Repair of Construction-Related Deterioration in Precast Deck-Panel Bridges

Atiq H. Alvi, Ivan Gualtero, Rajan Sen, and Gray Mullins

Precast, partial-depth deck panels have been used throughout the United States as stay-in-place forms and to provide a portion of deck strength. In Florida, fiberboard material was routinely placed along the edges of the panels to seal the overlay of concrete, rather than embed the panels in grout. This approach did not allow the concrete to flow fully underneath the panel ends and did not provide a reliable, rigid bearing. The seriousness of this seemingly minor change in practice was only fully recognized nearly two decades later, when seven punching shear failures occurred on major highways. This paper reviews eight repair methods employed by the Florida Department of Transportation to maintain 200 deck-panel structures until they could be replaced. The paper highlights the difficulties that were faced in devising repairs when the underlying cause of the damage was not understood fully. Full-depth bay replacement with cast-in-place concrete was the most effective approach but required extended lane closures. Full-depth precast panels could be installed during nighttime lane closures but cost more. The most important lesson learned was that flexible materials, such as asphalt, were best avoided to repair the bridge decks.

Bridge deck deterioration most commonly results from corrosion (*1*). Although corrosion damage is expensive to repair, its cause is well understood, and proven methods, such as cathodic protection, are available to mitigate it (*2*). By contrast, construction-induced problems in which identical bridges in identical environments are exposed to similar loading (e.g., northbound and southbound Interstate bridges over the same crossing) may not necessarily deteriorate in the same manner. Such unpredictable deterioration poses special problems to highway agencies responsible for bridge maintenance and service.

Precast deck-panel bridges have an excellent track record, except in Florida, where they have a long history of premature deterioration. The state was an early adopter of this type of bridge, and once had an inventory of nearly 200 of them, although the number has dwindled as they gradually have been replaced. Research has indicated that poor performance was the result of an unintentional construction error (*3–6*). Fiberboard bearings used to support precast panels were positioned at their ends with no overhang. That arrangement did not leave space for the concrete to flow underneath the panel and provide rigid support when the cast-in-place (CIP) concrete was poured (Figure 1). This error changed the load path for shear with disastrous consequences, which led to seven, localized punching shear failures from 2000 to 2007. Several of the bridges had been in service for more than two decades (Table 1). These failures highlight the enormous difficulties that are faced in repairing and maintaining bridges when the underlying cause of deterioration is unclear or cannot be predicted without destructive bedding evaluation at the panel ends.

This paper assesses eight repair methods used by the Florida Department of Transportation (DOT) to maintain such bridges in service. Background information on precast deck-panel bridges, including their expected structural response, is presented first. Information on the type of cracking that developed under service was retrieved from inspection reports. Particular reference was made to a bridge over an Interstate highway that experienced localized failure in 2000 after 20 years of service. This information provided a platform for a critical review of the repair methods. Additional information may be found in a comprehensive report (*7*) that was updated recently (*8*).

BACKGROUND

Precast deck-panel highway bridges were first constructed in Illinois in the early 1950s. Unlike today's full-depth precast decks, a precast deck panel served as a stay-in-place form for a CIP slab placed on top and in between the panels. As a result, field forming was needed only for the exterior girder overhangs, which resulted in considerable savings in construction time and costs. Bridges of this type were constructed successfully in several other states, most notably in Texas, where more than 1,650 of them exist in the state and county systems (*9*). Most of the bridges have performed well: 833 of them were rated Condition 8, and 20 were rated Condition 9 in the National Bridge Inventory, in which Condition 0 = failure and Condition 9 = excellent (*7*). These ratings are in contrast to Florida's dismal experience with this construction technique.

Deck-panel bridges were first constructed in Florida in the 1970s and by the early 2000s there were approximately 200 such bridges in the state. Of these, 127 are located in Districts 1 and 7. These districts consist of 17 counties, which range from the central to the southern regions of the state. Originally, full-depth CIP decks were planned but, during construction, a change was proposed to use the deck-panel option. In general, the precast panels were 8 × 10 ft in plan and 3.5 to 4 in. thick. They provided

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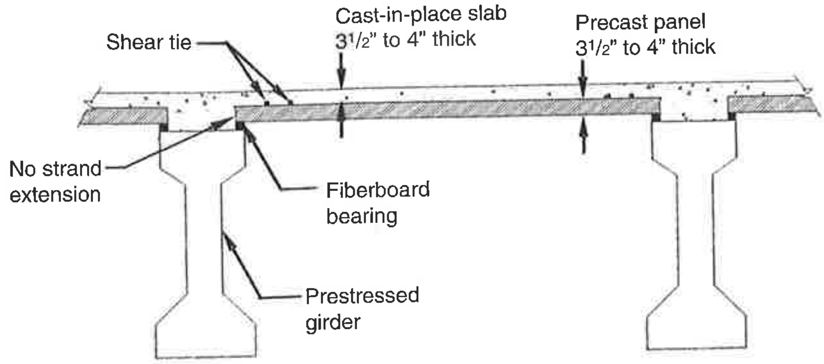


FIGURE 1 Cross section of precast, prestressed panel deck.

support for a 3.5- to 4-in. thick CIP overlay and were intended to act as a composite deck system under live and superimposed dead load (*4, 5*).

