Precast Concrete Pavement with their application and benefits.

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Abstract - *A brief about the "Precast Concrete Pavement (PCP) Technology" that has been discussed further in the paper publication, along with its applications and benefits. At that time, the said technology was believed to be a matter of technical curiosity, that is, to investigate if the PCP technology was technically feasible. No serious attempts or efforts were made then to develop the technology as an entirely cost-effective pavement rehabilitation strategy and to implement the technology on a production basis. However, the urgency of the need for new technologies in the face of aging roadways and the increasing need for timely repair and rehabilitation cannot be overstated. As more and more roadways are reaching maturity and the need for timely repair and restoration becomes acute and urgent need, highway agencies are looking for new technologies that will result in shorter lane closures and long-life pavements that are more economical over the total life cycle and do not require significant interventions for repair or restoration during their entire service life.*

Key Words: **Concrete, Precast Concrete Pavement, Cast-In-Place Pavement, Applications of PCP, Benefits of PCP**

1. INTRODUCTION

Pavement, the lifeline of any country, is a critical factor that fuels its growth. In a vast country like India, roads are the arteries that connect remote areas with more developed urban regions. With India boasting the second-largest road network in the world, spanning over 59,00,000 kilometers, the significance of pavement technology becomes even more pronounced. Urban areas have seen a significant rise in traffic recently, which makes road construction and maintenance challenging. While bituminous pavement can be built quickly, it needs to be maintained often. Conversely, concrete pavement requires very little maintenance but takes a very long time to construct. Another aspect for improvement with cast-in-place concrete pavement (CIP) is having the probability of quality compromise due to execution challenges.

Moreover, the extended duration of traffic diversion causes a rise in the probability of traffic congestion and accidents. In order to address the issue, PCP technology is being utilized and is rapidly gaining popularity around the globe. The use of this technology enables high-quality, rapid building and restoration of damaged pavement. By allowing for the completion of the construction or repair work at night, traffic congestion can be avoided during the day. PCP pavement construction differs significantly from CIP pavement construction in terms of the basic construction process. At a casting yard, pavement panels with the necessary dimensions and shapes are cast. After that, the panels are given the necessary amount of time to cure in the yard. After the panels have reached the necessary level of strength, they are moved to the construction location. A suitable foundation is created on-site, with a leveling course added to the base course to ensure even support for the PCP panels when they are installed. After placing the panels in their designated position, they are connected using dowel bars.

1.1 Types of Concrete Pavement

The following various types of concrete pavement are constructed worldwide:

1.1.1 Plain Jointed Concrete Pavement (PJCP)

PJCP is a type of concrete pavement that does not have any reinforcement. The pavement is provided with saw-cuts at suitable distances to define the pavement panel size, but there are no dowel bars provided at these joints. This type of pavement is suitable only for pavements with less traffic intensity and where heavy vehicles are not expected.

1.1.2 Jointed Concrete Pavement (JCP)

JCP is a concrete pavement type that does not possess any reinforcement within the panel; however, it is connected by dowel bars. These panels are saw-cut after 24 hours of casting to define the crack development path. The saw cuts, which later develop to be the joints of the pavement, are provided with additional plain MS dowel bars to facilitate load transfer between adjacent panels. The presence of the dowel bars enables the pavement to allow heavy traffic and high traffic intensities.

1.1.3 Joint Reinforced Concrete Pavement (JRCP):

JRCP is a concrete pavement type that is provided not only with plain MS dowel bars but also with additional reinforcement in the panels. This reinforcement improves the flexural strength of the pavement. The spacing of the transverse joint is up to 15 m, and cracks are allowed in the pavement. The reinforcement present in the pavement holds together these cracks, and the transverse joints are provided with dowel bars.

1.1.4 Continuously Reinforced Concrete Pavement (CRCP):

It is, a unique type of concrete pavement, is notable for its lack of joints and dowel bars. Instead, it showcases a continuous reinforcement at the panel's center, effectively preventing cracks from widening. These cracks, which naturally occur at intervals of 0.5 m to 1.8 m, are a key characteristic of CRCP. This pavement is particularly effective in areas with high traffic volumes, making it a practical choice for such locations.

1.1.5 Prestressed Concrete Pavement:

Concrete Pavements, which are 100 m to 150 m long, can be constructed by providing post-tensioning along the traffic direction. An expansion joint is required at the ends of this length. Post-tensioning is performed after the concrete is placed at the location. This post-tensioning not only helps improve the pavement performance but also improves the riding quality of the pavement.

