spalling was noted throughout widely scattered areas on the bridge, although principally in the two outside lanes, which carry the brunt of the heavy truck traffic. This surface spalling increased considerably during the winter of 1957 and 1958 until, in March 1958, a deck slab failure occurred in one of the approach spans. Again, in June, several spans away from the first failure, a second slab broke through. These two failures, coupled with the realization that surface spalling was increasing beyond normal expectations, prompted the Turnpike Authority to undertake a comprehensive program to investigate and rehabilitate the concrete deck. The program may be divided into four broad categories: survey of condition, probable cause, methods of correction, and prevention.

SURVEY OF CONDITION

A continuing series of monthly inspections was begun. These inspections call for a foot-by-foot observation of the entire deck, both top and bottom, each month. Special report forms were prepared to plot the size and location of all cracks, spalls, and patches in every panel of every span in each lane. From these inspections, many data have been accumulated which have helped to evaluate the progressive stages of deterioration.

Generally there are three categories of distress: individual cracks, spalls, and grouped fractures called "checkerboard cracking."

Of the individual cracks, three different kinds may be defined:

1. Underside transverse cracks of random spacing and exhibiting efflorescence. These have been attributed to the effects of deadload deflections while the concrete was being placed. They are normally 3 to 6 ft long.
2. Full depth, full width, cracks probably caused by contraction, deflection, or both.
3. Shallow, top surface cracks in alligator pattern caused by rapid drying.

Spalling first appears as a small pock mark, generally not much larger than one's fist (Fig. 1). Usually, the appearance of a spall corresponds with the appearance of rust on the surface directly over a reinforcing bar. By tapping the area around these spalls with a small chipping hammer, a dull, hollow sound is often noted indicating that there is a much larger ring of unsound concrete surrounding the spall. Over a period of several weeks, and particularly during the winter, these spalls will grow rapidly in area and somewhat in depth until relatively large areas of reinforcement steel are exposed (Fig. 2). It is not uncommon for a spall to grow into a pothole 2 ft in diameter and 2 in. deep in one month's time. Normally, about 200 sq ft of new spalled areas are discovered each month, although twice, during wintertime, new spalls were created at the rate of over 1,200 sq ft per month.

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Figure 1. First stage spalling.

Checkerboard cracking is a phrase used to describe the phenomenon of underside cracks appearing with uniform spacing in both a longitudinal and transverse direction and showing efflorescence (Fig. 3). The passage of surface water through these checkerboard cracks during rain storms verifies that they are fractures through the slab. The spacing pattern conforms to the spacing of the lower mat of reinforcement steel. As many as twenty separate new areas of checkerboard cracking, varying in size from 1 to 60 sq ft, have been observed during one monthly inspection on the Passaic River Bridge. This condition is rarely encountered on other structures. Invariably, checkerboard cracking occurs beneath existing spalled areas or beneath patches made to repair old spalls.

Full slab failures have developed on four separate occasions. These have always occurred directly in the wheelpaths and in areas of checkerboard cracking. They are best described as holes about the size of a desk with chunks of broken concrete wedged between the two mats of reinforcement steel (Fig. 4).

PROBABLE CAUSE

It seems clear that the more serious conditions are merely the final phases in a sequence of progressive deterioration. Although no positive picture can be drawn of this sequence, the following theory seems the most likely.

Fine surface cracks admit water which during the winter months is usually salt water. Then, a combination of freeze-thaw action and the frequency of heavy axle loadings tends to widen and deepen these cracks. Eventually, the water or brine reaches the top reinforcing bars which begin to oxidize. The expansion of the steel during oxidation combined with further freeze-thaw cycles causes the cracked concrete over the bars to pop out, and a new spall is developed. The continued action of heavy traffic on the spalled edge abrades the area and increases the size of the spall. Then, impact loading on the reinforcement steel loosens the bond between the concrete and the reinforcement. The structural integrity of the deck slab has then been seriously weakened. Stress cracks begin to appear on the underside of the deck in a checkerboard pattern caused by the overstressing of the bottom layer of reinforcement steel. The deck is now supported only by the irregular shape of the fractured concrete pieces which are interlocked. Constant vibration and deflection wear the edges of these fractured pieces until one chunk falls through. Then the slab begins to break apart, and the roadway must be closed to traffic.

