DECK PROTECTION SYSTEMS FOR BRIDGES CONSTRUCTED WITH PRECAST CONCRETE DECK SLABS

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ABSTRACT

This paper compares deck wearing and protection systems for bridges constructed with precast deck slabs (PDS). Literature was reviewed to identify systems used on bridges constructed with PDS and other types of bridges with concrete decks. Systems selected for comparison include the thin bonded hydraulic cement concrete overlay, waterproof membrane overlaid with asphalt, thin bonded epoxy concrete overlay, monolithically cast concrete overlay, and low permeability concrete PDS. Information on the design, construction steps, cost and performance of the systems is reported. Cost data based on bid tabulations in Virginia between 1999 and 2002 were used to compare the systems. Costing 15 to 87 percent of the conventional systems, the thin bonded hydraulic cement concrete overlay and the waterproof membrane overlaid with asphalt; the monolithic concrete overlay and the thin bonded epoxy overlay should be used as deck wearing and protection systems for bridges constructed with PDS.

Keywords: Bridge Deck, Deck Slab, Precast Concrete, Prestressed Concrete, Protection.

INTRODUCTION

Precast concrete bridge deck slabs (PDS) are a practical alternative to site cast concrete bridge decks in many situations. New decks can be constructed faster and existing decks can be replaced faster using PDS. The effectiveness of the construction increases as the length of the bridge and therefore the number of PDS increases. The effectiveness also increases with the volume of traffic using the bridge because the accelerated construction provides open travel lanes much faster than site cast concrete construction.

Many types of PDS have been used. Some are conventionally reinforced, some pre-tensioned, prestressed, some post-tensioned, prestressed, and some are prestressed, pre-tensioned and post-tensioned. Both composite and noncomposite designs and a variety of connection details have been used. PDS have been used on both steel and concrete beams. Because of the rapidly increasing interest in and use of PDS the National Cooperative Highway Research Program is funding a 30 month project on “Full-Depth, Precast-Concrete Bridge Deck Panel Systems.” The project is being done by The George Washington University in Washington D. C.

The Virginia Department of Transportation (VDOT) first used PDS to replace a deck on Rte 235 over Dogue Creek in Fairfax County in 1981.[1] One lane at a time was replaced with the PDS. Epoxy mortar was placed on the top flange of the steel beams prior to setting the PDS in place. A shrinkage compensating grout was used to fill the keyways between the PDS and the voids around the steel studs. Site cast concrete was placed at ends of the spans where the concentration of studs was high and along the center of the bridge to connect the PDS in each lane. An epoxy membrane was placed on the completed deck and an asphalt overlay was placed on the membrane. The overlay was replaced in 1991 and 2003. The membrane and the bottom ½-in of the original overlay are still performing. The deck is in excellent condition in 2004.

In 1999 VDOT used PDS to replace the deck on two bridges on Route 7 over Route 50 in Fairfax County.[2] In 2001 VDOT used PDS to replace the deck on two bridges on I95 over the James River in the City of Richmond. Because of the high volumes of traffic using the bridges and the lack of a suitable detour for traffic, both deck replacements were done at night with several PDS being placed during each lane closure.

When using PDS, bridge engineers and owners generally agree they need to provide a smooth riding surface and protection against the intrusion of chlorides. The most commonly used deck wearing and protection systems are the thin bonded hydraulic cement concrete overlay and the waterproof membrane overlaid with asphalt concrete. These wearing and protection systems are complicated, expensive and come with a high risk of failure. Less expensive systems that have been successfully used on site cast concrete bridge decks include a thin epoxy concrete overlay, monolithic cast increased cover over the reinforcement, and low permeability concrete. The less expensive wearing and protection systems can save considerable time and money.

OBJECTIVE

The objective of this paper is to compare deck wearing and protection systems for bridges constructed with PDS.

METHODOLOGY

Literature was reviewed to identify deck wearing and protection systems used on bridges constructed with PDS and other types of bridges with concrete decks. Information on the design, construction steps, cost and performance of the systems was obtained. Wearing and protection systems selected for comparison included the thin bonded hydraulic cement concrete overlay, waterproof membrane overlaid with asphalt, thin bonded epoxy concrete overlay, monolithically cast concrete overlay, and low permeability concrete PDS.