1.1.6 Prestressed Precast Concrete Pavement (PPCP):

PPCP is mainly used for repair and reconstruction purposes but has also been used for new construction. In this method, a concrete panel is fabricated at a casting yard, cured, transported to the work site, and placed in the prepared bed. The pre-stressing of the panels helps to reduce their thickness and also helps in handling and transporting them.

1.2 Precast Concrete Pavement Technology

Concrete panels used in PPCP systems are manufactured in a controlled environment in a yard, then they are transported to the project site, where they are installed (connected and supported) on a prepared foundation (either regraded or existing). PPCP can be used for repair, reconstruction, or new construction of 'Hot Mix Asphalt] (HMA) and Pavement Quality Concrete (PQC). Because the panels are fabricated off-site in a plant, they already gain the required strength before they reach the site, and the common defects like abrasion and potholes due to quality get rid of. In controlled conditions, good texturing is made. Long-term durability is improved as the panels are under compression for major sections.

The basic and important construction steps are:

1 Casting and curing precast panels in the yard.
2 Preparation of the base course by developing the crust or milling the existing surface at the site.
3 Transporting the panels to the site.
4 Place the panels, ensuring they are at the proper level.
5 Grouting activity as per design requirement.
6 Grinding unevenness at the joints (if any).
7 Sealing the joints with polysulphide sealant.

Fig.1.0: Prestressing

Fig.1.1: Casting

Fig.1.2: Curing

Fig.1.3: Transportation

Fig.1.4: Placing of Panels.

Fig.1.5: Grouting of Panels

1.3 Benefits of Precast Concrete Pavement.

The benefits or advantages of PPCP are elaborated below:

1. It allows fast pavement construction and repair. PPCP can save 75% of construction time at the site.
2. It assists in minimizing the unexpected and unforeseen risks related to traffic congestion caused during construction. Traffic jams cause 20% of emergency patient deaths in India.
3. It helps reduce road users' fuel consumption, thereby reducing user costs. According to "traffic data gathered by the 'Missouri Department of Transport' (DOT), the user cost incurred because of extended lane closure is decreased by" 25 %.
4. The use of PPCP can drastically increase the quality of construction. If designed to the same thickness as traditional Concrete Pavement, PPCP can last 50 years.
5. Pavement construction during any weather conditions is possible through the use of PPCP.
6. PPCP panels can be prestressed, which further enhances the pavement's performance and allows the optimum utilization of material, thereby making it eco-friendly.
7. Replacement and repair using PPCP panels are speedy and easy.
8. PPCP can be used to construct pavement in remote areas where it is difficult to provide all the required machinery for pavement construction and where it's challenging to maintain the required quality.

1.4 Applications of Precast Concrete Pavement.

1) Intermittent repairs of roads

Roads can be done without disturbing vehicular traffic.

Fig.1.6: Repair Works

2) Road Junctions

Junctions are repared with PPCP without any road closures.

Fig.1.7: Junction Repairs

3) Temporary Road.

Reusable Road panels can be used to construct temporary roads in new, developing townships and industries. Later, these panels can be reused for permanent road positions.

Fig.1.8: Reusable Road Panels.

4) Bus Pads and Helipads.

Temporary bus pads and helipads can also be constructed using removable PPCP.

Fig.1.9: Reusable Road Panels for helipads

5) Airfield Pavements.

Using PPCP, aprons and taxiways can be constructed and repaired immediately without delay. This would save considerable revenue for the airports.

Fig. 2.0: Reusable Road Panels for airfield.

6) Maintenance of Underground Utilities.

This technology eases the underground utility maintenance process.

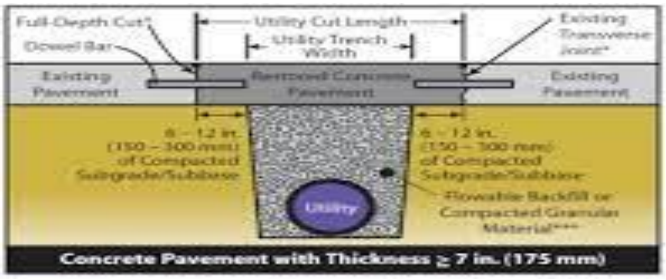

Fig. 2.1: Maintenance of underground utilities.

2.0 Different Types of PCP

The stresses produced within the PCP panels are largely determined by their dimensions. Higher flexural stress requires higher thickness and consequently increases the weight of the panel. The increase in the panel weight makes it challenging to handle. The type of PCP has a notable impact on the dimensions of a panel.

