Special Report

Precast Bridge Deck Design Systems

by

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The use of precast concrete for new bridge construction and for the rehabilitation of deteriorated bridges is economically and structurally amenable to today's systems engineering concepts.[1,2,3] Precast elements can be used for pedestrian, highway and railway bridges. They can be adapted to all types of structures having short, medium and long spans.

Precast products can be used for some or most of the components of a bridge's superstructure and/or substructure. Durability, ease and speed of construction together with reduced need for maintenance are all advantages in using precast concrete.

Depending on the span length and type of application, a precast element can be prestressed or nonprestressed. The largest precast elements used in bridges are prestressed box girder segments. Precast prestressed segmental construction started in Europe in 1948 as an efficient and economical means of replacing the bridges destroyed during World War II.

Segmental construction with its many ramifications was introduced to North America in the early seventies and during the last decade the technology gained from the numerous applications of the method has grown enormously. Spans ranging from 150 to 800 ft (46 to 244 m) can be efficiently built using segmental construction. When combined with a cable-stay system, the economical span can extend to at least 1300 ft (396 m).

The evolution of prestressed segmental bridge construction throughout the world is well documented.[4-12] This wide application has also motivated research and development. Results of some of the tests and a review of specific design problems have recently been reported.[13,14]

The AASHTO-PCI standard I girder sections are some of the largest precast elements used in bridge construction. Spans up to 150 ft (46 m) can be readily designed using these sections. Their introduction in the fifties sparked efforts to standardize design.

Based on these early sections, several states have developed their own standards. Subsequent modifications to these standards continue to be devel-

This report describes applications of full depth, precast concrete panels for the rehabilitation of deteriorated bridge decks and the construction of new bridges. Emphasis is placed on systems of construction and the economy derived in using precast concrete for bridge construction.
The report presents design systems, details of joints and joint material used for a number of highway and railway bridges. The advantages and a few of the difficulties involved in this construction method are discussed including some pertinent research work.

oped.[7,15] The current availability of high strength concrete provides further incentive for modifications. In some cases, these standard sections can be stretched to accommodate special long span applications.[16]

Precast I girders are used in conjunction with cast-in-place deck, stay-in-place metal forms, or stay-in-place precast concrete deck panels. Concrete stay-in-place deck panels are a significant precast element in bridge superstructures. Concrete deck panels can also be used with steel girders or stringers. In this capacity they are used for both new bridge construction and bridge deck rehabilitation.

The introduction of deck panels followed extensive research both in the laboratory and in the field. The current AASHTO Bridge Specifications cover the analysis, design and fabrication of deck panels.[17] The results from research and successful applications of deck panels are well documented. [18-24]

Integrally constructed girder and deck components are another type of important precast prestressed concrete element for bridge construction. Typical sections are shown in Fig. 1. These sections are suited for short span highway bridges because of their low cost and rapid erection.[25-28]

Solid and voided slabs can be used for spans of 35 and 50 ft (11 and 15 m), respectively.

Channel or multiple stemmed sections with cast-in-place decks can be used to span up to about 70 ft (21 m).

Single-stemmed sections and box beams can be used to span up to about 120 ft (37 m). The box beams may be used either as adjacent units or spaced apart.

Bulb tees, which incorporate features of the AASHTO-PCI I girders and single-stemmed sections can be designed to span up to about 180 ft (59 m).

The integral sections, especially the single and double box beam and the double-stemmed sections are particularly suitable for railway applications. These sections have been used to replace old timber trestles with speed and economy.

Full span, stay-in-place deck forms are another element with growing applications in bridge construction. Research results of laboratory tests on such systems are given in Ref. 29.

A need to rehabilitate the nation's infrastructure system is now widely recognized. An enormous number of bridges are either functionally obsolete or structurally deficient. The deck portion of a bridge superstructure is particularly vulnerable to deterioration. Traffic, weather, and chemicals used for ice control[30] all work to destroy a bridge.

Extensive deck deterioration is common in many bridges over 25 years old. Even in many newer structures deck deterioration is becoming increasingly evident.

Local patching and overlaying can be used as short-term repair methods during the early phases of deterioration. Eventually, total replacement of the deck is required. This is illustrated in Fig. 2.

Cast-in-place concrete deck is often used as a replacement deck. This method of construction, however, is very slow and labor intensive. Inclement weather and other on-site problems make quality control of concrete and other operations difficult. The ensuing result can be either a substandard repair job or a delay in completing the project.

A combined precast panel subdeck and cast-in-place top deck has become increasingly common today. The materials and methods used in this type of construction are similar to those of con-

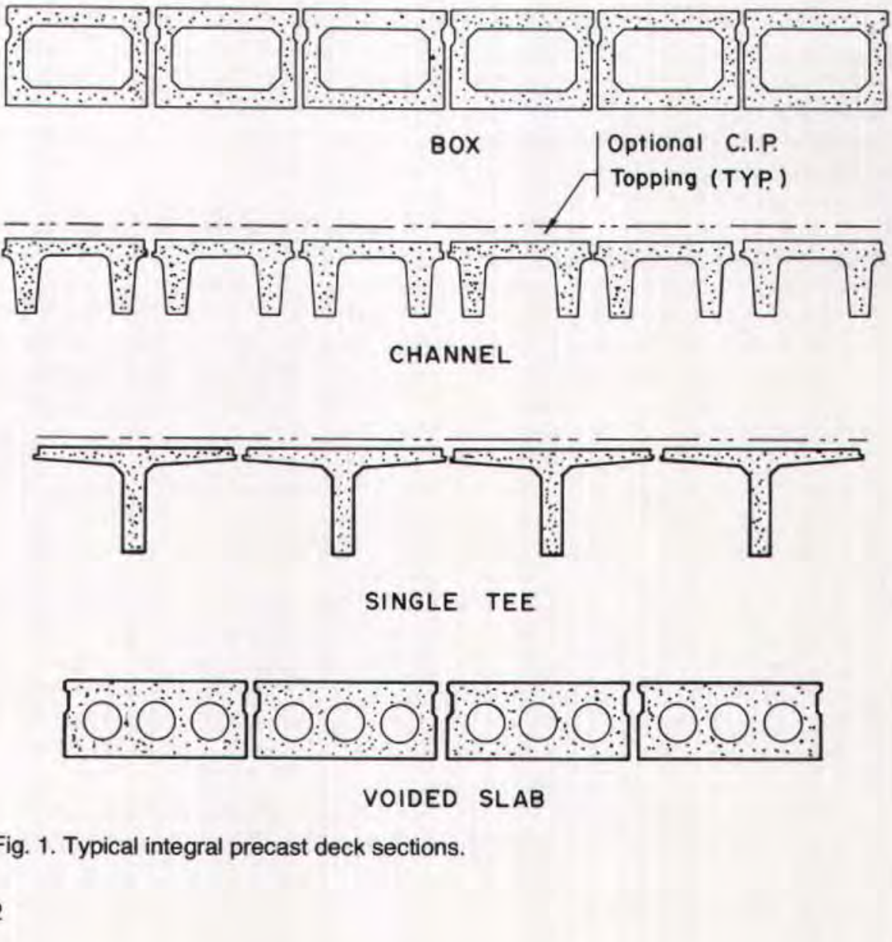


Fig. 1. Typical integral precast deck sections.

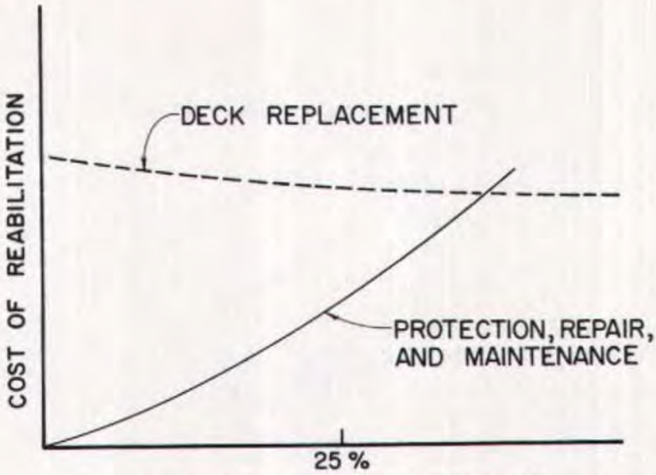


Fig. 2. Economics of bridge deck repair and rehabilitation.

ventional concrete construction (see Fig. 3) except that the cost of formwork is eliminated.

NEED FOR PRECAST CONCRETE

With urban expansion, traffic density on and around most bridges has increased dramatically. One very important criterion in selecting a deck rehabilitation system is that it must minimize interference with local traffic. Rapid construction using modular full depth, precast deck elements is particularly suitable in meeting such a requirement. Fig. 4 schematically illustrates a method where old cast-in-place deck is segmentally removed and replaced by full depth deck elements.

For short span structures, integral

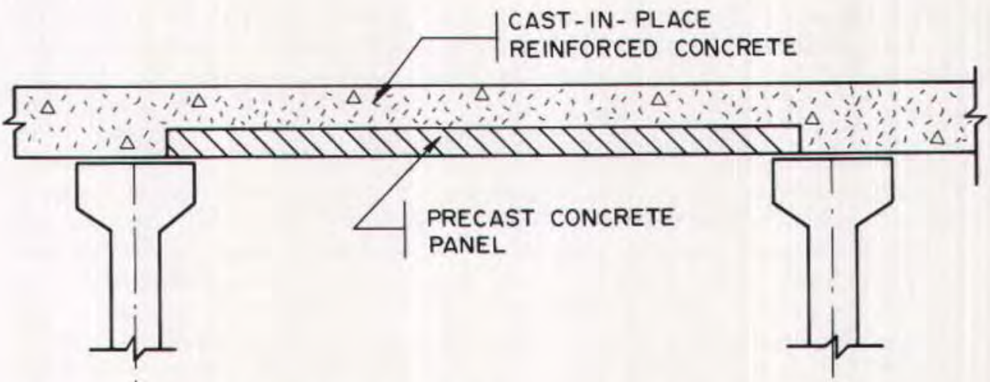


Fig. 3. Partial depth precast panel subdeck.

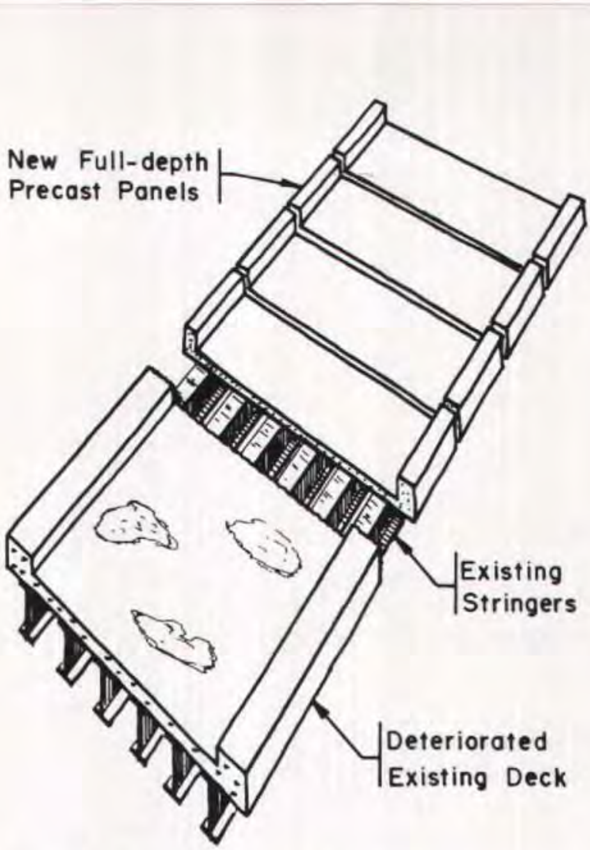


Fig. 4. Full depth precast panel application.

deck systems can be economically used to replace both deck and stringers simultaneously. For bridges where the deck supporting structure, i.e., the stringers or girders, are in good condition, only the deck portion may need to be replaced by precast elements.

Precast elements can provide an additional advantage of greater durability over cast-in-place concrete. Better quality control of material in a precast plant can result in higher strength concrete. One important point to remember is that precast concrete becomes increasingly economical with repetitive elements. However, certain special constraints related to the use of precast concrete should be recognized. The example below illustrates such a case.

Fig. 5 shows the plan, elevation and cross section of a bridge which is not level and square. The roadway is on both a vertical and horizontal curve. The spans have superelevation and skew. The old stringers may have partial length riveted cover plates. When a precast system is chosen, special fabrication and construction procedures should be followed to ensure that the precast elements achieve proper fit.

When an existing structure is composite, the replacement structure must also be composite. Even when an existing structure is not composite, because of greater load carrying capacity requirements and larger roadway width requirements of many rehabilitation projects, the replacement structures are often required to be composite.

Fig. 6 shows the basic load transfer requirements for a composite structure using precast elements. Figs. 6(a) and

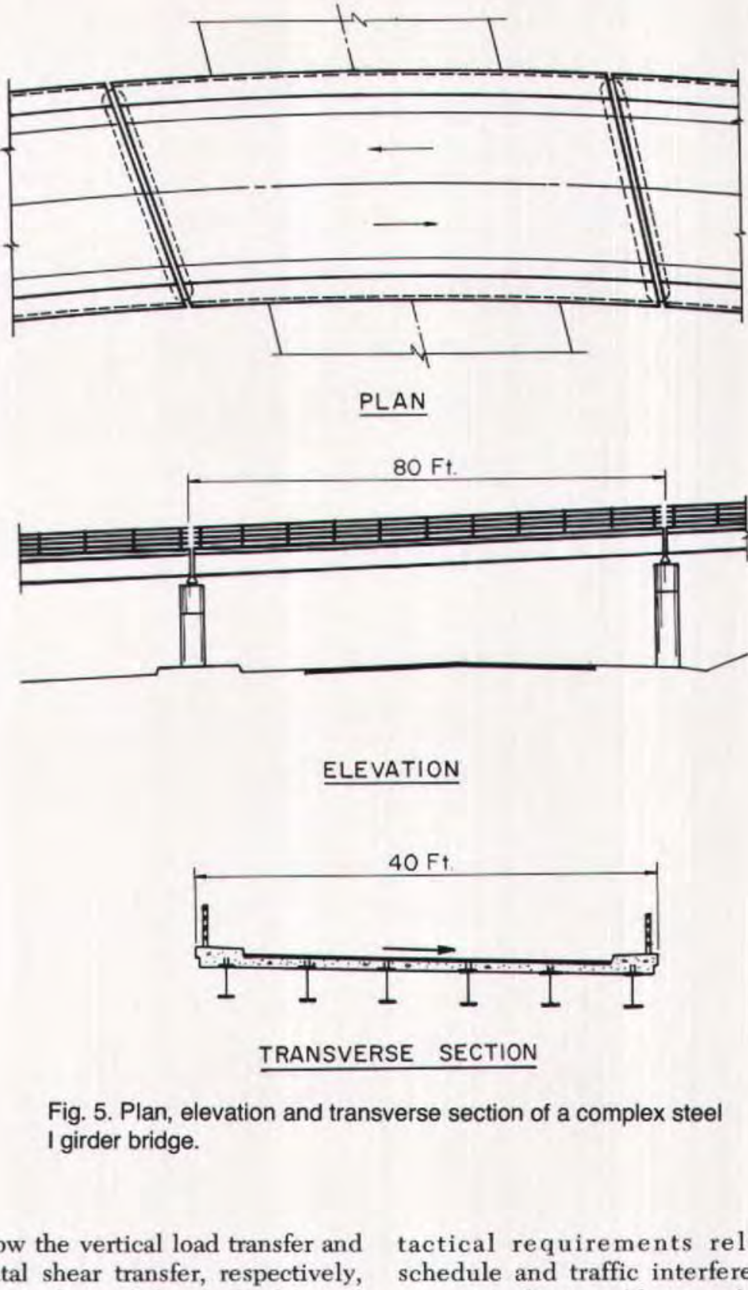


Fig. 5. Plan, elevation and transverse section of a complex steel I girder bridge.

6(b) show the vertical load transfer and horizontal shear transfer, respectively, at the interface of the deck slab and stringer. Figs. 6(c) and 6(d) show the horizontal in-plane forces and vertical shear transfer at the interface of adjacent deck slab panels.

A proper design must adequately address the following three criteria: (1) tactical requirements related to schedule and traffic interference, (2) geometric fitup problems and (3) load transfer, strength and serviceability requirements. The design, of course, must also meet the project's overall economic constraints.

In modular construction, the performance of joints is especially critical

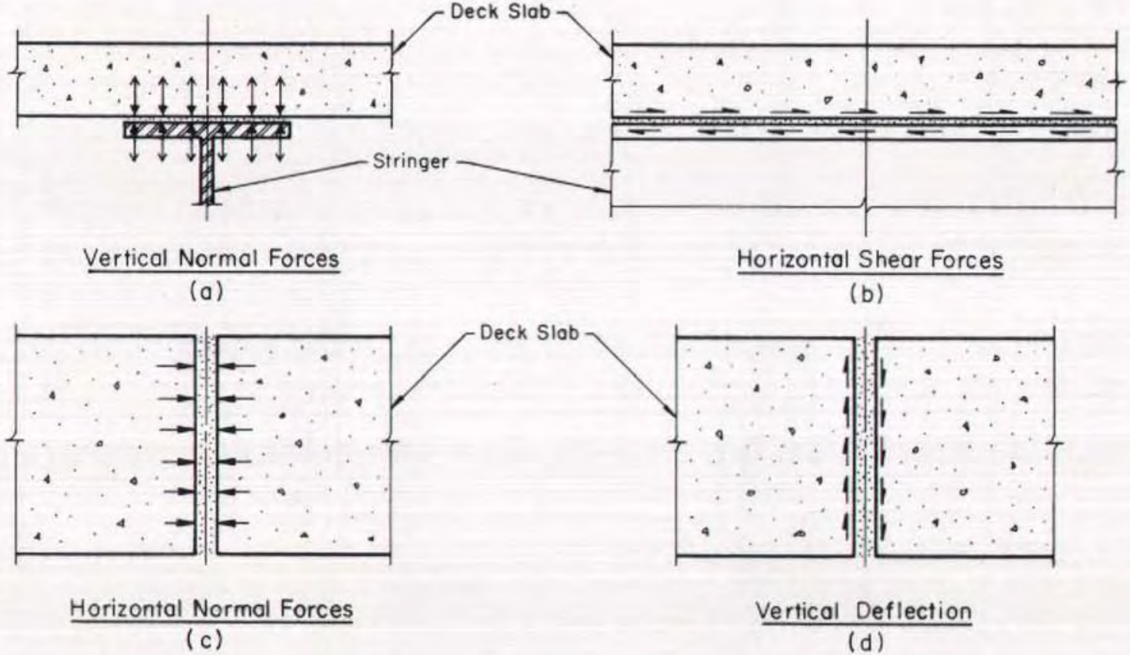


Fig. 6. Load transfer mechanisms of composite deck.

for the integrity of a structural system. The geometric configuration of a joint, in addition to the selection of an appropriate interface material contribute to the proper short-term and long-term performance of the structure.