Cost data based on bid tabulations in Virginia between 1999 and 2002 were used to compare the deck wearing and protection systems because of the availability of the large amount of data. The data were obtained from the Virginia Department of Transportation bridge office in Richmond Virginia. The data are for wearing and protection systems used on many types of bridges with concrete decks (cast in place concrete on steel or concrete beams, prestressed box beams, prestressed slabs, prestressed segmental, etc.). While the cost of a wearing and protection system will vary with location, access, bridge design, and material quantity, the relationships between the costs of the systems should reasonably approximate most situations.

RESULTS

DESIGN

A sketch of the five systems is shown in Figure 1. Each of the 5 systems is illustrated with PDS on 3 beams and a thin layer (60 degree lines) that represents 0.5 to 1.5-in of monolithic concrete that is precast on the top of the PDS to allow for grinding to provide good ride quality and surface profile after the PDS are installed. An arrow points to the protection system illustrated for each system.

CONSTRUCTION STEPS

Construction steps for the five systems are shown in Table 1.

COST

Average cost data based on bid tabulations in Virginia are shown in Table 2 along with life cycle cost estimates for a 30-yr life. A zero interest rate was used in the life cycle cost estimates. For

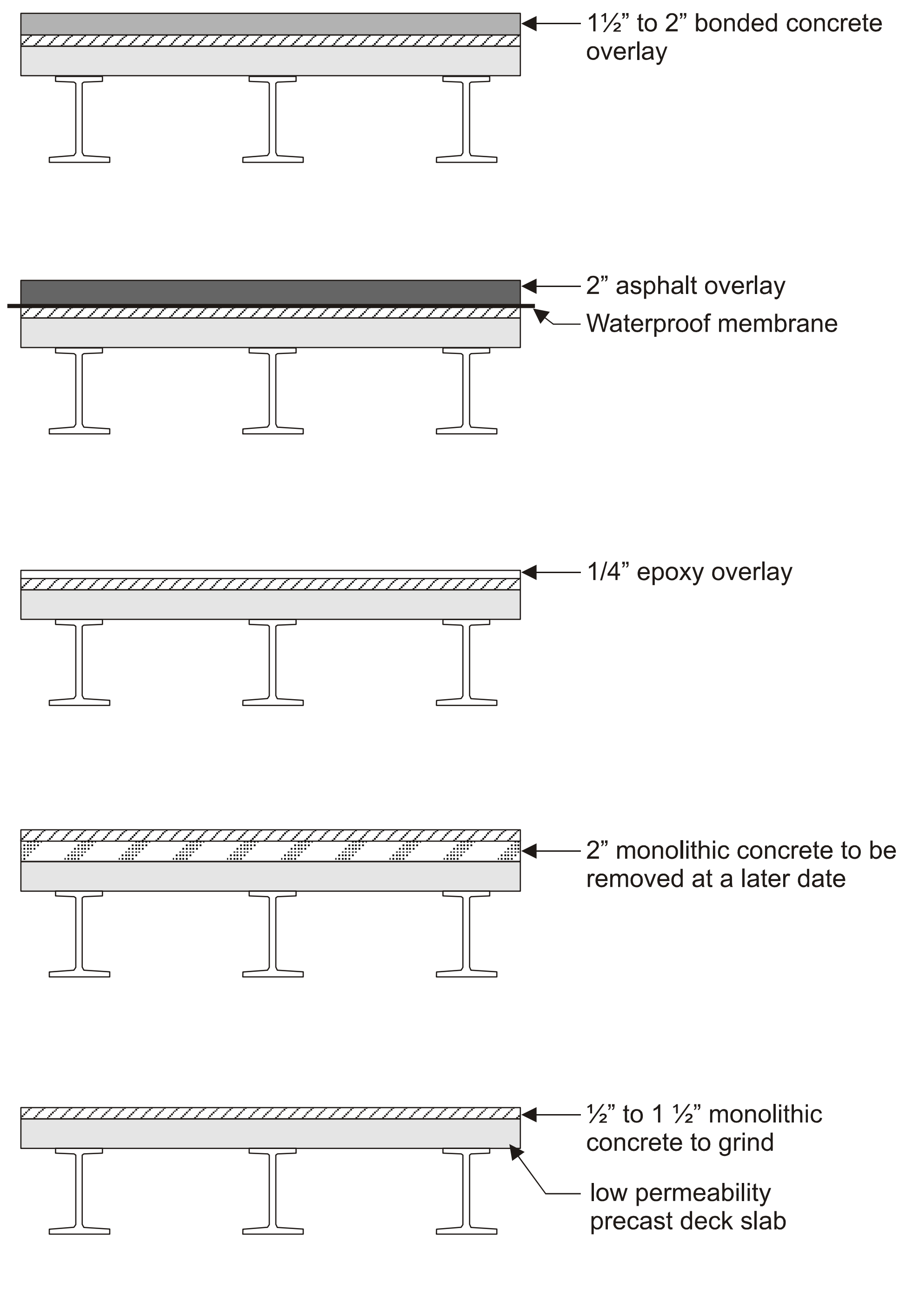

Fig. 1 Wearing and protection systems for precast deck slabs

Table 1. Construction steps for wearing and protection systems for precast deck slabs

Protection System	Construction Steps	Total
Thin Bonded Concrete Overlay	Install Slabs/Grind Surface/Shotblast Surface/Place Concrete Overlay/Cure Concrete Overlay/Groove Surface	6
Membrane/Asphalt Overlay	Install Slabs /Grind Surface/Place Membrane/Place Asphalt	4
Thin Bonded Epoxy Overlay	Install Slabs /Grind Surface/Shotblast Surface/Place Epoxy Overlay	4
Monolithic Concrete	Install Slabs /Grind Surface/Groove Surface	3
Low Permeability Concrete	Install Slabs /Grind Surface/Groove Surface	3

Table 2. Cost of wearing and protection systems for precast deck slabs, $\$/yd^2$

Protection System	Grind Surface	Shotblast Surface	Protection	Skid	Initial Total	Life, yrs	30 yr. Life
Thin Bonded Concrete Overlay	6	6	62	6	80	30	80
Membrane and Asphalt Overlay (replace both at 15 years)	6	0	27	18	51	15	96
