

Paving for the future- Precast Prestressed Concrete Pavement (PPCP)

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Abstract—Infrastructure is the basic element serving the needs of human being. With the increasing population, sustainability is a way to balance human needs with nature capability. In the U.S., there are more than 4 million miles of major public roadways, which pavement/roadway plays an important role in providing connection and transportation for human activities.

It is well documented that the pavement/roadway construction may increase traffic congestions, delays and user costs, whilst the severity of congestion is more intensified in urban and densely populated areas. As a result, there is a need to develop repair and construction practices and processes that accelerate construction time, thereby reducing traffic delays, user costs as well as associated work time losses, fuel consumption increase, and other social economic impacts. To minimize the effects of such traffic delays and to expedite the pavement construction process, numerous Departments of Transportation (DOTs) and concrete paving companies have experimented the use of Precast Prestressed Concrete Pavement (PPCP) for expediting the roadway construction.

This paper introduces a pavement construction method Precast Prestressed Concrete Pavement (PPCP) originally developed in Texas, United States. The state-of-the-art of the PPCP method will be reviewed. Then, its design concepts and field installation procedures will be discussed followed by a comparison of 5 demonstration projects. The comparison demonstrates that PPCP is comparatively sustainable and is a vital option for future roadway construction.

Keywords—Pavement, Precast Concrete; Prestressed; Sustainable Construction

I. INTRODUCTION

Pavements/ roads are means to provide connection and transportation for human. The idea of this paper -paving for the future is to introduce a sustainable construction method minimizing environmental and user impact during construction. With the increasing population projected to be reaching 8.1 billion in 2025 [1], it is especially crucial to choose better construction method. Based on the 2013 ASCE report card for American's infrastructure, there are more than 4 million miles major public roadways in U.S. - 32% are in poor or mediocre condition cost users \$67 billion a year in additional repairs and operating costs; 42% in congested

condition increased users \$101 billion in fuel consumption [2]. With the increasing traffic demand, the already overloaded roadways are stressed to shorten the pavement life and increase users cost. When reconstruction and/or new construction is needed, the constantly closure of roadways may causes traffic congestions, delays, increase the chances of accidents and user costs in extra fuel consumption with environmental pollution. There is a need to break this imperfect cycle. How to meet human Therefore, it is vital to search for better method to pave for the future.

The sustainable concepts in pavement construction are not new. They have been discussed widely in both practical and holistic ways in almost every stage of concrete pavement including design, materials, construction, use, renewal, and end-of-life recycling [3]. Moreover, the Portland cement concrete pavements have been proven to be durable and long lasting pavements [4].

Precast Prestressed Concrete Pavement (PPCP), a concrete pavement construction method developed in 2000, stands out for its superior than others in many ways such as sound theories and empirically proven -derived from more than 20 years laboratory and roadway experiments on cast-in-place post-tensioned method in Texas, thin slabs, durable with its post-tension [8], speedy construction, saving in user cost [4] and with demonstration projects validation.

The paper will introduce the state-of-the-art of the PPCP method with the design concepts and field installation procedures followed by 5 pilot projects experimented in U.S. including Interstate 35 near Georgetown, Texas in 2002[4], Interstate 10, El Monte, California in 2004 [10], Interstate 57, Sikeston, Missouri in 2005 [11], Highway 60, Sheldon, Iowa in 2006 [12], and Interstate 66, Middletown, Virginia in 2009[13]. The comparison of the above mentioned implementation projects in different states will be revealed.

II. SUSTAINABLE PAVEMENT CONSTRUCTION METHOD- PPCP

A. PPCP Design Concept

The first investigation in prestressed concrete pavement is in 1937 [14]. Followed by a series of further studies related to the PPCP research originated from 1985 [9], PPCP is then

developed in 2000 by Center for Transportation Research (CTR) sponsored by Texas Department of Transportation (TxDOT) and Federal Highway Administration (FHWA) [4].

The original design factors include: Elasto-Plastic Behavior-elastic range is considered; Load Repetition- the endurance of PPCP is related to the applied stress and number of repetitions; Subgrade Restraint-movement between slabs and sub-grade is related to friction and the slab dimension; Temperature Curling-slab curling when temperature changes can be resisted by slab weight; Moisture Warping-with the moisture difference between surface and bottom may induce warping; Pre-stress Losses-15%-20% loss is expected due to elastic shortening, creep, shrinkage, relaxation of the stress tendons, slippage of the stressing tendons, friction between the stressing tendons and the enclosing conduits and hydrothermal contraction; Buckling-hydrothermal changes within the concrete may induce buckling. The design variables include foundation strength, PCP thickness, slab length, slab width, magnitude of prestress, tendon spacing, and transverse joints [14].