REQUIREMENTS FOR COMPOSITE ACTION

Composite action implies that the CIP slab and the prestressed deck panel act in concert to resist the applied loading. This requires development of horizontal shear stresses at the interface of the CIP slab and the precast panel for flexure (*10*). Because the CIP slab is cast monolithically over the prestressed panel, it spans continuously over the prestressed beams. Thus composite action is required to resist both positive and negative moments.

If the surface of the precast panel is roughened, codes allow 80 psi of horizontal shear transfer (*11*). Because the interface is large at the middle of the panel, composite action is automatic; at its ends, composite action necessitates steel from the precast panel to extend into the CIP slab (*7*). Bearing length and height below the panel also must be sufficient so that vertical shear can be transferred to the prestressed girder. In the drawing shown in Figure 1, these conditions are not met; the panel is supported only by the fiberboard material at its end. Moreover, the steel strands from the panel terminated at the end of the panel and did not extend into the CIP concrete.

EXPECTED CRACKING

Under live loading, tension develops perpendicular to the traffic direction. Therefore, cracking can be expected only in the longitudinal traffic direction (transverse to the panel). In the mid-span region, visible longitudinal cracks can occur on the underside of the precast panel if the loads exceeded the cracking moment at the section. Similarly, in the negative moment region, longitudinal cracks

TABLE 1 Localized Deck Failures

Bridge No.	District (Bridge Location)	Year Built (Failure Date)	Condition Rating Before Failure	Rainfall in Week Before Failure, days (in.)	ADT (% truck)	Failure Size (in.)	Location in Panel	Comment
170146	1 (Sarasota, I-75 NB over Bee Ridge Road)	1981 (2/12/2000)	6 (satisfactory)	0	34,000 (30)	18 × 24	Edge or corner?	Failure at asphalt patch with full-depth spall repair
170086	1 (Sarasota, I-75 NB over Clark Road)	1980 (11/27/2000)	7 (good)	2 (0.68)	34,000 (30)	36 × 60	Corner support	Localized full-depth CIP Repair
170085	1 (Sarasota, I-75 SB over Clark Road)	1980 (12/20/2000)	7 (good)	4 (0.2)	34,000 (30)	18 × 18	Corner	Asphalt patch adjacent to M1 repair
100332	7 (Tampa Crosstown Viaduct WB Span 38)	1980 (10/2/2002)	5 (fair)	2 (0.55)	23,000 (8)	48 × 30	Near corner	Asphalt patch
100332	7 (Tampa Crosstown Viaduct WB Span 70)	1980 (9/5/2003)	5 (fair)	3 (1.1)	23,000 (8)	24 × 36	Edge	Failed M1 repair with flexible patch material
100332	7 (Tampa Crosstown Viaduct WB Span 39)	1980 (3/5/2007)	5 (fair)	3 (0.21)	23,000 (8)	18 × 8	Edge	Failed localized patch repair
100436	7 (I-75 over East Broadway Avenue CR 574, and CSX Railroad)	1983 (9/12/2007)	5 (fair)	3 (0.54)	45,000 (30)	24 × 24	Edge	Failed localized patch repair

NOTE: ADT = average daily traffic; NB = northbound; SB = southbound; WB = westbound; CR = county road; M1 = repair involving removal of patched concrete section.

can develop in the CIP slab that spans the prestressed beams. This type of cracking has been reported by highway authorities (e.g., in Iowa and Michigan) (*7*).

OBSERVED CRACKING

Observed cracking in the Florida bridges was at variance with the expected crack pattern. Inspection records, which extended over 20 years, were compiled for all 127 deck-panel bridges in Districts 1 and 7. Figure 2 summarizes defects cataloged in the last five inspection reports for a bridge constructed in 1980 that experienced a localized failure 20 years later (Figure 3). The most recent inspection had been conducted just 6 months before failure (*7*).

Figure 2 shows the following:

- Longitudinal cracks developed along beam lines at the top in 1985 and remained dormant for 11 years. The long interval suggests that fatigue was a factor.
- Transverse cracks were first reported in 1998 at the top of the slab and not at the bottom. Transverse cracks crossed longitudinal cracks, which led to spalling.
- Spalling repairs were noted in the 1998 and 2000 reports.