Membrane and Asphalt Overlay (replace overlay at 15 years)	6	0	27	18	51	15	69
Thin Bonded Epoxy Overlay (15 yr. Life)	6	6	21	0	33	15	60
Thin Bonded Epoxy Overlay (30 yr. Life)	6	6	21	0	33	30	33
Monolithic Concrete (30 year life)	6	0	24	6	36	30	36
Monolithic Concrete (90 year life)	6	0	24	6	36	90	12
Low Permeability Concrete (90 year life)	6	0	0	6	12	90	4

example, the initial cost of the asphalt overlay and membrane is $51 ($6+$0+$27+$18). The 30-yr life cycle cost is $69 ($51+$18) if the overlay is replaced after 15 years.

PERFORMANCE

The service life of a deck wearing and protection system is the piece of information that is necessary for a life cycle cost analysis. Unfortunately, reaching a consensus on service life is difficult if not impossible. Consequently, the service life values used to compare the deck protection systems (shown in Table 2) are estimates that come from more than 30 years of experience with these systems. The reader can easily use different life values and see the effect on the life cycle costs of the systems.

COMPARISON OF DECK WEARING AND PROECTION SYSTEMS

Thin Bonded Hydraulic Cement Concrete Overlays

Thin bonded concrete overlays are the most expensive deck wearing and protection system based on initial cost. Cost data indicate the average cost of a bonded concrete overlay, including grinding, surface preparation and saw cut grooves is $80 per square yard. Properly constructed, thin bonded concrete overlays can last 30 years or more. Unfortunately, some overlays have cracked and delaminated and had to be replaced before the bridge was opened to traffic. Good surface preparation, low shrink concrete mixtures, and good curing are required for successful thin bonded overlays. Factors that can contribute to premature delamination of the overlay include poor surface preparation, use of mixture proportions with high shrinkage, use of thick overlays, early shrinkage cracking in the overlay, creep and shrinkage of the newly constructed PDS, and differential movement between adjacent PDS at the joints. Differential movement at the joints typically causes a reflective crack in the overlay, reducing the level of protection at the joints. Reflective cracking is typically not a problem in panels that are post-tensioned, prestressed transversely to the joints. While long lasting overlays have been successfully constructed, they come with a high initial cost and high risk of early failure.

