CURRENT APPLICATIONS OF PRESTRESSED CONCRETE PAVEMENTS

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ABSTRACT

Prestressed Concrete Pavements have been constructed for over 60 years. The first projects were built in Europe in the 1940s, and since then, they have been used with success in other countries. In the last decade, a number of these pavements have been constructed in the United States and Asia. Further application of this technology has been constrained by different reasons, but mainly due to the lack of a standard design method and well defined construction procedures.

Construction of Prestressed Concrete Pavements not only allows producing high quality concrete pavements, but also permits using materials in a more rational way. Usually, Prestressed Concrete Pavements thicknesses are 30 to 40 percent thinner than conventional concrete pavements. This is why this technology fulfils today's needs for greener construction methods that require preservation of natural resources, such as cement and aggregates.

In the United States, these pavements have been constructed in the States of Pennsylvania, Mississippi, Arizona, Illinois, Texas, California, Missouri, Iowa, Delaware, and Virginia with performances rating from good to excellent and exceeding all engineering expectations. All these projects have contributed to the improvement of design and construction methodologies that have been implemented elsewhere. In Latin America, this technology is finding niches of application and it is expected that its use will increase dramatically in the next few years.

This paper presents a summary of cast-in-place Prestressed Concrete Pavements built in the United States that have helped develop practical design and construction guidelines for Prestressed Concrete Pavements. This work will provide a stepping stone towards their standardization and application around the world.

1. INTRODUCTION

Prestressing concrete consists of applying a calculated, predetermined force to a structural member within specific limits. Eugene Freyssinet (France) is regarded as the pioneer investigator of prestressed concrete. He found out that high quality concrete and high-tensile-strength steel are required for an adequate prestress retention.

Prestressed concrete is currently used in many forms in the construction industry. Some examples of its applications include elevated parking lots, bridge beams, on-ground slabs, buildings, water tanks, etc. Using this technology allows for a more rational use of materials, specifically concrete and its components. Besides, prestressed concrete elements are lighter than conventional concrete ones, which in some instances, cannot even be used because of their limitations in weight or volume.

Pavement designs of arterial highways are often done using concrete because it offers advantages over asphalt pavements in bearing capacity and also because of its low maintenance requirements, when designed and constructed properly. Prestressed

Concrete Pavement (PCP) is a highly promising alternative to conventional concrete pavements such as continuously reinforced concrete pavement (CRCP) and jointed concrete pavement (JCP). During the last few years, prestressed pavements have gained popularity and some projects have been built in the United States and around the world. Results from research have shown that PCP provides a long-term, low-maintenance pavement alternative with a competitive life-cycle cost, when compared with conventional reinforced pavements. The experience gained on this paving technology shows that properly designed and constructed PCP might provide maintenance-free pavements with a long service life.

2. DESIGN OF PRESTRESSED PAVEMENTS

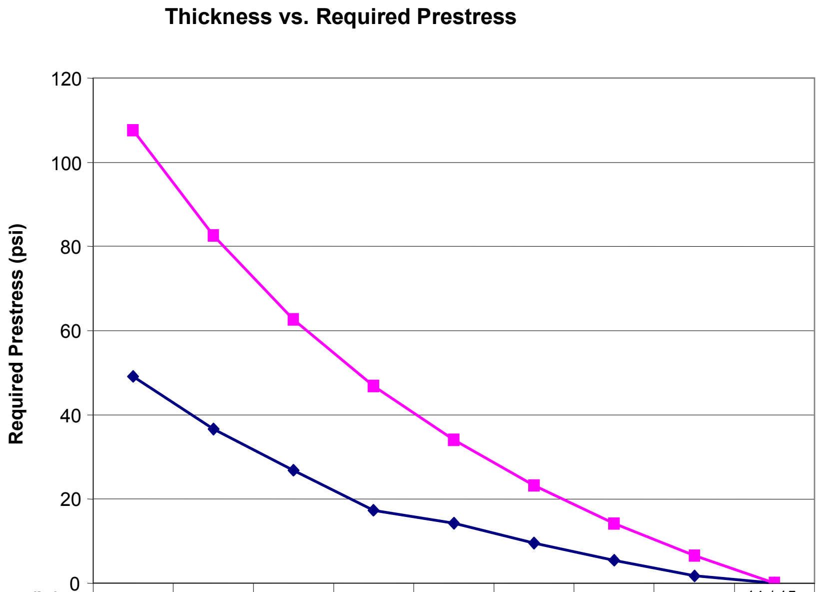
Concrete is basically a compression material, meaning that its strength in tension is relatively low. Therefore, prestressing forces make use of its outstanding compressive strength and minimizes the negative effects of tensile stresses in the pavement when subject to service loads. By reducing tensile stresses in the pavement, there is an implicit reduction or elimination of common slab cracking. At the same time, using prestressed slabs supported on the ground allows to span over long distances, voids, and “non-ideal” base materials. This means that PCP requires a reduced number of joints for a given length, when compared to a jointed pavement. Typically, slab lengths go from 80 m to 350 m depending on the conditions of the project, but common lengths are around 100 m. This helps reducing excess movements at the end of the slabs due to temperature fluctuations.