Longitudinal cracks along beam lines indicate a loss of continuity so that the slab acts as simply as support between the girders. This behavior was confirmed in field tests conducted on the Peace River Bridge near Punta Gorda, Florida (*3, 4*). Simple supports imply higher positive moments and zero negative moments that can be resisted readily by the deck slab. This observation is reflected in the inspection reports (Figure 2) in which no deterioration was recorded for 11 years.

Transverse cracking was sporadic and occurred in the top slab. In part, this cracking was reflective (i.e., cracks occurred at the transverse joints of the panel projected on the CIP slab). This type of cracking leads to spalling, especially when transverse and longitudinal cracks intersect.

FDOT Bridge Inspection Report (Deck)

05/08/00

<u>**Unit: 0 Decks**</u>

ELEMENT/ENV:98/4 Conc Deck on PC Pane 1309 sq.m. ELEM CATEGORY: Deck/Slabs

CONDITION STATE (5)	DESCRIPTION	QUANTITY	RECOMMENDED FEASIBLE ACTION
2	Repaired areas and/or spalls/delaminations and/or cracks exist in the deck surface or underside. The combined distressed area is 2 % or less of the deck area.	1309	0 Do Nothing

ELEMENT INSPECTION NOTES:

Minor longitudinal and transverse cracks are present on the deck top. Moderate abrasive wear is present throughout. <u>There is a .1m x .1m x 10mm spall with no exposed reinforcing steel at the south end of an asphalt patch at the center of the west lane, 3 m from the Abutment 5 joint. Minor cracks and spalls are present in and on the edges of random patch areas.</u> Minor longitudinal and transverse cracks are present on random deck panels and in random repair areas.

05/04/98

G1.01 DECK (TOP)

The deck top exhibits Class 1 to Class 2 longitudinal and transverse cracks throughout. The longitudinal cracks appear to run over or adjacent to the beams. Repairs made to the deck top in Span 1 exhibit Class 1 to Class 5 cracks and Class 1 spalls along the edges of the repairs. The deck exhibits moderate abrasive wear throughout. <u>There is a deck repair 8m x 1.2 m at Abutment 5.</u>

06/19/96

G1.01 DECK (TOP)/SURFACING

The deck top contains longitudinal class 1 cracks that run along the beams and occasional class 1 cracks at the panel joint. These cracks are due primarily to the deck panel type construction. <u>These cracks have shown no significant change since May 1985.</u>

08/24/94

G1.01 DECK (TOP)/SURFACING

The deck top contains class 1 cracks that run longitudinal along the beams and occasional class 1 cracks at the panel joint. These cracks are due primarily to the deck panel type construction. These cracks were first noted in the May 1985 report and appear to show no change.