METHODS OF CORRECTION

After the various conditions had been documented, a three-point repair program was devised:

1. Completely replace all seriously damaged slabs and those that indicated incipient failure.

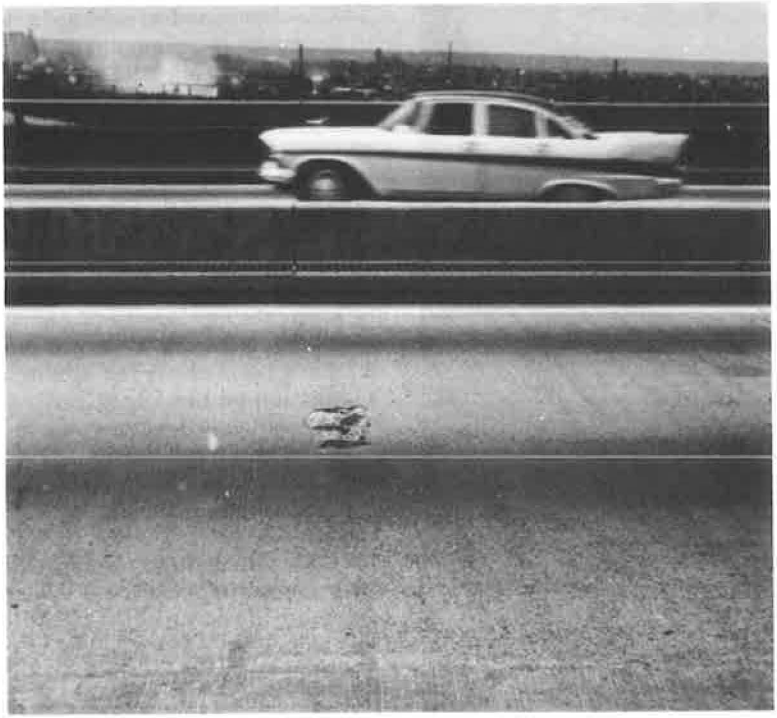

Figure 2. Second stage spalling.

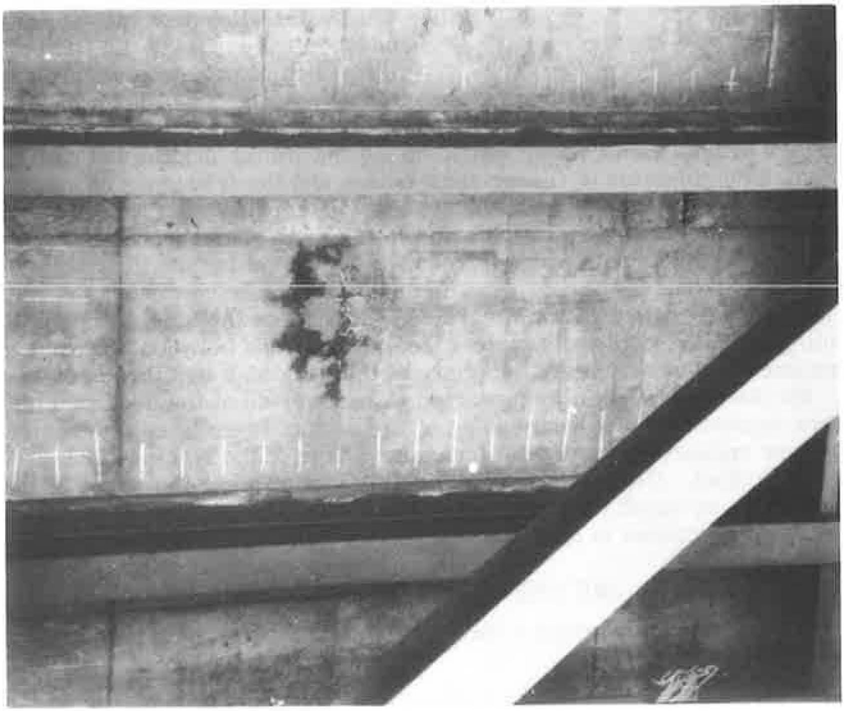

Figure 3. Underside checkerboard cracking.