With these criteria and requirements in mind, this report examines the details of structural systems, precast elements, joint configurations and joint materials for full depth, precast concrete panel decks and a number of bridge rehabilitation projects.

APPLICATIONS PRIOR TO 1973

Several bridge decks were constructed using full depth, precast panels prior to 1973.[31] The construction of the two-lane **Pintala Creek Bridge** in Montgomery County, Alabama, is one of the earliest examples of full depth precast concrete panels used for bridge deck construction. This bridge is composed of four 34 ft (10 m) long spans.

Full depth and full width precast panels 6½ in. (165 mm) thick, 7 ft (2 m) long and 26 ft (8 m) wide, complete with curbs, were placed uniformly over the stringers. A 1 ft 6 in. (0.46 m) space was left between adjacent panels. The inter-panel space was filled with cast-in-place concrete (see Fig. 7).

When the **Kosciuszko Bridge**, Brooklyn-Queens Expressway, New York, was under reconstruction in 1971, full depth, full width precast panels were used to build a temporary trestle to detour the expressway traffic which included heavy trucks. The details of this construction are shown in Fig. 8. The combined curb and railings used in this project were also precast modules, bolted to the deck slab.

Based on research performed at Purdue University,[32] in 1970 the Indiana State Highway Commission sponsored two projects in order to utilize full depth precast panels. One involved new construction and the other a rehabilitation job. Superior quality control and the resulting excellent durability of precast concrete were the primary motivations for these projects.[33]

The newly constructed structure was the **Big Blue River Bridge** over Indiana State Road 140 near Knightstown. The 200 ft (61 m) long structure had steel I beam girders at 6 ft (1.8 m) on centers, continuous over three spans, 70, 60, and 70 ft (21, 18 and 21 m) long, respectively. Full width panels were typically 4 ft (1.2 m) long and 39 ft (12 m) wide. Panels were transversely pretensioned and the deck was nominally post-tensioned in the longitudinal direction.

A similar method was used to replace the deteriorated decks of the then 30-year-old **Bean Blossom Creek Bridge** on Indiana State Road 37, near Bloomington. The existing structure was an eight-panel through type Pony truss, each about 125 ft (38 m) long. In both structures, no overlay was used, and the top of the precast slabs served as the riding surface. The structures were instrumented and their performance was monitored. Scholer recently reported their performance to be quite satisfactory.[33]

Applications of full depth precast panels in bridge deck construction prior to 1973 can be summarized as follows. The deck-stringer systems were primarily noncomposite, although incidental development of composite action was reported. The spans did not have any skew or superelevation. More projects involved new construction rather than rehabilitation. Fewer geometric fitup problems were experienced with new constructions than with replacement decks. The method was used for both permanent and temporary construction. Those structures in general have performed very well. Minor problems were mainly due to the partial failure of joints, especially at slab-to-slab interfaces.

Two structures merit separate mention. These are: (1) the Hannover

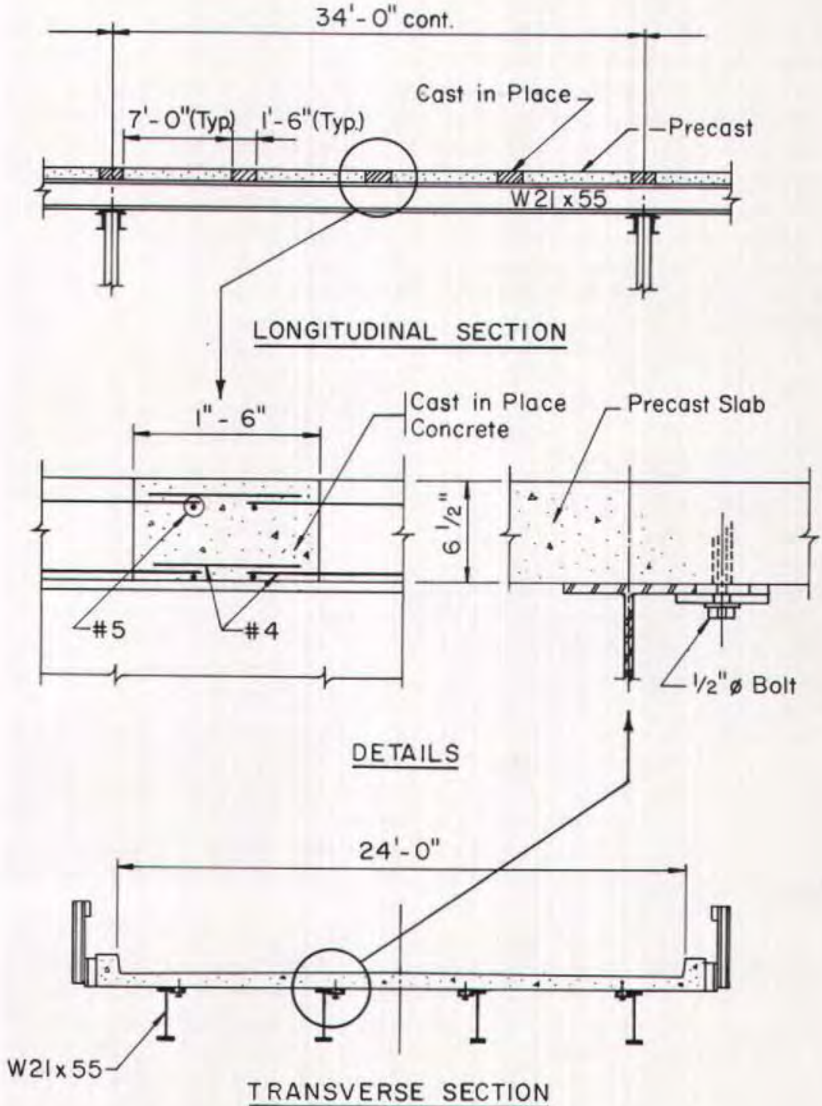


Fig. 7. Pintala Creek Bridge, Montgomery County Commission, Alabama.

Curved Viaduct Ramp (Fig. 9); and (2) the Emil-Schulz Bridge (Fig. 10). These were major spans, both built in Germany, using precast decks on steel box girders. They were both composite. Epoxy mortar was used as the joint material along with high strength bolts as shear connectors.[34]

The designs used and the experience gained in the applications prior to 1973 provided the knowledge base for future developments.

1973 AND AFTER

Significant advances have been made since 1973 with the construction of major bridges, some over 1000 ft (305 m)

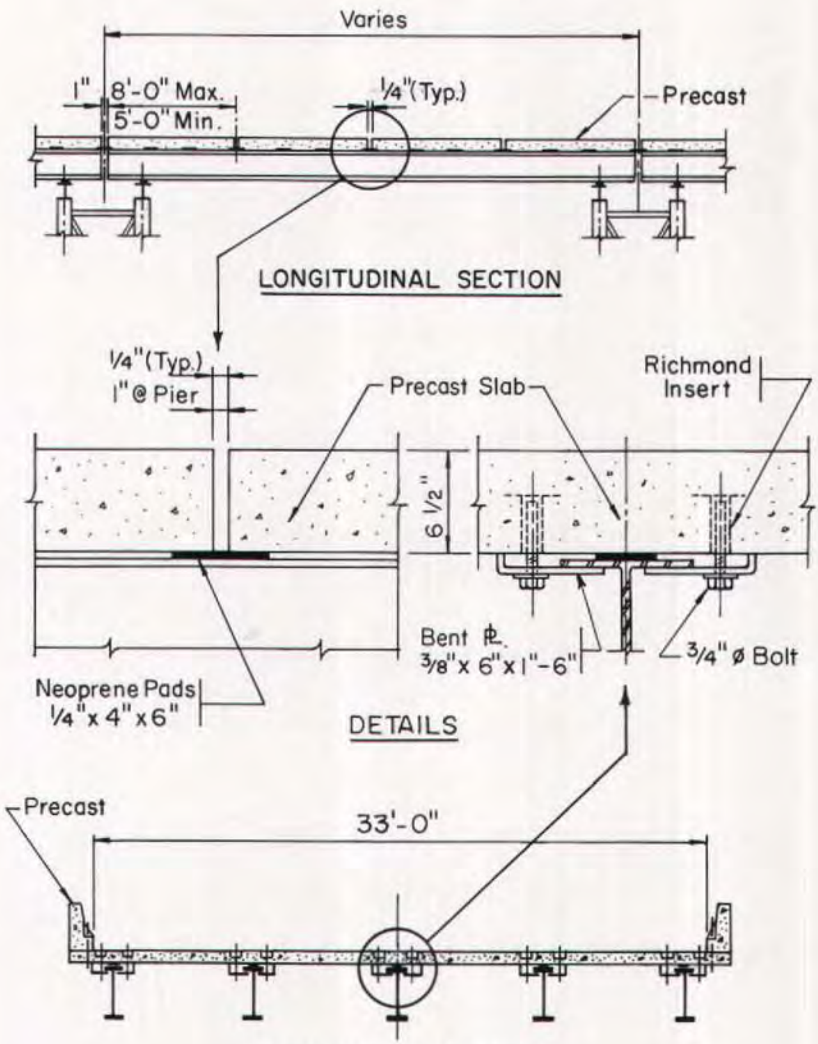


Fig. 8. Kosciuszko Bridge, Brooklyn-Queens Expressway, New York.

long. Many of the spans are composite while some are continuous. A few of the designs involved complex geometries.

The details of the interfaces are the key to precast slab stringer design. Specifically, there are three locations of interface: (1) the bedding plane at the slab to stringer; (2) the shear connector pocket area; and (3) the slab-to-slab joint. The major emphasis of this report is in addressing these interface details of bridges completed since 1973.

The details used in a bridge design depend mainly on the respective transportation agency and the consulting engineer involved. Such details reflect their standard practice, previous experience and design philosophy. The following information is presented in a

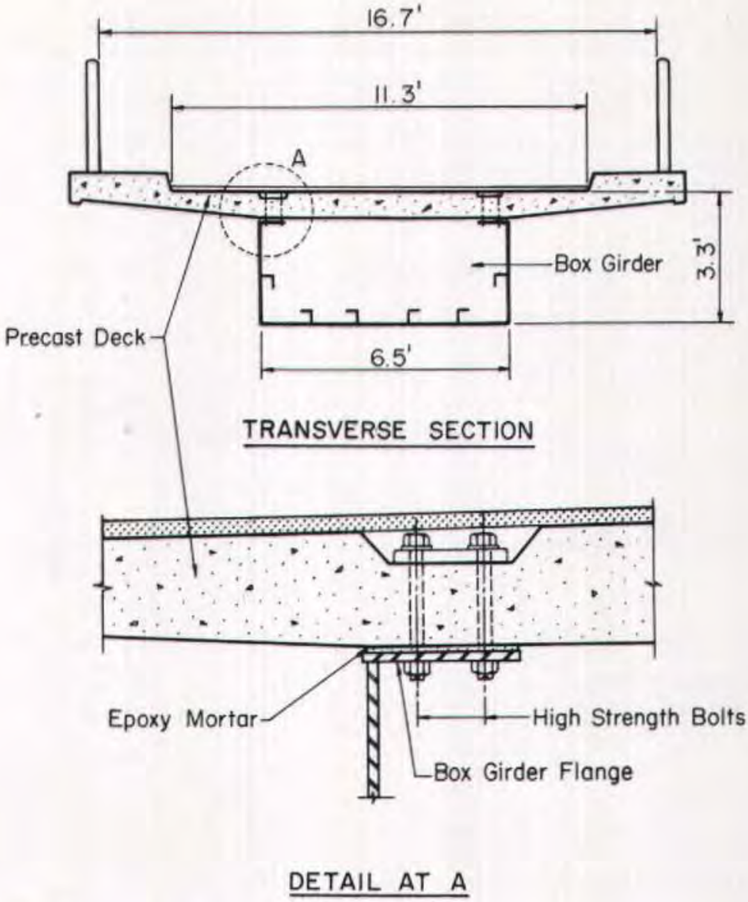


Fig. 9. Hannover Viaduct, Germany.

fairly chronological order, grouped under the headings of specific transportation agenices.

New York State Thruway Authority (NYSTA)

In 1973, NYSTA initiated a research and development program which included construction of a prototype bridge at the Harriman Interchange. This structure has all the complex attributes of the bridge shown in Fig. 5.

With this concept in mind, a feasibility study was undertaken of the bridge with emphasis on design details and construction procedures related to the slab-on-steel stringer system.[31,35,36] To-date, three bridges have been renovated using these methods.

Some of the features common to all three bridges are as follows: The bridges have a composite deck system carrying HS20-44 type loading. Replacement precast deck panels were conventionally reinforced. Low modulus 100 percent solids epoxy mixed with bag sand was used as mortar. Typically, one part epoxy to two parts sand provided a flowable mix for use at the panel joints. Proportions of 1:2.5 gave a trowellable mix which was placed at the

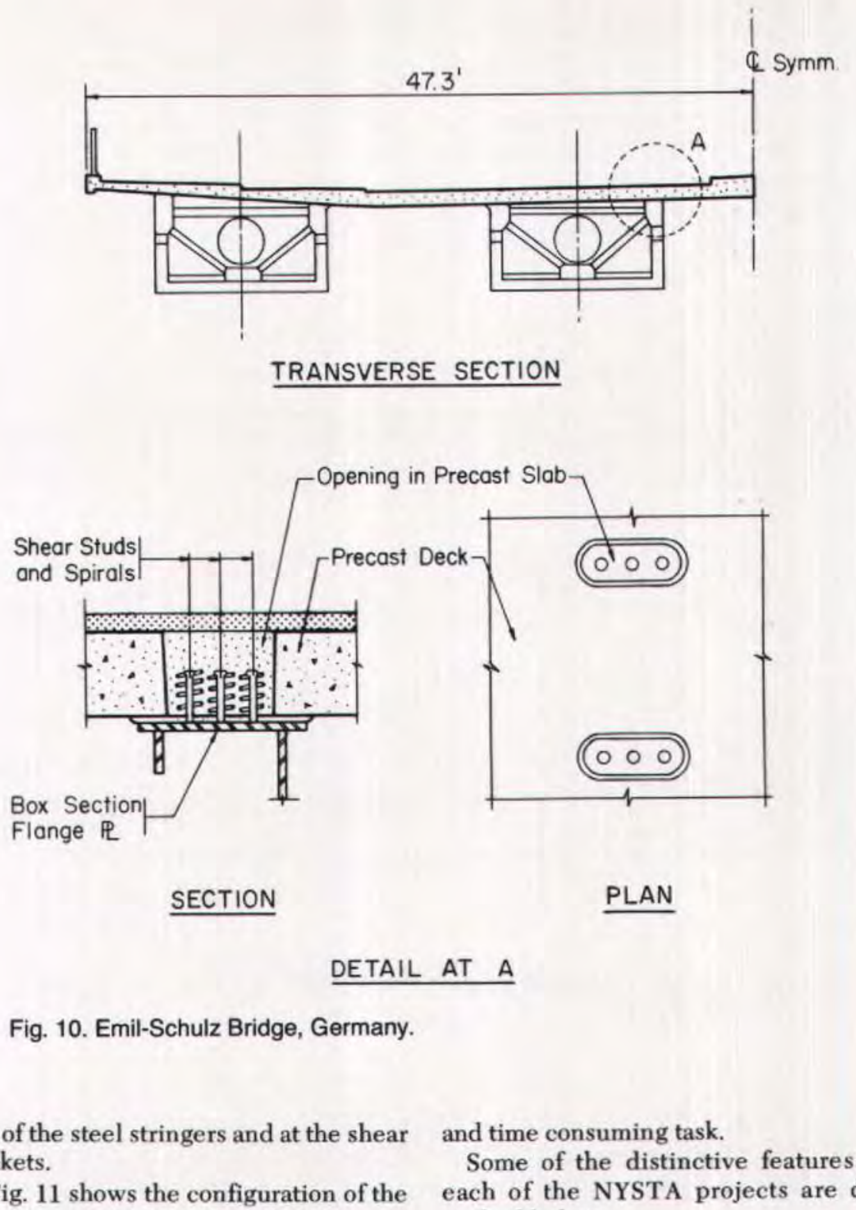


Fig. 10. Emil-Schulz Bridge, Germany.

top of the steel stringers and at the shear pockets.

Fig. 11 shows the configuration of the panel-to-panel joints. An oblong funnel was needed to place flowable epoxy mortar in the joint. The use of adhesive tape at the bottom opening of the joint was not effective in containing the epoxy mortar. The opening subsequently had to be blocked by additional formwork. Existing composite deck and spiral shear connectors had to be removed which proved to be a laborious and time consuming task.

Some of the distinctive features of each of the NYSTA projects are described below:

Amsterdam Interchange Bridge (1973)—Fig. 12 shows a view of the two-lane bridge consisting of four simple spans: 33, 59, 66 and 60 ft (10, 18, 20 and 18 m) long, respectively. This bridge was designed to carry about 2000 AADT over the mainline Thruway. The deteriorated deck of one-half of the 66 ft (20.1 m) span was replaced by using precast panels on an experimental basis.

Fabrication of the precast panels and all other construction work was done entirely by the NYSTA maintenance department personnel. No contract was let to any outside agency.

A staged construction sequence was used to maintain at least one lane of traffic open although very brief interruptions of traffic were allowed during the actual placement of each precast element.

