# DESIGN, FABRICATION, AND ERECTION OF FULL-SCALE PRECAST CONCRETE BRIDGE DECK PANELS WITH CONTINUOUS SHEAR POCKETS

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## ABSTRACT

More than 18,000 bridges in the United States are currently classified as ‘structurally deficient’. One of the most common deficiencies in bridges is deterioration of concrete bridge deck systems. In composite steel girder bridge construction, it is often desirable to replace the concrete deck while leaving the bridge’s supporting superstructure intact. Current practice in steel girder bridge deck replacement requires removal of the existing concrete deck and all shear connectors on the girder top flange. New shear connectors are then installed in discrete clusters along the girder length to achieve composite action between bridge components. Removal and replacement of original shear connectors in current projects account for a significant portion of construction resources. Recent research funded by the Transportation Research Board has proposed a preliminary design of a deck system utilizing continuous shear pockets which accommodate existing shear connectors with minimal modification. However, to date, such a system has not been proven as viable. In this study, a full-scale precast concrete deck panel system with continuous shear pockets was designed, fabricated, and erected. Specific aspects of design and pre-planning unique to continuous shear pocket deck systems were investigated. By demonstrating the practicality of continuous pocket deck systems, significant benefits in cost, schedule, and safety are possible on future bridge deck replacement projects.

**Keywords:** Deck Replacement, Accelerated Bridge Construction, Continuous, Shear Pockets

## INTRODUCTION

In the United States, more than 26% of the nation's bridges are currently categorized as either structurally deficient or functionally obsolete. Although these bridges do not pose immediate life safety risks, these deficiencies limit the functionality of bridges and require substantial repairs and remediation to return bridges to satisfactory operating condition[1]. Of these deficient bridges, approximately 60% are of the concrete slab/I-girder type[2].

Among the most common deficiencies identified in aging I-girder type bridges is deterioration of the concrete bridge deck. On many bridges with deck deterioration, the supporting girders remain in acceptable condition and capable of continued service. In such cases, removal and replacement of the concrete bridge deck is often the most attractive solution[3]. Substantial research effort has been devoted to the topic of rapid bridge deck replacement in recent years. Much of the bridge deck replacement research has been performed under the broader topic of accelerated bridge construction (ABC), which is a relatively new trend aimed at fast-tracking infrastructure construction projects.

Many early bridge deck replacement systems consisted of partial depth precast concrete panels requiring a cast-in-place concrete overlay. More recently, the use of full-depth precast concrete deck panel systems with field grouted joints has emerged as preferred practice[4]. Most full-depth precast concrete deck panels achieve composite action with supporting steel girders by utilizing shear connectors welded to the girder top flange which are eventually coupled to replacement panels by non-shrink grout installation.

Current deck replacement practice requires complete removal of 'old' shear connectors prior to installation of 'new' shear connectors[5]. The 'new' connectors are often installed in discrete clusters along the girder length. In hidden shear pocket applications, these clusters of connectors fit into preplanned discrete pockets cast into the underside of replacement deck panels and are not visible from the deck top surface. Precise layout and installation of the 'new' shear connectors is required to assure proper fit of connectors into corresponding pockets. The effort currently expended on projects to remove and install new shear connectors accounts for a significant portion of construction resources on bridge deck replacement projects.

Recent research funded by the Transportation Research Board has proposed the preliminary concept of a deck system utilizing continuous shear pockets[4]. Such pockets are capable of accommodating existing shear connectors without the need to remove and replace all existing connectors. Continuous pocket systems show great potential, but such a deck system has not yet been fully developed or experimentally demonstrated.

## BENEFITS OF CONTINOUS SHEAR POCKET SYSTEMS

### CONSTRUCTION SCHEDULE

Substantial improvement in construction schedule can be achieved by the use of continuous shear pockets on bridge deck replacement projects. Discrete pockets of shear connectors, as currently used, require substantial effort in pre-construction planning, detailing, coordination, surveying, and installation. In addition, despite best efforts by design and construction professionals to preplan and align pockets with clusters of connectors, conflicts often occur during installation which slow progress further.