The different kinds of panel dimensioning are:

2.1.1 Reinforced Precast Concrete Panel (RPCP)

RPCP panels are utilized for handling heavy weights. There are one or two layers of reinforcement attached to the panels. A study funded by Florida DOT conducted an APT on PCP panels designed for temporary pavement use, measuring 1.83m x 3.66m x 0.10m, showing highly satisfactory performance ("Tawfiq and Armaghani 2016"). PCP panels measuring 4.0m x 3.5m x 0.33m were employed for repair purposes in the Philippines, as stated by Enriquez et al. in 2013. "Burnham (2007)" and "Gary L. D. (2006)" utilized panels measuring 3.66m x 3.66m x 0.23m in Minnesota and Colorado. Research investigating how a mix of concrete as well as panel dimensions impact the thickness of a panel found "that the best size for reinforced PCP panels is" 3.50m x 4.40m ("Vaitkus et al. 2019").

2.1.2 Pre-tensioned Precast Concrete Panels

This have nominal reinforcement bars added to them and aid in reducing panel thickness. To facilitate the transfer of load among the panels, the panels are additionally outfitted with an appropriate dowelled LTM. The panels size is restricted to 3.5M x 4.5M (''Smith and Snyder 2016")

2.1.3 Post-Tension Precast Panels (PPCP)

Two panels of PCP are post-tensioned along the traffic direction, and one PPCP panel is "pre-tensioned perpendicular to the direction" of traffic. Post-tensioning enhances the building process and offers a superior riding surface by acting as a load transfer mechanism. The service life of PPCP panels measuring 3.65 m x 2.44 m was found to be remarkable in testing conducted by ('Alwehaidah and Russell in 2018'). PPCP "panel dimensions in Indonesia are" 2.5m x 8.2m ("Tayabji et al. 2013") ("Nantung et al. 2010"), in California, they are 11.28 m x 2.44m ("Chen and Chang 2015"), in Missouri, they are 3.0 m x 11.58m ("Gopalaratnam et al. 2006"), in Iowa Bridge approach slab they are 6.10m x 4.3m ("Merritt et al. 2007"), in Texas they are 11.58 m x 3.0m ("Merritt et al. 2001"), in Delaware they are 7.3 m x 3.0m ("Tyson and Tayabji 2009") and in Mississippi, they are 7.3 m x 2.36 m ("Tayabji 2001")

2.2 Load Transfer Mechanism (LTM)

The LTM is provided in concrete pavement to facilitate the transfer of the axle load from the loaded panel to the unloaded panel. The presence of an LTM facilitates the transfer of a part of this load to the adjacent panel, thereby reducing the stresses developed in the loaded panel. In Cast-in-Place (CIP) pavement, inter-panel load transfer is facilitated by aggregate interlocking, LTM, and base load transfer. The absence of aggregate interlocking in the PCP aggravates the significance of an efficient LTM. An efficient LTM reduces the probability of damage to the base layers by avoiding uneven panel deflection upon vehicle passage. In the absence of an LTM, the base is damaged, which causes cracks in the panel. LTE (Load Transfer Efficiency) of over 70 % must be ensured for efficient and optimal long-term pavement performance ("Smith and Snyder 2016"). A few of the essential types of LTM are discussed below.

2.2.1 Hook and Tie LTM ("Yeoman 1957")

Hooks are present at the center of the depth of the panel. These hooks are interlocked, and the panel is rotated into its final position, as shown in Fig. 2.2. It is only for light traffic conditions; no practical implementation has been documented.

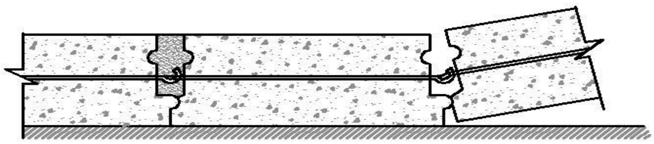

Fig.2.2 Hook and Tie LTM

2.2.2 Threaded Sliding LTM ("Tsuji 1996")

The dowels are "inserted into a long dowel slot present in 1 panel". A string is tied to the outer end of the dowel. The string is inserted through the short dowel slot provided in the adjacent panel. Once the panels are placed into their final position, the string is pulled out, and the dowel slides into its final position, as shown in Fig. 2.3

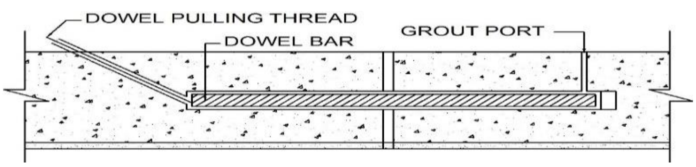

Fig. 2.3 Thread Pulled Sliding Slot LTM

2.2.3 Sliding Slot LTM ("Tayabji et al. 2012")

Panels are provided with slits running from the top surface to the dowel slot. These slits are used to slide the dowels inserted into the long dowel slots so that the dowel takes its final position. The slot is later filled out with an appropriate grout material Fig. 2.4 Patents restrict it. Hence the construction of the panels is complex with slit arrangement with a possibility of surface damage while the casting of slit arrangement.