The overall width of the deck is 45 ft (13.7 m). Full depth panels measured 8

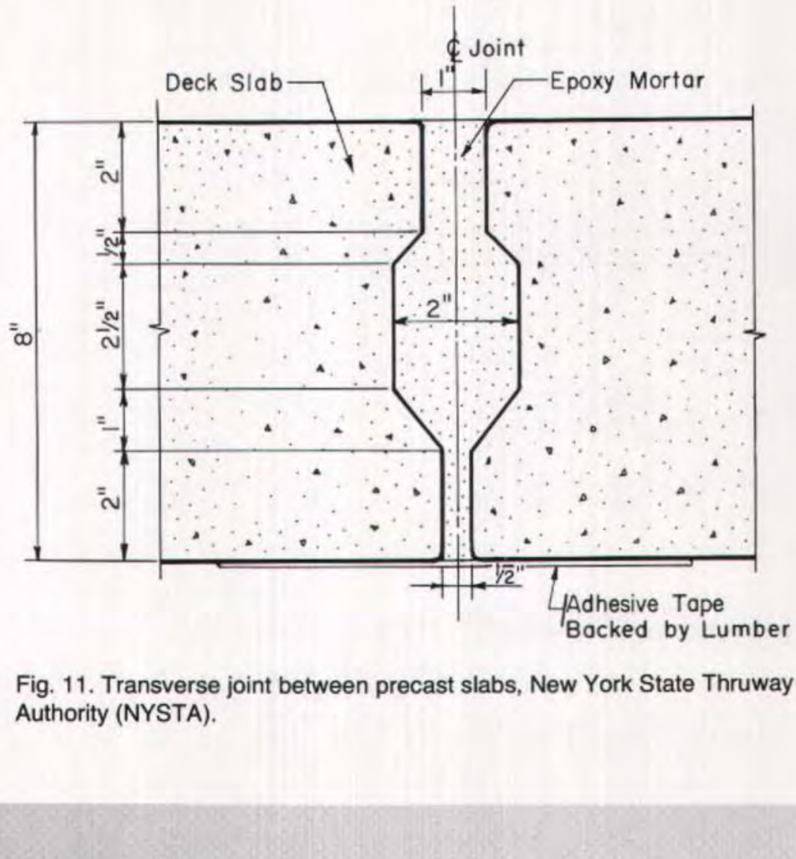


Fig. 11. Transverse joint between precast slabs, New York State Thruway Authority (NYSTA).

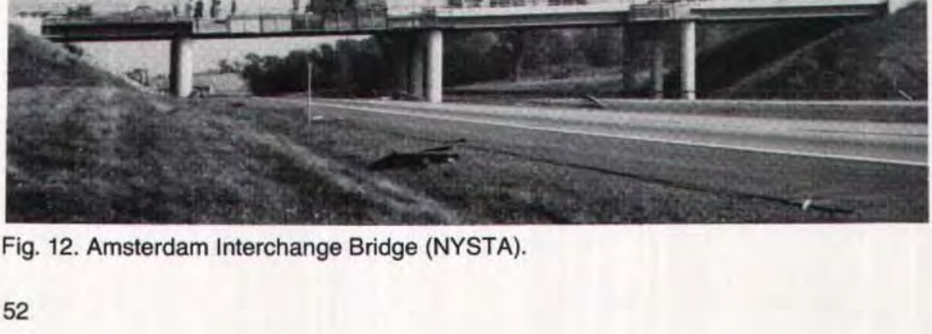


Fig. 12. Amsterdam Interchange Bridge (NYSTA).

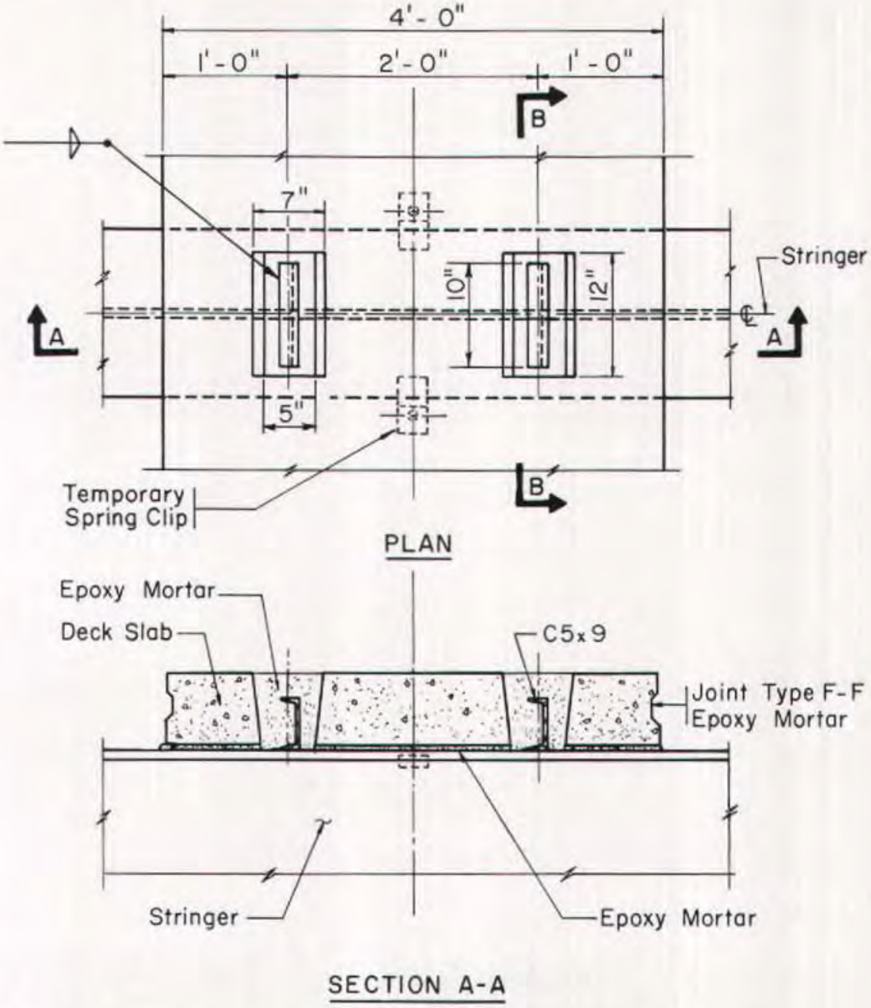


Fig. 13. Plan and section of welded channel shear connection (NYSTA).

in. (203 mm) x 4 x 22 ft (1.2 x 6.7 m). They were designed to cover one-half the width of the bridge.

Cast-in-place concrete was used down the centerline of the bridge which has a 6 ft (1.8 m) wide flush median mall. Figs. 13 and 14 show the details of the bedding area and the shear pockets. Fig. 15 shows the casting of epoxy mortar in the shear pockets. Field welded standard channel sections were used as shear connectors. These were installed by department personnel without difficulty.

A "dry" system detail using long high strength bolts was also used on a few panels on the same span. Field application of torque for these large high strength bolts was difficult. Plan and section diagrams of these bolted connections are shown in Figs. 16 and 17. The gap between the bottom of the precast slab and the top of the stringer required shims. Achievement of full tension in the bolts could not be fully

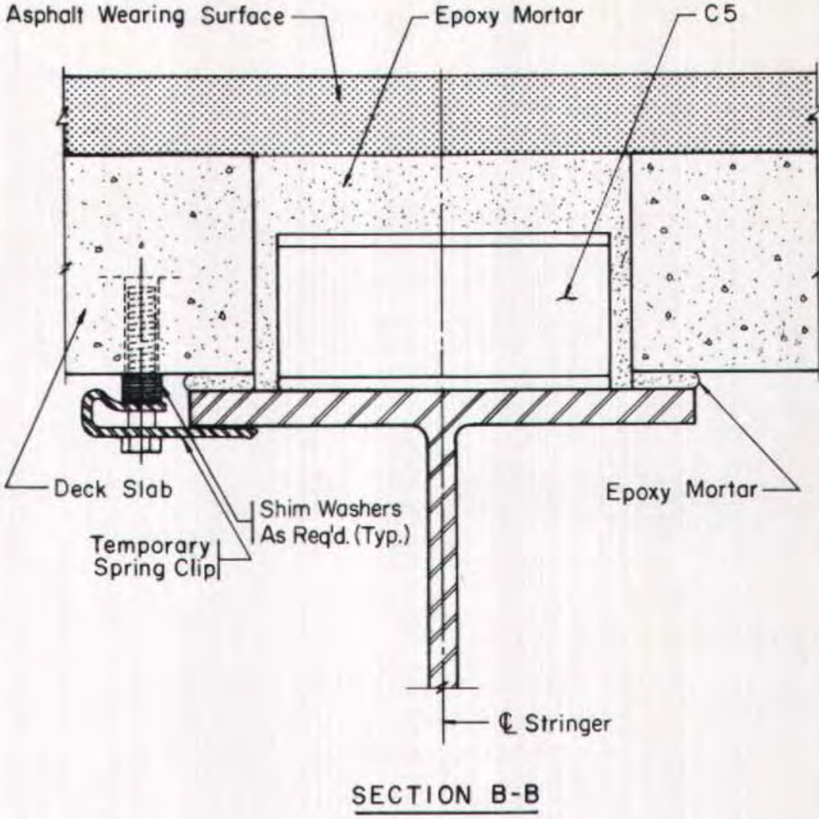


Fig. 14. Detail of welded channel in shear pocket (NYSTA).

Fig. 15. Casting of epoxy mortar in shear pocket (NYSTA).

ascertained. Possible breakage of slabs because of excessive motion due to tensioning was also feared. For these reasons, bolted connections were not used in subsequent NYSTA projects.

NYSTA protective system of a sheet membrane overlaid with asphalt concrete was applied on the rehabilitated deck.

Because of the attached importance of the Amsterdam Interchange Bridge rehabilitation scheme, the construction was highly supervised by professional and management level personnel from the NYSTA, the consulting engineers and the epoxy supplier. The bridge has performed very well over the period since rehabilitation. Close field inspection resulting in better quality control may be credited as an important ingredient for this success.

Krum Kill Road Bridge (1977)—This is a 50 ft (15 m) long single span, six-lane mainline throughway bridge carrying

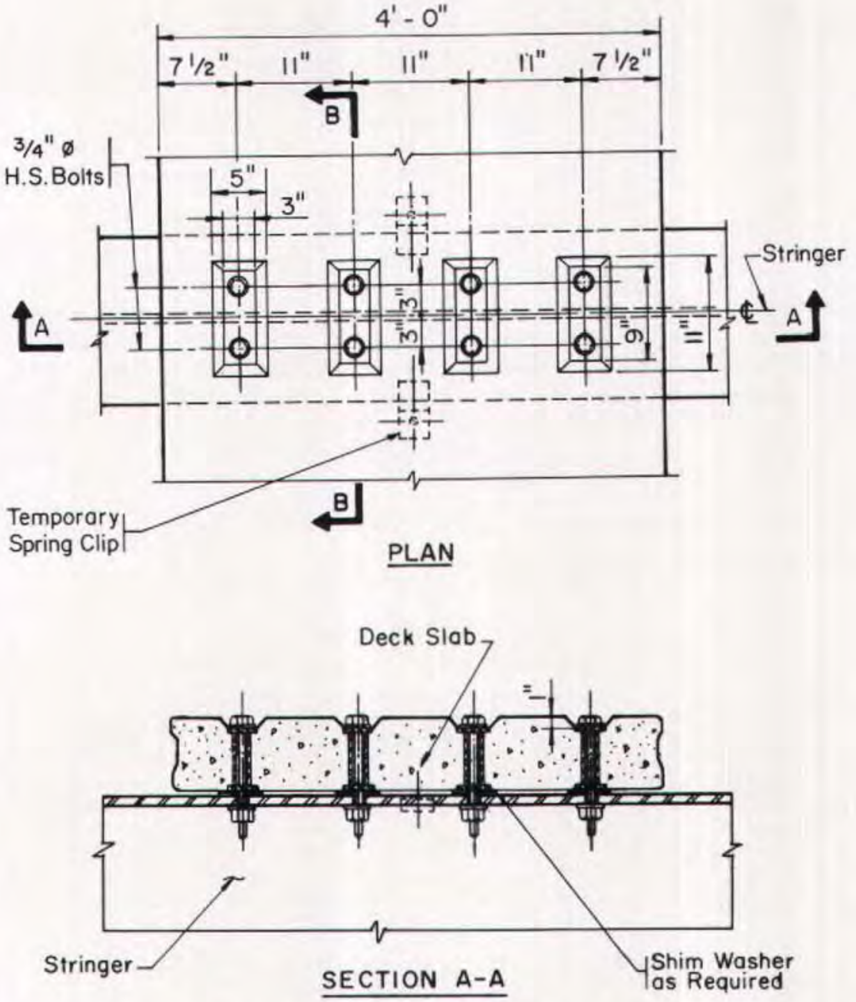


Fig. 16. Plan and section of bolted connection (NYSTA).

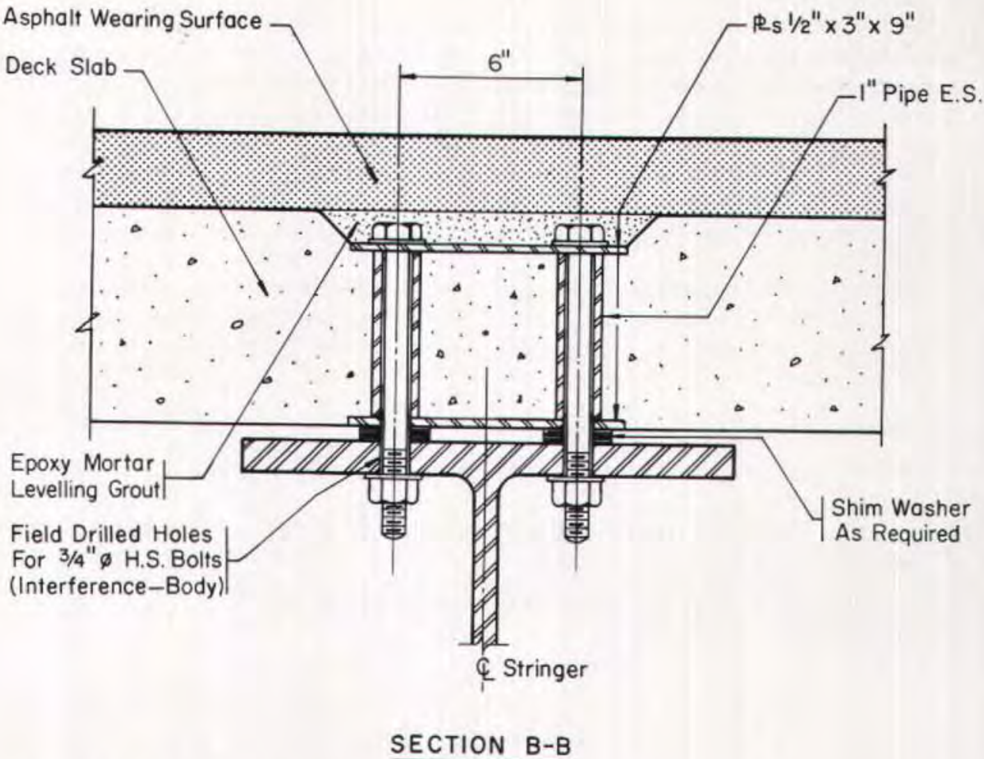


Fig. 17. Detail of bolted connection (NYSTA).

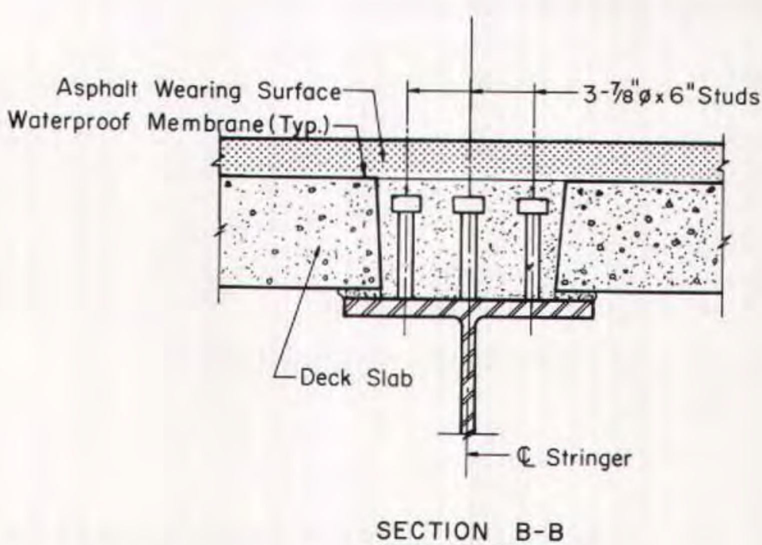


Fig. 18. Detail of welded studs in shear pocket (NYSTA).

AADT 22000 over Krum Kill Road near Albany. Figs. 18 and 19 show the plan and section details of the joints. These details are similar to the Amsterdam Interchange Bridge, except that standard welded shear studs were used instead of channel sections.

The precast slab panel work including delivery and installation, was contracted. The balance of the work was completed by the NYSTA. The spans are slightly skewed but level. There are two structurally separate spans supported on common abutments. Each structure carries two active traffic lanes and one inactive lane for future use. The latter was used effectively to detour traffic during construction.

Precast panels, 7½ in. (190 mm) thick and 5 ft 2 in. (1.6 m) long, of two different widths were used. For each structure, 42 ft (13 m) wide panels were

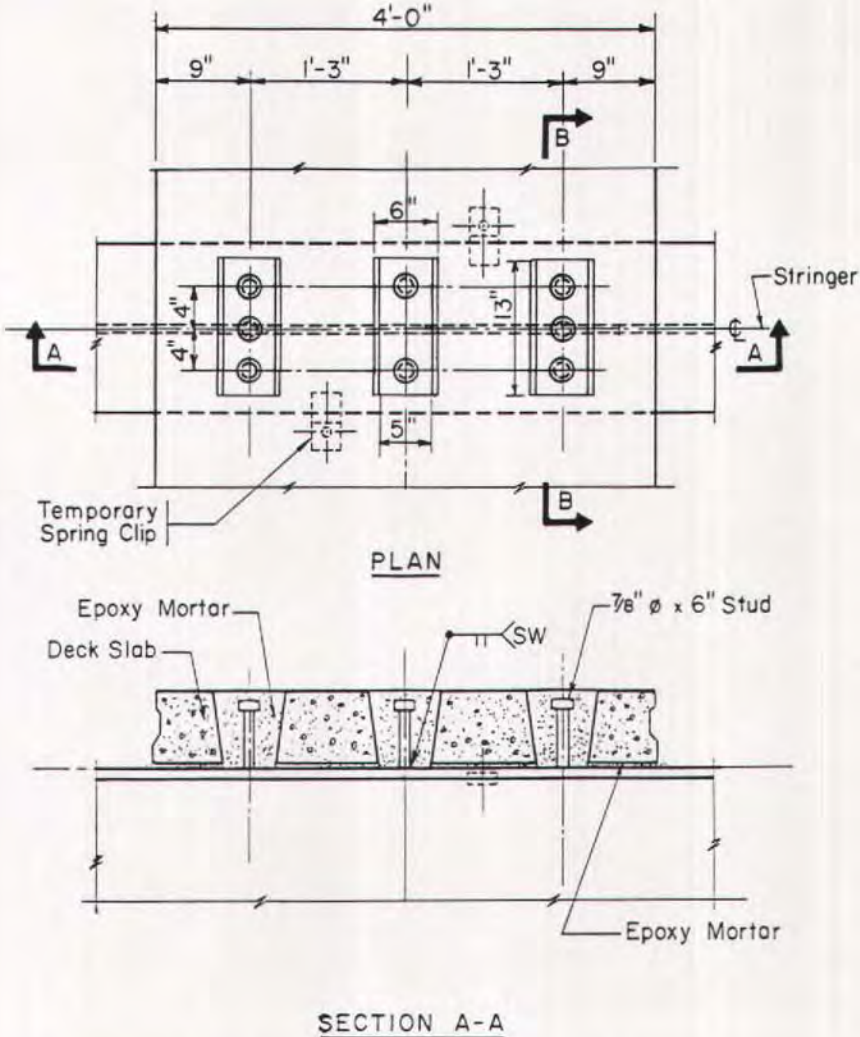


Fig. 19. Plan and section of welded stud connection (NYSTA).

