The large majority of short to medium span bridge system in the United States is the composite beam/slab system. The beam is generally precast prestressed concrete or structural steel I-beam. Cast-in-place (CIP) reinforced concrete deck system, as the most commonly used system, has the primary advantages such as field adjustment to produce a smooth roadway profile. But the CIP bridge deck slabs experience cracking shortly after construction due to its tendency to shorten relative to the beams, which is resulted from the temperature gradients and differential creep and shrinkage. They generally require major repair or replacement work in only 15 to 25 years, while the beams generally last much longer. In addition, nearly one-half of the about 600,000 highway bridges in the United States are in need of replacement or rehabilitation. The objective of this paper is to present a creative full-depth precast/prestressed concrete bridge deck system that enables fast efficient construction, yields superior performance in service and reduces long-term maintenance and replacement costs. The proposed bridge deck system is transversely pretensioned and longitudinally post-tensioned, which results in significant reduction in maintenance and greater durability of the overall structure. The typical precast deck unit is 2.4 m (8 ft)-long and full-width of the bridge with shear key. The newly developed one inch and a quarter diameter studs are incorporated to produce the composite action between the deck and bridge, which greatly reduces the amount of required studs and save the construction time. A possible construction procedure is discussed in the paper. As a crack-free system, the proposed bridge, which greatly reduces the amount of required studs and save the construction time. A
INTRODUCTION

The large majority of short to medium span bridge system in the United States is the composite beam/slab system. The beam is generally precast prestressed concrete or structural steel I-beam. As the most commonly used system, cast-in-place (CIP) reinforced concrete deck system has the primary advantages of field adjustment to produce a smooth roadway profile. It is convenient for providing continuity between the beams and the deck, i.e. composite action, and for continuity between the deck and the railing for crash worthiness. However, CIP has the intrinsic weakness of its tendency to shorten relative to the beams due to temperature gradients and to differential creep and shrinkage. They generally require major repair or replacement work in only 15 to 25 years, while the beams generally last much longer. In addition, approximately one-half of the about 600,000 highway bridges in the United States require replacement or rehabilitation. Since a large number of these bridges carry heavy traffic, it is very necessary to remove and replace the deck in a short period.

Numerous attempts have been made to correct this weakness, with varying degrees of success. One of the earliest FHWA “High Performance Concrete (HPC)” Showcase Program bridges was the 120th and Giles Road Bridge in Sarpy County, Nebraska, which was opened to traffic in 1997. The deck was made 55.2 MPa (8000 psi) HPC concrete. Strict curing specifications were placed, which included misting, spraying of a curing compound and placement of wet burlap for seven days. Upon inspection of the deck several weeks after completion of the bridge, significant cracking was observed on the bottom surface of the deck. There have been similar observations on other bridges, even with use of Type K expansive cement and shrinkage compensating admixtures. Additional drawbacks of CIP concrete decks are low speed of construction and the need for strict field quality control.

There are currently two types of precast prestressed deck panel systems. The more common one utilizes 76.2 mm to 127 mm (3 to 5 in.) stay-in-place pretensioned panels that span between beam edges and are totally separated over beam top flanges. They house the positive transverse moment reinforcement, which is generally pretensioning strand. Negative moment reinforcement is provided in a CIP composite topping. This system sometimes experiences reflective cracking over panel edges. In addition, experiments in the NCHRP 12-41 project have confirmed that lack of anchor of the transverse strand reinforcement in individual panels into the beam supports reduces arching action and the system’s load capacity compared to full-bridge-width CIP or precast panel systems. Another major drawback of this system is the need for conventional forming and construction of overhangs.

The second precast concrete deck system, often used in replacement projects, is full-depth, full-width precast panels that are about 2.4 m to 3 m (8 to 10 ft) long. These panels are conventionally reinforced in the transverse direction and post-tensioned along traffic. They have been placed primarily on steel plate beam bridges with the horizontal shear stud connectors clustered in pockets at about 0.6 m (2 ft) spacing. The pockets are grouted after the panels are post-tensioned. This system does not have the flexibility of use with precast prestressed beams as the horizontal shear reinforcement cannot be conveniently clustered in pockets. In addition, pockets and post-tensioning ducts require grouting. The system generally has no transverse prestressing, and is thus subject to cracking under service conditions.