B. PPCP Field Installation Process

The basic elements of PPCP as shown in Figure 1 including Joint Panel, Base Panel, and Central Stressing Panel which are fabricated in controlled environment and then assembled onsite with certain sequence. The PPCP construction procedure involve with a series of individual precast panels that are pre-tensioned transversely to the traffic flow during fabrication and post-tensioned parallel to the traffic flow after placement in the designated locations [4, 5].

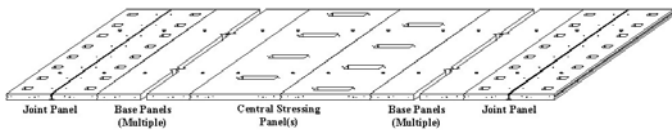


Fig. 1. PPCP Panels [4]

The basic PPCP construction process is summarized in Figure 2 and Figure 3 illustrated common PPCP procedure with some minor variants such as the site condition and special requirement in each state. After each stage, pavement can be opened to traffic shortly when needed.



Figure 2. PPCP Construction Process (*if needed)



Fig. 3. The Construction Process of CaDOT's Demonstration Project [5]

C. PPCP Projects

To further demonstrate PPCP method, several PPCP projects including Texas I-35, California I-10, Missouri I-57, Iowa Highway 60, and Virginia I-66 are investigated as follow. The variation of each installation process will be revealed.

Interstate 35, Frontage Road- Georgetown, Texas [4, 6]

This is the very 1st pilot project constructed on the North bound frontage road of Interstate 35 near Georgetown, TX in 2002. The project is selected with a simple geometric layout with 2% uniform cross-slope to test and fine-tune basic precast paving techniques. The PPCP is constructed on both sides of a new bridge with total length of 2300 feet (700 meters). The PPCP panels are placed transverse to the flow of traffic with the 225 feet full-width panels and 325 feet partial-width panels as shown in Figure 4.

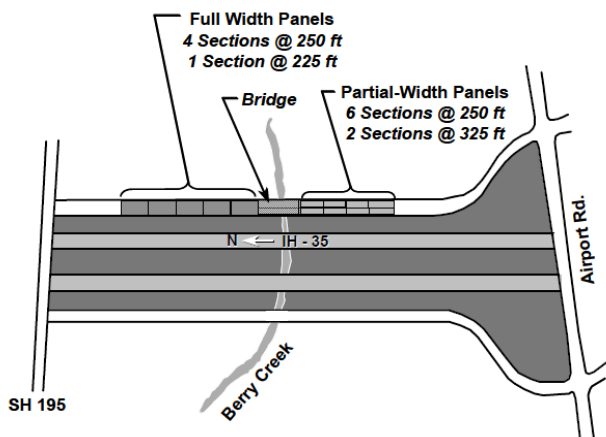


Fig. 4. Location and Layout of the PPCP pilot project-IH35, Georgetown, Texas [4]

A single layer of polyethylene sheeting acting as friction reduction layer is placed over 2-in. hot-mix asphalt pavement, followed by the placement of 8 in. thick PPCP panels (prestressed with 80.5 psi -equivalent design life of 14 in. conventional pavement) designed with cast-in armored joints. Once panels are placed in designated location, the post-tensioning will be applied every 250 ft slabs within 24 hours. The PSCP2 Design Program is used to design for decreasing the environmental effects. The project reveals that the reasonable placement rate is 25 panels in 6 hours. Comparing with the average cost of conventional pavement can be as low as \$40/SY, the overall construction cost PPCP was higher, approximately \$160/SY.

The delay time was computed with QUEWZ developed by the Texas Transportation Institute (College Station, Texas) and later modified by Transtec, Inc. (Austin, Texas). With the hypothesis scenario, it reveals that the user delay cost of precast pavement is \$680,610/day as respect to \$124,500/day of conventional pavement shown in Table 1. [6].

Table 1. Daily user delay costs comparison -precast vs. conventional pavement construction [6]

Construction Method	Precast 1-1	Precast 2-1 (frontage road)	Conventional
User Delay Costs (\$/day)			
50,000 vpd	\$1,810	\$1,670	\$383,700
105,000 vpd	\$124,500	\$63,740	\$680,610

Interstate 10, El Monte, California [10]

The project is constructed on eastbound Interstate 10 approximately 2 miles west of the San Gabriel River Freeway (Interstate 605) in El Monte, California in 2004. This widening project is adding 27 feet of traffic lanes and 10 feet shoulder to the existing pavement to accommodate new high-occupancy vehicle (HOV) lanes. With the change in cross-slope from 1.5 percent in the traffic lanes to 5 percent in the shoulder, the thickness of the panels varied from 10 to 13.1 in. (equivalent design life of 14 in. conventional pavement). The size of the

panel is uniformed with 37 feet long full-width panels and 8 feet width (not match-cast). There are 31 panels formed including 3 joint panels, 4 central stressing panels, and 24 base panels.