Waterproof Membrane Overlaid with Asphalt

A waterproof membrane overlaid with asphalt is the second most expensive deck protection system based on initial cost. Cost data indicate the average cost of a membrane and asphalt, including grinding is $51 per square yard. The installed membrane accounts for most of the cost. A properly installed membrane and rut resistance asphalt are required for a successful membrane and asphalt overlay installation. The risk of early failure is high because of the complexity of the construction procedures. Rutting and shoving of the asphalt overlay can also be a problem. Differential movement between the PDS at the joints may cause a reflective crack in the membrane and asphalt overlay, reducing the level of protection at the joints. The incidence of cracking is likely less for membranes that are flexible and tough. Reflective cracking is typically not a problem in panels that are post-tensioned, prestressed transversely to the joints. Replacement of the overlay every 15 years can be expected. The membrane may or may not have to be replaced when the overlay is replaced. The initial cost of the asphalt overlay on membrane is about 64 percent of a bonded concrete overlay but on a life cycle basis the cost is approximately 14 percent less (replace overlay after 15 years) to 20 percent more (replace membrane and overlay after 15 years). The construction of a long life asphalt base mix and an asphalt surface mix that is replaced after 15 years eliminates the need to replace the membrane after 15 years and the 30-yr life cycle cost is less than for a bonded concrete overlay.

Thin Bonded Epoxy Concrete Overlays

The epoxy overlay is a deck protection system that has been successfully used for 27 years on conventionally reinforced concrete bridge decks. The epoxy overlay has been shown to prevent the infusion of the chloride ions and can be expected to provide a skid resistance wearing and protected system for decks for 15 to 30 years depending on traffic volume.[3] The epoxy overlay should perform just as well on PDS. The system is easily applied. Two layers of epoxy and aggregate are placed on a shot blasted surface. The average cost is $33 per square yard including grinding and shot blasting. It costs 75 percent of a concrete overlay and 63 to 87 percent of an asphalt overlay on a membrane. However, on a life cycle basis, the cost can be 41 percent of a concrete overlay and 34 to 48 percent of an asphalt overlay and membrane when the epoxy overlay lasts for 30 years. An additional benefit of the epoxy overlay is that it is only ¼ inches thick and if spalls occur, they do not have a major impact on the ride quality and repairs are easily done. By comparison, the spalling of an asphalt overlay leaves a much deeper hole. The thin epoxy overlay is not prone to cracking and delamination like the hydraulic cement concrete overlay. The epoxy overlay is flexible and less likely than a concrete overlay to crack and delaminate over the joints between the PDS due to differential movements. AASHTO guide specifications for the thin bonded epoxy overlay were published in 1995.[3] Thin bonded epoxy concrete overlays should be considered for use as a deck wearing and protection system for PDS. For added protection a layer of epoxy could be placed over the joints between the PDS prior to placing the epoxy overlay.

Monolithic Hydraulic Cement Concrete Overlay

The monolithic hydraulic cement concrete overlay wearing and protection system is another low cost alternative to the conventional protection systems. The system involves casting an extra 2 inches of concrete on the PDS at the time the PDS are cast. After all of the PDS are installed, a diamond grinding machine is used to correct surface irregularities and provide the final deck profile. Grooves are saw cut for skid resistance. Good skid resistance is obtained when diamond grinding is used to correct the profile of concrete pavements. Saw cut grooves are not required. If the diamond ground surface is acceptable for concrete pavements it should be acceptable for bridge decks. Elimination of saw cut grooves would save $6 per square yard.

Based on the average cost of bridge superstructure concrete in Virginia of $438 per cubic yard a 2-in thick monolithic concrete overlay would cost approximately $24 per square yard. Diamond grinding and saw cut grooves would each add another $6 per square yard for a total of $36 per square yard. The cost should be much lower because only the cost of the material increases as the overlay portion of the PDS is cast. The monolithic hydraulic cement concrete overlay wearing and protection system can be expected to protect the deck as long or longer than a quality thin bonded hydraulic cement concrete overlay. At 30 years, if the top 2 inches of the monolithic concrete contains sufficient chlorides to warrant renewal and replacement, a thin bonded hydraulic cement concrete overlay can be placed at that time. However, because of the low permeabilities that are achieved with today's concretes that are prepared with low water to cement ratios and pozzolans or slag, it is reasonable to expect that the monolithic concrete would not contain sufficient chloride ions to warrant removal for more than 150 years (see later discussion on low permeability concrete).[4] If the monolithic hydraulic cement concrete is replaced at 30 years, (same age as the thin bonded concrete overlay) the life cycle cost is 45 percent of that of a hydraulic cement concrete overlay. If replaced at 60 years, the life cycle cost if 23 percent of the hydraulic cement concrete overlay and if it lasts 90 years, it is 15 percent. The monolithic concrete overlay wearing and protection system has the lowest risk of problems since the concrete is cast on the PDS as they are fabricated. The problems with an overlay delaminating and cracking are eliminated. Differential movement at the joints may cause a crack, reducing the level of protection at the joints. Reflective cracking is typically not a problem in panels that are post-tensioned, prestressed transversely to the joints.