By reusing existing shear connectors on bridge deck replacement projects, approximately one-quarter of the traditionally performed tasks are no longer required[5]. For instance, traditionally performed construction tasks omitted in continuous pocket construction include: removal of existing shear studs, milling and preparation of girder top flanges, surveying new stud locations, and installation of new shear studs. By omitting these tasks, significant improvements can be made in already time-critical schedules of deck replacement projects.

### WORKER SAFETY

Significant improvements in the safety of workers installing replacement deck panels are also achieved by the use of continuous shear pockets. By current practice, deck installation workers spend a considerable amount of time on elevated bridge girders altering shear connector layouts to receive replacement panels. During this time, workers are not only exposed to common fall hazards, but also must avoid tripping over newly installed shear connectors. In contrast, if continuous shear pockets are utilized, minimal modifications to existing conditions allow workers to experience a reduced exposure to dangerous hazards.

### PROJECT COST

Finally, the cost of deck replacement projects can be reduced by utilizing continuous shear pockets. While more than a quarter of U.S. highway bridges currently require some form of remediation, limited funding is available for such improvements. Reduced construction tasks and shorter schedule durations promise to reduce deck replacement project costs and allow more efficient use of limited bridge maintenance budgets.

## OBJECTIVES AND SCOPE

This research program is intended to demonstrate the practicality of design, fabrication, and erection of full-scale precast concrete bridge deck panels with continuous shear pockets. More specifically, the authors aim to:

- Address unique previously unexplored challenges inherent to continuous shear pocket construction
- Demonstrate constructability and erection feasibility of full-depth bridge deck panels with continuous shear pockets
- Encourage further research and implementation in this research area

The topic of continuous shear pockets as detailed herein is examined as part of a larger comprehensive study investigating the development and testing of a nonprestressed full-depth concrete deck panel system and innovative panel-to-panel connection types. In some cases, specimen design decisions were governed by other aspects and goals of the project. However, a primary goal of this investigation remained to demonstrate the practicality and durability of continuous shear pockets and design decisions were made accordingly.

## SPECIMEN DETAILS

In this study, a replacement deck system comprising of four full-depth precast concrete bridge deck panels with conventional reinforcing steel was designed, fabricated, transported, and erected in the laboratory in order to evaluate the feasibility of such a system. As shown in Figure 1, the system was designed as a two panel across system (shown), with the other two panels beyond (not shown.) The completed full-scale bridge specimen included three supporting girders supporting two design lanes for a total deck width (between control lines A and E) of 23 feet. The bridge length (perpendicular to the plane of Figure 1) was 16 feet.

