Development and Implementation of Precast Paving Notch System for Accelerated Bridge Repair

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***Abstract*—Differential approach pavement settlement and the resulting formation of 'bumps' at the end of the bridge is a recurring problem for many State highway agencies. One of the main contributing factors in this settlement is deterioration or failure of the bridge paving notch. The conventional replacement procedure typically involves construction of a time-consuming, cast-in-place concrete paving notch followed by replacement of approach slab pavement. The objectives of this work were to develop a new, precast paving notch system and to verify and evaluate the structural capacity and implementation feasibility. The goal with rapid replacement would be a bridge approach slab support that can be installed in single-lane-widths to allow for staged construction under traffic during a single overnight closure. This paper presents a summary of the laboratory testing and field implementation of the precast paving notch system.**

***Index Terms*—paving notch, bridge settlement, accelerated bridge repair, laboratory testing, field implementation, field monitoring**

I. Introduction

Approach pavement settlement and the resulting formation of 'bumps' at the end of the bridge are recurring problems for many State highway agencies. [1] These 'bumps', generally manifested by differential settlement at the roadway/bridge deck interface, cause driver discomfort, impede traffic flow, exert excessive impact traffic loadings on the abutment, and draw substantial annual maintenance and repair expenditures. [2] One of the main contributing factors in this settlement is deterioration or failure of the bridge paving notch. A paving notch (also known as a corbel or a paving support) consists of a horizontal shelf constructed on the rear of a bridge abutment and is used to support the adjacent roadway pavement. [3] These paving notches have been observed to deteriorate/fail due to a number of complex factors including horizontal abutment movement due to seasonal temperature changes, loss of backfill materials by erosion, inadequate construction practices, foundation soil settlement, heavy traffic loads, salt brine that leaks through the expansion joint, and open expansion joints that fill with dirt and debris and 'push' the approach pavement off the paving notch. In some cases, the condition of the paving notch deterioration may not be noticed until the deterioration reaches a critical state and the approach pavement is removed (Fig. 1).

Although problems with the paving notch may be resolved through improved construction practices, a separate but equally important issue that bridge owners are frequently faced with is the need to replace critical bridge components during strictly limited or overnight bridge closure periods, especially in urban areas where bridge closures may cause considerable economic impact and inconvenience to the traveling public.

[4] The conventional repair procedure for this problem typically consists of removing the deteriorated paving notch concrete while preserving as much of the existing reinforcing steel as possible; constructing wood forms; and placing time-consuming, cast-in-place (CIP) concrete followed by replacement of the approach slab pavement. The conventional replacement method (Fig. 2), however,

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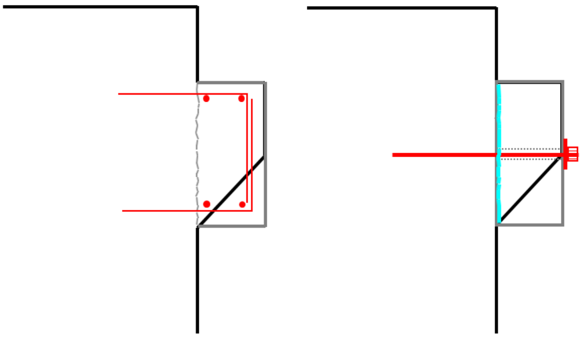
requires that the bridge be taken out of service for an extended period of time, which disrupts the traveling public. [5], [6] The notable number of bridges that exhibit the failing paving notch problem and, more importantly, their location on highly traveled roadways warranted the development of a much more quickly-installed option. With such a system, situations where the deterioration is unknown until approach pavement removal could be addressed with minimal traffic disruptions.

Figure 1. Paving notch failure/deterioration.

The objectives of this work were to develop a new precast paving notch system, and to verify and evaluate its structural capacity and implementation feasibility. The precast paving notch system was intended for use in either new construction or for rapid replacement. The goal with rapid replacement would be a bridge approach slab support that can be installed in single-lane-widths to allow for staged construction under traffic during a single overnight closure. The proposed system (Fig. 2) consists of a rectangular, precast concrete element that is connected to the rear of the abutment using high-strength threaded steel bars and an epoxy adhesive that is similar to that used in segmental bridge construction.



(a) Conventional (CIP) (b) Proposed (precast)

Figure 2. Conceptual drawings of paving notch system.