The design of a PCP shall meet two main conditions:

1. The critical stresses at the PCP must not cause fatigue failure of the prestressed slab, and
2. The combination of wheel loads, slab’s temperature gradient, and moisture stresses should not exceed flexural strength of concrete

So, the design of a PCP consists on calculating the prestress force required in the slab. This design force should consider prestress losses, which are estimated and discounted through the design process. Then, strand spacing is calculated using an iterative process that varies length and thickness until an optimum solution is found. Figure 1 illustrates how a new pavement design requires a higher prestress level of the slab than an overlay that could be placed on top of an existing pavement. For instance, if a 14 in.-thick slab is designed, then a PCP will show no benefit, meaning that it would no be really needed. That would correspond to the thickness design of a typical concrete pavement for a highly trafficked highway. However, a 9 in.-thick slab could be designed using a PCP, for which a prestress level of about 48 psi would be required for a new pavement. This same figure shows how an overlay of a pavement usually requires a much lower prestress level than a new pavement.

Once the design thickness of the PCP is defined, the joint hardware has to be selected according to the conditions of the project and looking at constructability issues. For instance, a PCP designed for a rural area would not have as many constraints as one designed for urban environments. Usually, horizontal and vertical clearances, traffic volume, and other conditions have to be considered in the selection of the hardware.



PCP Thickness (in)	6	7	8	9	10	11	12	13	14 / 15
Pavement Overlay	49.1	36.6	26.8	17.3	14.2	9.5	5.4	1.7	0
New Pavement	107.6	82.6	62.6	46.8	34	23.2	14.1	6.5	0

Figure 1 – Required prestress level for PCP based on slab thickness.

3. CONSTRUCTION OF PRESTRESSED PAVEMENTS

Ideally, a pavement is constructed over a stabilized base or interlayer that provides adequate support to the top layer. One of the advantages of PCP over conventional concrete pavements is the fact that PCP might be constructed over weak layers of material. Usually, the PCP slab is placed on top of a low friction interface layer (e.g., polyethylene sheet), which reduces the friction stresses developed between the concrete and support layer. Then, prestressing tendons are placed at the calculated spacings and using the adequate hardware. Next, a concrete paver pours the concrete as needed on the ground. The type of paver depends on the magnitude of the project itself. Finally, mid-slab prestressing pockets or gap slabs are used to apply the prestress force at the required level. Up to 3 stages of prestressing have been used in projects in the United States and 2 stages have been mostly used.

Table 1 displays some of the cast-in-place PCP constructed from 1971 to 1993 in the United States. These applications were constructed in both highway and airport pavements across the country. Most of these projects have exhibited from good to very good performance.

Table 1 – Location of PCP project across the United States (1971-1993) [1]

Project Location, State in the USA	Construction Year	Application	Length, km (mi)	Slab Length, m (ft)	Slab Thickness, cm (in.)	End Prestress, kPa (psi)	Support layer	Gap Slab
Dulles	1971	Highway	1.0 (0.6)	122-232 (400-760)	15 (6)	1400 (203)	Cement treated base	Yes
Pennsylvania	1973	Highway	2.4 (1.5)	183 (600)	15 (6)	2250 (326)	Asphalt treated base	Yes
Mississippi	1976	Highway	4.0 (2.5)	137 (450)	15 (6)	1600 (232)	Asphalt treated base	Yes
Arizona	1977	Highway	1.9 (1.2)	122 (400)	15 (6)	1500 (218)	Lean concrete base	Yes
Texas	1985	Highway	1.6 (1.0)	73 & 134 (240 & 440)	15 (6)	2200/3300 (319/479)	Concrete/Asphalt pavement	No
Pennsylvania	1989	Highway	3.7 (2.3)	122 (400)	18 (7)	2600 (377)	Lean concrete base	Yes
O’Hare	1980	Airport	0.244 (0.15)	122 (400)	20-23 (8-9)	---	Sand, Asphalt/CRCP	Yes
Rockford	1993	Airport	0.366 (0.23)	366 (1200)	18 (7)	3850 (558)	Lean concrete base	No

Figure 2 displays the construction of a PCP with a gap slab [2]. Note that this technique employs one construction joint and one active joint per constructed slab. Figure 3 shows a finished gap slab, the joint on the left side of the image is the construction joint and the one of the right side corresponds to the active (moving) joint [2].