Figure 4. Slab failure.

2. Experiment with the most promising repair techniques for moderately damaged slabs.
3. Search for methods to reduce future spalling.

Deck Replacement

The criterion used for determining full deck replacement is the existence of underside checkerboard cracking. It is clear both from the history of slab failures and from plain common sense that a large area of fractured concrete beneath a deep pothole will not remain intact for long in a dynamically loaded deck. Therefore, each spring for the past three years all such slabs have been completely removed and replaced while keeping at least two lanes open to traffic in each direction.

The reconstruction procedure begins with a saw cut along the perimeter of the area to be replaced. Then the reinforcing bars are burned off, and the entire slab, including old reinforcement, is demolished and discarded. New forms are then set in the conventional manner except that the deck is increased in thickness to $7\frac{1}{2}$ in. by eliminating the haunch. To insure proper coverage of all reinforcing steel, special carrying bars are welded to studs at each mat elevation along the top of each stringer.

Concrete for the first reconstructed slabs was designed in accordance with the ACI recommendation (1). The design included air-entraining and water-reducing additives. Retarders or accelerators were used according to weather conditions and the requirements for reopening the lanes to traffic.

Figure 5. Nonshrinking concrete being placed over fresh conventional concrete.

On the whole this design proved quite satisfactory. However, after a year's time some of the replaced areas showed evidence of hairline cracks along the longitudinal joint between the new and old concrete. In addition there was a tendency for transverse cracks in adjacent old slabs to project across the new one. To offset this, a special metallic aggregate (Embeco), non-shrinking concrete topping was designed for use in later contracts. This new scheme called for concrete of conventional design to be placed in the lower $5\frac{1}{2}$ in. of the new slab. Then, while the lower portion was still in a plastic state, the top 2 in. was filled with the metallic aggregate concrete and finished in accordance with standard practices (Fig. 5). The specially prepared metallic aggregate used in the concrete mix has the unusual quality of expanding in volume during the setting and curing stages to form a void-filling, shrinkage-compensating system. The resulting concrete is strong, dense, waterproof, and elastic--precisely the characteristics sought for in bridge decks. The new concrete system has shown a remarkable resistance to the projection of cracks, and no defects have been noted to date. So far, about 20 percent of the old concrete deck has been replaced in this manner.

The cost of the two-layer concrete replacements is high, on the order of \$360 per cu yd, including demolition and new reinforcing steel but excluding traffic protection. However, all contracts have been awarded on an accelerated progress schedule and all prices reflect a great deal of overtime payment costs.

Figure 6. Excavated surface ready for nonshrinking concrete topping.

Surface Replacement

In areas where surface spalling has been extensive but where there is no checkerboard cracking, an intermediate technique called topping is often used. This technique requires the excavation of a large surface area, defined as something greater than 20 sq ft, down to a depth of 2 in. (Fig. 6). Great care must be taken in these larger topping areas to avoid damage to the reinforcing steel and to avoid overzealous use of cutting hammers which could break through the base concrete. With prudent care, however, this topping method can be much more economical than the making of many small patches because it requires less saw cutting, allows more productive use of mixing equipment, and permits the use of mechanized finishing equipment.

The concrete mix used in the topping method is the same in all respects as that used in the top 2 in. of the replacement slabs. But, because the nonshrinking topping concrete is being placed on an old concrete surface rather than against fresh, plastic concrete, the remaining old concrete that is exposed after excavation must be scrupulously cleaned and primed with a rich bond coat of metallic aggregate grout, generously applied.

About 20,000 sq ft of this type of topping construction have been used to date. So far only one minor edge failure at the corner of one slab has been noted. This probably resulted from improper compaction during placement.

Although nonshrinking metallic aggregate concrete is expensive, it affords many benefits that commend its use for bridge deck surfaces. The characteristics of high strength, high density, and crack resistance, make it an especially valuable material for repairing troublesome concrete.

