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DESIGN & ANALYSIS OF CONCRETE PAVEMENT

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Abstract:

According to the anticipated high use of commercial vehicles at the site, it is essential to give thorough attention to the design and selection of materials for the pavement structure. The expenses associated with pavement represent a substantial component of the overall expenditure for highway infrastructure. Therefore, it is essential to exercise caution while choosing the appropriate pavement type and specifications for the different layers comprising the pavement structure. Picking of pavement type, whether it be flexible or cement concrete, must be approached with great caution. The variables that contribute to traffic safety in relation to pavement include skid resistance, the capacity to drain water to prevent hydroplaning, and visibility during nighttime conditions. Cement concrete pavement has a notable initial advantage compared to bitumen pavement in this aspect, since the inclusion of surface texturing is an essential component of the standard building procedure for such pavements. In addition, their lighter color confers them with enhanced nocturnal visibility. Concrete pavements that are inadequately conceived and built are recognized for their extensive durability. The cement concrete roads that were previously created in the nation, albeit having a limited length, have shown exceptional performance, providing reliable service even under more demanding conditions than initially anticipated.

Keywords: Cement concrete, rigid pavement, Traffic, Joints,
Cement **1.0 Introduction**

Reinforced concrete pavement has a notable starting advantage compared to bitumen pavement in this aspect, since the inclusion of surface texturing is an essential component of the standard building process for such pavements. In addition, their lighter color confers upon them enhanced nocturnal visibility. In regions characterized by low precipitation levels and where hydroplaning is not the primary concern, it is feasible to develop a concrete mixture that maintains sufficient skid resistance even after the textured surface finish has deteriorated, provided that suitable materials of acceptable quality are accessible. Concrete pavements that are inadequately built and constructed have been seen to have an extended lifespan. The cement concrete roads that were previously developed in the nation, although their length was significantly restricted, have shown exceptional performance, providing reliable service even under more demanding conditions than first anticipated. In the early phases, cement concrete undergoes hydrothermal changes that result in the development of minute, fragmented micro-cracks. Under conditions of escalating or recurrent loads, the micro-cracks have a propensity to propagate and coalesce, ultimately leading to the occurrence of fracture and subsequent collapse. In order to mitigate the occurrence of intrinsic micro-cracking, it is advisable to use just the lowest amount of water necessary to achieve complete compaction of concrete. The cost viability of constructing rigid pavement is evident due to the fact that rigid pavements need less thickness compared to bituminous pavements under equivalent traffic load conditions [1].

One of the primary drawbacks associated with inflexible pavement is its substantial initial cost for rectification, which is much higher in comparison to bitumen roads. This is due to the need of replacing the whole concrete slab when it becomes damaged. Moreover, the inflexible pavement has a tendency to experience failure at the construction joints located between the neighboring slab panels, as it functions as a vulnerable plane inside the structure. Additionally, there is a delay in permitting regular traffic on freshly built rigid pavements due to the fact that concrete typically needs a curing period of 28 days in order to reach its maximum compressive strength

[2]. Consideration should be given to the design and construction of the sub-grade and subbase, as these elements play a crucial role in ensuring the structural integrity and ride comfort of various pavement types. The bearing strength, consolidation, and moisture susceptibility of pavement performances are significantly impacted by the characteristics of the sub-grade and subbase [3]. Bituminous paved roads have accelerated degradation during rainstorms compared to concrete roads, while gravel roads pose safety and health concerns due to excessive dust formation in dry weather conditions. The challenges associated with dust generation and the detrimental effects of wet weather on road infrastructure may be effectively mitigated by the use of concrete road construction [4]. According to the cited source, rigid pavements typically have a lifespan exceeding 40 years, while bituminous pavements have a lifespan of around 10 years. Rigid pavements exhibit a reduced need for maintenance, in contrast to bituminous roads which require regular repairs as a result of damage incurred from vehicular activity and weather conditions. Additionally, rigid pavements possess a heightened resistance to automotive fuel spills and are environmentally benign, since concrete is entirely recyclable [6].