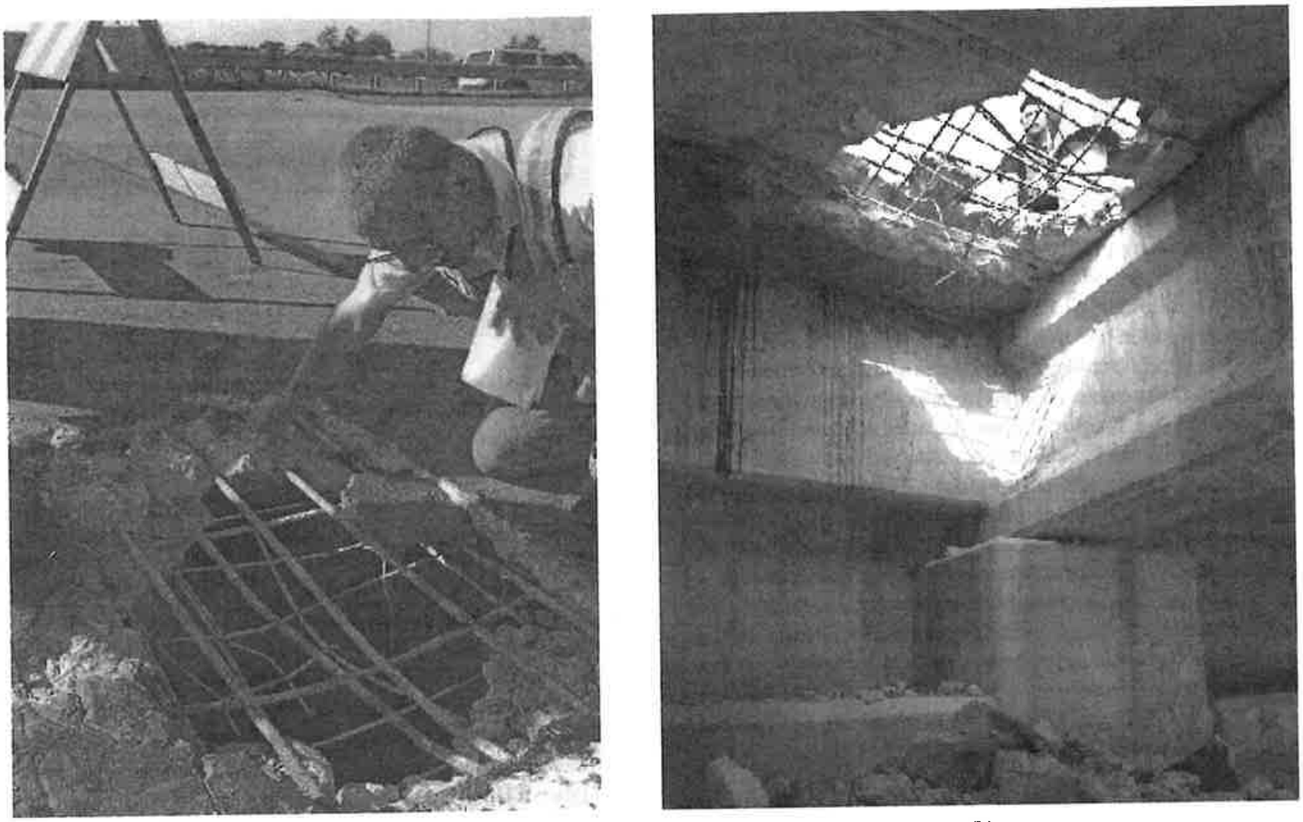
01/04/93

<u>Deck Component</u>

1.01 Deck (Top)

There are Class 1 and 2 cracks that run longitudinally along the beams, with an occasional Class 1 transverse crack at the panel joints. These cracks are due primarily to the deck panel type construction. These cracks were first noted in the report dated 5/85 and appear to show no change.

FIGURE 2 Excerpt from inspection report, Bridge No. 170086, deck assessment.



(a) (b)

FIGURE 3 Failed panel on Bridge No. 170086: (*a*) View 1 and (*b*) View 2. (Source: *Sarasota Herald*.)

SHEAR CRACKING

Shear in beams and slabs is associated with diagonal tension. If a diagonal tension crack extended through the CIP slab to the surface, it would appear as a crack that was parallel to the original longitudinal crack. In the case of shear failure, a second parallel crack would emanate, in addition to the longitudinal cracking first observed (Figure 4).

Shear capacity of the compromised section was exceeded when lane markings coincided with the longitudinal panel joints in the traffic lane that carried the heaviest load (i.e., right lane). With this configuration, wheel loads from trucks needed to be transferred to the prestressed girder through the fiberboard. Code-based calculations indicated that the punching shear capacity in this case was lower than the maximum wheel load, which resulted in localized failure (*7*). In these calculations, the capacity of the CIP concrete was disregarded because of the spalling.

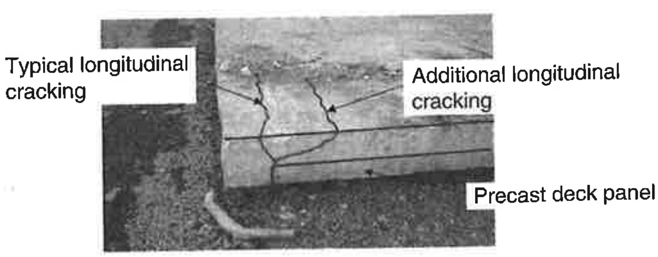


FIGURE 4 Additional longitudinal cracking from shear.

BRIDGE DECK REPAIR METHODS

The Florida DOT allocated $78 million in 2001 to replace the existing precast deck-panel systems on I-75 in Districts 1 and 7 with full-depth CIP concrete decks. Presently, the decks of 51 bridges have been replaced. Most of the funding was consumed in District 1. Because it was difficult to acquire additional funding on account of the sluggish economy, the remaining deck-panel bridges will have to be repaired and rehabilitated, rather than replaced as originally planned.

Repair Types

Eight repair methods have been used by the Florida DOT. Because the underlying effect of the construction error was initially unknown, repairs were undertaken on the basis of individual judgment. The following repairs, employed historically, were reviewed:

- Crack repair,
- Maintenance spall patching,
- Localized spall repair,
- Grout packing,
- M1 repair,
- Full-span M1 repair with grout packing,
- M2 repair, and
- Full-depth bay replacement.

After a better understanding was gained from a prioritization study (*7*), the District 1 and 7 Structures Maintenance Office adopted a policy that only full-depth bay replacement addressed the construction error and thus was the only repair considered permanent.

Crack Repair

Most longitudinal and transverse cracking occurred in the top slab. The cause was determined from finite element modeling (*7*) to be creep-induced by prestressing forces in the precast panel and differential shrinkage between the CIP concrete and the deck precast panel. Once longitudinal cracking begins, sporadic transverse cracks can develop in the deck.