Patching

In slabs that are generally sound and where spalls are too widely spaced to use topping, various patching methods have been used. Of the many important requirements in a good concrete patch, the most important of all is the removal of enough of the damaged concrete. Three or four times the area of the original spall must usually be removed.

The second most important requirement is saw-cutting of the patch edges. On the Passaic River Bridge, the rate of failure of feather-edged patches is from five to ten times higher than those made with saw cut edges (Fig. 7).

As for patching materials, a variety of portland cement and epoxy resin products have been used. Of the portland cement products, the nonshrinking metallic aggregate concrete has been, by far, the most successful. After saw-cutting the perimeter and removing all the unsound concrete, the prepared holes are filled with water and left to soak overnight. The following day the holes are de-watered and a rich grout of metallic-aggregate mortar is brushed into the hole as a prime coat. Then a metallic-aggregate concrete with a 1-in. slump, similar to that used in the top of replacement areas, is placed and screeded.

The rate of failure of such patches is

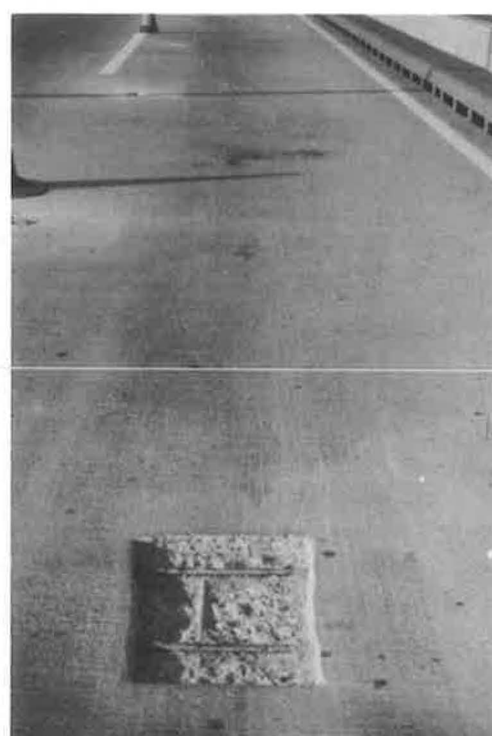

Figure 7. Pothole well prepared for patching.

approximately 3 percent. Nearly all concrete patch failures occur during the first few weeks and are attributed to the effect of live-load deflections acting on the deck and agitating the patch while it is still plastic. Such agitation inhibits the forming of a good bond. However, 4,600 sq ft of such patches remain intact on the deck today—many of them several years old.

Of the epoxy resin products, many various types and brands have been used over the past four years. Essentially, these have all been two-component epoxies with amine curing agents. The two parts are mixed with a coarse silica sand, in volumes varying from 1:1 to 1:5.

At first, experience with epoxy resin patches was rather unhappy, with one notable exception. Epoxy resin patches showed a rate of failure of 50 percent during the first year of traffic. In nearly all cases of such failure, peripheral cracks first appeared around the edge (Fig. 8). The patches then loosened and began to break apart under impact. This failure was caused by the inherent brittleness of many of the epoxy formulations used and by the different coefficients of expansion between epoxy and concrete. The development of peripheral cracks can be reduced by adding a flexibilizer to the epoxy formulation, but most of these flexibilizers tend to increase greatly the curing time and thus cancel one important benefit of using epoxies.

A highly successful exception to this experience is the coal-tar epoxy resin formulation (Guardcoat 140 resinous paving cement) which is a two-component epoxy with bitumen added. This material, when mixed at the ratio of 1:5 with 8-30 mesh silica sand has proved to be sufficiently flexible while maintaining a 2-hr curing time. To date, several hundred of these coal-tar epoxy resin patches have been installed, and so far, not a single failure has been noted. This emphasizes the importance of selecting the proper epoxy system for the job requirements.