Fig. 20. Placement of 42 ft (13 m) wide panel, Krum Kill Road Bridge, NYSTA.

Fig. 21. Placement of 21 ft (6 m) wide panel, and longitudinal joint, Krum Kill Road Bridge.

Fig. 22. Harriman Interchange Ramp Bridge, NYSTA.

placed over six stringers and 21 ft (6.5 m) wide panels were placed over three stringers. A 3 ft (0.91 m) wide longitudinal joint at the crown line was cast in place over continuity reinforcing bars extending from two adjacent panels. Fig. 20 shows the placement of 42 ft (13 m) wide panels. Fig. 21 shows the placement of 21 ft (6.4 m) wide panels and the longitudinal joint.

During construction, cracks over the reinforcing bars were detected in the precast panels. The cracks were treated with a penetrating epoxy sealer. Durability of the deck has not been affected any further.[37] The performance of the bridge has been satisfactory although several joints have shown signs of leakage where construction debris was found in the keyway. This problem indicates the need for a thorough inspection of all joints prior to placing epoxy mortar.

Harriman Interchange Ramp (1979)—This is a three-span, two-lane ramp carrying AADT 9000. Each span is 75 ft (23 m) long. The roadway is on an 800 ft (244 m) radius horizontal curve. The roadway is also on a vertical curve and is superelevated. Individual spans are markedly skewed. Fig. 22 shows a view of the bridge. The NYSTA let a contract on the complete rehabilitation of this bridge. The connection details of this structure are similar to those shown in Figs. 18 and 19.

Based on available drawings of the existing structure and an actual field survey, a computer program was written to generate numerical tables of each precast concrete slab panel and plot out their geometries for verification. This information was incorporated in the contract drawings and the slab panels were fabricated accordingly.

Full width panels, 8 in. (203 mm) thick by 4 x 54 ft (1.2 x 16.5 m) covered about 9000 sq ft (840 m^2) of deck area. Traffic was maintained using a detour ramp.

Although NYSTA had similar construction experience behind it, this was the first such project for the contractor. Perhaps for this reason, the epoxy mortar was found to be of unsatisfactory quality at some places with evidence of improper proportioning. Structural weakness of the spans is not suspected but cracking and some leakage through the panel joints has been detected.[37]

The design and construction of this bridge were admittedly very complex. The problems encountered emphasize the need for careful inspection of materials and components in this type of construction.

Fig. 23. Clark Summit Bridge, Pennsylvania Turnpike Commission.

Fig. 24. Placement of new precast panel deck and deteriorated condition of old deck (Clark Summit Bridge).

Pennsylvania Turnpike Commission

Clark Summit Bridge (1980)—This 1627 ft (496 m) long bridge consists of two parallel structures carrying two lanes each way.[38-40] Its peak point is about 140 ft (43 m) high.

Fig. 23 shows a view of the bridge. Fig. 24 shows placement of panels at one of the structures while two-way traffic was maintained using the parallel structure. The figure also shows the severely deteriorated condition of the deck at the time of rehabilitation.

Typically, 6¾ in. (171 mm) thick slab panels were 7 ft (2.1 m) long with a full roadway width of 29 ft (8.8 m) weighing 18,000 lbs (8165 kg) each.

Elastomeric strips and epoxy mortar grout were used for bedding over existing stringers. Non-shrink cement grout was placed at the transverse joints and nominal longitudinal post-tensioning was used. Fig. 25 shows manual longitudinal tensioning. The deck structure was noncomposite.

Similar details were used in the redecking of another bridge which is described next.

Quakertown Interchange Bridge (1981)—Fig. 26 shows the two-lane divided interchange overpass and Fig. 27 (top) shows a schematic elevation of the structure. This is a suspended cantilever system with composite deck in the suspended span and noncomposite deck in the cantilever span.

Precast panels, 6½ in. (165 mm) thick with varying haunch thickness, are 7 ft 7¼ in. (2.3 m) long and 17 ft 6 in. (5.3 m) wide [see Fig. 27 (bottom)] and cover one-half the width of the structure. A cast-in-place concrete median barrier was installed between two half-width precast panels. Figs. 27 (bottom) and 28 show the slab panel sizes and connection detail, respectively.

Existing bulb angle shear connectors were left in place as the old slab was removed. The slab panels with shear pockets were cast with sufficient precision that the precast slab fitted well when set in place. Elastomeric strips were glued to the top of the flanges to contain the epoxy mortar which provided uniform bedding of the precast panels.

Fig. 25. Longitudinal post-tensioning (Clark Summit Bridge).

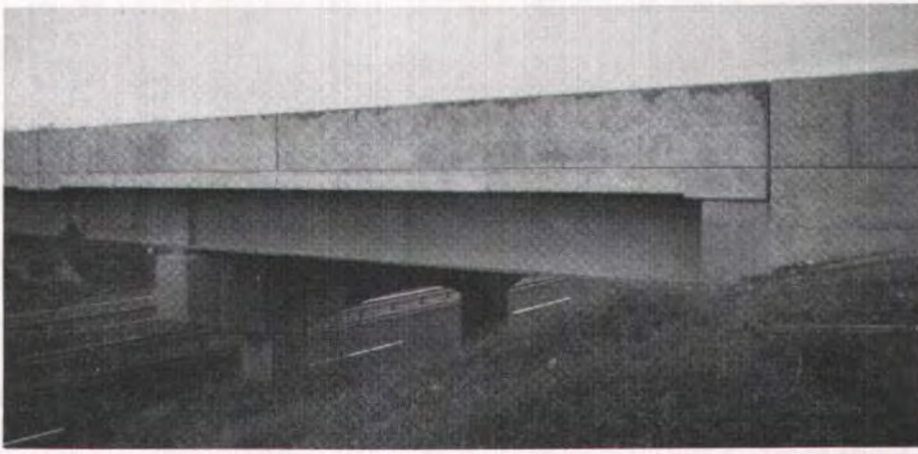


Fig. 26. Quakertown Interchange Bridge, Pennsylvania Turnpike Commission.

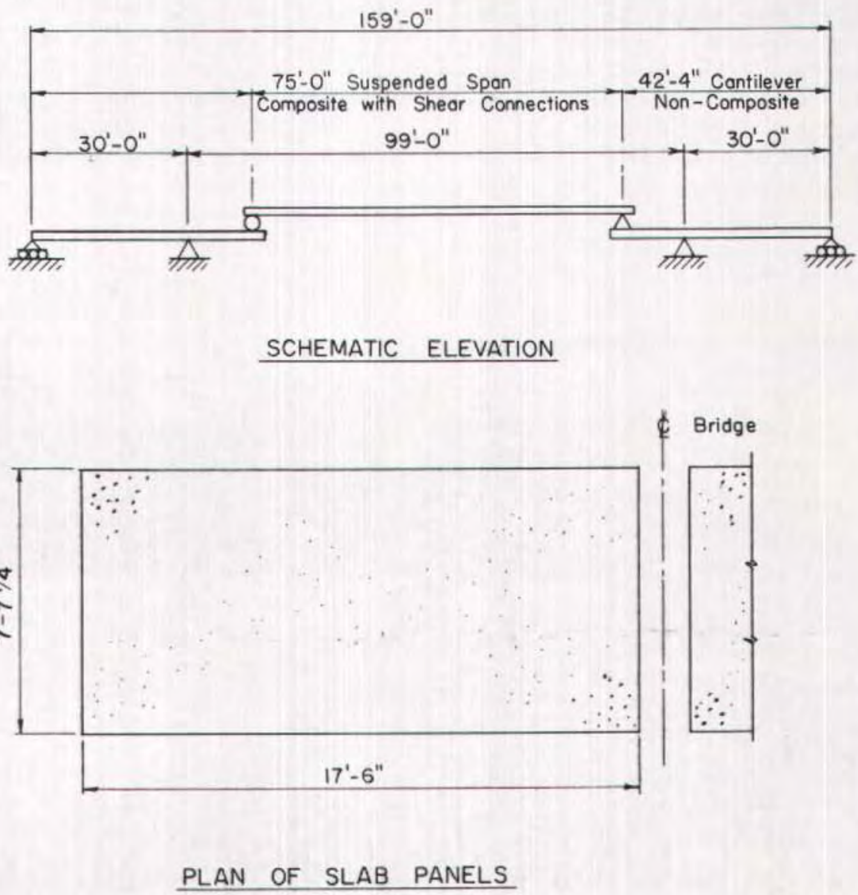


Fig. 27. Schematic elevation and panel dimensions, Quakertown Interchange Bridge.

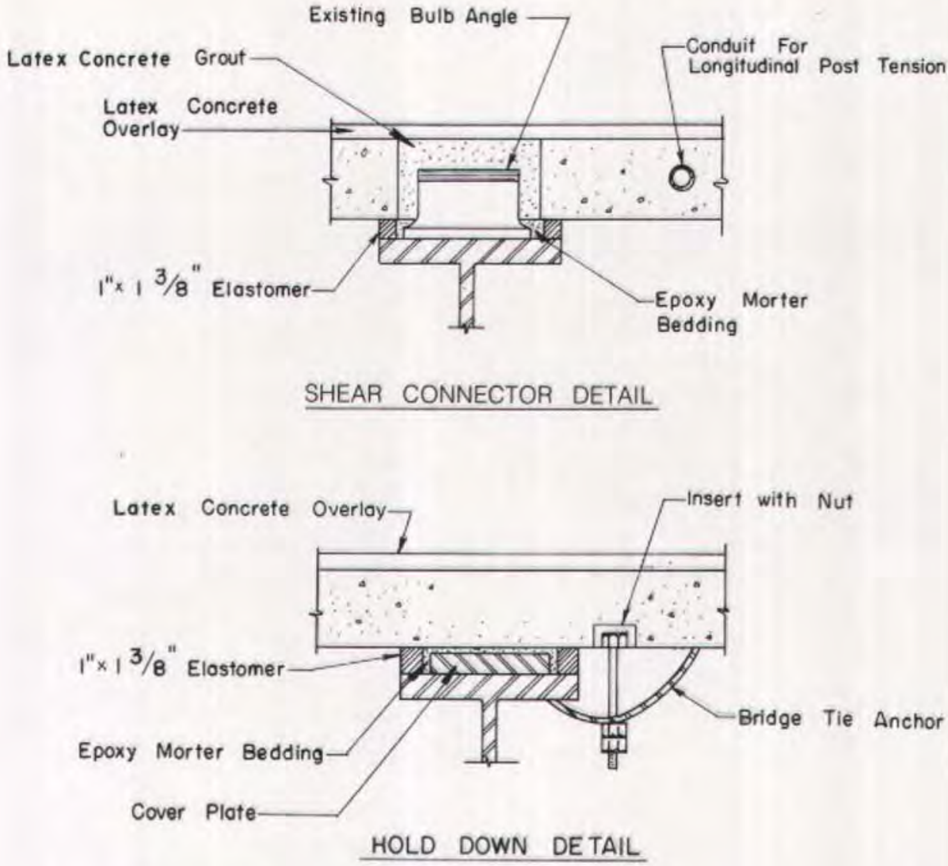


Fig. 28. Connection details, Quakertown Interchange Bridge.

This method allowed the precast panels to ride over the existing cover plates in the negative bending moment region. Latex modified concrete was used in both the shear pockets and transverse panel joints. The transverse joints were pulled together by using nominal longitudinal post-tensioning. Latex modified concrete was also used as the riding surface overlay.

In addition to providing rapid erection, the construction of the two bridges described above has proven to be cost effective compared to conventional deck replacement methods. These two bridges have also performed extremely well.

Massachusetts Turnpike Authority

Connecticut River Bridge between West Springfield and Chicopee—Fig. 29 shows an overview of this 1224 ft (373 m) long, four-lane divided highway. A typical interior span is 224 ft (68 m) long. Figs. 30(a) and 30(b) show the elevation of a typical span together with the cross section of the bridge.

Separate twin east and west bound roadway decks are supported on common floor beams. Traffic was maintained by restricting construction to one side of the bridge which allowed two-way traffic on the other side. The reha-

Fig. 29. Connecticut River Bridge, Massachusetts Turnpike Authority.

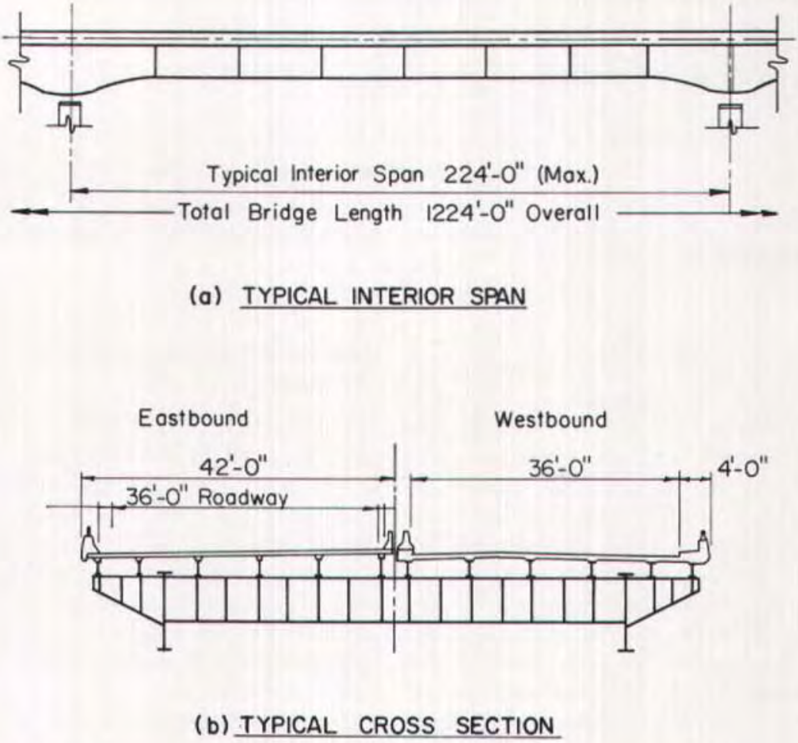


Fig. 30. Schematic elevation and section of typical span, Connecticut River Bridge.

bilitation of the east bound roadway was completed and opened to traffic before the target date. The west bound roadway was completed in 1982.

The precast slabs were transversely pretensioned and longitudinally post-tensioned. To reduce the dead load, lightweight aggregate concrete [115 lb/ft^3 (1842 kg/m^3)] with $f_c' = 5000$ psi (34.5 MPa) was used for the precast concrete

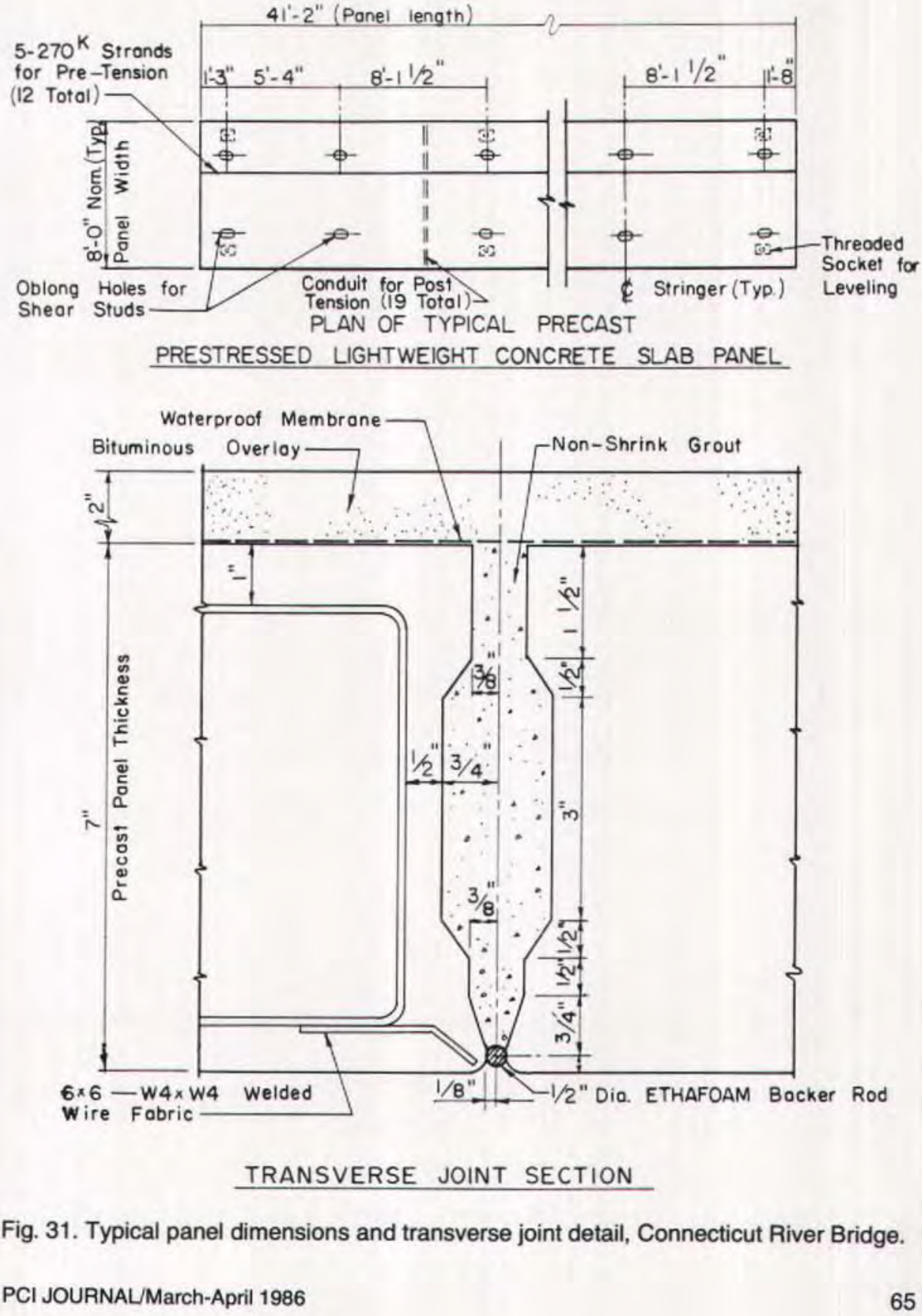
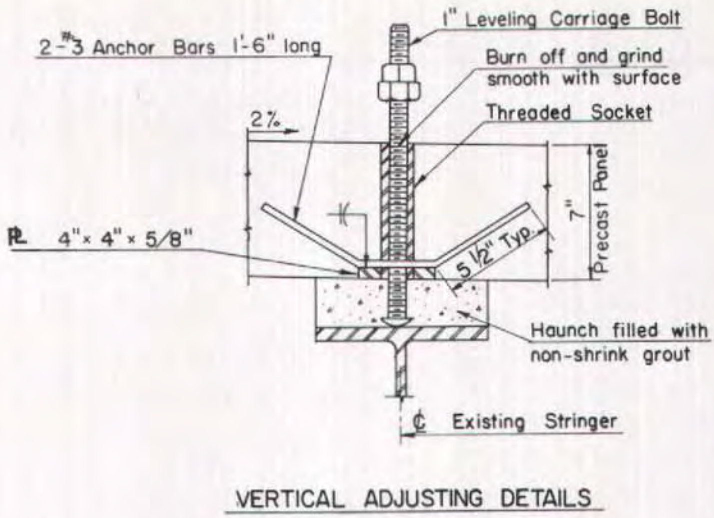


Fig. 31. Typical panel dimensions and transverse joint detail, Connecticut River Bridge.