As stated previously, there are slight variation from project to project. This base of this project is lean concrete base, followed by the rolling over a polyethylene sheeting and the placement of the 200 psi prestressed non-armored joint panels. Two temporary post-tensioning strands are applied after each panel is placed in the designated location. The placement rate improved with experience: 16 panels in 5 hours on the first night and 15 panels in 3 hours on the second night. The epoxy-coated strands are post-tensioned every 124 feet with a ring anchor, or “dog bone” and a mono-strand stressing ram as shown in Figure 5. The much shorter post-tensioning length is merely to provide additional evaluation opportunity in this case. The under-slab grout ports cast into the panels are used to pump grout beneath the precast panels to fill any voids between the pavement and the lean concrete base. Then, the diamond grinding as the finishing to meet CALTRAN’s pavement smoothness specifications. The total cost was approximately \$224/SY. The compatible fast-setting concrete mixes pavement cost is between \$600-\$1,200/SY.



Fig.5. The monostrand stressing ram used from the central stressing pockets [10]

Interstate 57, Sikeston, Missouri [11]

The reconstruction project located in I-57 approximately 10 miles north of the I-55 interchange in Sikeston, Missouri as shown in Figure 6 is completed in 2005. The “crowned” pavement cross-section is 38 feet wide as shown in Figure 7, including two 12 feet wide traffic lanes, 4 feet inside shoulder and 10 feet outside shoulder without changes in vertical curvature. To match the existing 8 in. pavement and two percent crown surface, the thickness of the panels varied from 10 7/8 in. at the peak of the crown down to 7 in. at the edge of the inside shoulder and 5 5/8 in. at the edge of the outside shoulder as shown in Figure 7. Full-width panels of variable thickness with header-type expansion joint are applied on the uniform horizontal grade.



Fig. 6. The Location of PPCP Demonstration Project in Sikeston, Missouri [11]

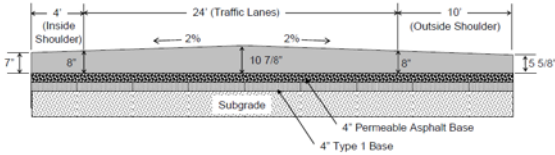


Fig. 7. The Cross Section of the PPCP panels [11]

The reconstruction project include removing the existing JRPC, placing PPCP panels and cast-in-place concrete pavement as shown in Figure 8. The subgrade was then re-graded with 4 in. permeable asphalt treated based over 4 in. dense graded granular base as shown in Figure 8. The polyethylene sheeting is placed over the prepared base and epoxy was applied to the mating faces and keyways of the panels prior to installation of precast panels to avoid potential voids.



Fig. 8. The cast-in-place pavement constructed adjacent at the end of PPCP section [11]



Fig. 9. Sand filled in the Permeable Asphalt Treated Base [11]

Laser alignment is used to align the installation of precast panels. To help close the joints prior to final post-tensioning, temporary post-tensioning rams are used when consecutive panels installation. The post-tensioning is applied from the joint panels instead of central stressing panels as shown in Figure 9. Non-continuous keyway between panels is utilized. The installation rate of panel installation including applied epoxy, install panels and temporary post-tensioning is suggested to be 20-30 minutes. Mechanical pusher was used to feed post-tensioning strands through the panels. The expansion joint seals were installed for extreme weather condition in MO. To meet MoDOT smoothness specifications, diamond grinding was applied. Two-piece tie bars were cast into the joint panels abutting the cast-in-place pavement to prepare for the tying PPCP to cast-in-place pavement as shown in Figure 10. The construction cost is approximately \$248/SY.



Fig. 10. Post-tensioning from the joint panels [11]

Highway 60, Sheldon, Iowa [12]

The newly construction project located at either end of the northbound bridge over Floyd River on highway 60 east of Sheldon, Iowa is constructed in 2006 as shown in Figure 11. A 2 percent cross slope “rooftop” crown constructed on either side of the pavement centerline with uniformed 12 in. thickness and 77 feet long of the partial-width panels. There are three types of panels including “abutment panels”, base panels and joint panels. The “abutment panels” with trapezoid shape have keyways caste into 2 in. diameter pin sleeves. The length of the “abutment panels” vary from 8 ft 10 in. to 16 ft 11 in and 16 ft 11 in. to 25 ft. The base panels are 20 ft long and 14 ft wide. The joint panels located at the end of the approach slab. The panels are not match-cast with keyways for both the transverse and longitudinal joint between individual panels.