As a result of experience, all Turnpike contracts now specify either nonshrinking metallic aggregate concrete, or coal-tar epoxy resin concrete, for all pothole patching. The criterion for selecting one or the other material is simply a matter of the time available. Where lanes can be closed down overnight or where concrete deck replacement is being made elsewhere within a lane, the portland cement material is used because the curing time is of no concern and the cost is slightly lower. But where lanes can be closed for only a few hours, coal-tar epoxy resin patches are used (Fig. 9).

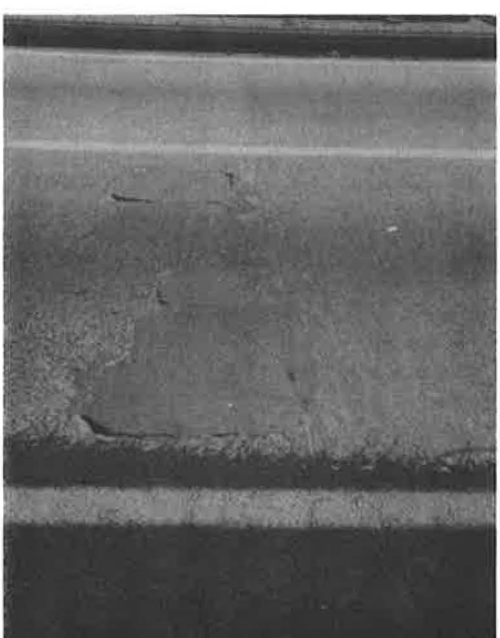

Figure 8. First stage of epoxy patch failure.

The difference in cost was considerable at one time—ranging from $20 to $25 per sq ft for the epoxy resin patches down to $13 per sq ft for the metallic aggregate patches, exclusive of traffic protection. The latest bid prices, however, have been more competitive, showing $8.90 per sq ft for coal-tar epoxy resin patches and $8.50 per sq ft for nonshrinking concrete patches.

Surface Sealing

The final corrective method tried in the repair program was the use of thin waterproofing surface materials. The idea here, of course, was to seal both large and small cracks in an effort to cut off the first link in the chain of deterioration.

Silicone solutions were tried first. These were mixed with mineral spirits to

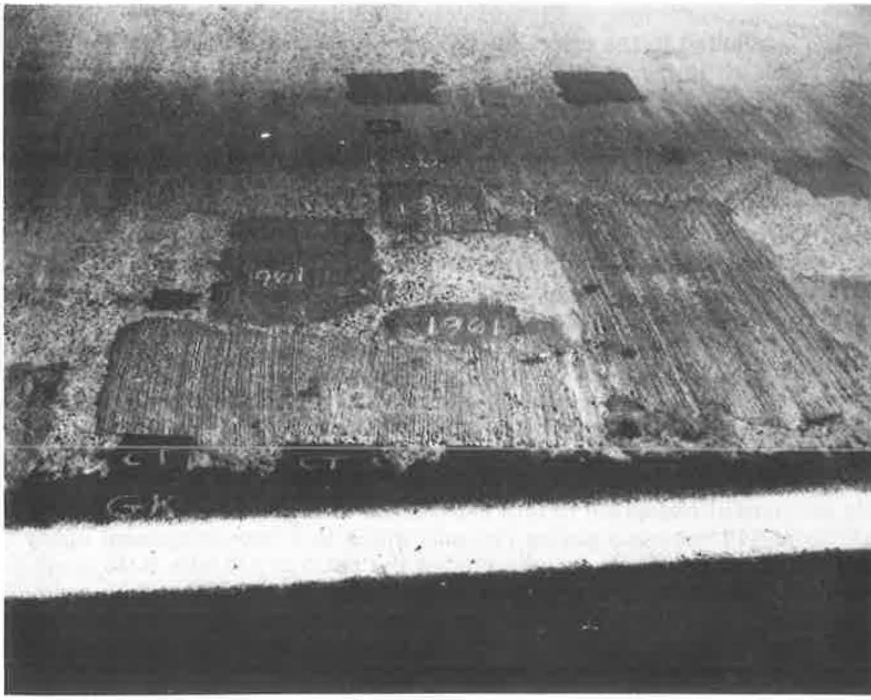

Figure 9. Group of successful patches made from nonshrinking concrete and coal-tar epoxy.