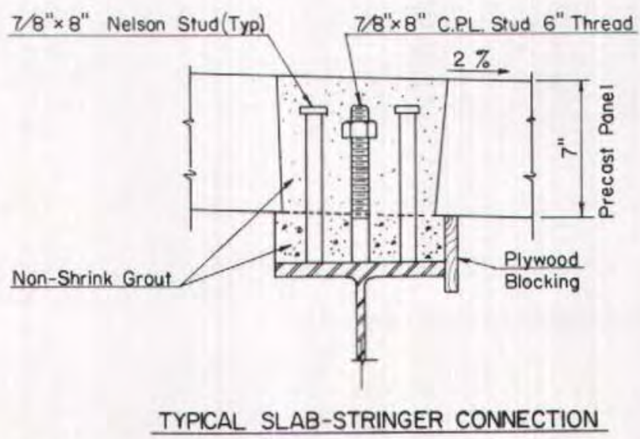


Fig. 32. Slab and stringer connection details, Connecticut River Bridge.

Fig. 33. Bridge No. 1 over Rondout Creek, New York State Department of Transportation (NYSDOT).

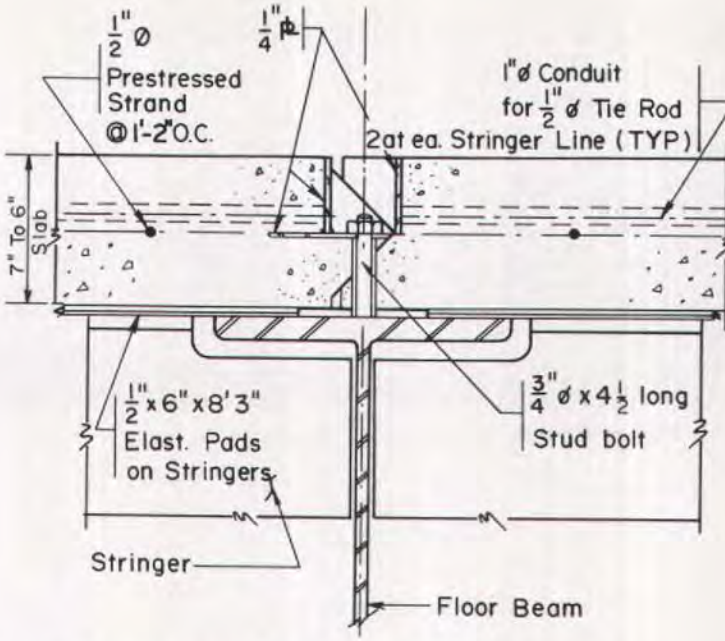


Fig. 34. Connection details, Rondout Creek Bridge.

slabs and the cast-in-place parapets.

Fig. 31 shows the plan of a typical full roadway width slab panel and the details of the transverse slab joints. For drainage purposes, the cross slope of the roadway was provided by detaching the existing stringers and resetting them with varying elevations. Precast panels were set in proper elevation by using a system of leveling bolts.

Non-shrink cement grout was used as bedding, in the stud pockets, and in the transverse joints. The deck was not composite. Welded studs in grouted pockets were used to hold down the slab to prevent buckling during post-tensioning. Fig. 32 shows details of the leveling bolts and stud connectors.

The protective system of a membrane overlaid with asphalt concrete was employed. Epoxy mortar was used for setting granite curbs which are traditionally used in Massachusetts highway bridges.

Chicopee River Bridge between Ludlow and Wilbraham—Encouraged by the success of the Connecticut River Bridge deck rehabilitation project, the Turnpike Authority proceeded to rehabilitate this bridge by using essentially the same technique.

The bridge is on the same four-lane, divided highway and has twin separate east and west bound roadway structures. Each has five spans resulting in a total length of 837 ft (255 m).

The superstructure consists of concrete deck on stringers supported by floor beams and welded plate deck girders of uniform depth. Precast deck slabs covered the full width of each of the roadways. To expedite construction, the stringers were not reset. The cross slope of the roadway was obtained by integrally precasting haunches at the bottom of the precast deck panels.

The east bound roadway was completed in 1983 and the west bound

Fig. 35. Bridge No. 6 over Delaware River, NYSDOT.

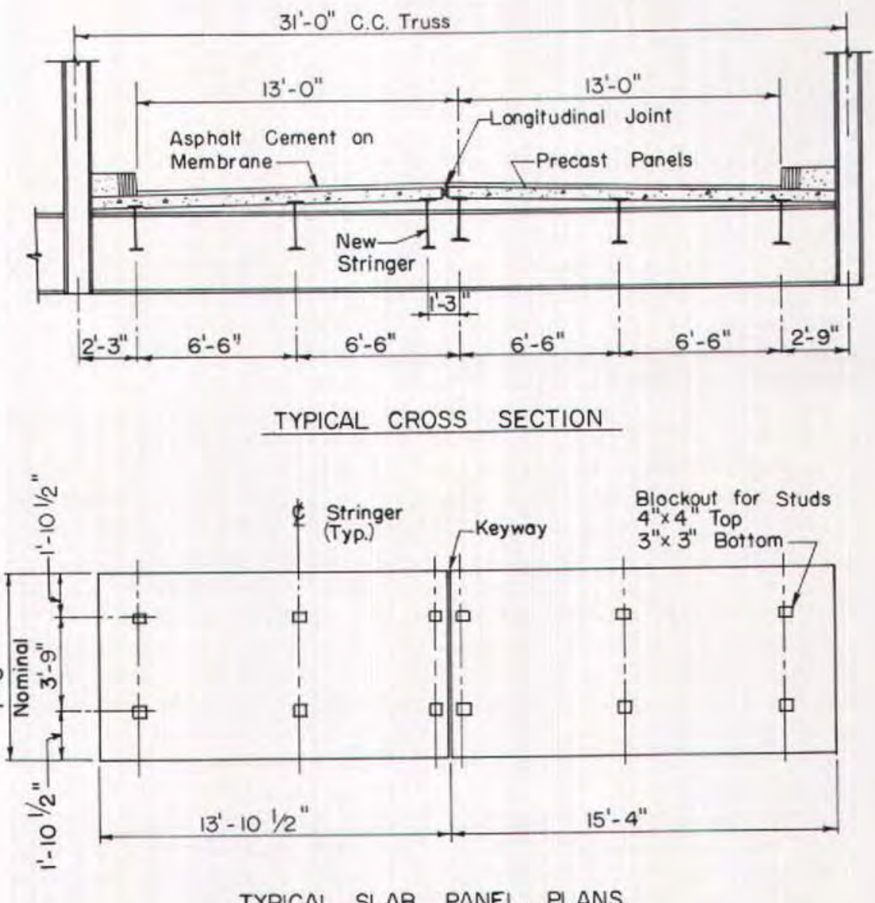


Fig. 36. Typical bridge section and panel dimensions, Bridge No. 6, NYSDOT.

roadway was finished by the target date of July 4, 1984. To further expedite rehabilitation of the west bound roadway, precast parapets were used. These were bolted down to the precast deck panels. Traditionally used granite curbs were preset in the precast parapets.

The Turnpike Authority engineers believe that besides allowing rapid rehabilitation of an existing bridge under traffic, superior quality decks have been installed with cost effectiveness using precast concrete.

New York State Department of Transportation (NYSDOT)

NYSDOT probably enjoys the distinction of having built the largest number of bridges as well as the most different types of bridges using full depth precast concrete deck panels. At least four bridges have been built over a period of 8 years. During this time the NYSDOT has developed different details to suit the needs of specific projects. Significant details are described in the fol-

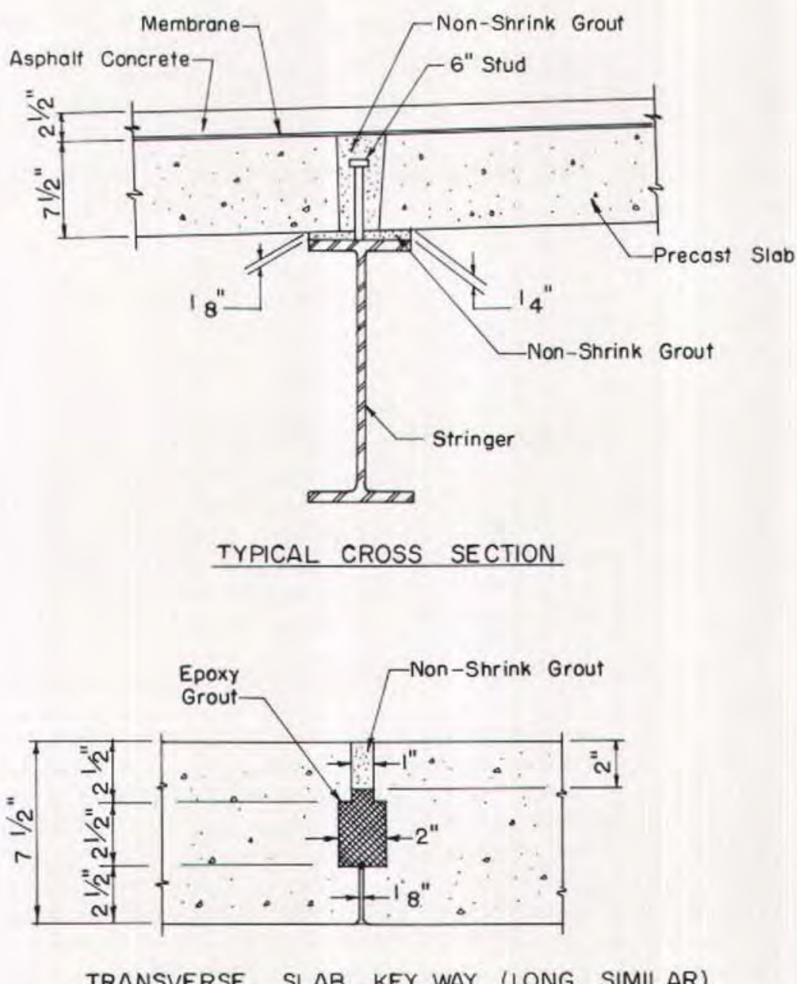


Fig. 37. Connection details, Bridge No. 6, NYSDOT.

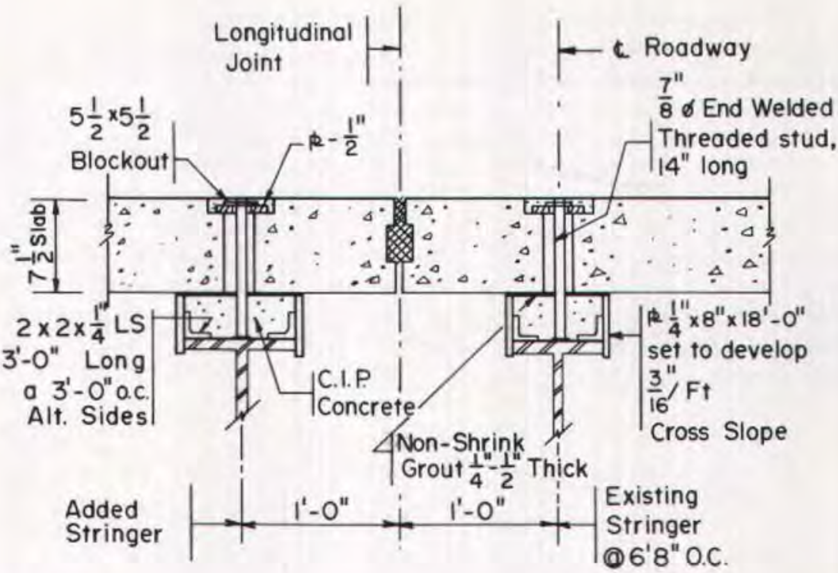


Fig. 38. Connection details, Southwestern Boulevard Bridge over Cattaraugus Creek, NYSDOT.

lowing projects.

Bridge No. 1 over Rondout Creek, Kingston (1974)—This is a nearly 1100 ft (335 m) long, two-lane suspension bridge with a 700 ft (213 m) long main suspended span. Fig. 33 shows an elevation of the bridge.

Typically, about 9 ft (2.7 m) long panels have full roadway widths of about 24 ft (7.3 m). Panel thickness varies from 7 in. (178 mm) at the crown to 6 in. (152 mm) at the edges. In addition to allowing rapid construction, the use of precast panels was chosen to control dead weight effects by selective sequential placement. The slab panels were transversely prestressed to accommodate handling stresses.

Reinforced Vee-groove transverse joints and longitudinal tie rods across the joints were used.[41] A ½ in. (12 mm) thick elastomeric bearing pad was used at the interface between the bottom of the slab and top of the stringer. These details are shown in Fig. 34.

Bridge No. 6 Over Delaware River (1978)—This is a three-span, two-lane truss bridge with a total length of 675 ft (206 m). Fig. 35 shows an overview of the bridge.

Typically, 7½ in. (190 mm) thick panels are 7 ft 6 in. (2.3 m) long and about half of the roadway width, resulting in a longitudinal joint. Fig. 36 shows a typical cross section and plan of slab panels. Fig. 37 shows the details of a slab stringer connection, and details of slab transverse and longitudinal joints.

Epoxy mortar grout was used in the transverse and longitudinal joints of adjacent slab panels. Non-shrink cement grout was used as the bedding between slab and stringer and in the stud pocket. Welded stud shear connectors were used. Traffic was maintained by way of staged construction.

Reflected cracks appeared along the longitudinal joint and were later patched. This was of no structural significance. The bridge has reportedly performed well otherwise.

Southwestern Blvd. Bridge Over Cat-

Fig. 39. Batchellerville Bridge, NYSDOT.

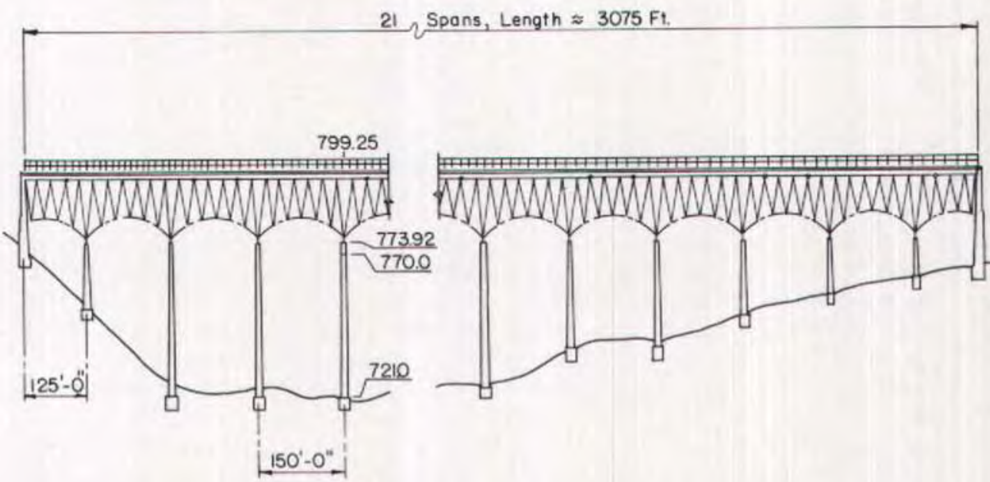


Fig. 40. Schematic Elevation, Batchellerville Bridge.

taraugus Creek (1979)—This is a two-lane, 550 ft (168 m) long, three-span truss bridge, with span lengths of 180 ft (55 m) each. The spans have a skew of about 22 deg.

Typically, 7½ in. (190 mm) thick, 8 ft (2.4 m) long panels are about 21 ft (6.4 m) wide. Trapezoidal slab panels are used to accommodate the skewed span ends. The transverse and longitudinal slab joints are similar to those used for Bridge No. 6. The detail of the slab

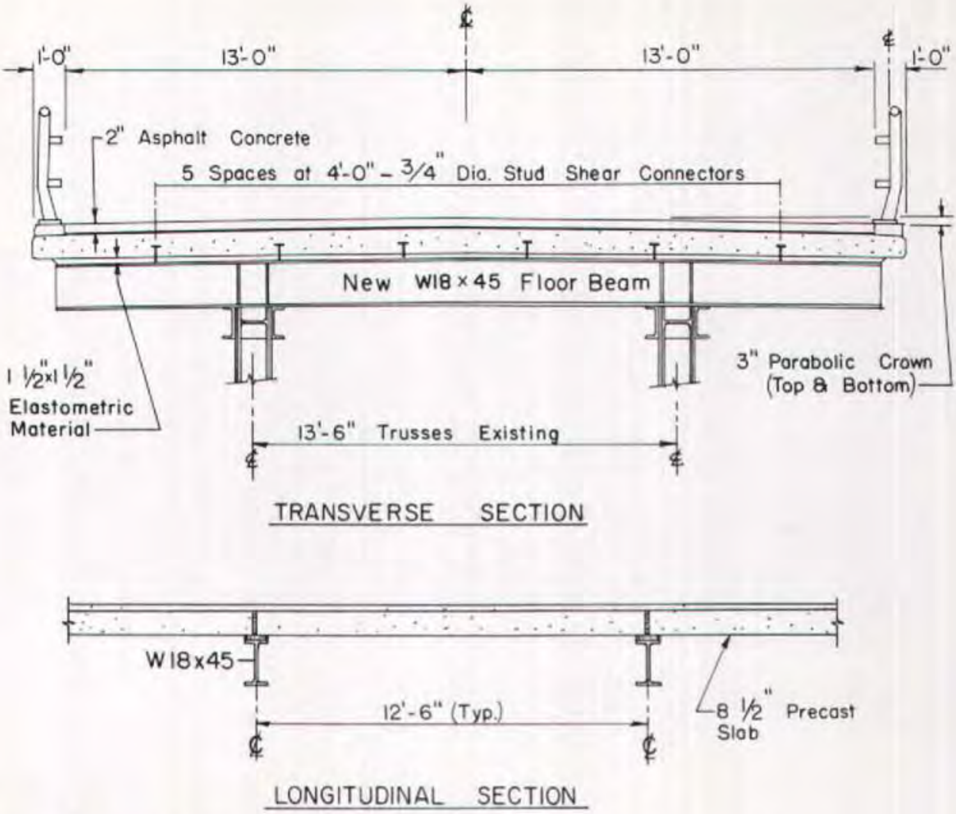


Fig. 41. Typical sections, Batchellerville Bridge.

stringer connection, however, is different and is shown in Fig. 38.