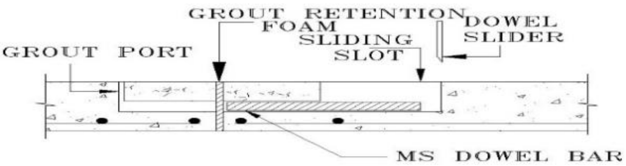

Fig. 2.4 Sliding Slot LTM

2.3 Base Preparation Method (BPM)

Precast Concrete Pavement (PCP) is a marvel of engineering, with a base that is precisely fabricated, often not matching the base course top surface. As a result, careful positioning of the PCP panels is required to guarantee even transfer of load "from the panel to the base course. Any deviation from this could result in stress concentration" at the point of contact in the precast slab, which is something that needs to be prevented. Moreover, achieving the required Modulus of Subgrade reaction (K) value is crucial for the panel to obtain a good support condition.

As per IRC: 58 (2015), a layer of DLC ("Dry Lean Concrete") as a base course is a game-changer, significantly improving the K value. This reassures the audience of the effectiveness of DLC. However, it is essential that the layer of DLC prepared on the site has the required compaction and strength, and a uniform surface to ensure the panels are supported uniformly. After providing a layer of DLC of the required thickness and surface accuracy, the finer surface undulations/ roughness can be corrected using a leveling course. The treatment required below the PCP panels will vary for different soil conditions. The PCP behavior under varying soil conditions had been analyzed, and J W Bull (1986) presented useful design charts. BPM for various conditions of soil has been different and had been described in detail below.

2.3.1 Soft Soil Conditions

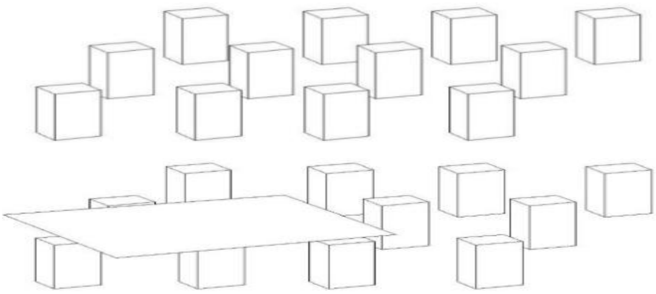

Fig. 2.5 Concrete Mattress (Micro Piles) for Sub-base.

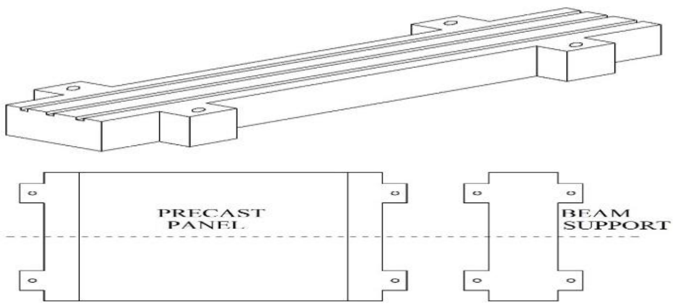

Fig. 2.6 Modie Slab

2.3.2 Medium or Hard Soil Condition

PCP base preparation for hard or medium "soil conditions is comparable to CIP pavement base preparation. The course of base could be prepared by using DLC as well as gaining the necessary modulus of subgrade reaction; however, PCP requires additional leveling treatment". The BPM needed varies greatly depending on the PCP kind which is being built and the expected traffic volume ("Tayabji and Wouter 2015"). The following BPM types were created for PCP:

2.3.3 Use of Polyurethane Foam

As a result of its ability to swell, the polyurethane foam raises the concrete panel to the appropriate level (Fig. 2.5). Additionally, all of the spaces beneath the panel are filled in by the foam's swelling ("Thrasher 2018") ("Tayabji 2014"). To avoid raising the panel above the necessary level, extra care must be taken to make sure that no more foam is placed below it. This method is very expensive, requires careful execution, and requires expert supervision.