2.0 Materials

Rigid pavement comprises a range of materials, including cement, fine aggregate, coarse aggregate, water, reinforcing steel, dowel bars, and tie bars. OPC grade 43, which adheres to the specifications outlined in IS 8112, finds primary use in the construction of rigid pavements. The cement in question must possess a minimum fineness of 225 m2/kg. The maximum allowable soundness of the cement should be 10 mm. The minimum duration for the first setting period of cement is 60 minutes. The compressive strength of cement after 7 days of curing should range between a minimum of 33 MPa and a maximum of 37.5 MPa. The acceptable range for the specific gravity of cement is often stated as being between 2.6 and 3.8. Fine aggregates, such as sand, are often used in the construction of stiff pavements. The primary materials used are river sand and broken stone. The specific gravity of sand is expected to be around 2.7. The primary criterion for coarse aggregate in stiff pavement is the gradation of the material. The maximum size of coarse aggregate used in pavement construction is often limited to 20 mm. Additionally, the material employed for this purpose is highly graded. In stiff pavement applications, the aggregate material often exhibits a specific gravity ranging from 2.5 to 3.2, with a value of 2.7

being representative of the majority of aggregates used. The water used in the construction of a cement concrete firm pavement should meet the standards for potable water, and it is advisable to refrain from using seawater whenever feasible. The use of reinforcing steel into cement concrete rigid pavement serves to mitigate the occurrence of cracks. Dowel bars serve as a means of weight transmission throughout joints. The material exhibits shearing, bending, and bearing resistance. Dowel bars with a diameter ranging from 25 to 38 mm and a length between 610 and 915 mm are often used in construction. These dowel bars are typically placed at a spacing of 300 mm centers over the width of the slab. Tie bars are used to connect two segments of a stiff pavement made of cement concrete. The diameter of tie bars is comparatively less than that of dowel bars.

3.0 Considerations Relating to the Structure and Functionality of Rigid Pavements

3.1 Pavement design

Whereas concrete pavement uses construction materials more efficiently, notably aggregates, than bituminous pavement, it is significantly more susceptible to overloading in terms of structural strength degradation. The idea of equivalent standard axel loads (ESALs), which is based on functional criteria, does not effectively represent their structural reaction and is not a suitable design criterion.

3.2 Concrete mix design

The functional as well as structural needs of pavements should be considered while designing concrete mixes. It should not only have the necessary flexural strength, but it should also have the necessary wear resistance and skid resistance. While the texturing of the surface would primarily determine the skid resistance of new pavement, the materials - notably the aggregate - would be chosen to maintain appropriate skid resistance long after the first texture wears off. Where such materials are not easily accessible, a two-layer bonded structure with a more wear and skid resistant mix design for the top layer may be contemplated.

3.3 Quality control of construction

If one wanted to achieve the rapid building of a significant length of pavement, it would be necessary to use highly automated construction techniques. The use of central mixing and batching plants, transit mixers, and paving and finishing trains has the potential to significantly reduce the level of unpredictability often seen in manual or semi-mechanized construction processes. However, it is important to maintain a continuous monitoring of the availability of new materials, as well as the strength and workability of concrete.

3.4 Maintenance and rehabilitation

Cement requires minimal regular care, with the exception of occasional joint seal replenishment. Resin repair technique is the most effective method for maintaining joint spalls or contraction cracks. Bonded concrete technology is a viable option for improving the riding experience and enhancing the structural strength of concrete pavements via the process of surfacing.

4.0 Cement Concrete Pavement Construction

4.1 Construction of Pavement slab

The building of cement concrete pavement involves many standards, including the incorporation of a cement grouted layer, a rolled concrete layer, and a cement concrete slab. A layer of open graded aggregate mix, with a minimum aggregate size ranging from 18 to 25 mm, is applied over the prepared sub-grade using cement grout. The aggregates are then compacted by a dry rolling process. The loose thickness is compressed in order to get a compacted thickness that is 80% of the original rolled thickness. The grout is manufactured by combining coarse sand, cement, and water. The cement-to-sand ratio is often considered to range from 1:1.5 to 1:2.5. Lean mix concrete is often used in the construction of rolled concrete layers. A lean mixture consisting of aggregate, sand, cement, and water is formulated and applied onto a properly prepared sub-grade and sub base course. The rolling process is executed in a manner similar to that of WBM (Wet Bituminous Macadam) construction. The loose thickness of concrete exhibits a 20% increase compared to its compacted or finished thickness. There are two distinct strategies for constructing cement concrete slabs: the alternate bay method and the continuous bay method. The alternate bay building technique refers to the practice of creating bays or slabs in a sequential manner, with one bay being built in succession while allowing the following or intermediate bay to be constructed after a break of around one week. As seen in Figure 1, the alternative bay building method involves the sequential construction of slabs in the order of x, y, z, and so on, while allowing gaps between each bay denoted as x', y', z', and so on. This approach offers enhanced operational ease for the installation of slabs. The process of constructing joints is relatively simplified. The continuous bay technique involves the sequential laying of slabs or bays, denoted as x', y', and z'.