Batchellerville Bridge (1982)—The general view of the bridge is shown in Fig. 39 and Fig. 40 shows a schematic elevation. This bridge is significant in many ways. It is a very long bridge with a span of 3075 ft (938 m). The roadway provides the only direct route to a remote community.

The user community was given the option of a staged construction with a long total construction time or closing the bridge completely for 6 months. The community opted for the 6-month bridge closing, with a provision for ferry service during this time.

The contract provided for a field construction schedule of 6 months from April 15 through October 15, 1982. Options for cast-in-place as well as precast slab were given. The successful low bidder opted for precast construction. This was unique because the selection of precast slab was the contractor's choice and not required by the owner.

Fig. 41 shows the cross section and the longitudinal section of the rehabilitated structure. The roadway was widened. The design called for full width precast panels placed over newly installed floor beams. The crown of the roadway was built into the panels by using curved panels.

Transverse slab joints were located over the floor beams, and the panel length varied from about 11 ft 8 in. to 13 ft (3.6 to 4.0 m) depending on the spac-

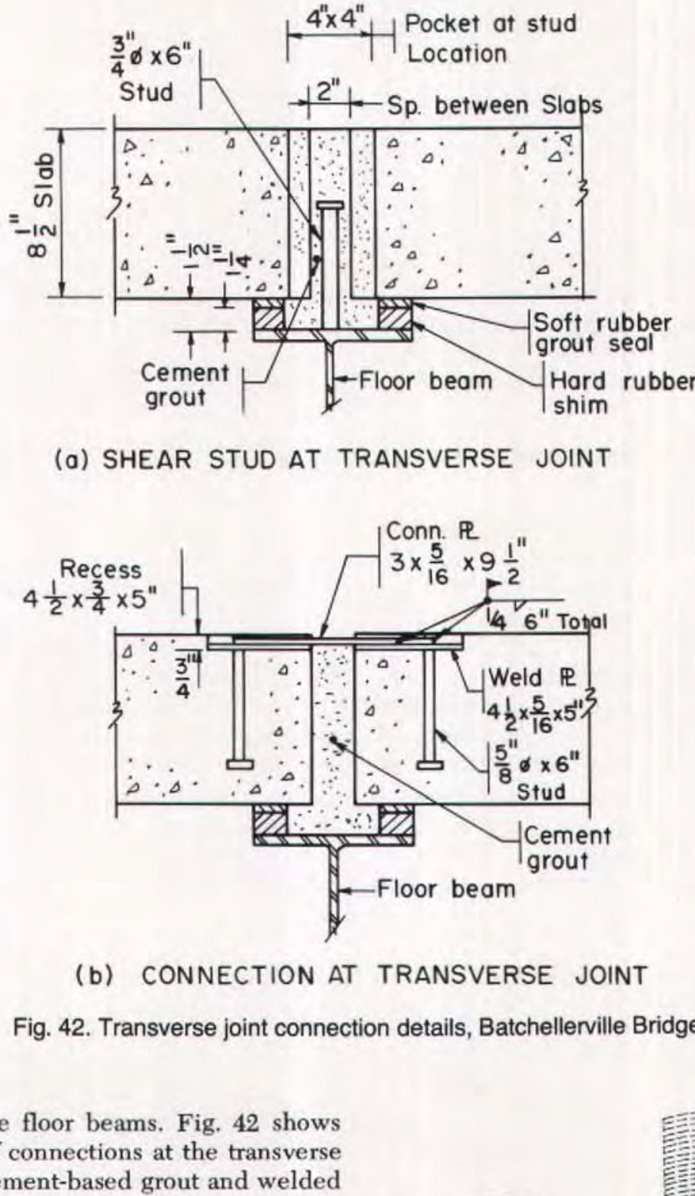


Fig. 42. Transverse joint connection details, Batchellerville Bridge.

ing of the floor beams. Fig. 42 shows details of connections at the transverse joints. Cement-based grout and welded stud shear connectors were used along with elastomeric pads to dam the grout flow.

The contractor had most of the panels precast during the previous warm construction season. The panels were stored in a covered area under insulated conditions for the winter and then transported to the site during construction as needed (see Fig. 43).

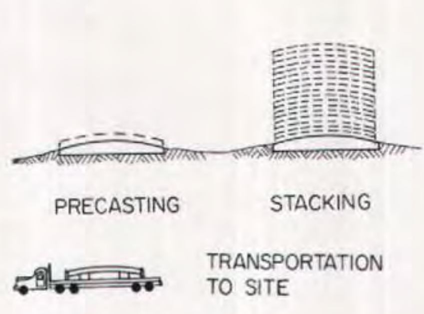


Fig. 43. Casting, storage and transportation of crowned precast panels, Batchellerville Bridge.

Due to an extended winter, the actual bridge closing and construction started on April 30, 1982. Whole sections of slabs were removed, along with the old, short floor beams. Installation of new, longer floor beams, and precast slabs progressed rapidly. Traffic was reopened on October 8, 1982, a week ahead of schedule.

This project demonstrated the combined cost and time effectiveness which is achievable through the application of precast concrete slabs in large scale bridge deck replacement.

California Department of Transportation

CA-17 High Street Overhead, Oakland (1978)—The nearly 1750 ft (534 m) long structure consists of twin (left and right) bridges on an extremely busy urban freeway (AADT 170,000).[39-42] Fig. 44 shows the structure.

Precast concrete panels were used to rehabilitate only the outside south bound lane of the "left bridge." By using precast panels, it was possible to maintain full peak period traffic during the evening rush hours. The structure had 32 spans with lengths ranging from 30 to 76 ft (9.1 to 23.2 m). Portions of the roadways were on horizontal curve, and some of the spans had pronounced skew.

The conventionally reinforced concrete panels were precast near the site and included concrete barriers. Typically, 6½ in. (164 mm) thick slabs were 30 to 40 ft (9.1 to 12.2 m) long and about 14 ft 2 in. (4.3 m) wide, spanning over two steel I-beam girders 8 ft (2.4 m) on center, with 3 ft (0.91 m) overhangs on both sides.

The levels of slabs had to be maintained precisely. Fig. 45 shows details of two-headed bolts and threaded inserts which were used to adjust the precast panels. Leveling devices were placed on girder lines at 8 ft (2.4 m) maximum spacing.

Fig. 46 shows the panel dimensions and details of shear connections consisting of four ⅞ in. (23 mm) diameter 6 in. (152 mm) long welded studs placed in 4 in. (102 mm) long and 12 in. (305 mm) wide oblong shear pockets. The pockets were located at 2 ft (0.61 m) on center. Fast hardening, high strength and sulphate resistant, calcium aluminate cement mortar and concrete were used at the joints.

Fig. 44. CA-17 High Street Overhead, California Department of Transportation (CALTRAN).

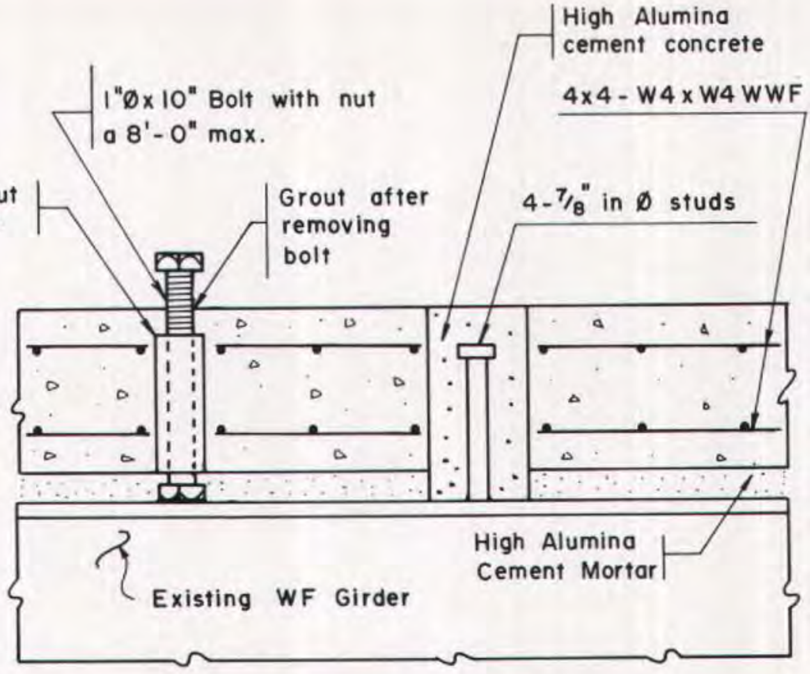


Fig. 45. Details of temporary support and levelling (CALTRAN).

Maryland State Highway Administration and Federal Highway Administration

Woodrow Wilson Memorial Bridge, Washington, D.C. (1983)—This is a 5900 ft (1800 m) long bridge over the Potomac River. It comprises a girder, floor beam and stringer deck support system.[43] Typically, 8 to 10 ft (2.4 to 3 m) long lightweight precast concrete panels were about 47 ft (14 m) wide and 8 in. (203 mm) thick. An additional 5 in. (127 mm) haunch over the fascia girders was used to accommodate negative bending moment due to overhang required by widening of the roadway.

The panels were post-tensioned both transversely and longitudinally, so that sliding bearing surfaces had to be provided. Methylmethacrylate polymer concrete and mortar were used at the joints. Welded stud shear connectors were used. Fig. 47 shows details of the deck panels and Fig. 48 shows details of the connections.

Rehabilitation of the project was completed 8 months ahead of schedule, $6 million under budget, and without disrupting the flow of traffic.[43]

Delaware River Joint Toll Bridge Commission

Milford-Montague Toll Bridge (1982)—This is a 1150 ft (351 m) long, four-span, continuous deck truss two-lane bridge.[44,45] Fig. 49 shows an aerial view of the structure. The four span lengths are 275, 300, 300, and 275 ft (84, 91, 91, and 84 m).

The existing 24 ft (7.3 m) wide "cartway" was widened to a 27 ft 6 in. (8.4 m) roadway between parapets. This required the addition of a new stringer and relocation of four existing stringers, changing the stringer spacing from 7 ft 4 in. to 6 ft 3 in. (2.2 to 1.9 m).

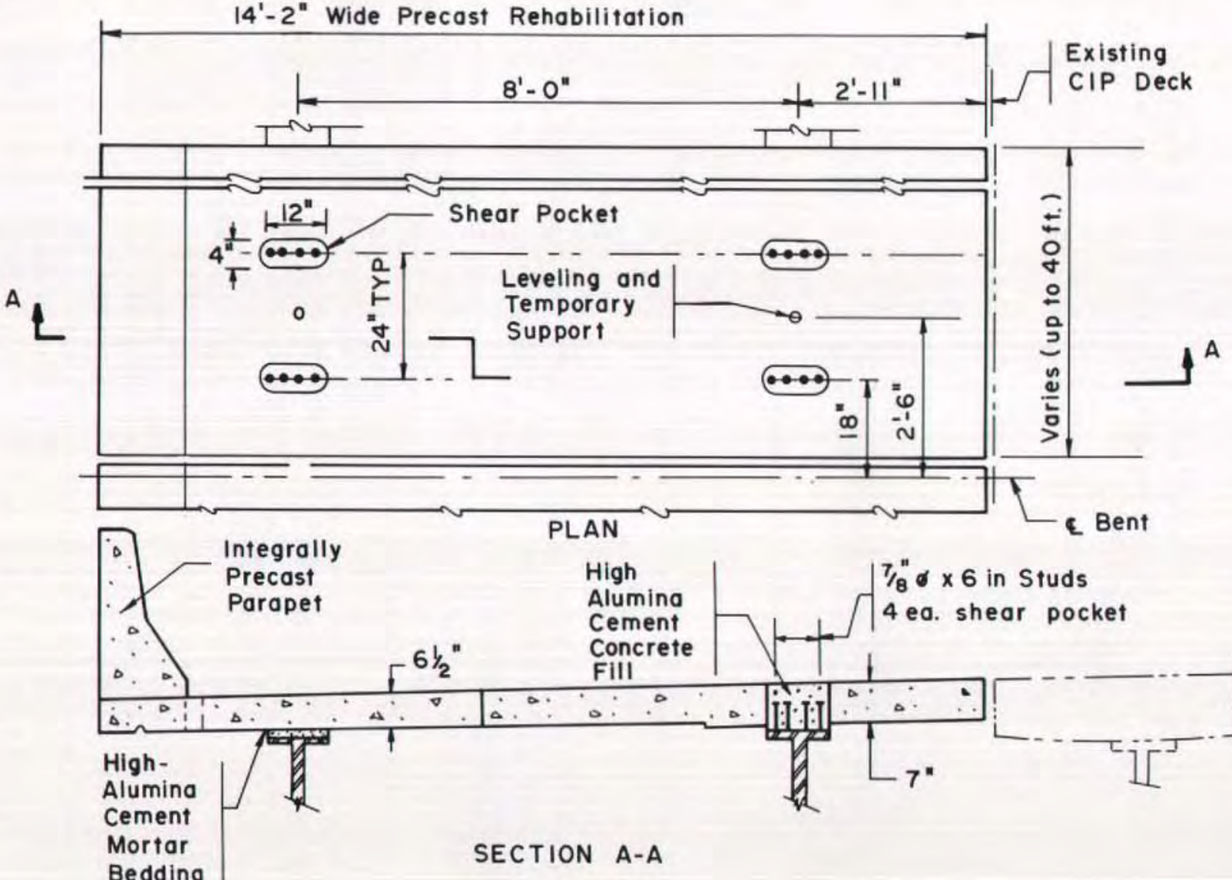


Fig. 46. Panel dimensions and shear connection details (CALTRAN).

Traffic was maintained during construction by staged construction of one-half of the bridge and allowing alternate one-way traffic on the other half. Typically, 7½ in. (190 mm) thick precast slabs were 12 ft 6 in. (3.8 m) long and about 15 ft (4.5 m) wide. Panels covered one-half the width of the new roadway, and resulted in a construction joint down the longitudinal centerline and crown of the roadway.

The bare top surface of the precast slab was designed to be used as a riding surface, without the benefit of any overlay. Hence, the panels were set on the stringers to precise finish grade using temporary leveling bolts and threaded inserts. Next to it, a hold-down bolt through a sleeve insert was used. Fig. 50 shows the leveling and hold-down bolt details.

Polypropylene tubes were placed as

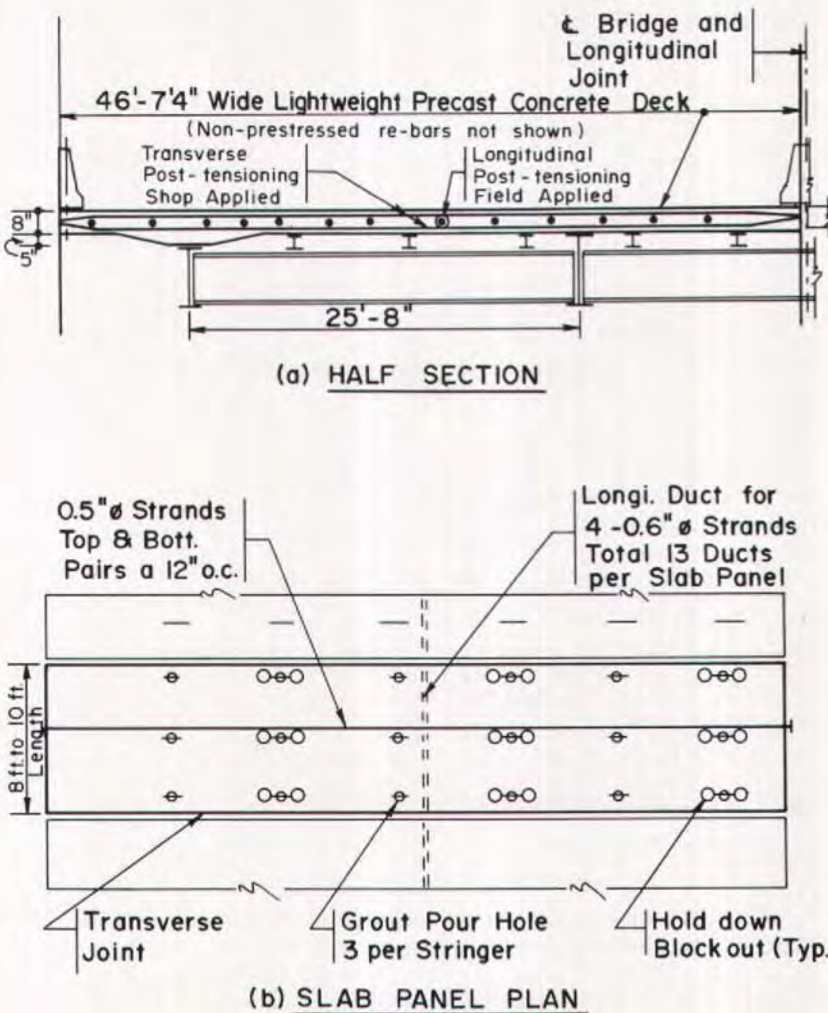


Fig. 47. Panel dimensions, Woodrow Wilson Memorial Bridge, Maryland State Highway Administration and Federal Highway Administration.