II. Laboratory Testing

The laboratory testing program was developed to verify the structural capacity of the developed precast paving notch system. The testing consisted of a series of static and cyclic load tests conducted in four phases. The precast paving notch specimens used in the laboratory testing were normal weight concrete, 12 in. x 12 in. x 4 ft – 0 in. in size, with ½ in. diameter prestressing strands and stirrups spaced at 8 in. and 12 in. on centers, respectively (Fig. 3).

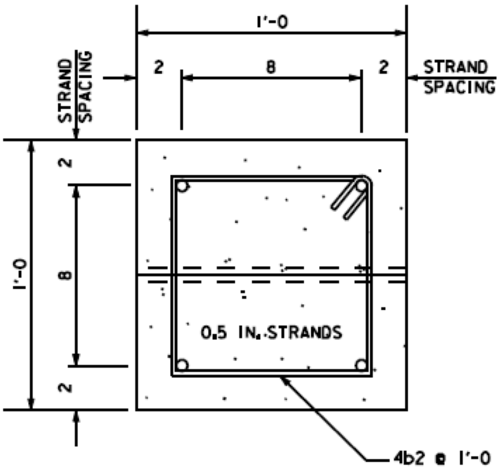


Figure 3. Drawing of laboratory testing specimen.

For the static and cyclic load tests, slip (displacement) between a simulated abutment (a 4-ft-cube concrete block) and the paving notch specimen was monitored using displacement transducers mounted on the top and bottom surfaces of the paving notch specimen. Following successful completion of the service level static and cyclic load tests, the paving notch system was loaded to failure to obtain a measure of the ultimate strength of the precast concrete components and connection details. The following sections describe the general testing procedures and present typical testing results.

A. Phase 1 – Post-Tensioned without Epoxy Adhesive

The first phase of testing was intended to investigate the post-tensing (PT) force needed to prevent slip of the paving notch system (i.e., friction force between the abutment and the paving notch specimen) without using an adhesive. [7] Assembly of the paving notch system involved attaching the paving notch specimen to the abutment block with 1 in. diameter Dywidag threaded bars–127.5-kip ultimate strength capacity – spaced at 3 ft on center. After attachment, the paving notch system was post-tensioned using a compact lightweight hydraulic jack containing a socket wrench and ratchet device that allows the nut to be tightened as the bar elongates. The paving notch system was instrumented with three displacement transducers: one transducer on top surface of the paving notch specimen directly above the load point and two transducers on the bottom surface of the paving notch specimen directly below the Dywidag threaded bars. A sample photograph of the assembled precast paving notch system instrumented with displacement transducers is presented in Fig. 4.

Before the first static load test started, the paving notch system was post-tensioned to 77 kips (i.e., [7] approximately 60 % of the bar ultimate strength). During testing, a single point load, using a hydraulic jack placed under the center of the paving notch specimen, was slowly applied to a 32-kip load. The force was then slowly released to zero and the loading sequence repeated three times. A total of six static load tests were conducted with each test completed in a similar manner with the exception of the PT force applied to the system. The next static load test involved the specimen with 10% less PT force applied to the system (i.e., approximately 50% of the ultimate strength of the bars). The static load test was repeated until the PT force was down to 13 kips (i.e., approximately 10% of the ultimate strength of the bars). The load-slip measurements were made for each static load test and sample plots are presented in Fig. 5.

Figure 4. Assembled precast paving notch system (Phase 1).

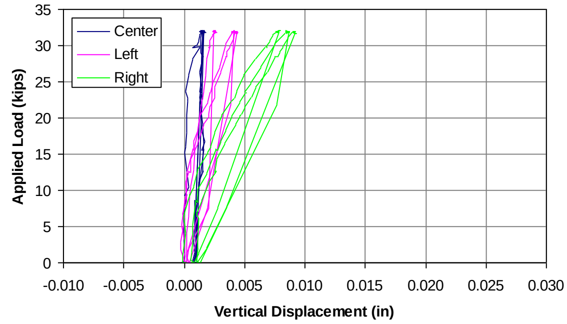
Before testing, it was expected that, when there was adequate frictional resistance, any displacement induced by an applied load would return to zero when the load was removed. This was confirmed by the first static load testing where virtually no residual displacement (slip) occurred when the specimen was attached to the abutment with 77 kips of force. The first indication of slippage was observed at 26 kips of PT force and the slippage continued to increase as the PT force was further reduced. The testing was stopped at 13 kips of PT force as the manifestation of residual displacement (slip) was obvious.