Methods to repair cracks are well known and described in the literature (*12*). Cracks can be repaired by epoxy injections or sealants. Crack injection is a structural repair intended to restore the structural strength of the deck. Sealants penetrate and cover the cracks to avoid the entry of water and other impurities into the deck (*13*). If a crack is active, (i.e., it opens and closes under loading), epoxy crack injection should not be used, because it does not have the flexibility of a sealant. Initially, sealants were used in the early stages of deck-panel deterioration. After the fundamental construction error was identified, however, cracks were no longer sealed, nor were sealants used on any of the seven failed decks (Table 1).

Maintenance Spall Patching

After a second, parallel crack occurs (Figure 4), the concrete trapped between the two cracks, which already is internally cracked, starts to crumble; a spall develops and is repaired by patching. The Florida DOT classifies deck patching on the basis of the depth of the repair (*14*). The most common and simplest repair method is maintenance spall patching, which is used to repair spalls in the CIP portion of a deck. When a deficiency such as a spall appeared on the bridge deck, it was common practice for Florida DOT maintenance crews to patch the spall with flexible, "cold patch," asphaltic concrete.

To patch with asphaltic concrete is not labor-intensive and can be done in a matter of minutes with minimal disruption to the traveling public. It is also an inexpensive procedure. The maintenance crew closes a lane temporarily, if necessary; cleans debris out of the spall with hand tools; and patches the spall with a ready-mix bag. The asphalt patch is intended to minimize immediate danger to the motoring public as well as to avoid an increase in the size and intensity of the spall (Figure 5).

This repair method was never meant to be a permanent solution. The maintenance crew was to return within a week and perform a permanent repair in accordance with the policy of the District Structures Maintenance Office. Sometimes, however, other priorities meant that these temporary patches remained in place for extended periods of time. This practice proved to be detrimental, especially in cases in which asphalt was used to patch spalls inside or adjacent to a deficient repair. Rather than distributing the load evenly, the flexible asphalt, which had negligible compressive strength, would pound the precast panel below the surrounding CIP section, which resulted in an increase in the area and depth of the spalls and in the cracks of the precast panel (*15*).

In the worst cases, the pounding punched a hole through the lower deck panel. Six of the seven punching failures (Table 1) occurred after rainfall. Water filled the crevices between the panel and patch material in which subsequent wheel loading caused pumping action between the asphalt and the precast panel until failure (*15*). Four stand-alone asphalt patches and two asphalt patches had been used to address deficiencies within existing CIP repairs.

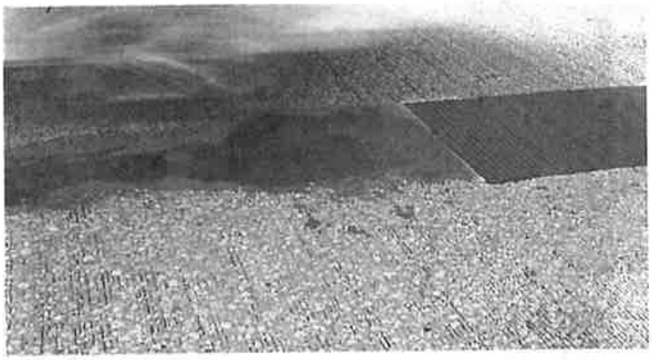


FIGURE 5 Spalls patched with asphalt and walking spalls.

Localized Spall Repair

Unlike the maintenance spall patch, localized spall repair technically is considered permanent. This repair method is the immediate follow-up to the previously described repair. It is performed with a concrete repair material. Like patching, localized spall repair is not labor-intensive and can be done at a relatively low cost. If high-strength, fast-setting material is used, this repair can be performed during nighttime lane closure to reduce the impact on traffic.

The Florida DOT has had limited success with the longevity of localized spall repairs. Because of the lack of composite action, new spalls can appear after some time in the areas adjacent to the repaired spall. After a spall is created, the residual shear capacity of that region is almost zero, even after it is patched. Therefore, the shear that was to be supported by that region has to be redistributed to sections adjacent to the spall. This creates additional stresses in that region and accelerates its deterioration, which generates new spalls, referred to as "walking spalls." In general, these too were treated with flexible repair material (Figure 5). Better understanding of the underlying causes of spalls, however, has led to a change in the use of localized spall repairs. Once considered permanent, now they are used only as a temporary measure. One of the seven failures reported in Table 1 occurred at an area in which localized spall repair had been done.