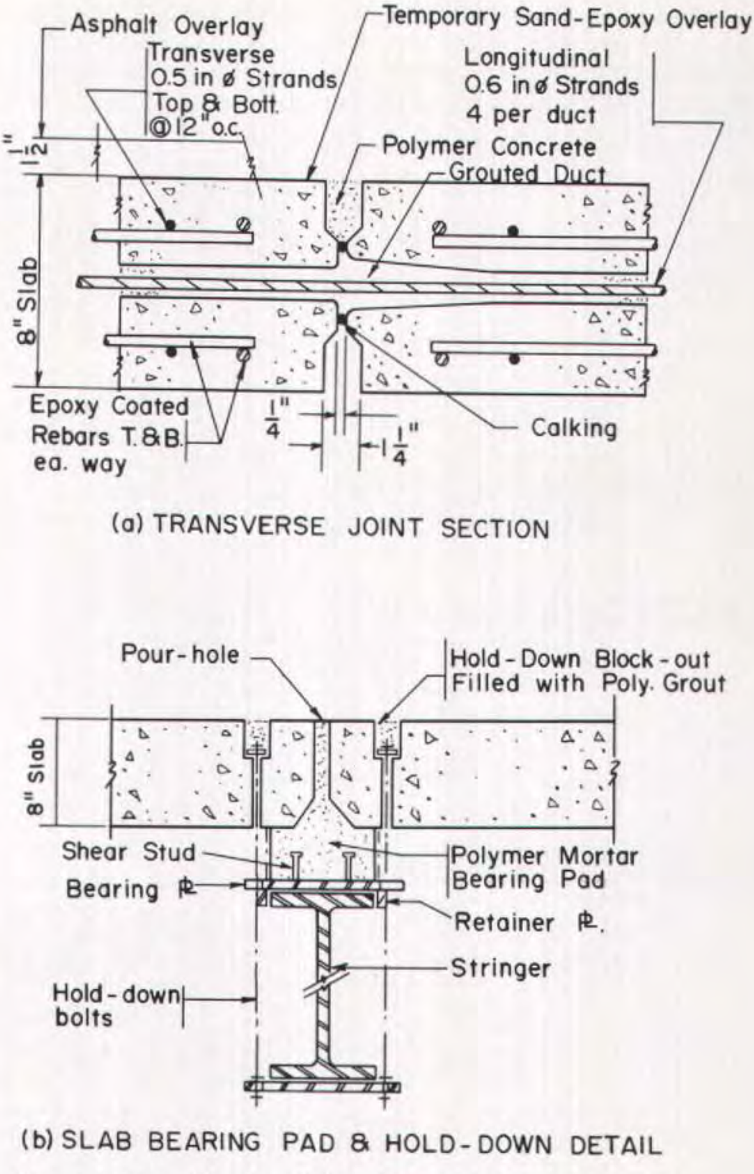


Fig. 48. Joint details, Woodrow Wilson Memorial Bridge.

seals and flowable epoxy mortar was used to fill the space between the top of stringers and the bottom of slabs. The leveling bolts were later removed and replaced by a second set of hold-down bolts. The holes on top of the bolts were filled with epoxy mortar. Fig. 51 shows the detail which was designed to provide a tight transverse joint.

Slab panels were match cast in series, 13 units at a time, and were longitudinally pretensioned using threaded rods. Reverse threaded couplings were placed in the blockouts at the slab in-

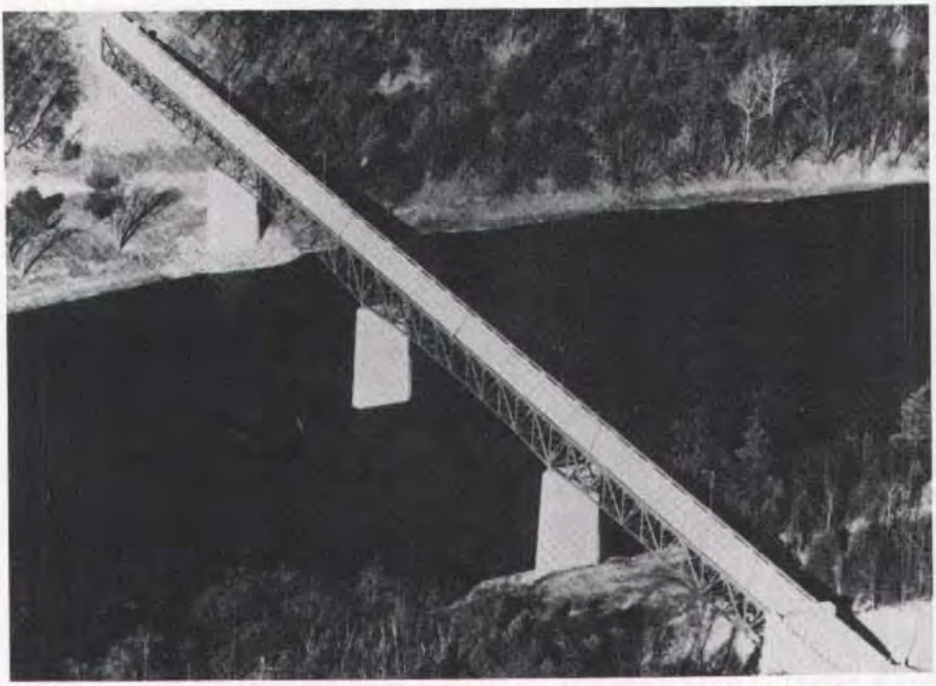


Fig. 49. Milford-Montague Toll Bridge, Delaware River Joint Toll Bridge Commission.

terfaces at the time of pretensioning. The couplings were removed prior to removal of the slabs from the casting beds and transportation to the site. The same couplings were used to post-tension the transverse joint after the slabs were installed in place.

This method provided positive compressive stress at the transverse joints and in the slab, and eliminated the need for any post-tensioning ducts or grouting. The slabs were "buttered" with neat epoxy at the transverse butt joint interface prior to post-tensioning.

Pennsylvania Department of Transportation

Freemont Street Bridge, Bellevue (1984)—This is a four-lane, 300 ft (92 m) long reinforced concrete supported bridge on twin concrete arches spanning 180 ft (55 m). Smyers has described the significant design and construction features for the rehabilitation of this structure.[46]

Steel, cast-in-place concrete, and precast prestressed concrete competed as possible replacement structural components. After careful evaluation, precast prestressed concrete was selected as the most suitable material for this project.

Slab panels were typically 10 in. (254 mm) thick, 6 ft 8½ in. (2.0 m) wide, and 30 ft (9.1 m) long spanning over two spans between floor beams at 15 ft (4.6 m). No stringers were used.

Ten slab panels, placed side by side, constituted the full deck width. The longitudinal joints between slabs were filled with polymer mortar and transversely post-tensioned. Combinations of leveling bolts, neoprene pads, flexible tubing grout barriers, dowel rods, and polymer mortar were used between the slabs and floor beams.

The replacement floor beams also were precast elements. Traffic was

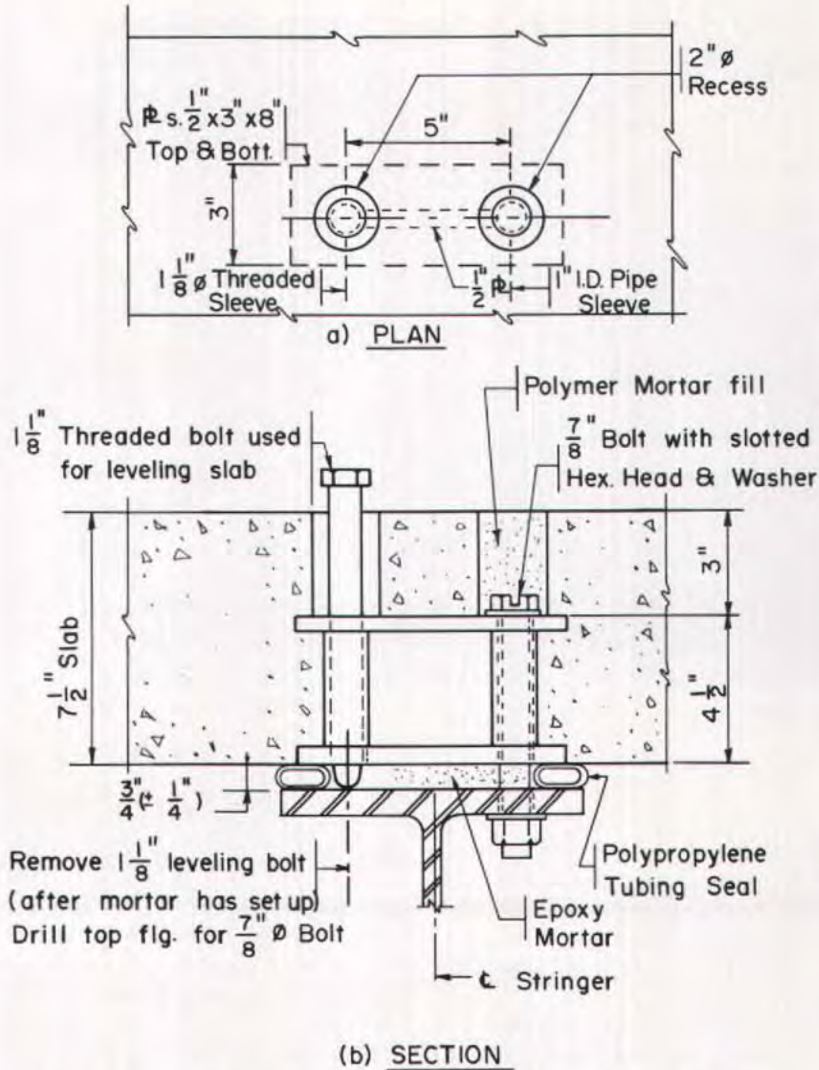


Fig. 50. Levelling and hold-down bolt details, Milford-Montague Toll Bridge.

maintained on this bridge by way of phased construction of one-half of the bridge at a time. This required a two-piece set for each floor beam element. Epoxy adhesive was used at the shear-keyed butt joint of the two pieces which were post-tensioned. Post-tensioning was also used as a connection between the floor beams and the cast-in-place concrete arch columns.

Illinois Department of Transportation

US-24 Mississippi River Bridge, Quincy—This structure is a two-lane, nearly 2200 ft (671 m) long, cable-stayed bridge. Fig. 52 shows an elevation of the structure.[47] A 900 ft (275 m) main span is flanked by 440 ft (134 m) side spans on each end, which in turn are flanked by

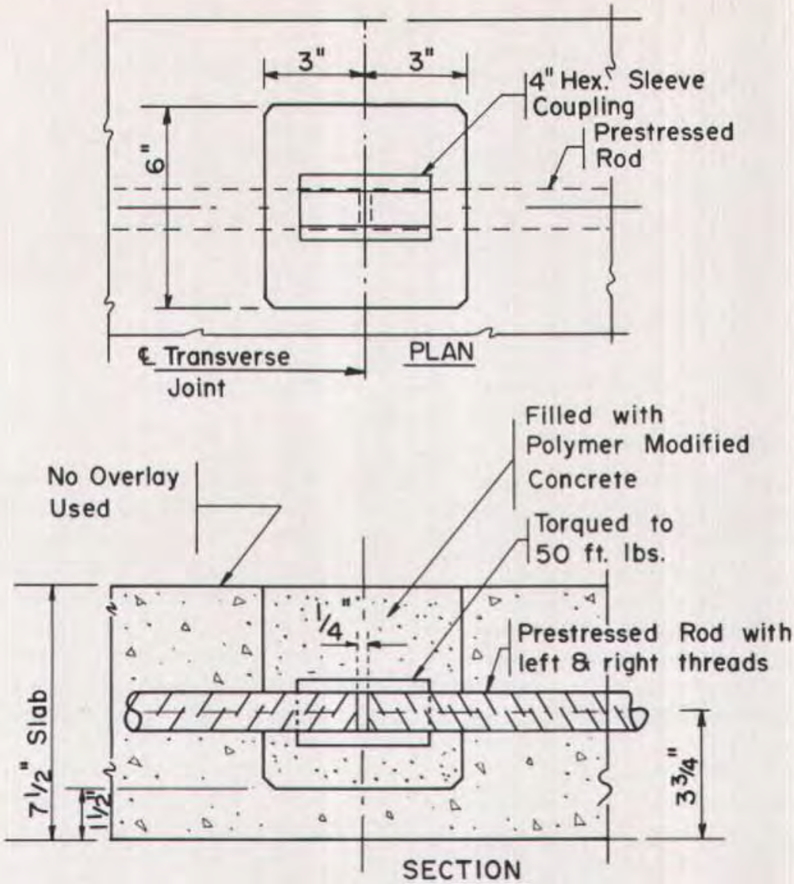


Fig. 51. Transverse joint details, Milford-Montague Toll Bridge.

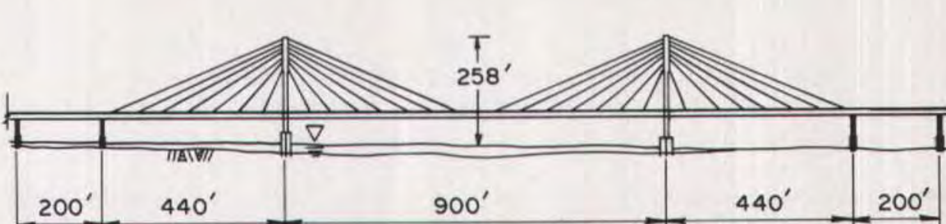


Fig. 52. US-24 Mississippi River Bridge, Quincy, Illinois Department of Transportation.

200 ft (61 m) transition spans. There are several thousand feet of approach spans.

Full width, full depth, precast deck panels are supported on a system of steel stringers, floor beams and welded girders. Fig. 53 shows a section of the precast deck. The curb-to-curb roadway width is 32 ft (9.8 m) and the full width of the panel is 46 ft 6 in. (14.2 m). The lengths of the panels varied from 9 to 11

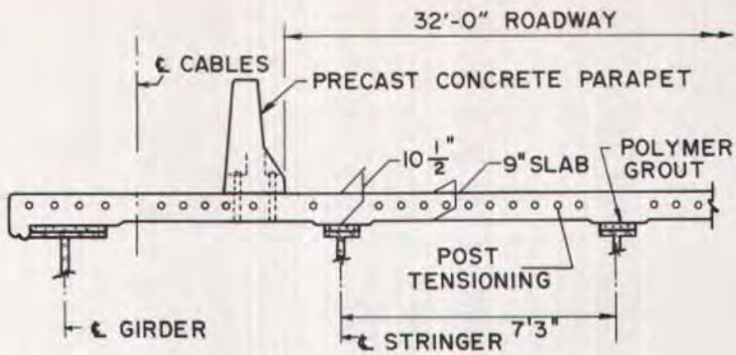


Fig. 53. Precast deck section, US-24 Mississippi River Bridge.

ft (2.7 to 3.4 m).

The panels are designed to take compressive forces by composite action. Three to five panels are post-tensioned to form a group. Each group is subsequently connected to the adjacent group by splicing the post-tensioning tendons and grouting the intervening space. Placement of individual panels is sequenced to control dead load bending moments.

Vertical location of panel is controlled by using a leveling device. Composite action is achieved by the use of welded studs placed in shear pockets in the panels. The shear pockets and the space between the top of the steel and underside of the slab is filled with polymer grout.

RAILWAY APPLICATIONS

Several railway companies in North America have used precast concrete deck panels for the rehabilitation of bridges. Canadian Pacific rehabilitated a 400 ft (122 m) long bridge. Amtrak used precast decks with monolithic ballast curb to rehabilitate an existing single-track, concrete deck bridge.[39] Santa Fe initiated an experimental project in 1974 and its success has led to the rehabilitation of a number of their bridges. The Santa Fe experience is described here in further detail.[48-50]

Rehabilitation programs have been carried out on bridges on mainline, double-track sections, and also single-track sections. In the case of double-track sections, traffic was maintained by taking one track out of service at a time for a few days, and replacing up to 48 ft (15 m) length of track per day. In the case of the single-track section, traffic was rescheduled, and the track was taken out of service only a few hours at a time, replacing about 30 ft (9 m) length of track per day. In all cases, traffic was maintained without interruption.

The Atchison, Topeka and Santa Fe Railway Company

Precast prestressed panels have been successfully used to rehabilitate old timber-ballasted decks over steel deck-girder spans. Many of these bridges were originally built about 90 years ago with open decks. Later, the bridges were converted to timber-ballasted decks. Typically, the steel girders have riveted flange and cover plates and lateral bracing systems.

Over the years, the tops of the girder top flange and cover plates, and the lateral bracing systems have severely corroded away, resulting in significant loss of sections. Deck replacement was imperative. Inconvenient and expensive flange plate and bracing replacement

Fig. 54. A Santa Fe Railway Bridge.

Fig. 55. Deteriorated condition of bridge girder top flange, Santa Fe Railway.

and/or strengthening would be required if the use of the timber deck was continued.

Fig. 54 shows a typical Santa Fe Bridge, one without walkways and railings. Fig. 55 shows a typical deteriorated condition of the top flange. The top flange was sand blasted to white metal prior to the placement of precast panels. Fig. 56 shows a section of a deck, and Fig. 57 shows a detail at the interface of the slab panel and girder.

Typically, 8 in. (203 mm) thick panels are 14 ft (4.2 m) wide and 8 ft (2.4 m) long. In addition, 5 and 6 ft (1.5 and 1.8 m) panels are used as needed.

Panels are transversely prestressed with thirty-two ½ in. (12 mm) diameter, 270 K strands. Nonprestressed reinforcement is used in both longitudinal and transverse directions. The use of transverse prestressing provided a relatively thin and watertight slab. Fig. 58 shows typical slab dimensions and reinforcement details.

Plywood strips, ⅝ in. (16 mm) thick and ¾ in. (19 mm) wide, were bonded at both sides of the top flange by using epoxy paste. The top flange was then topped with trowellable epoxy mortar covering the rivet heads. The level of expoxy was slightly higher than the top of the plywood screed, to ensure complete contact with the bottom of the precast panels.

Fig. 59 shows a typical slab placement operation. The transverse joints between the slabs were tight at the bottom

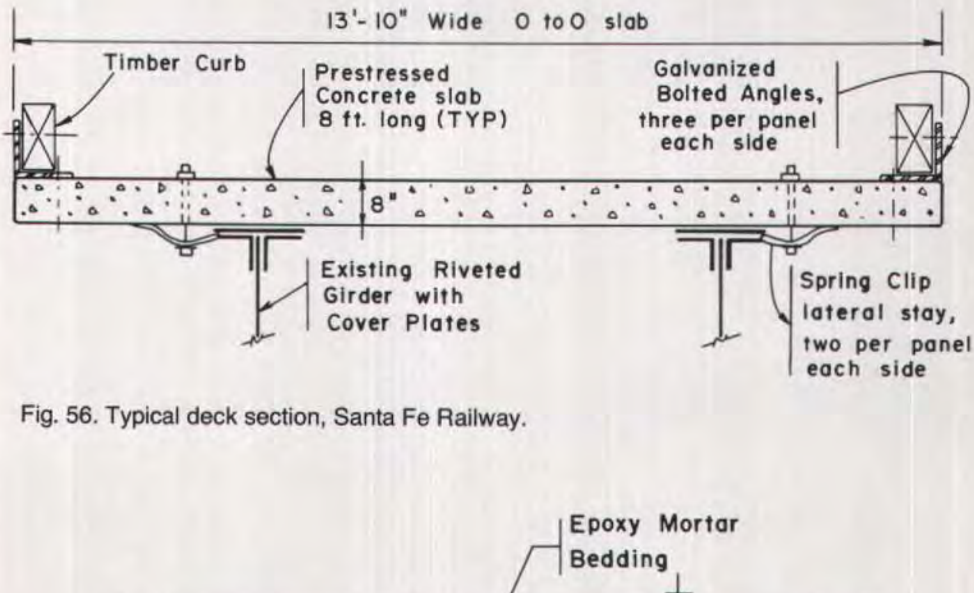


Fig. 56. Typical deck section, Santa Fe Railway.