Fig. 2.7: Polyurethane Foam for BPM.

3.0 Life Cycle Cost

When comparing the life cycle costs of Precast Concrete Pavement (PCP) and Traditional Concrete Pavement (TCP), it is important to understand and consider the long-term expenses associated with maintenance, repairs, and replacement over the entire lifespan of the pavement. Although the initial construction costs may differ, the life cycle costs provide a more comprehensive assessment of the total cost of both pavements.

The following are some factors that need to be considered:

1. Durability and Maintenance: PCP is known for its durability, strength, and stability. The controlled manufacturing process, use of high-quality materials, and advanced reinforcement result in long-lasting pavements. PCP panels are less susceptible to cracking, spalling, and other forms of deterioration, resulting in lower long-term costs. While still durable, TCP may require more regular maintenance activities such as joint sealing, crack repairs, and top surface treatments.

2. Service Life: The service life of PCP is often longer than that of TCP. Precast concrete panels are cast in a controlled factory environment, ensuring consistent quality and uniformity, resulting in a longer-lasting pavement requiring less frequent replacement or rehabilitation. TCP, although durable, may have a shorter service life due to factors like weathering, traffic loading, and material variability.

3. Traffic Disruption and User Costs: During maintenance or rehabilitation activities, the disruption to traffic flow and the associated costs can significantly impact the overall life cycle costs. PCP offers benefits in this aspect due to its modular design. Individual precast panels can be easily removed and replaced without affecting the entire pavement section. This minimizes traffic disruptions and reduces user costs. Conversely, TCP requires larger sections to be replaced or repaired, resulting in more significant disruptions and higher user costs.

4. Rehabilitation and Retrofitting: Over the entire life cycle of a pavement, rehabilitation or retrofitting may be needed to address changing traffic demands or incorporate new technologies. PCP offers flexibility in this regard. The modular nature of precast panels allows for easier rehabilitation and retrofitting options, such as adding new features or upgrading the pavement. TCP may require more extensive and costly rehabilitation activities, potentially leading to higher life cycle costs.

5. Environmental Impact: The environmental impact associated with pavement materials and maintenance practices is important. PCP can be designed with sustainable features, such as incorporating recycled materials and employing eco-friendly manufacturing processes. Additionally, PCP's durability and reduced maintenance requirements contribute to lower life cycle environmental costs. TCP may have higher environmental costs due to the need for regular maintenance activities and potential material waste. It is worth mentioning that the life cycle costs of PCP and TCP can vary based on site-specific conditions, climate, traffic loads, and maintenance practices. Performing a comprehensive life cycle cost analysis specific to the project's needs and considering these factors will provide a more accurate comparison and assist in making informed decisions about pavement selection.

4.0 CONCLUSION

This study introduces a new technology: precast concrete pavement (PCP). It further explains the various applications and advantages of this technology. It focuses on the detailed financial comparison of PCP with traditional concrete pavement. It further studies the feasibility of the technology for various applications. The study concludes with the following points: PCP technology focuses on constructing concrete roads using precast pavement slabs. This allows for better quality and faster pavement construction. The technology helps reduce carbon emissions by 70% compared to traditional concrete pavement. Apart from being fast and of higher quality, it also allows for longer concrete roads. A detailed comparison of the cost of PPCP with traditional concrete roads shows that the construction cost of PPCP is 9.95% higher than traditional concrete pavement, and the life cycle cost is 5% less.

The various applications of PCP and their feasibility are mentioned below:

- Implementation in urban areas will help users commute without delays or waste time, energy, and fuel. Additionally, it will save them from hazardous situations created during road construction.
- Implementation in Rural Areas, where obtaining and maintaining the quality of roads becomes a challenge due to a lack of focus and difficulty obtaining the material needed. This can be avoided completely by using factory-made products like PCP.
- Implementation in Military applications, like the construction of helipads, airfields, and roads in high-risk zones where labor and civilians can't stay for longer durations. This removes the threat to civilians and provides military support to construct roads in worse terrain conditions.
- Implementation in Hilly regions is especially important as it is very challenging to construct a traditional bituminous or concrete pavement in hilly areas where the traffic cannot be diverted from anywhere. In such scenarios, the construction of PCP can be conducted in fewer traffic durations by the closure of roads, and the traffic can be freely allowed in the daytime or high traffic times.

This technology is suitable for implementation in specific cases where the traffic flow is highly valuable and traffic disruption cannot be tolerated, wherever there is hilly terrain and resource availability is a problem, and in industrial applications where the flow of work cannot be disturbed for road repairs and construction.

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