Fig. 11. The PPCP demonstration project in Sheldon, Iowa[12]

The crushed limestone aggregate is applied as the base shown in Figure 12. To assure proper cross slope and elevation, the base was prepared with bulldozer, tripod-mounted rotating laser and portable plate vibratory compactor. A polyethylene sheeting was also rolled out over the prepared base just prior to the panel installations. The temporary post-tensioning was applied with adjacent panel installation. To disregard the surface condition, the high-viscosity, gel-paste joint epoxy was applied to connect panels. The project is especially different with Bi-direction post-tensioning. As the panels are installed, the longitudinal post-tensioning strands were fed through the ducts. After all the panels are installed, the transverse post-tensioning strands were then fed through the ducts across the longitudinal joint. The longitudinal post-tensioning was first applied, followed by filling epoxy and then the final transverse post-tensioning was applied after 24 hours curing. The experience reveals that underslab grouting process needed to be completed prior to the tendon grouting. Diamond grinding was also applied to meet IADOT requirement. The construction cost including fabrications, grading, anchoring the slab to the abutment and all the PPCP installations is approximately \$739/SY.



Fig. 12. Prepare the aggregate base [12]

Interstate 66, Middletown, Virginia

The project located in the westbound I-66 mainline, the Middletown, Virginia with roughly 1,020 feet in length (shown in Figure 13) is completed in 2009. The panels were 8.75 in. thick and 12 by 10 feet and 27 by 10 feet for the single lane (lanes 1 and 2 individual replacement) and double lane (lanes 3 and 4 simultaneous replacement), respectively. A total of 306 panels are fabricated with 2 Joint Panels, 1 Central Panel and multiple base panels.

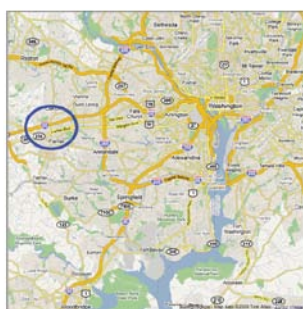


Fig. 13. The location of the PPCP project on I-66 in Northern Virginia [13]



Fig. 14. Geotextile fabric is placed as a friction reduction layer [13]

The base was first removing the existing pavement and then No. 10 aggregate was hand graded and leveled. Followed by geotextile fabric as a friction reducing layer shown in Figure 14, the installation of the panels and the temporary post-tensioning is applied with bars when the consequent panel installed. Place the temporary panels to link the new PPCP addition with the existing pavement. The post-tensioning was applied from expansion joints at the ends in each section. Finally, the grouting and grinding were applied. The installation rate is improved with experience. The PPCP panels are installed no more than 8 panels during the first 2 weeks; 10 panels during 3rd week; 12 panels for the single lane width and 6 panels for the double lane width during a 6-hour work window. The total PPCP bidding cost is \$377-\$410 /SY.

The innovative contracting was applied in this project. It extended the selected method of repairing pavement replacement within specified area and limited the bidding price as high as \$5 million for the bidding contractors. The trial installation and user cost evaluation are conducted in the project. The cost comparison show that the net savings of \$172,451 or 4.24 percent using the PPCP method for slab replacement as shown in Table 2.

Table 2. Cost comparison of PPCP and baseline CIP for mainline on I-66 project [13].

Cost category	Actual cost		Discounted cost	
	PPCP as-built case	Baseline CIP alternative	PCPS as-built case	Baseline CIP alternative
Agency Costs	\$2,936,654	\$1,513,396 – initial	\$2,936,654	\$2,742,801
		\$1,513,396 – 10 year reconstruction		
User Costs	\$962,940	\$557,913 – initial	\$962,940	\$1,329,244
		\$949,507 – 10 year reconstruction		
Initial cost and user cost - Total			\$3,899,594	\$4,072,045
Total savings with PPCP technology				\$172,451
Percent savings				4.24%

III. FINDINGS

The PPCP concept and constructed projects are discussed previously. The benefits found in implementing PPCP projects are unified include: the speed of construction- no extra time required for curing, open to traffic once the construction finished each stage; reduced user delay costs (from approximately \$680,610/day to \$124,500/day); material savings-reduced pavement thickness (40–50% of a conventional pavement thickness), fewer joints (slab lengths of up to 440 ft), less maintenance, and enhanced durability (cracks are pulled closed by post-tensioning), overnight or weekend construction, greater control with prefabrication [6,7], reduced disruption to local business and improved safety and reduced traffic control cost [12]. Above mentioned benefits stressed that the concept and construction of PPCP is a sustainable choice. It can be a good choice for future paving.

The comparison of each PPCP project is summarized in Table 4. It shows that the pavement design needed to adjust based on the site condition, project characteristics, environmental condition and the state requirement. As the PPCP method experimented in different state, the demonstration projects are generally small in size which leads to the high construction cost. The optimized approach may be reach with continuous improvement from the demonstration projects. The lower cost can be expected with larger scale implementation.

IV. CONCLUSION

The PPCP method was theoretically sound with sustainable variants. With the aforementioned successful demonstration projects in the US, the method is providing a sustainable choice for paving the future.

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