It appears, therefore, that a need exists for a cost-effective concrete deck system that has the following characteristics: (a) Precast concrete installed when most of the creep, shrinkage and heat of hydration have taken place; (b) Prestressed concrete in which the level of prestressing is high enough to result in zero residual tension at service conditions, both in the longitudinal and transverse directions; (c) Panel system that allows for simple construction and creation of composite action with the beams, especially concrete beams; and (d) Panel system that allows for the prestressing to be introduced before composite action takes place, so that the much stiffer beams do not attract most of the prestressing.

This paper presents an innovative full-depth precast/prestressed concrete bridge deck system that enables fast efficient construction, yields superior performance in service and reduces long-term maintenance and replacement costs.

DESCRIPTION OF THE PROPOSED SYSTEM

Figure 1 shows two 1.2 m (4 ft) by 14.2 m (46'-6") wide by 152.4 mm (6 in.) thick panels displayed for demonstration purposes at the yard of Concrete Industries in Lincoln, Nebraska. The panels for the Skyline Rd. Bridge will be 2.4 m (8 ft) long (along traffic) and as wide as the bridge, i.e. 15.7 m (51.5 ft).

The panels shown in the photo were designed for a beam spacing of 3.6 m (12 ft), which is the widest beam spacing allowed in Nebraska and many other states, and for a skew angle of 30°, which is near the limits for skewed panels in this system. For larger skews, right angle panels may be more convenient to use. The panels were made by Rinker Materials of Bellevue, Nebraska, and shipped to Concrete Industries, Lincoln, Nebraska. This allowed a full-scale demonstration of the ability to handle ship and install these panels, as most casual observers would tend to believe that they are too flexible to handle and ship. It also demonstrated the excellent working relationship between the two major precasters in the state.

As Figures 2, 3 and 4 show, each panel is reinforced with 16 mm (#5) bars at 304.8 mm (12 in.)
spacing in the longitudinal direction. The transverse reinforcement is pairs of 12.7 in. (0.5 in.) diameter Grade 1862 MPa (270 ksi) low relaxation strands at 609.6 mm (24 in.) spacing. The two strands in the pair are spaced vertically to allow one in. clear concrete cover. The effective pretensioning stress (after accounting for time dependent losses) amounts to about 2.4 MPa (350 psi). Considering arching effects and strand continuity, theory has shown this quantity to be adequate for beam spacing up to 3.6 m (12 ft). To assure a short transfer length of prestressing, an innovative detail was used. High strength wire spiral was placed around each pair at the end 0.6 m (2 ft).

One of the primary innovations of this system is the fully open gap in the panel over each of the beam lines. To preserve the tension in the continuing strands and, thus, the pre-compression in the concrete, the absent concrete strip in the gap is substituted with 4-22 mm (4#7) bars at the location of each pair of strands. These bars can be viewed as “prestressed rebar”.

Within the space in any given gap, the tension in each pair of strands is equal to the compression in each set of four bars. In the solid concrete between beam line gaps, the tension in the strands is equal to the compression in the concrete. The bar size is determined by its ability to resist buckling during prestress release and bending during handling and erection. The value of a totally open gap is to avoid conflicts with the composite action studs, and more importantly to greatly simplify post-tensioning in the longitudinal direction.

Besides the precast panels, there are other components of the system that involve innovation: Large diameter studs placed at the centerline of the beam in one row at 152.4 mm (6 in.) spacing. NCHRP 12-41 project and additional funding by NDOR included extensive ultimate and fatigue studies on 31.8 mm (1 ¼ in.) diameter studs. It has been demonstrated that each 31.8 mm (1 ¼ in.) stud is equivalent to about two 22.2 mm (7/8 in.) diameter studs. A bridge has already been constructed with this new size and has performed equally to conventional design. Using these large studs greatly reduces fabrication costs of steel plate girders, improves safety in the field and speeds up total construction.

The hanging supporting system, or plastic shim stacks, can be placed at the corners of the panels at each beam line, see Figure 5. The height of support or shim stack is expected to be provided by the designer. The designer would calculate the support or shim heights after accounting for deflection due to panel weights and additional loads. After the panels are set in place on the support or shims, further minor profile adjustments can be accommodated in the topping thickness.

Grouting of transverse shear key joints between panels is done using a high performance concrete flowable grout. There is no need to use shrinkage-compensating admixtures in this grout as the joints will have in-service residual compression due to longitudinal post-tensioning. The grout strength should match that of the panels, a minimum of 34.5 MPa (5000 psi).