From this test, the research team learned and realized that the PT force needed to prevent slippage was less than originally anticipated. It was further postulated that an even smaller level of PT force could be used when an adhesive is used as part of the connection. This led to a modification to the original proposed solution. The next phase of the testing program describes the static load testing of the modified solution.

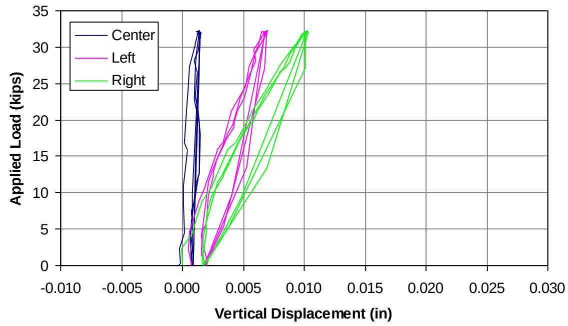
B. Phase 2 Drilled and Epoxy Grouted Anchor (One Row of Stainless Steel Bars)

The proposed solution was modified to provide a simpler, easier to install system. Two ¾ in. diameter stainless steel threaded bars were drilled into the abutment approximately 10 in. in depth, at 3 ft on center, anchored with [8] Epcon anchoring adhesive; [9] Unitex epoxy adhesives were applied to the interface between the abutment and the paving notch specimen; and the specimen was then attached to the abutment using a long wrench to provide clamping between the paving notch and the abutment.

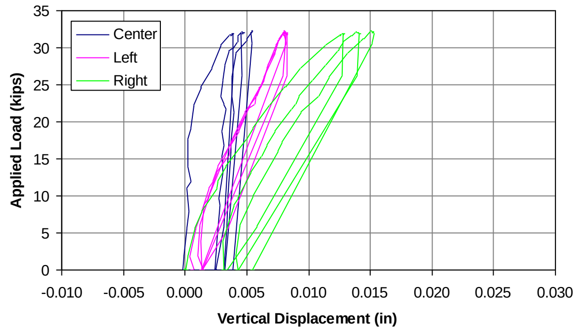
During testing, the specimen was instrumented with five displacement transducers: three on the top surface of the paving notch specimen and two on the bottom surface of the specimen. The specimen was then loaded with two hydraulic jacks placed directly below the stainless steel bars as shown in Fig. 6. The same basic loading procedure used in Phase 1 was used except, in this test, the zero-to-32-kip load cycle (16 kips for each jack) was repeated four times. After the four service-level cycles, the specimen was loaded to failure. Presented in Fig. 7 are the results of this testing. As shown, virtually no slip was observed during the four cyclic loadings and the precast paving notch system failed at approximately 62 kips.



(a) PT force: 77 kips



(b) PT force: 51 kips



(c) PT force: 26 kips

Figure 5. Load-slip test results for Phase 1.

After the test was completed, the connection was visually inspected. Fig. 8 shows a crack in the abutment concrete that seemed to propagate upward near the connection. It appeared that the failure during Phase 2 testing was a result of a combination of shear and outward prying. It was speculated that this phenomenon was due to the vertical force being applied slightly eccentrically, which caused bending stresses at the interface surface. In attempt to further improve the performance, an additional row of stainless steel bars (i.e., one set of bars close to the top and one set close to the bottom) was added to enhance system resistance to prying. This further enhancement will be discussed later as part of Phase 4.

Figure 6. Assembled precast paving notch system (Phase 2).