Grout Packing

Most deck-panel bridges in Florida were built with fiberboard bearing material to support the precast deck panels on the girders. With this method of construction, no positive (rigid) bearing is provided at the ends of the precast panel. As a result of the effects of creep and shrinkage, initial separation and longitudinal cracks are inherent in precast deck-panel construction. However, the few bridges in Florida that used positive bearing have performed much better and consequently have had longer service lives. The most important conclusion drawn from the forensic study (*7*) was that the lack of positive panel bearing was clearly the main factor responsible for the occurrence of major deck deterioration, such as cracking, delamination, spalling, failing repairs, and, in the worst case, localized punch-through deck failures.

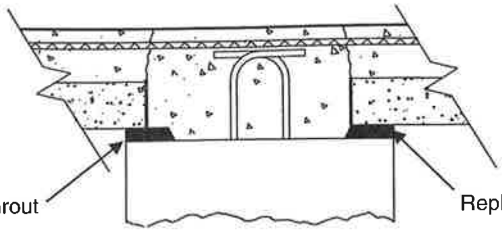


FIGURE 6 Bearing detail after grout packing repair.

Grout packing is a form of repair in which the fiberboard bearing material is replaced with nonshrink Portland cement grout or epoxy grout to provide positive bearing (Figure 6). Grout packing is more cost-effective than other, more involved repair methods and causes little to no disruption to traffic because the work can be performed with a bucket truck or scissor lift from beneath the bridge.

None of the failures reported in Table 1 had grout-packing repairs performed on them. This method was developed to address the initial construction error. To be effective, however, however, grout packing must be applied to a bridge before spalls and failing repairs cause it to deteriorate. In 2000, the Florida DOT performed grout-packing repairs on six bridges on I-75 in the Tampa area. Eleven years later, those bridges still performed satisfactorily (*16*).

M1 Repair

After several patches and repatches, an M1 repair generally is performed in the affected area. The M1 (and M2) were the Florida DOT's recommended methods of repair in the 1980s (*4*). In an M1 repair, all the patched, spalled, and unsound concrete section is removed and replaced by repair material (Figure 7). Unlike localized repairs, the depth of M1 goes to the top of the precast panel. Although M1 repairs hold up better than localized repairs, the edges eventually separate, and walking spalls continue in front of the repaired area because the bridge deck system does not act compositely.

Although this repair method was implemented to address the construction error, it did not work as anticipated. Two of the seven failures described in Table 1 were associated with M1 repairs. On Bridge No. 170085, a walking spall was patched with asphalt adjacent to an M1 repair, and on Bridge No. 100332, Span 70, asphalt was used to patch a deficiency within an existing M1 repair.

Full-Span M1 Repair with Grout Packing

This somewhat modified M1 repair also was used to repair longitudinal spalling along the edge of a beam. The difference is that the CIP concrete portion on top of the precast beams is fully removed, and additional steel is added to the area on top of the beams. The fiberboard bearing material is replaced with nonshrink Portland cement grout or epoxy to provide positive bearing. This repair is extended longitudinally throughout the length of the span.

This procedure is labor-intensive, costly, and disruptive to traffic. However, with the exception of full-depth bay replacement, full-span M1 repair is the next most effective repair method, because it fills the spalled area under the wheel lines with sound, incompressible material and provides positive bearing for the deck panels. Nevertheless, even these repairs can lead to deficiencies, such as longitudinal cracks within or adjacent to them. None of the failures reported in Table 1 was associated with M1 or grout packing as a method of repair.

M2 Repair

The M2 repair method, which was developed specifically for precast deck-panel deficiencies, was not encountered in any of the inspections. M2 repair (Figure 8) is used to fix cracks and spalls along transverse joints of the precast panel. The unsound material is removed approximately 6 in. on each side of the transverse joint,

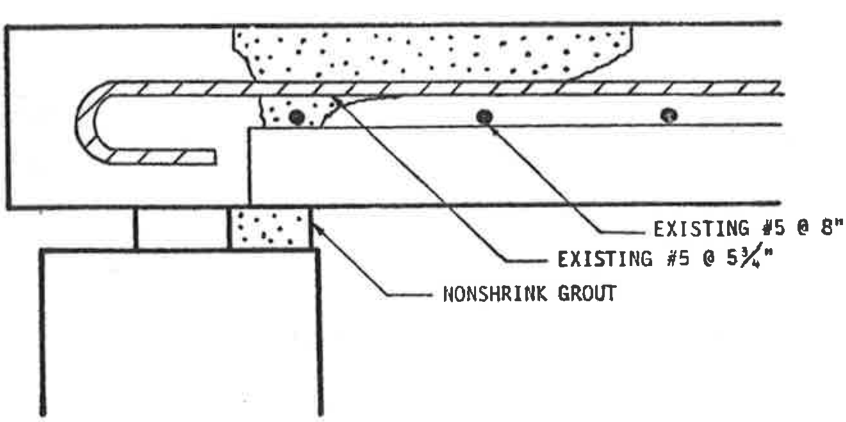


FIGURE 7 M1 with grout packing repair detail (*4*).