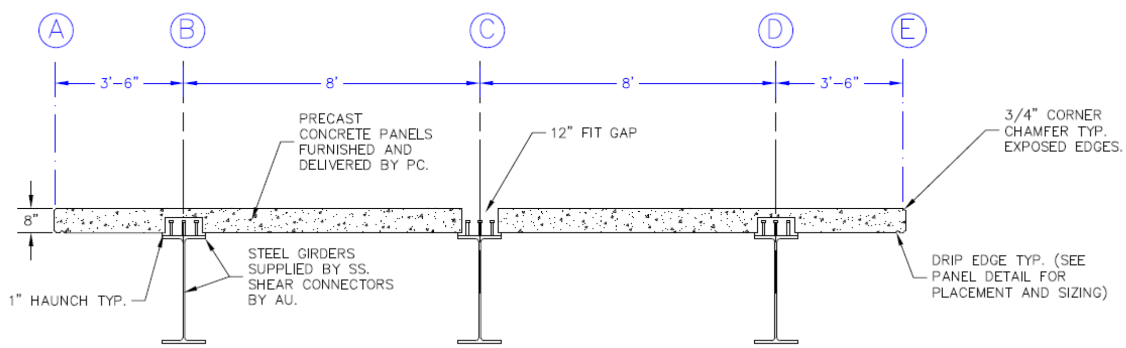


Figure 1: Bridge Specimen Elevation Before Grout Installation

Each deck panel included a continuous pocket to accommodate existing shear connectors along the girder top flange. These pockets are located along control lines B and D in Figure 1 and extend the full panel length. Figure 2 shows a typical continuous shear pocket location. It is important to note that the pocket continues the entire length of the precast panel, in contrast to commonly used discrete shear connector pockets. After initial placement of panels was complete, non-shrink grout was installed through preplanned grouting penetrations along control lines B and D to achieve composite action with existing supporting girders below.

Figure 2: Continuous Shear Pocket Detail Before (left) and After (right) Placement

## UNIQUE DESIGN AND PLANNING CONSIDERATIONS

### CONGESTION OF CONNECTIONS

In planning a continuous shear pocket system, it becomes obvious that congestion both in panel design and existing shear connector placement complicates the detailing process. Ideally, panels would have an unobstructed continuous shear pocket along the entire length capable of accommodating all existing studs. However, in reality, reinforcing steel is needed in this region and often must pass directly through the shear pocket.

To reduce congestion and minimize interference between shear connectors and panel reinforcing steel, the authors spaced the primary reinforcing in the panels as widely as permitted by applicable design code requirements. In this study, ¾ in. diameter shear connectors were attached to the girder top flanges at intervals of 5 in. along the girder. This represents a common pitch utilized in bridges in the project sponsor's locality[6].

In this study, shear connectors placed on the girder top flange were carefully positioned to avoid conflict with reinforcing steel passing through the pocket. This was accomplished by omitting a row of connectors at conflict locations. In real-world deck replacement applications, it is likely more feasible to survey reinforcing steel locations at the continuous shear pocket prior to panel placement and remove shear connectors in these conflict areas only. Most commonly, only minimal modification will be required as the reinforcing will likely fall between two adjacent rows of connectors.

### DURABILITY CONCERNS

Skeptics often contend that continuous pocket construction is impractical due to potential cracking of panels above the pocket location prior to final installation. In this study, geometry of the continuous pocket was selected in an effort to avoid premature cracking.

After satisfying design code requirements for top and side clearance (between shear connectors and adjacent concrete surfaces), it was possible to maintain 3 in. of intact concrete above the continuous pocket. This concrete above the pocket is sufficient to accommodate top reinforcing steel in the slab, while still allowing a typical 8 in. thickness of deck panel.

In order to increase durability of the panels, the decision was made to extend the bottom reinforcing steel directly through the pocket. This not only provides a tensile strut for lifting as discussed later, but also contributes to crack control, development of reinforcing steel, and maintaining panel continuity in pre-installation operations. This reinforcing steel can be seen extending across the pocket in Figure 2. After final installation and grouting of the replacement deck system, durability concerns are minimized and risks are similar to conventional discrete pocket or cast-in-place deck systems.

It is interesting to note that the design of continuous pocket systems differ from the design of other typical deck replacement systems. In continuous pocket systems, it becomes necessary to design for pre-placement considerations, as well as for behavior in the final grouted condition. Essentially, each panel must be designed with the capability to resist all handling forces with a prismatic strip of concrete 'missing' across the primary flexural direction.

## LIFTING CONSIDERATIONS AND SPREADER BEAM DESIGN

Previous limited research into the use of continuous shear pockets stressed the importance of designing panels for all stages of construction and also recommended the use of a load spreader beam to assure panels are only subject to vertical forces while lifting[4].