Low Permeability Concrete PDS

The time required for chloride ions to diffuse from the concrete surface to the reinforcement and cause corrosion induced spalling is a function of the type of reinforcement, the depth of the cover over the reinforcement and the permeability of the concrete. The quantity of chloride to cause corrosion of a strand may differ from that of conventional reinforcement. The greater the cover depth the greater the time required. A rapid chloride ion permeability test (AASHTO T-277) is used to measure permeability and results are reported in coulombs. The test is used to rank concrete permeability as follows: over 4000 coulombs, high; 2000 to 4000, medium; 1000 to 2000, low; and 100 to 1000, very low. Diffusion constants can also be used to compare the permeability of concretes. Samples are ponded with chloride solution and after sufficient time, the chloride content at various depths is measured and used to calculate the diffusion constant. The lower the diffusion constant, the lower the permeability and the longer it takes for chloride ion to reach the reinforcement.

Most reports on time to corrosion of reinforcement in decks are based on experiences with older conventionally reinforced bridge decks that were typically constructed with Portland cement and with a water to cement ratio of 0.45 or higher. The low permeability concretes currently being used to construct PDS have a significantly higher resistance to the penetration of chloride ions and moisture than the concretes in these older decks. Table 3 shows the permeability to chloride ion at 1 year of concrete deck mixtures.[4] Mixtures with pozzolans and slag and water to cement ratios of 0.35 and 0.4 have a permeability to chloride ion that is approximately one forth to one tenth of that of mixtures with Portland cement and a water to cement ratio of 0.45. The diffusion constant for the conventional deck concrete was 5×10^{-8} $cm^{2/sec}$.[4] The diffusion constants for the low permeability concretes were 0.2 to 1×10^{-8} $cm^{2/sec}$.[4] The diffusion constants for the low permeability concretes are approximately one fifth to one twenty fifth of that of the conventional deck concretes. Chloride corrosion induced spalling could be expected in these older decks in 37 years.[5] Conventionally reinforced PDS constructed with low permeability concrete (water to cement ratio of 0.35 to 0.4 and pozzolans or slag) and free of cracks can be expected to be free of chloride corrosion induced spalling for 4 to 10 times longer. PDS with low permeability concrete that are prestressed, pre-tensioned and/or post-tensioned and therefore free of cracks, should not have chlorides present in sufficient quantities to cause corrosion of reinforcement with a 2-in cover for 150 to 370 years. The use of a protection strategy other than casting the PDS with low permeability concrete is difficult to justify for PDS that are prestressed, pre-tensioned and/or post-tensioned. Unlike segmental, prestressed, post-tensioned bridges in which a deck replacement strategy has not been developed, the PDS can be replaced with new PDS.

Table 3. Permeability to chloride ion at 1 year for concrete deck mixtures, coulombs (AASHTO T277) [4]

Water to cement ratio	0.45	0.40	0.35
Portland cement	3200	2500	1700
5 percent silica fume	1000	800	500
24 percent flyash	500	500	300
50 percent slag	900	800	700

CONCLUSIONS

1. Use of low permeability concrete in PDS is by far the most practical and economical of the wearing and protection systems for PDS that are prestressed, pre-tensioned and/or post-tensioned. Use of concretes with low water to cement ratios and pozzolans or slag should provide a service life of more than 150 years at a cost that is 15 percent of a thin bonded concrete overlay.
2. For PDS in which a sacrificial concrete overlay is warranted, the monolithic concrete overlay wearing and protection system is by far the most practical and economical.
3. For PDS in which an impermeable layer on the deck surface is warranted, the thin epoxy overlay wearing and protection system is by far the next most practical. The low cost and ease of maintenance make it ideal for PDS.
4. Use of the thin bonded hydraulic cement concrete overlay and the waterproof membrane overlaid with asphalt concrete should be reduced. These protection systems are the most complicated and expensive and come with a high risk of failure.

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