Fig. 1 illustrates the cement-based concrete construction process.

5.0 Steps in the Construction of a Cement Concrete Pavement Slab

5.1 Preparation of sub grade and sub-base

The foundation or sub-base that is used for the installation of a slab of concrete must adhere to the following specifications: ensuring the absence of any areas with low stability in the sub-grade or sub-base; guaranteeing that the uniformly compacted sub-grade or sub-base extends a minimum of 30 cm on both sides of the intended width for concrete placement; ensuring proper drainage of the sub-grade ; and obtaining a minimum modulus of sub-grade reaction of 5.54 kg/cm2 as determined by a plate bearing test. The sub-grade is meticulously prepared and thoroughly inspected a minimum of two days prior to the commencement of the concrete pouring process. The sub-grade or sub-base is maintained in a wet state throughout the placement of cement concrete. If deemed essential, it is recommended to immerse the concrete in water for duration of 6 to 20 hours prior to being placed.

5.2 Placing of forms

Steel or natural wood shapes are used for the intended purpose. The steel forms used in this context are composed of M.S channel sections, with a depth equivalent to the thickness of the pavements. The length of the section is a minimum of 3 meters, unless it is on curves with a radius less than 45.0 meters, in which case a shorter section is used.

5.3 Batching of material and mixing

Once the quantities of elements for the garden mix have been determined, the fine aggregate and coarse aggregate are proportioned by weight in a weigh-batching equipment. They are then loaded into the heap, along with the appropriate amount of cement. The process of batching materials is conducted by using one or more complete bags of cement as the base. The commencement of the mixing procedure for each batch occurs within one and a half minutes after all the components have been added in the mixture.

5.4 Compaction and finishing

The settling of pavement occurs via the use of either a mechanized finishing equipment or a manual screed that employs vibrations. In situations when the width of a slab is very narrow, such as at the corners of traffic intersections, it may be appropriate to use manual consolidation and finishing techniques.

5.5 Floating and straight edging

The longitudinal float is used to further enhance the compaction of the concrete. The longitudinal float is positioned parallel to the center line of the roadway and is progressively moved from one side of the pavement to the other. Once the process of longitudinal floating is completed and any extra water has evaporated, the surface of the slab is assessed for its slope and level using a straight edge.

5.6 Belting, brooming and edging

Immediately before to the solidification of the concrete, the surface is encircled by a dual-layered canvas belt. The application of short strokes is transverse to the carriage route. Following the process of belting, the pavement is then subjected to a broom finish using a fiber broom brush. The broom is carefully drawn over the pavement in a transverse manner, spanning from one edge to the other. The act of sweeping the pavement is performed in a direction that is perpendicular to the center line. Prior to the formation of the concrete's first set, the perimeter of the slab is meticulously refined using an edging tool.

5.7 Curing of cement concrete

The curing process for the complete pavement of the recently installed cement concrete is conducted in line with the following prescribed method: During the first drying process, the surface of the pavement is completely enveloped by cotton or jute mats. Before being deployed, the objects are fully soaked with water and positioned with the wet side facing downwards to ensure close and continuous contact with the surface. The final curing process is conducted using one of the following methods: During the curing process, the exposed edges of the slab are covered with damp soil, which is free from any stones. The soil is consistently maintained in a saturated state with water for a duration of 14 days. The impervious membrane approach involves the use of a non-slippery impervious membrane on the pavement. A liquid substance is administered with the aid of a pressurized spray nozzle in order to evenly coat the whole surface with a consistent layer.

6.0 Different Types of Joints:

Joints serve as the discontinuities inside the concrete pavement slab, facilitating the release of stresses resulting from temperature fluctuations, variations in sub-grade moisture, and concrete shrinkage, among other factors. Concrete pavement consists of many distinct kinds of joints, including expansion joints, contraction joints, warping joints, and construction joints. Figure 2 illustrates the schematic representation of the positions of several joints.