Figure 10. Coal-tar epoxy resin roadway surfacing.

produce a solution containing 2 percent of silicone solids and this mixture was sprayed over the entire deck surface. This type of treatment had no measurable effect on the old concrete and spalling continued during the next two years at about the same rate as before. It is too early to tell what effect this treatment has had on the new replacement concrete.

Two years ago, a coal-tar epoxy resin roadway surfacing material was laid on 3,000 linear feet of one lane. This material was a two-component epoxy resin mixed and applied to a sand-blasted deck surface from a specially designed distributor truck at the rate of 3 lb per sq yd. While the epoxy was still wet, emery grit was sprinkled over the entire area to produce a tough, skid-resistant surface (Fig. 10).

This latter type of treatment has markedly reduced the rate of spalling in the old concrete. To date, an 80 percent reduction has been realized in the rate of new spalled areas created. As a further note, at least one-half the spalls that did occur under the resinous paving cement were confined to one nest in one slab, and that area of the slab soon cracked underneath. This failure was evidence of greatly weakened concrete, and indicated further that, in this one slab, the treatment was too late to expect much benefit. Curiously enough, the epoxy application also reduced substantially the number of old patch failures within the area—an unexpected bonus.

PREVENTION

Based on experiences with the Passaic River Bridge deck, revised standards for the Authority's new bridge deck design have been recommended. At the Lincoln Tunnel Interchange, now under construction, this design is being used. It features an 8-in. reinforced concrete slab constructed in the light of modern concrete technology, a coal-tar epoxy resin waterproofing sealer applied to the slab surface, and a 1½- in. thick asbestos neoprene-asphalt wearing surface. This composite design of a structural concrete slab protected by an efficient sealer and a flexible wearing course is expected to produce a highly serviceable bridge deck that can resist weather attacks and sustain the tremendously increased traffic volumes on the New Jersey Turnpike.

ACKNOWLEDGMENTS

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REFERENCE

1. "Recommended Practice for Selecting Proportions for Concrete." Jour. Amer. Concrete Inst., ACI 613-54.

Discussion

M. SCHUPACK, of Schupack and Zollman, Stamford, Connecticut—The author is to be complimented on reporting the unfavorable as well as favorable remedial measures. It would be most helpful to the profession if more information on unsatisfactory incidences were made known.

Having worked as a designer on the Passaic River Bridge and having been in charge of checking the shop drawings for this bridge, the writer is familiar with the detail and design considerations of this structure. It appears that in all discussions of bridge deck problems, whether bridges of this size or for small bridges made up of stringers only, there is little discussion of the effect of secondary bendings introduced in the deck because of the bending of the deck in conforming to the deformation patterns of the total structure. These deformation patterns are based on the relative stiffness of the component parts of the structure and the types of connections made between various components. In any case it is generally very difficult to avoid some interaction stresses and these stresses should be given consideration in areas where members may be subjected to large stress if they interacted inadvertently. It appears to the writer that consideration should be given, particularly on the Passaic River Bridge, to the participation of the deck and the bending mode of the deck due to various loadings.

The major crossing of the Passaic River, which consists of 275-, 375- and 275-ft continuous spans, unlike the Hackensack River Bridge of the Jersey Turnpike, has details that tended to minimize completely longitudinal interaction of the bridge slab with the structural system. Sliding details are used on most stringers with a free joint every fourth floor beam. This was done to minimize the inadvertent participation