In the final installed and grouted condition, the bridge deck is designed to act as a one-way reinforced concrete slab across the roadway width. The grouted continuous shear pockets (directly above the support girder) will act in negative flexure to resist traffic loadings. However, in the preconstruction condition (un-grouted), it becomes obvious that the same negative flexure would have the tendency to induce tension in the concrete above the continuous pocket and compression in the lower reinforcing bar spanning the pocket. Therefore, consideration should be given to locate crane pick points as necessary to induce positive bending effects only through pocket locations during handling.

In this study, lifting device locations were preplanned and spreader beams were designed accordingly. Spreader beams were oriented as to prevent inducing moments in the direction which would tend to 'hinge' the pocket location. A schematic of the final lifting configuration is shown in Figure 3.

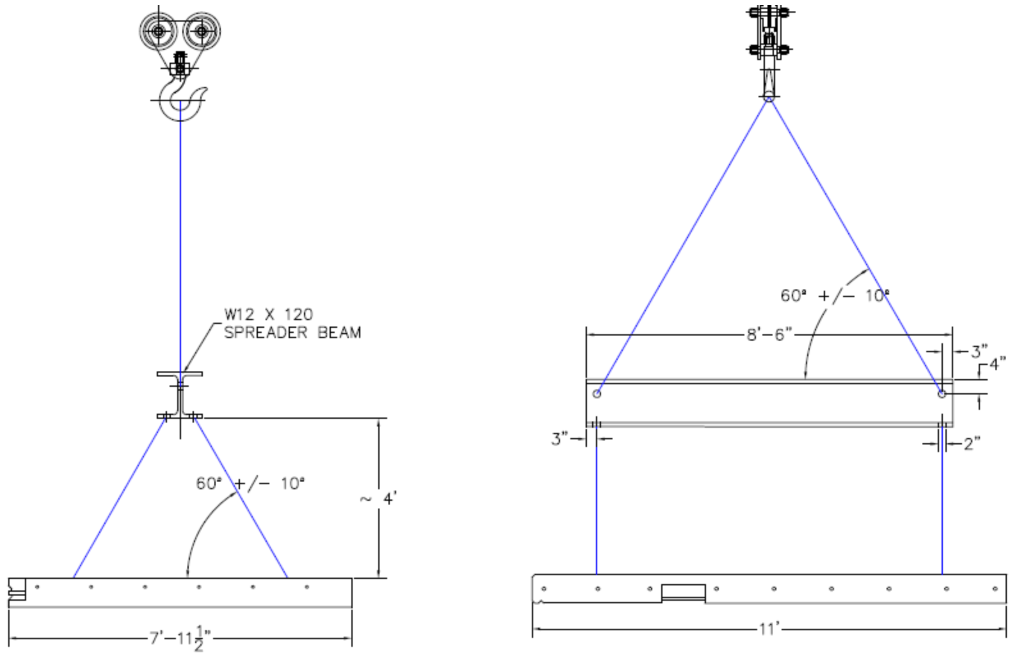


Figure 3: Final Lifting Configuration

TRANSPORTATION AND TRUCKING CONSIDERATIONS

In addition to the previous discussion of lifting considerations, it is critically important to preplan the transportation of precast deck panels when continuous shear pockets are used in order to minimize potential damage from freight. Recommendations to assist in planning transportation unique to the presence of continuous shear pocket systems include the following:

- Provide cribbing at multiple locations along length to avoid inducing larger than necessary moments or amplifying road impact movements.
- Provide cribbing near each side of the shear pocket if cribbing is positioned parallel to pocket location.
- Prohibit placing cribbing within the pocket to support to panel as this may induce undesirable negative curvature in this region
- Load straps are to be positioned only in regions where cribbing is present to avoid inducing unnecessary moments
- Require the fabricator/transport company to submit a transportation plan and assure compliance with all requirements prior to movement of panels

**RESULTS**

## FABRICATION

Panel fabrication was performed by a company with significant experience in the manufacture of precast concrete construction. In order to form the continuous shear pocket within the panel formwork, a section of dense blue foam was utilized. This foam served as a form for the concrete, while also allowing reinforcing bars to span through the pocket. Figure 4 shows completed formwork prior to concrete placement. After initial concrete curing was complete, panels were successfully removed from formwork and foam without exhibiting any signs of premature cracking.