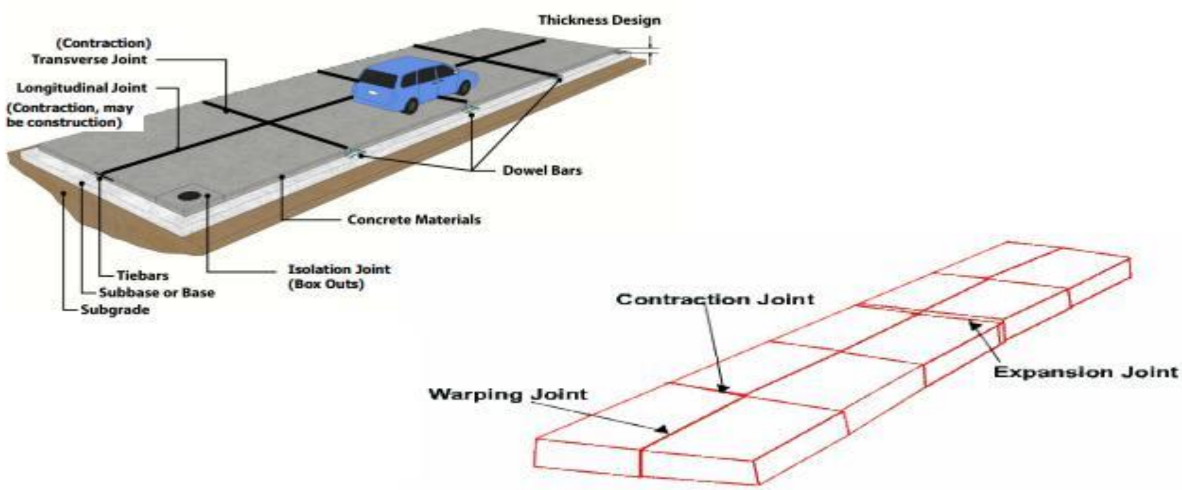

Figure 2 illustrates the precise placement of joints inside a cement concrete pavement.

6.1 Expansion joints:

Enlargement joints, as its name implies, are designed to accommodate the expansion of pavement slabs by creating room inside the pavement. Expansion occurs when the temperature of the slab surpasses the initial temperature at which it was placed. Typically, the joint has a transverse orientation. Expansion joints are also capable of relieving loads that arise from contraction and warping. Figure 3 depicts an expansion joint seen inside a cement concrete pavement.

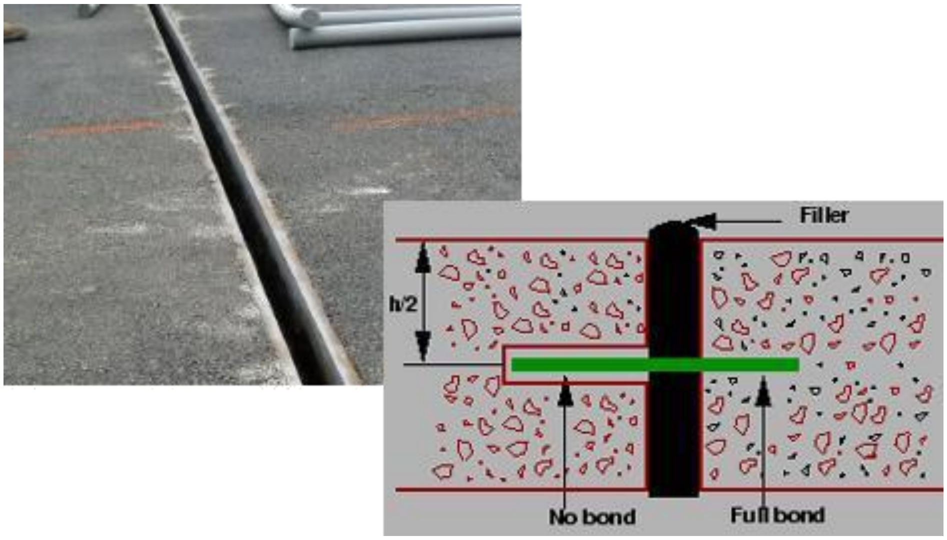

Fig. 3 Expansion joint in cement concrete pavement

6.2 Contraction joints

When the internal temperature of concrete falls below the temperature at which it is first placed, the concrete slab undergoes contraction. When a slab is placed over a long distance, the process of contraction results in the generation of tensile strains, leading to the formation of cracks in the slab. By including appropriately spaced transverse joints, the occurrence of cracks in locations other than the joints may be mitigated. Figure 4 illustrates the presence of a contraction joint inside a cement concrete pavement.