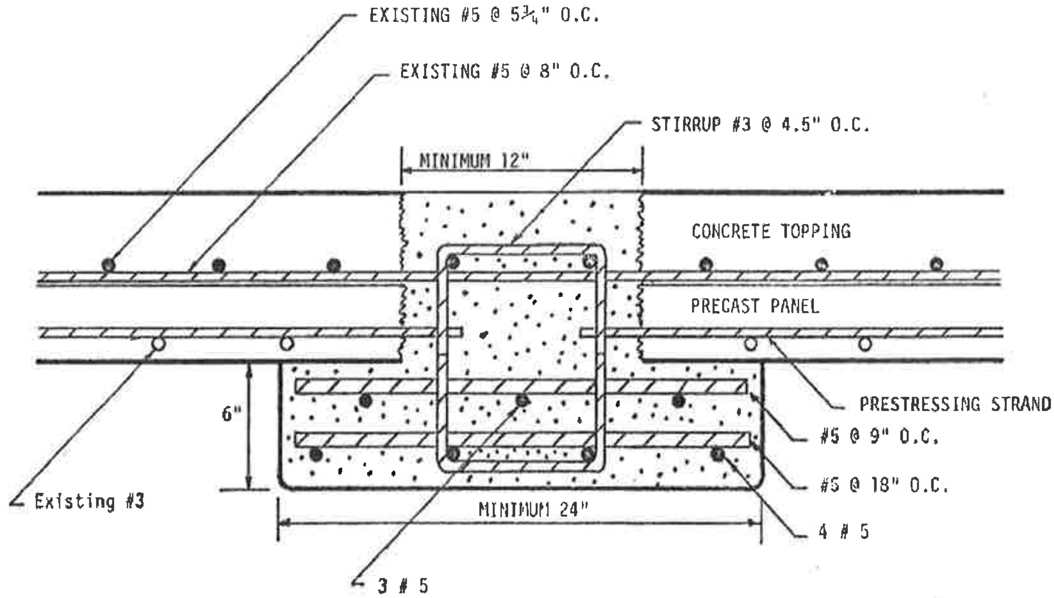


FIGURE 8 M2 repair (*4*).

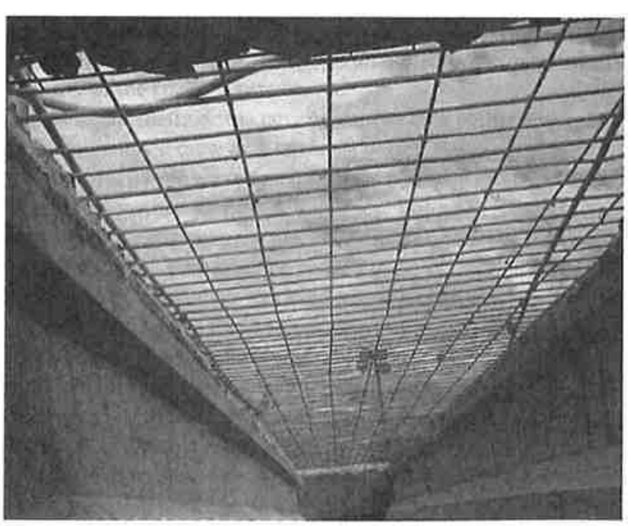
and an inverted T-beam is formed with the bottom of the precast panel that sits on the flange of the inverted T-beam. The flange of the T-beam is required to be at least 24 in. wide. The inverted T-beam is provided a positive bearing on the girders (*4*). M2 repairs are more costly than other repair methods and have an adverse impact on traffic flow.

Full-Depth Bay Replacement

Full-depth bay replacement is the most effective repair method for deficient precast deck-panel bridges (Figure 9). As stated previously, it is the directive of the District Structures Maintenance Office to use this method for all permanent repairs. At a minimum, the repair is done in a bay (the transverse distance between two beams) and throughout the length of the span.

When only one bay is replaced, the CIP concrete and precast panel are demolished, which leaves only the reinforcing steel grid originally within the CIP section for continuity. A new bottom steel mat is designed (Figure 9) and placed as an alternate to the precast panel. A standard compression test is performed to verify that the concrete has gained the required strength before the bridge or repaired area is opened to traffic. None of the failures reported in Table 1 occurred on decks that had been repaired by full-depth bay replacement.

Table 2 provides an overview of the eight repair methods discussed, and highlights their advantages, disadvantages, and effectiveness.



(a)

(b)

FIGURE 9 Full-depth bay replacement repair: (*a*) existing and (*b*) new steel.