Figure 2 – Construction of a gap slab in a PCP.

Figure 3 – Finished gap slab used in a PCP.

Figure 4 shows how a PCP is constructed using central stressing pockets instead of gap slabs [3]. Note how the steel forms are placed on top of a polyethylene sheet that lies down on the supporting base. Longitudinal cables contained in PVC ducts emerge from the central stressing pockets and stretch to the ends of the slab, where the transverse joint is located. This technique only uses one active joint per slab. Figure 5 illustrates a concrete paver pouring concrete and approaching a transverse joint [3].

Figure 4 – Central stressing pockets used in a PCP.

Figure 5 – Concrete paver and transverse joint of PCP.

Figure 6 displays the moment when the steel forms are removed from the PCP. Note that a curing compound was already applied on top of the concrete; right after the paver placed the mix [3]. Figure 7 shows a nosed prestressing jack that was used to prestress the longitudinal tendons of the pavement that come out from the central stressing pockets [3].

Figure 6 – Removal of steel forms from central stressing pockets.

Figure 7 – Stage I stressing at central stressing pocket.

Figure 8 shows the grouting operations of the PCP. This activity is performed after the concrete has gained the design strength and tendons have been fully prestressed [3]. Figure 9 displays how the central stressing pockets are patched with concrete after the final prestressing stage. This is the last stage in construction before the pavement is marked and prepared for traffic [3].

Figure 8 – Grouting operations after final prestressing stage.

Figure 9 – Patching of central stressing pockets.

4. ADVANTAGES OF PRESTRESSED PAVEMENTS

The main advantages of a PCP when compared to a conventional concrete paving method like reside mainly in a more rationalized utilization of the construction materials, specifically concrete. Some of the advantages of using PCP instead of conventional pavements include the following:

1. The PCP technology allows constructing long contiguous concrete slabs with fewer joints than jointed pavements, which results in smoother pavements.
2. Thinner slabs are used in PCPs, which means less concrete is used. This implies having fewer problems associated with concrete (e.g., delamination and segregation). Having thinner slabs allows using this type of pavement where vertical clearance is limited, like underneath bridges or tunnels.
3. Prestressing the concrete brings benefits because its outstanding compressive strength is utilized and at the same time tensile stresses in the pavement are greatly reduced.
4. When the PCP is carefully designed and constructed it can be considered as maintenance-free during its entire life.

PCP construction implies the use of relatively thin concrete slabs; therefore, pavement deflections should be always limited. A secondary failure may occur in subjacent layers if deflections are very high. The excessive deformation would then cause PCP failure. Some facts that limit the widespread use of PCP include the following:

1. The absence of a standard design methodology.
2. The unfamiliarity of pavement engineers with methods of design and construction.
3. The initial higher construction cost, due primarily to the cost of the transverse joints and hardware.
4. The perception that repairs of cracking in PCP is more laborious than in conventional concrete pavements.

5. SUMMARY AND CONCLUSIONS

This paper explains how PCP technology offers another possibility for today’s demanding needs in the pavement construction industry. Heavy loads and high traffic volumes are circulating on highway networks, which require special considerations starting at the design stage and throughout construction. Thus, PCP offers some advantages over conventional concrete pavements mainly because it uses relatively thin slabs. Prestressing a concrete slab makes use of its outstanding compressive strength and also minimizes the negative effects of tensile stresses in the pavement. Furthermore, if the design and construction of the PCP are well thought and carried out, the pavement might turn into a zero-maintenance structure, making it a competitive and cost-effective paving technique.

The major difficulties limiting the widespread application of PCP are the absence of a standard design methodology and the lack of knowledge of pavement engineers about prestressed concrete and the possibilities for its use. However, it is truly believed that the results obtained from past and current PCP projects in the United States and their outstanding performance will aid spreading their use in many regions around the world.

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