Post-tensioning is done using a unique process. 16-15.24 mm (16-0.6 in.) diameter strands are threaded between the pairs of strands and groups of four bars. The gap over the beams can be viewed as an open channel post-tensioning “duct, or sheathing.” The criticism in recent years of lack of quality grouting of post-tensioning ducts is totally eliminated here. The tensioning of the strands is done individually using a light weight mono-strand jack. Post-tensioning is done after the transverse joints attain adequate strength (about 10.3 MPa (1500 psi)) and before composite action is effected. This puts the post-tensioning force fully in the deck rather than inefficiently sharing it with the much stiffer beams. The pre-compression in the deck is about 5.5 MPa (800 psi). This would allow for no tension in the deck even in the negative moment zone of the beams over the piers. This system is therefore highly resistant to transverse cracking, which has been a major problem in recent years.

Longitudinal gap over beams is filled with expansive cementitious grout similar to that used in filling ducts in conventional bonded post-tensioning. Grout in that gap, similar to grout in P/T ducts, is not precompressed. A mix has been developed in Nebraska for the grout that achieves high strength, flowability, and expansion during initial set. Topping is 50.8 mm (2-in.) silica fume composite overlay that has excellent moisture penetration resistance.

**POST-TENSIONING THE END DECK PANEL**

The end deck panel of the bridge is designed to work as the post-tensioning anchorage block. In order to show the constructability of the post-tensioning procedure, a bridge deck panel specimen was made in the university structure lab for demonstration purpose (see Figure 6). All 16 strands were post-tensioned in this specimen. It showed that the post-tensioning procedure was doable and the tensioning device was very easy for operation.

**CONSTRUCTION STEPS**

1. Determine the elevations of the support system and install them.
2. Set the panels sequentially from one end, starting with the special anchorage end panel, then the typical panels, then the special end panel. Use two CAT 950F Front End Loaders or similar equipment to install each panel.
3. Grout the shear keys between the panels. Make sure the ends are fully sealed to prevent accidental leakage into open channels.
4. Install post-tensioning strands. Post-tension the deck panel according to the construction documents.
5. Fill open channels and place overlay concrete.
IMPLEMENTATION

The bridge chosen as a prototype for this system is located at Skyline Drive and West Dodge Road in Omaha, Nebraska (see Figure 7). The project is 198 St. to Skyline Drive (EACNH-STPC/E-6-7 (114)). The bridge will carry Skyline Drive traffic over West Dodge Road (US 6 Expressway). Current average daily traffic is 1445 estimated to increase to 3110 by the year 2022. This project is scheduled for the letting of August 2002. Construction commenced in April of 2003 and the bridge is due to be completed and open to traffic by November of 2003.

CONCLUSIONS

Deck is connected with a basic component of most bridges built in the U.S., regardless of whether the supporting elements are steel or concrete beams, arches or trusses. On the other hand, decks are the major source of bridge deterioration and deficiency. Deck replacement must be done quickly to avoid loss of revenues to the traveling public. In particular, the proposed bridge deck system can result in as much as 50% reduction in construction time of deck slabs. The deck obtained is compressed in two directions resulting in significant reduction in operation and maintenance and in greater durability of the overall structure. The space between beam flanges is fully covered with deck panels, thus protecting workers against accidental falling. Rapid construction and reduced maintenance diminish the probability of workers’ injury.

REFERENCES


Figure 1. Plan View of Typical Precast Prestressed NUDECK Panel
*Note: The numbers show the order of the construction steps.
Full-depth Precast/Prestressed Concrete Bridge Deck Panel System

Figure 2. Plan View of Prestressed NUDECK Panel (1 mm=0.0394 in., 1 MPa=0.145 ksi)

Figure 3. Cross Section of Prestressed NUDECK Panel (1 mm=0.0394 in.)

Figure 4. Precast Prestressed NUDECK Panel Details

Inserts for railing connection

76.2 mm diameter grouting hole (needed for wide flange concrete beams only)

4-22 mm rebar @0.6 m

2-12.7 mm diameter pretensioning strands @0.6 m
Figure 5. Arrangement of Post-tensioning Strands (1 mm = 0.0394 in.)

Figure 6. Bridge Deck Panel Specimen for Post-tensioning Demonstration

Figure 7. Implementation of Proposed Bridge Deck Panel System