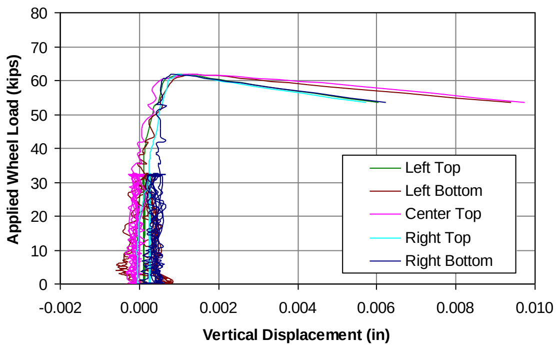
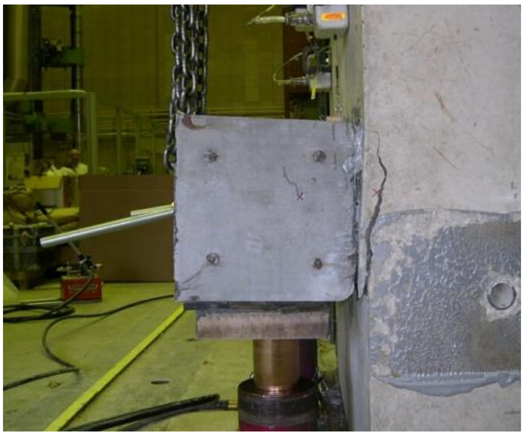


Figure 7. Load-slip test results for Phase 2.



(a) Side view showing cracked abutment

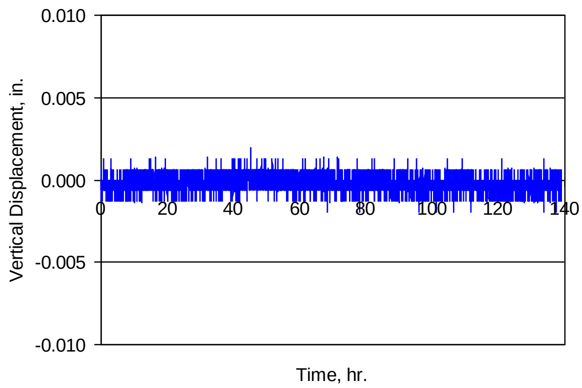
(b) Failed abutment concrete

Figure 8. Post-test inspection illustrating typical cracking failure.

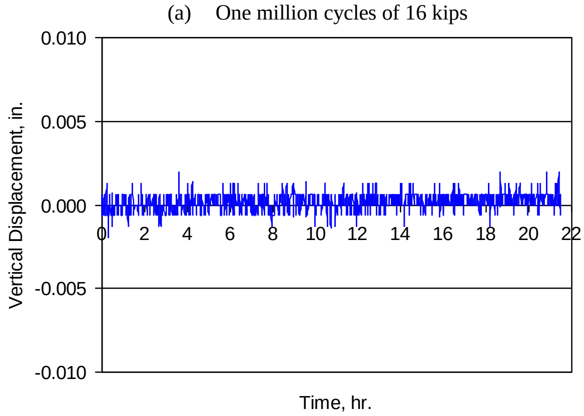
After removing the precast paving notch from the abutment (Fig. 8), it was observed that there was an obvious indication that the failure occurred primarily in the abutment concrete. This finding indicated that the strength of the epoxy adhesives was adequate.

C. Phase 3 – Iowa DOT's Current CIP Paving Notch Repair System

At the end of Phase 2, the Iowa DOT desired to compare the strength of the proposed system to their current CIP repair system. Based on the details provided by the Iowa DOT, a CIP paving notch repair system was constructed. The Iowa DOT's CIP repair specimen consists of bent epoxy-coated reinforcing bars inserted into drilled holes and fastened with epoxy adhesive. Conventional plywood forms were constructed around the cage for the placement of normal weight concrete to complete the construction of the paving notch. Upon the completion of the construction, the CIP repair system was loaded to failure with two hydraulic jacks placed at the same location where the stainless steel threaded bars would have been located in the previous static load tests. The CIP repair system failed at approximately 46 kips.



(a) One million cycles of 16 kips



(b) 100,000 cycles of 32 kips

Figure 9. Fatigue load test results.

D. Phase 4 – Drilled and Epoxy Grouted Anchor (Two Rows of Stainless Steel Bars)

The last phase of the testing program consisted of the application of a cyclic load to the twice modified precast paving notch specimen to simulate a finite number of wheel load applications. The purpose of this testing was to investigate the long term performance of the system subjected to repeated loadings. Due to the prying effect observed in Phase 2, the design was modified so that the precast paving notch system has two sets of ¾ in. diameter stainless steel bars that were drilled and grouted approximately 10 in. into the abutment. Two cyclic load tests were conducted on the system: the first with one million cycles of a 16-kip load and the other with 100,000 cycles of a 32-kip load. During this testing no slip was observed (Fig. 9).