TABLE 2 Excerpts from Inspection Report, Bridge No. 170086, Description of Repair Types, Characteristics, and Effectiveness

Repair Type	Favorable Characteristics	Unfavorable Characteristics	Effectiveness of Repair
Crack repair	Helps keep out debris and impurities that may accelerate deterioration.	Does not impede the deterioration process or help structurally.	Not effective
Maintenance spall patching (asphalt)	Easy to place without much disruption to traffic. Very inexpensive repair.	Only for temporary use. If left longer than a week, could be detriment rather than a benefit to the bridge.	Not effective
Localized spall repair	Provides a repair with compressive strength in comparison to maintenance patching with asphalt.	The nature of the deck panel system not acting compositely, the localized repairs start to separate at the edges. New spalls described as "walking spalls."	Not effective
Grout packing	Good to slow down deterioration process. Provides positive bearing and extends bridge life. No traffic impact.	Does not mitigate deficiencies that were present before grout packing.	Good to slow down deterioration
M1 repair	Repair replaces deteriorated CIP component by extending to top of precast panel.	Can separate from panel, start to separate at the edges, and new walking spalls start to appear. Process is moderately labor intensive and impacts traffic.	Better than spall repair but not very effective
Full-span M1 repair with grout packing	Repair fixes transverse cracking and spalling along precast panels. It has worked well in other parts of the state.	Process is labor-intensive and affects traffic.	Effective
M2 repair	Lasts longer than any other type aside from full-depth bay replacement.	No bridges with this repair were encountered in study.	na
Full-depth bay replacement	Addresses the root cause of problem: elimination of vertical and longitudinal separation between precast deck panel and CIP surfaces.	Costly, labor-intensive, and causes significant impact to traveling public.	Very effective

NOTE: na = not applicable.

Full-depth bay replacements are problematic if average daily traffic on an Interstate is high, which it was on the I-75 Bridge No. 100436, across East Broadway Avenue and the CSX Railroad. The last recorded failure is shown in Table 1. Traffic analysis and lane closure calculations indicated that I-75 in this area could tolerate lane closures at night only. Therefore, the bridge was temporarily repaired and shored in September 2007, and a repair project was programmed to start construction in late 2009.

The District Structures Maintenance Office hired a firm to develop a pilot project to replace the deficient bays on Bridge No. 100435 and its twin bridge on I-75, Bridge No. 100436, without daytime lane closure (*17*). An innovative method of full-depth bay replacement was devised (*18*) on the basis on the successful findings of a similar system used in other states (*19*). The deteriorated deck was removed and replaced in 30-ft long sections with full-depth, precast concrete panels at night only (Figure 10). Near-surface-mounted bars of reinforced carbon polymer fiber were installed to transfer shear into the existing deck.

Construction took place during the fall of 2009 and was the first time that this method was applied in Florida. The method was unique, in that it transferred forces between the full-depth, precast panels longitudinally, rather than transversely, with the near-surface-mounted bars of reinforced carbon polymer fiber (*19*). The project was successfully completed in spring 2010.

(a) (b)

FIGURE 10 Full-depth panel: (*a*) removal of existing deteriorated deck and (*b*) new installation.

SUMMARY AND CONCLUSIONS

Deterioration of bridge decks caused by the use of compressible bearing material under precast deck panels is difficult to predict. With respect to the exact position of the fiberboard material, little to no positive (rigid) bearing may be present. Its use changes the load path for shear, which causes delamination and loss of composite action between the precast panel and the CIP overlay. This problem tended to manifest itself when lane markings coincided with the longitudinal panel joints (girder line) in the most heavily loaded traffic lane (i.e., right lane) (*7*), although not always. Unfortunately, initial attempts to repair the decks tackled the symptoms, rather than the underlying cause, and were unsatisfactory, which the seven, localized shear failures revealed (Table 1).

A review of eight repair methods employed over two decades indicated that most were unsuitable. Grout packing was a good method, because it provided a rigid shear support for the panels. However, it needed to be done early. Both M1 and M2 repairs with grout packing were acceptable repair procedures. Eventually, however, their effectiveness weakened because of the separation between the precast panel and the CIP section as the result of long-term creep and shrinkage effects (*7*).

Full-depth bay replacement with CIP concrete was the most effective repair method, because it addressed the initial construction error and thereby provided positive bearing and eliminated the vertical and longitudinal interface between the precast deck panel and CIP concrete surfaces. However, the method was difficult to apply to highways with high average daily traffic because of the extended lane closures required to allow concrete to cure. In such conditions, the use of full-depth, precast, modular deck replacement is recommended. A summary is provided in Table 2 of the relative advantages, disadvantages, and effectiveness of the repair methods.

The most important finding of the study was that asphalt patching can actually exacerbate rather than mitigate the deterioration problem. Six of the seven punching shear failures were associated with asphalt patching intended as a temporary repair. Given this history, the use of asphalt (or similar material) should be prohibited, even to patch spalls temporarily in precast deck-panel bridges.

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