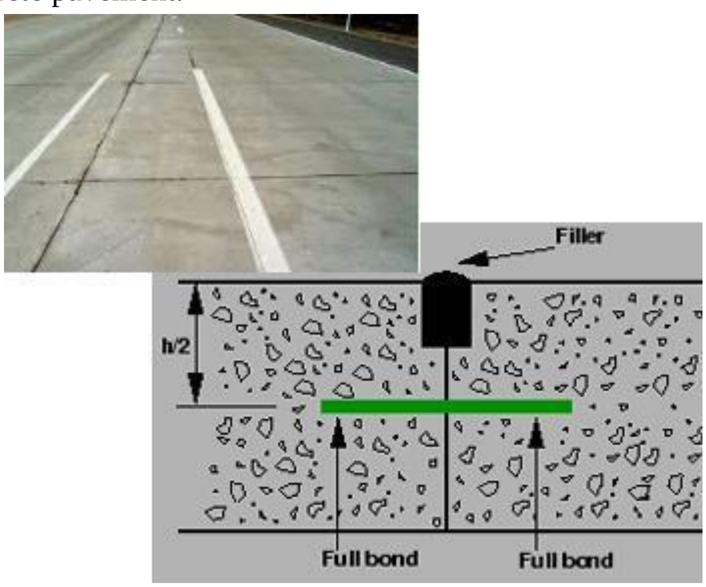

Fig. 4 illustrates a contraction joint seen in a cement concrete pavement.

6.3 Warping joints

Warping joints, sometimes referred to as hinge joints, are specifically designed to alleviate warping strains. The hinges allow for rotational movement, but there is no significant gap between the neighboring slabs. Warping joints may exhibit either longitudinal or transverse orientations. One significant distinction between warping joints and expansion or contraction joints is in the prevention of substantial variations in joint width in the former.

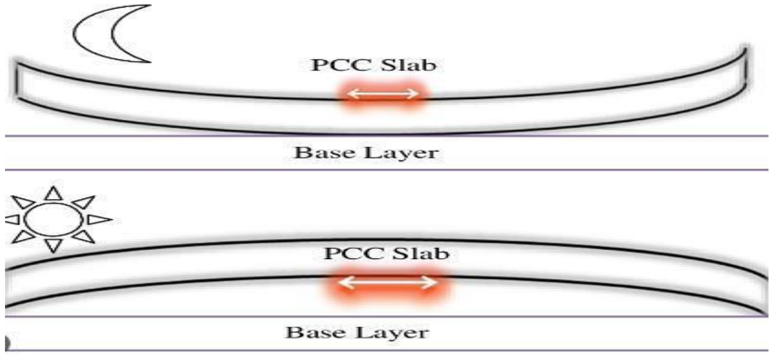

Fig. 5 Warping joints

6.4 Construction joint

The implementation of a construction joint is seen required in instances when work must be temporarily halted at a specific location where no other joint would typically be present. To ensure regularity in shape, it is recommended to put a cross-form while constructing such junctions. It is recommended to maintain reinforcement continuity across the joint.

7 Conclusions

Cement concrete has many benefits in comparison to pavement that is malleable. Concrete pavements that are designed and built in a satisfactory manner exhibit favorable functional stability, possess an extended service life, and need little maintenance. In order to fully maximize the performance of concrete pavements on expressways, it is essential to ensure that the specific requirements pertaining to the structural mechanism of concrete, the environmental mechanism of paving concrete, and the stiffness of paving concrete are met sufficiently. In terms of cost, they provide a very favorable comparison with bituminous pavements, especially when considering the initial expenses. When the expenses associated with the whole life cycle are taken into account, the cost benefits of the product become quite appealing. In addition, they provide enhanced fuel efficiency.

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