(a) Load test setup

(b) Side view of the failed interface

Figure 10. Photographs of ultimate load test setup and post-test inspection on the specimen with four stainless bars (two rows).

Following successful completion of the cyclic load testing, the precast paving notch system specimen was loaded to failure to obtain a measure of the ultimate strength of the precast concrete components and connection details (Fig. 10). The paving notch system failed at approximately 112 kips.

From the post-test visual inspection of the failed specimen (Fig. 10), it appeared that the failure of the system was a result of abutment concrete cracking. After initial cracking, the research team continued to load the specimen until the paving notch severed from the abutment. In general, the failure pattern was similar to what was observed in Phase 2.

III. Field Implementation

Following successful laboratory testing, a field implementation site in Marion County, IA was selected. The bridge which was the subject of this implementation is a 126.3 ft x 40 ft, three-span prestressed concrete beam bridge that consists of two 34.9 ft end spans and a 56.6 ft center span with seven beams spaced at 6.33 ft on center.

The final design (Fig. 11) for the field implementation was modified from the original design that was used in the laboratory investigation based on the test results and lessons learned. The precast paving notch was designed for [10] the AASHTO live loads and all prestressing strands used in the precast paving notch system conformed to ASTM-A416 Grade 270 low relaxation strands. Each 1 1/2 in. hole in the precast paving notch was formed using a corrugated metal sleeve meeting the requirements of ASTM A619-04 and galvanized in accordance with ASTM A527-71. In addition, the length of the paving notch system was adjusted to account for elastic shortening, creep, and shrinkage.

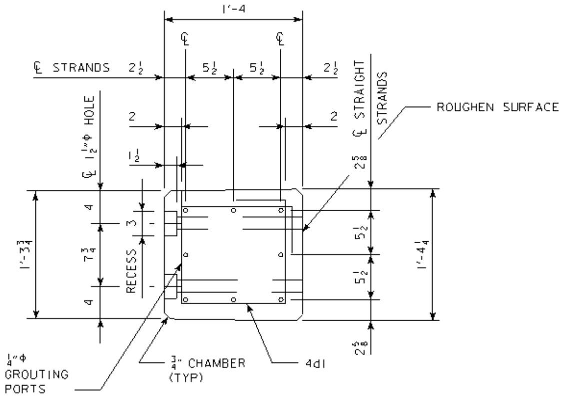
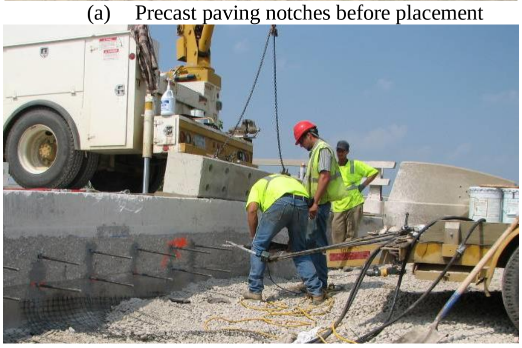
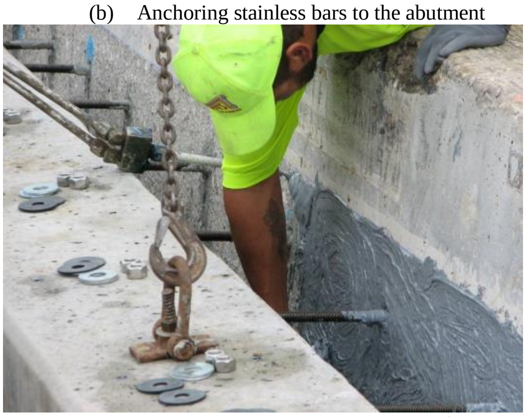


Figure 11. Cross section of the final design.

(a) Precast paving notches before placement



(b) Anchoring stainless bars to the abutment



(c) Applying epoxy at the adjoining surfaces

(d) Installation completed

Figure 12. Photographs showing the installation of the precast paving notch system.