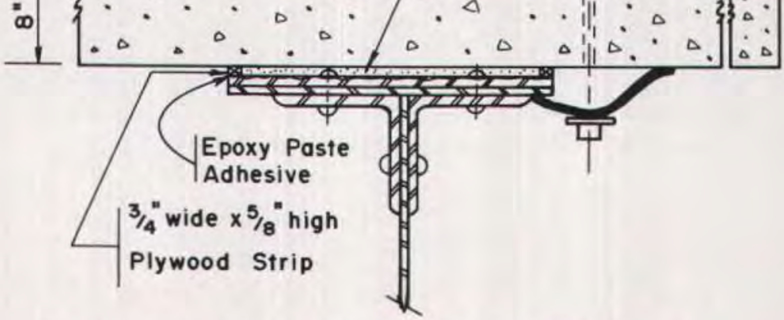


Fig. 57. Slab and girder connection detail, Santa Fe Railway.

and open by ¼ in. (6 mm) at the top. The bottom and sides of the transverse joint were first sealed by epoxy gel and later filled with pourable epoxy mortar. All epoxy used was water-compatible and silica sand was used as the aggregate.

Composite action develops due to adhesion of the epoxy mortar and due to mechanical action of the existing rivet heads. The development of composite action was verified by instrumentation and testing. Strength reduction due to the loss of flange plate thickness was augmented by the development of composite action. However, composite action was not used to increase the load rating of the bridges.

It was not necessary to replace the top

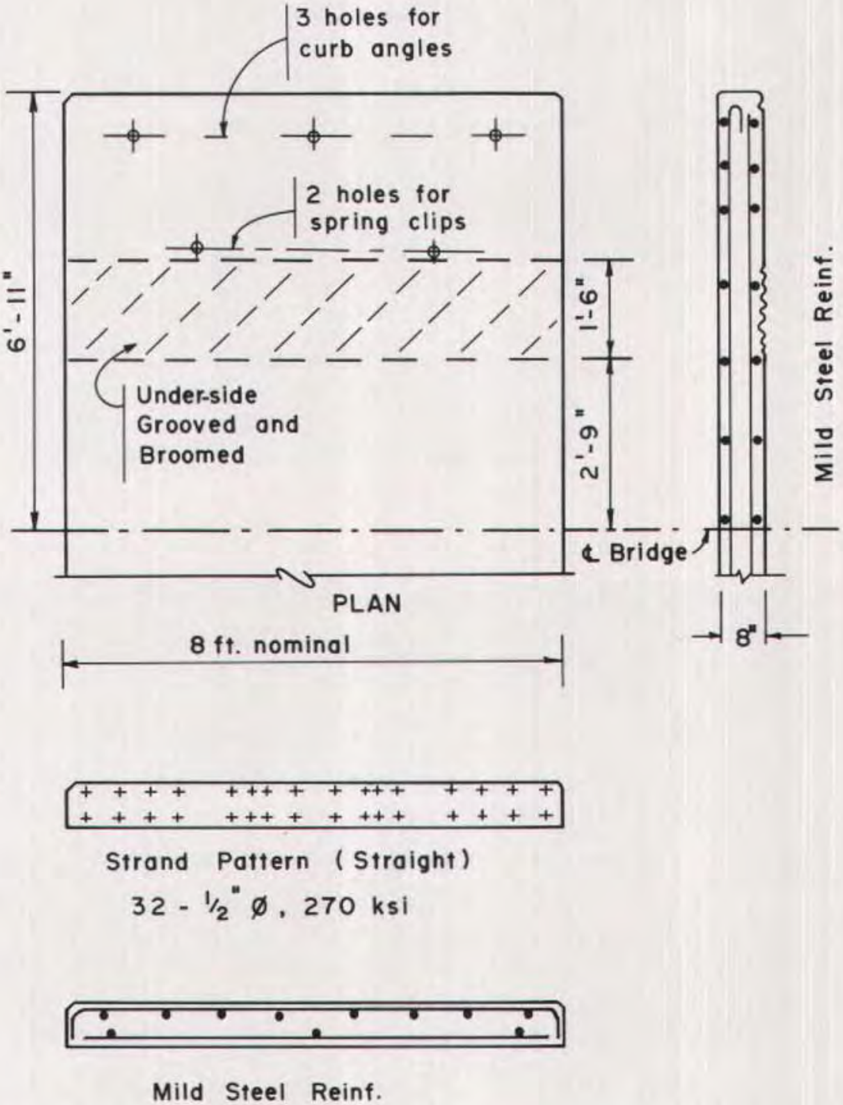


Fig. 58. Typical slab dimensions and details, Santa Fe Railway.

part of the lateral bracings because of the lateral stiffness provided by the concrete slab. The spring clips shown in Fig. 57 provide lateral restraint should the epoxy bond ever fail.

The prestressed slab with epoxied joints resulted in a watertight deck. This protects the steel girders and thereby substantially increases the time period of the painting and maintenance cycle. The concrete deck also has resulted in better riding quality.

Fig. 59. Precast slab placement, Santa Fe Railway.

Fig. 60. Setup for one-third scale model tests.

The system has been used for decks with or without walkways and handrails. In recent applications, new ties and ballast are preplaced on the panel and treated timber ballast curbs, steel walks and handrails are prefastened. With these techniques, along with use of fast setting epoxy, even greater speed of construction has been achieved.

The actual material cost of a precast concrete system is about 25 percent higher when compared to in-kind-replacement of timber-ballast deck. Other costs being equal and considering all the other values gained, the precast concrete system is deemed more cost effective in the long run.

Santa Fe has also successfully used twin-box sections and inverted-channel sections for the rehabilitation of many short span trestles.

RESEARCH

The responsibility of the bridge engineer in providing public safety and in obtaining the best value for the expenditure dictates that new technology be assured by prior research and investigation. An excellent example of this is the current application of partial depth precast panels, which was developed by several laboratory and field investigations.[20]

Because of the urgency and realities of bridge deck rehabilitation, the application of full depth precast deck had to go ahead of research. In effect, the bridge engineers have taken their experiments directly to the field.

With the application of this technology a number of uncertainties have been identified. These concern the structural systems, components and materials. Several research projects have recently attempted to address some of the issues.

Kao and Ballinger reported on static and fatigue load tests on precast ribbed bridge deck panels.[51] The panels were polymer-impregnated and post-tensioned. The test model used full-sized components, and up to three precast panels were used together. The test results confirmed the excellent behavior of the modular system, the transverse joints and the shear pocket joints.

Biswas et al., reported on design and

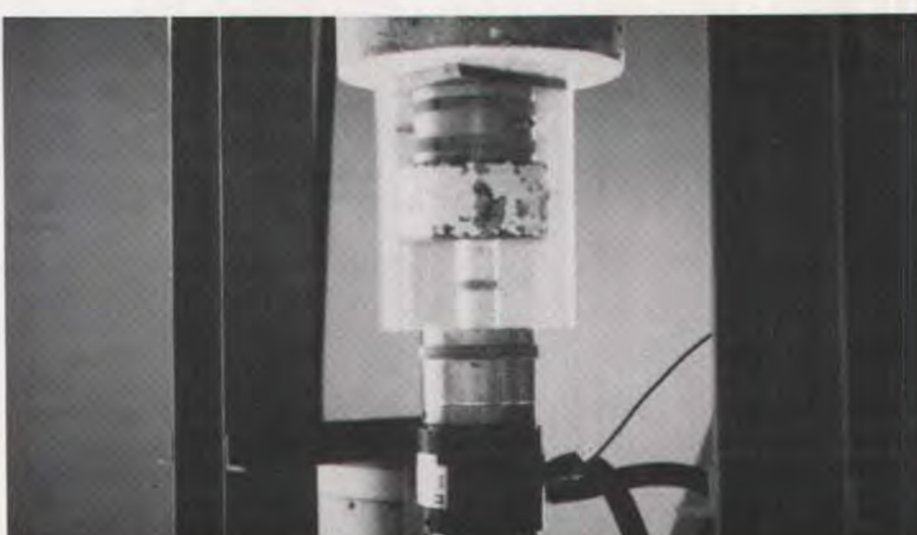


Fig. 61. Setup for repeated load tests on epoxy mortar sandwich specimen.

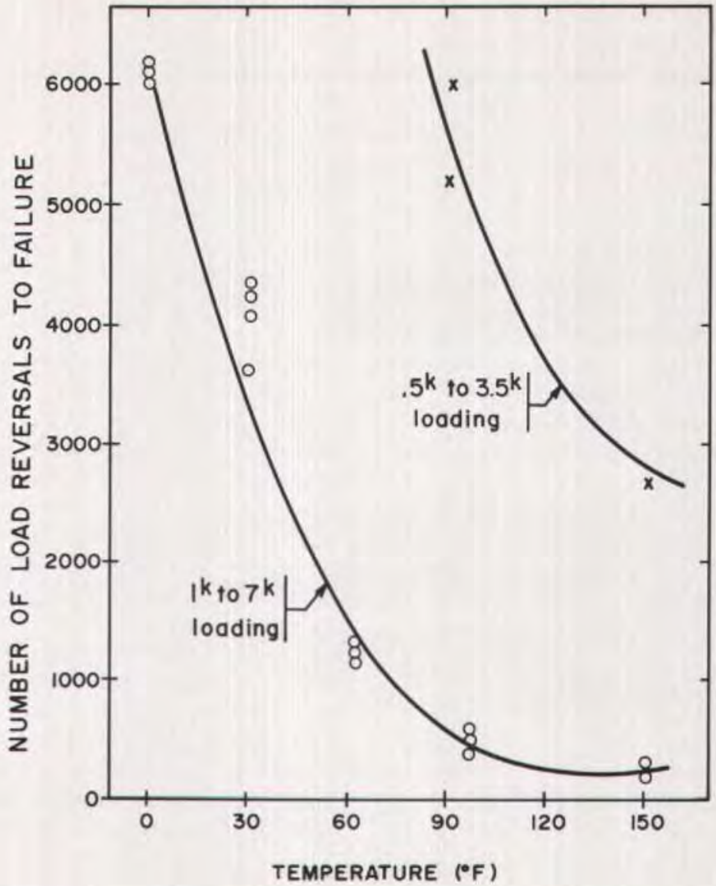


Fig. 62. Resistance of epoxy mortar to repeated loads at different temperatures.

test results of one-third scale model of a 60 ft (18 m) span bridge of modular construction using precast concrete panels.[52] Fig. 60 shows the setup of the one-third scale model at the Texas Transportation Institute. Test results confirm the predicted behavior of the composite deck structure. Subsequent tests on the same model have demonstrated satisfactory performance under fatigue loads.

Polymer-based structural mortars are often used as the joint material for precast elements. Satisfactory short-term and long-term performance of this material is a key to the success of modular construction. Biswas, et al., recently reported on the strength and durability of a typical polymer mortar (silica-sand epoxy).[53]

Fig. 61 shows the setup for repeated load test on a sandwich specimen. Fig. 62 indicates the varying resistance of the material at different temperatures. Fig. 63 shows specimens for freeze-thaw testing with varying amounts of moisture in the silica sand. Fig. 64 depicts the degradation of material property with increasing moisture content. Results indicate that the resistance of such material may be affected by severe repeated loads, extreme temperature cy-

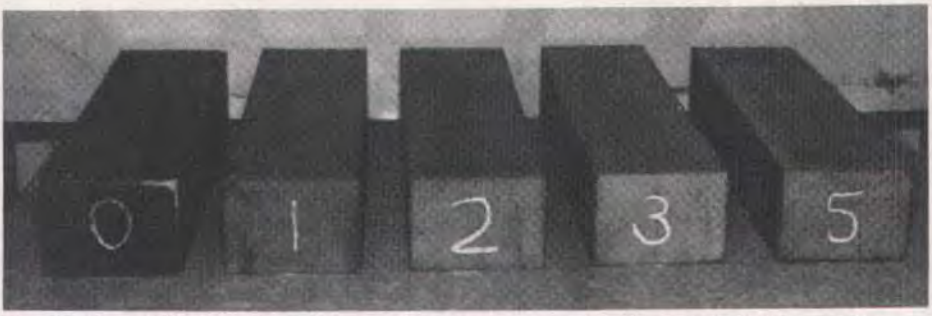


Fig. 63. Freeze-thaw test specimens of epoxy mortar with different moisture content.

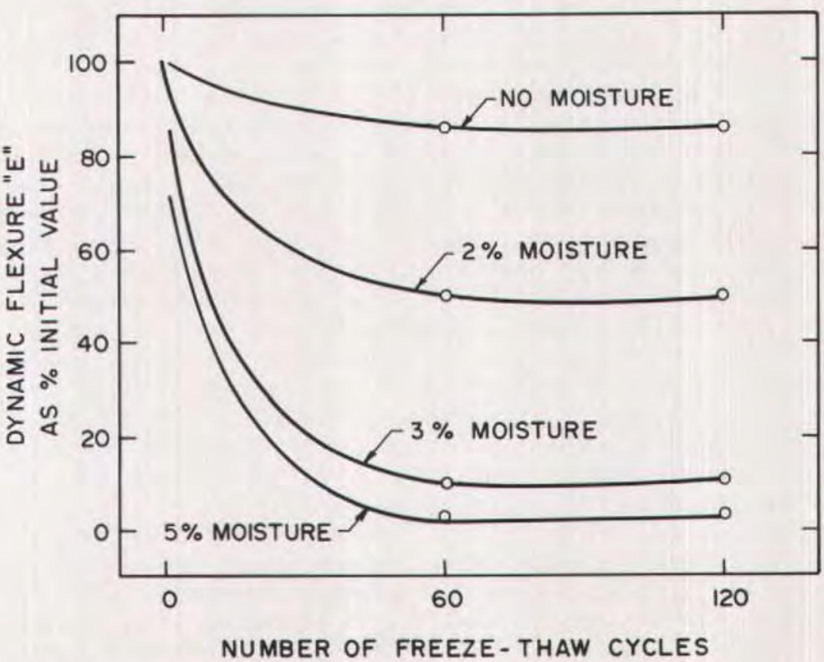


Fig. 64. Degradation of epoxy mortar with freeze-thaw cycles.

cles and the presence of moisture in its components.

Currently, several investigations are being conducted on the behavior and practical aspects of precast decks at Duke University, Transportation and Infrastructure Research Centre, the FHWA and Texas Transportation Institute, and other research laboratories.

Most applications of full depth precast deck have been on steel girder bridges because this type of construction was prevalent for the older bridges which now need rehabilitation. Recently, however, the feasibility of using precast panels for replacing decks built with AASHTO-PCI standard prestressed concrete I girders has been discussed. Some of these earlier bridges are approaching ages when they may need deck replacement. In 1983, Martin reported on designs and results of laboratory tests on connections for modular concrete bridge decks.[41]

Recent studies of Berger[42] and Kempf[45] have shown the structural and cost effectiveness of using full depth precast concrete decks. The ever-increasing demand for new bridges and bridge deck rehabilitation will make this construction method even more important in the future.[54]

CONCLUDING COMMENTS

Full depth precast concrete decks have been used for rehabilitation and construction of numerous bridges since the late sixties. This construction method has been used successfully for both highway and railway bridges. All types of bridge superstructure, e.g., common deck over girder bridges, truss bridges, steel box girder bridges, suspensions bridges and cable-stayed bridges, have been built using precast decks. Designs have included skew, superelevation and crowned profile.

The primary objective in the use of full depth precast concrete deck panels has been rapid construction, especially for the rehabilitation of bridges situated in heavily congested areas. The purpose of some of the earlier projects was to determine the feasibility of using this construction method. Subsequently, a number of major bridges were successfully completed within very restrictive schedules and under severe operational constraints. In many of the projects, traffic was maintained without interruption on the bridge during construction. The system has also proved to be cost competitive compared to alternative construction methods.

In practice, short term and/or long term cost effectiveness has been achieved in major bridge rehabilitation projects by several transportation organizations, e.g., the Pennsylvania Turnpike Commission, New York State Department of Transportation, and the Atchison, Topeka and Santa Fe Railway Company.

One engineer at NYSDOT stated that "The Department would not hesitate to use the system in the future even if time and maintenance considerations were not critical."

Another engineer at the Pennsylvania Turnpike Commission reported that "The Commission is very pleased with the performance and costs of their bridge decks. Plans are complete for another precast slab bridge deck, and it is certain that the Commission will use more precast slab bridge redecking in the future."

The use of full depth precast panels expedites the installation of a new deck whereas the removal of the old deck and deteriorated shear connectors, preparation of the top flange plus other procedures are extremely time consuming operations. Appropriate material and application methods for riding surface overlays, and types of ancillary structures, i.e., median barriers, curbs, railings and parapets should be chosen to fully capitalize on the construction time gained by using precast panels.

Mortars used at various joints in modular construction are critical components of the complete system. In their capacity as interface media in precast construction, they are subject to the same set of load effects as the principal concrete and steel structural components, and should be considered as structural materials.

Fast-setting non-shrink cement in addition to various polymer components such as epoxies, acrylics and latexes have been used as binders for the mortar. Occasionally, cement has been modified, i.e., combined with a polymer, for mortar. These materials are commonly considered as grout, filler or patching material. Data on quality control procedures and long term material strength and durability properties that are available for conventional structural materials are not usually available for these materials.

Both pretensioning and post-tensioning are often used in conjunction with the application of precast slabs. Under some circumstances, however, reinforced concrete precast slabs may be used without any prestressing.

The application of full depth precast concrete deck for the construction of new bridges in addition to the rehabilitation of deteriorated bridge structures has progressed steadily. The practical experience gained from such applications combined with the knowledge being learned from ongoing research will undoubtedly give this construction method a promising future.

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NOTE: Discussion of this report is invited. Please submit your comments to PCI Headquarters by November 1, 1986.

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