Figure 4: Continuous Shear Pocket Formwork (left) and Concrete Placement (right)

## TRANSPORTATION

Utilizing the recommendations reviewed previously, a transportation plan was orchestrated with the manufacturer and shipper prior to the panel shipping date. The panels were successfully transported along 130 miles of highway road with no significant load shifting or damage. The loaded trailer configuration is shown in Figure 5 upon arriving at the project site.


Figure 5: Loaded Trailer Upon Arrival to Project Site

RIGGING/LIFTING

Offloading and lifting of the panels was accomplished successfully by the use of preplanned lifting embeds and a spreader beam. Panels were readily moved to their final location without difficulty using an overhead gantry-type crane. Although every effort was made for the panel to remain level throughout the lift, it was unavoidable for one side of the panel to touch down prior to the other. This brief eccentric loading of the panel did not cause damage to the replacement panels. All panels were successfully placed in final position without incident or premature damage. The lifting configuration utilized is shown in Figure 6.

Figure 6: Panel Rigging and Lifting

GROUTING

One area of particular concern for the research team was assuring that the non-shrink grout injected through the top of the panels would flow freely to achieve composite action along the full continuous pocket length. Grout injection ports and vent ports were provided at three foot spacing along the continuous pocket as suggested by previous preliminary research work[4]. This spacing proved satisfactory to allow flowing of grout to all required areas and resulted in an acceptable final grout installation as shown in Figure 7.

Figure 7: Grout Installed in Concealed Continuous Pocket (left) and Grout Injection (right)

## CONCLUSIONS AND FUTURE WORK

This experimental program has successfully demonstrated the design, fabrication, and erection of full-scale precast conventionally reinforced concrete bridge deck panels with a single continuous shear pocket along the length of each panel. Panels included in this investigation were successfully designed, fabricated, transported, and installed without exhibiting signs of premature damage or cracking.

After being installed and grouted, continuous shear pocket systems are essentially identical to currently commonly used discrete shear pocket systems. Load testing currently underway will validate the use of continuous pocket systems in final service conditions. By demonstrating the practicality of continuous shear pocket systems in I-girder type bridge deck remediation, substantial improvements in schedule, cost, and worker safety are possible on many future bridge deck replacement projects.

Future investigation involving continuous shear pockets is suggested as follows:

- Investigate continuous shear pocket use in larger width deck panels capable of spanning three or more girders
- Utilize continuous shear pocket systems on a full-scale bridge deck replacement pilot project

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**REFERENCES**

1. *Report Card for American Infrastructure* 2010. American Society of Civil Engineers (ASCE). Reston, VA, USA.
2. *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges. Report No. FHWA-PD-96-001.* Federal Highway Administration (FHWA), Washington, D.C. 1995.
3. *Accelerated Bridge Construction: Experience in Design, Fabrication, and Erection of Prefabricated Bridge Elements and System.* Publication No. HIF-12-013. 2011. U.S. Department of Transportation Federal Highway Administration (FHWA) Office of Bridge Technology, McLean, VA, USA.
4. Badie, S. and Tadros, M. 2008. *NCHRP Report 584: Full-Depth Precast Concrete Bridge Deck Panel Systems.* Transportation Research Board, Washington, D.C. USA.
5. Umphrey, J., Beck, D., Ramey, G., and Hughes, M. 2007. Rapid Replacement of Four GDOT Bridge Decks. *Practice Periodical on Structural Design and Construction, ASCE,* February 2007: 48-58.
6. *Bridge Bureau Structures Design and Detail Manual*, Alabama Department of Transportation (ALDOT), 2008. Montgomery, AL, USA.