The installation of the precast paving notch system required preparation and attachment procedures similar to those followed during the laboratory test phase. Photographs of the installation of the precast paving notch system are shown in Fig. 12. A list and brief description of the principal installation steps are summarized as follow:

- Following closure of the bridge, a strip of approach pavement near the bridge was removed and the existing, deteriorated paving notch was saw-cut and removed until sound concrete was identified.
- Several holes, 12 in. deep, were drilled into the existing concrete abutment. The location of the holes was based upon the geometry of the precast paving notch and various field measurements. Then, epoxy grout was injected into the drilled holes followed by the insertion of 3/4 in. diameter stainless steel threaded bars. Note that the holes in the abutment were drilled slightly larger than the stainless steel bars to provide tolerance for field variability and improved workability.
- The precast paving notch system was placed with special care so as to not damage the paving notch and the threaded stainless bars. Prior to placement, the adjoining face of the precast paving notch system was roughened to a coarse broom texture to enhance the bond between the abutment and the paving notch.
- Epoxy was then applied to both faces of the adjoining surfaces. The epoxy material used was suitable for bonding hardened concrete to hardened concrete and was proportioned and applied according to [9] the manufacturer's recommendations. The set time of the epoxy was such that final bolt-tightening was completed before the epoxy pot life expired.
- The paving notch system was attached and clamped to the existing abutment concrete with the stainless steel bars passing through the drilled holes and anchored to the abutment with heavy hex stainless nuts and washers.
- Excess epoxy squeezed out of the joint onto the surface of the precast paving notch was then removed. With concrete sealer applied to the precast paving notch end sections, the installation was completed.

Once the installation was completed, the paving notch system was continuously monitored to determine if there was any slippage between the paving notch and the abutment while in service. The paving notch system was instrumented with a monitoring system programmed such that a text alert message be sent to bridge owners if there was slip exceeding 0.01 in. The monitoring results indicated that virtually no slippage has occurred between the abutment and the precast paving notch, thereby indicating that the installation technique utilized in the field was effective.

IV. Concluding Remarks

Overall, the effectiveness and feasibility of the use of the precast paving notch system was demonstrated through a laboratory investigation and field implementation. Based upon the results of the laboratory testing and a post-test visual inspection of failure surface, and a field implementation and monitoring program, the following observations and concluding remarks were made:

A. *Laboratory Investigation*

- When epoxy adhesives were used, a solid connection between the precast paving notch and the abutment can be achieved by hand-tightening ¾ in. diameter stainless steel treaded bars that were drilled and grouted approximately 10 in. into the abutment.
- In comparison between Phase 2 (one row of stainless steel bars) and Phase 4 (two rows of stainless bars) test results, the use of an additional set (row) of stainless threaded bars improved the ultimate load carrying capacity of the precast paving notch system by approximately 80% (from 62 kips to 112 kips).
- In comparison to the ultimate strength of the Iowa DOT's current CIP paving notch repair system, the proposed precast paving notch system showed larger ultimate load carrying capacity (i.e., failure occurred at 46 kips for the CIP repair system used in Phase 3 vs. at 112 kips for the precast paving notch system used in Phase 4).
- None of the tested precast paving notch specimens failed during testing. In all cases, failure occurred in the abutment concrete at the connection interface.
- No significant slippage was observed during cyclic testing.
- The laboratory tests performed in this investigation are believed to be conservative. In all tests, the specimens were loaded with a single point load or a combination of two point loads applied directly to the paving notch specimens. In reality, however, the traffic load will be distributed over the depth of the pavement, thereby inducing smaller load on the paving notch system. Note that the ultimate load that caused the initial failure was 3 to 4 times larger than what could be expected.

B. *Field Implementation*

- The stainless steel bars drilled and grouted into the existing abutment provided a simple, effective solution for anchoring the precast paving notch system to an existing abutment. The continuous monitoring system instrumented on the paving notch system provided evidence that there was no slip at the connection between the abutment and the precast paving notch system under traffic loads.

- No major obstacles were encountered during the handling and installation. The U-shaped lifting anchors were adequate for moving the precast paving notches and left only small holes that were later easily filled and sealed.
- Even with no experience prior to this project, the field installation of the precast paving notch system only required approximately one day of a bridge closure. However, it is believed that the installation speed may be improved when contractors become more familiar with the required installation techniques.
- While the field implementation of the precast paving notch system was a successful process, it should be noted that the success of the project can only be achieved by good workmanship, inspection and quality control.
- The developed system may be adapted to other bridges with different widths, thicknesses and skew angles. It may also allow for replacement of an existing paving notch under traffic if partial-width (i.e., staging) construction method is used.

Acknowledgment

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