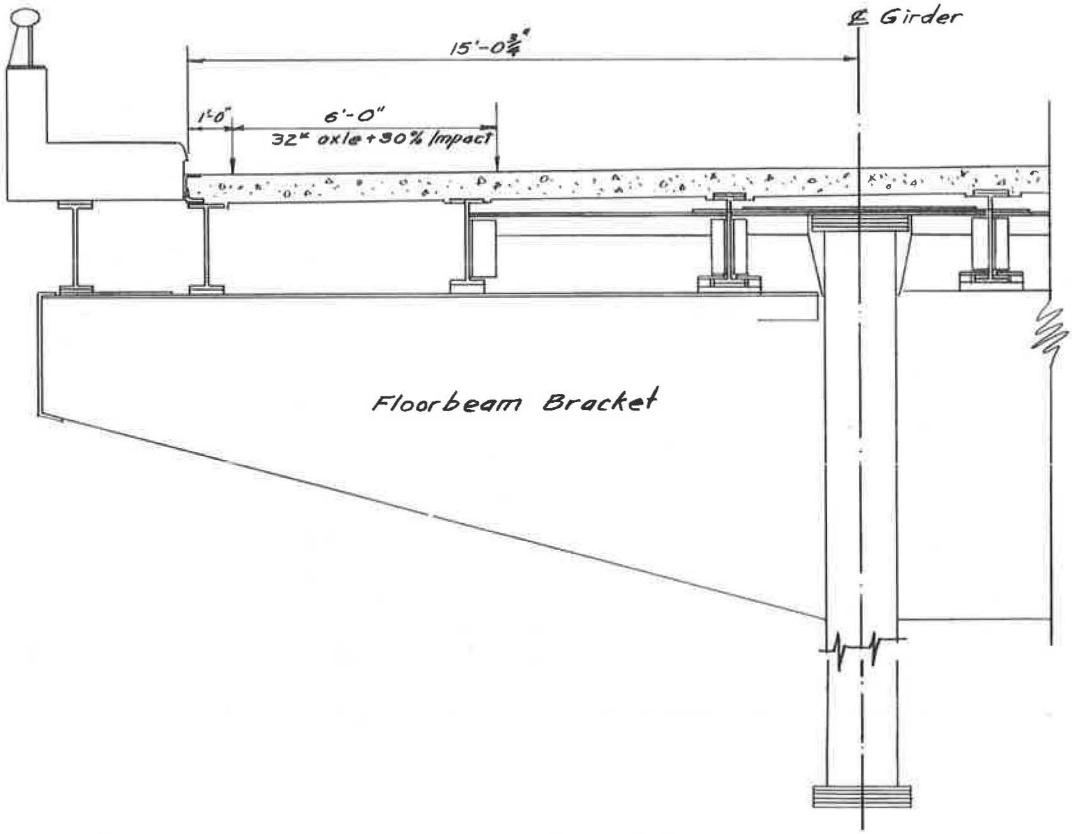

Figure 11. Cantilever bracket detail of floor beam.

stresses introduced into the tension splice of the floor beam to the floor beam bracket.

Figure 11 shows the cantilever bracket detail of the floor beam. The outside lane is fully carried by this cantilever. Because of the high traffic count of heavy trucks that run in the curb lane, it is very likely that the floor beam bracket receives almost the full design load many times a day. This is very unlike most structural elements used in bridge construction. In this condition and because of the details selected, it is not unlikely that the bridge slab tends to act as a partial tension flange for the floor beam. Axial tension stresses in the transverse direction would no doubt be very detrimental to the performance of this slab.

Approximate computations indicate a possible transverse axial tensile stress of about 70 psi in the slab due to a truck load in the curb lane. This stress was obtained assuming that the slab acted as a tension flange and the bottom flange of the bracket as a compression flange. With dual axles and a higher impact than 30 percent, this stress could be higher. Contributing to the problems of concrete placed under rather adverse construction conditions, over finishing, improper placement of reinforcing steel, and inadequate slab thickness, is the matter of the interaction of the slab in both longitudinal and transverse bending. The provision made in the steel details for minimizing the longitudinal interaction may have caused secondary problems not contemplated.

This condition indicates the need to give special consideration to the design of structural elements and assemblies whose predominant load is live load that is frequently applied. This condition is particularly critical where the impact may exceed the maximum of 30 percent usually specified.

ORRIN RILEY, Closure—Mr. Schupack has presented a thorough and interesting analysis of one of the primary factors that may have contributed to the cause of the initial cracking in the Passaic River Bridge deck. Because his discussion is concerned primarily with considerations for preventing recurrence, rather than maintenance and repair, it is beyond the scope of the original paper. Nevertheless, he has made a valuable contribution to the literature of improved bridge deck performance.