Analysis & Design of Precast Concrete Pavement

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Abstract- *Concrete pavements are widely used in road construction due to its long life and low maintenance cost. Precast pavement technology is a new and innovative construction method that can be used to meet the need for mass & rapid construction of roads. These panels are assembled off-site, transported at site and can be directly used soon after it is layed. This system requires minimal curing at site, gives the desired strength and are suitable for carrying high volume traffic. The paper summarizes the various components of precast pavement, analysis of stresses acting over the pavement at different stages of production by using SAFE software. Design of joints, lifting anchors and precast panel.*

I. INTRODUCTION

A. General

Over a period of last 20 years the traffic volumes have been drastically increased on highways. Also, use of multi-axle vehicles with heavy containers causes high maintenance of prevailed flexible pavement. Thus, up-gradation of highways with rigid pavement is very essential. Pavement reconstruction and rehabilitation have a significant impact on the resources and traffic disruption because of extensive and extended lane closures. Using a new method of 'Precast concrete pavement (PCP)' is an innovative and most efficient solution for the construction. PCP are fabricated at the factory under controlled conditions which ensures a better quality of product. It requires minimal curing at site and can be used directly after it is layed. This technology gives faster production, avoids delays in project and a durable pavement of desired quality.

Its applications are in urban or congested areas or on major corridors where the traffic volumes are high and lane closures are critical for construction and maintenance PCP is the best possible solution. Also, in extreme climatic, site conditions, high altitudes and under-water where construction is very difficult PCP's can be used.

Different roads conditions have different pavement requirements. The challenge is to consider all this requirements and provide the most durable and economic PCP. These requirements are nothing but the parameters of design which should be very carefully selected. This requires careful investigation of traffic load and volume considering the future traffic over the design period. Further site conditions, type of road, selection of pavement size, analysis, calculation of forces, design of panels, Casting, transportation, placement on site and maintenance. The paper emphasis on parameters of design, analysis of forces, selection of panel size and design of pavement (analytical).

II. OBJECTIVE OF STUDY

- To decide the various parameters for design of PCP.
- To analyze the forces acting on the precast concrete pavement when in working condition using SAFE software.
- To develop an effective and economical panel size.
- To design all the components of precast concrete pavement to resist the overlaid forces.

III. LITERATURE REVIEW

The comprehensive literature review conducted as part of this research and is organized as follows:

Tayabji et al [1] summarized the field data collected from the intermittent repair projects as well as from continuous application projects and presents the findings of the data evaluation os U.S. Strategic Highway Research Program 2. This paper on the whole described the performance of PCP.

Sapozhnikov and Rollings [2] had put a light on the past history in the former Soviet Union found these precast, prestressed slabs to be structurally sound for aircraft operations and particular advantages for construction in adverse weather, rapid installation, maintenance on unfavorable soils, and construction in remote or environmentally sensitive areas. It also described the design, materials, construction, and performance of this precast, prestressed Russian concrete pavement technology.

AASTHO PCPS TIG [3] contains the specification, prefabricated design requirements and the design proceedings based on the traditional mechanistic approaches required to design the concrete pavement.

Tayabji[4] had submitted all the international research work done by the various countries in the world to American trade Initatives as a part of International technology scanning program. This preport represents the overview of the of the ongoing research being done in the field of precast concrete pavement.

Switzer et al. [5] showed a detailed report of overnight rapid replacement of six panels of rigid airfield pavement performed at Washington Dulles International airport in 2003. It has not only shown the application but also demonstrates the way of execution by use of the PCP.

Meritt et al. [6] gave a technical report about the use of PCP on American highways and its feasibility. It showed that, the initial construction costs may at first be higher for a precast pavement, but the savings in user costs far outweigh any additional construction cost.

Tayabji and Dan Ye [7] prepared The Second Strategic Highway Research Program on Precast pavement technology undertaken by Transportation Research board of USA in Feb, 2013. It contains the overview of all the work of PCP technology done by various Department of transport and Private industries in USA. It also explained the various theories , mechanism and terms in reference to PCP.

IRC 58 [8] gave the standard guidelines for the caste in place design of concrete pavement, it showed critical stress conditions, joint stress transfer consideration and design of dowel bars.

DIN 15018 [9] gave the guidelines for lifting load calculation and the values of various constants used in the calculations.

IV. TECHNICAL CONSIDERATION

A. General

Several PCP systems are available for repair and continuous applications. Although these systems differ with respect to certain aspects of design, fabrication, and installation, they share many common features and requirements. These common features include the following:

a. Concrete requirements: Since the concrete pavement fails due to bending stresses it is designed for flexural stresses. The flexural strength should be determined by modulus of rupture under third point loading. It must be a minimum of 4.5 MPa. The w/c ratio must be in the range of 0.37 – 0.5. M30 and higher grade concrete is recommended for PCP.

b. Jointing and load transfer at joints: These two important design features for PCP it ensure that adequate load transfer will be available at all active longitudinal & lateral joint. Dowel bars are provided to transfer these loads it is selected on the basis of IRC:58-2002. A horn shaped dowel bar is provided for the economic and efficient placement of dowel bars as used in Kasugai city roads, Japan.

c. Support condition (bedding): IRC:58-2002 recommends a dry lean concrete (DLC) as a sub-base particularly for pavements with high intensity of traffic followed by granular sub- base course below it. The minimum value modulus of subgrade reaction (k) is taken as 8.4 kg/cm^3 for CBR value 30% with untreated granular sub-base and maximum of 38.9 kg/cm^3 for 100 mm of DLC as per IRC-58 and designed for the worst case.

d. Panel reinforcement: A double mat of reinforcement is typically used for jointed precast concrete panels to mitigate any cracking that may develop due to lifting and transporting operations. The amount of reinforcement is typically at least about 0.20% of the panel cross-sectional area in both directions, depending on the panel dimensions. An advantage of panel reinforcement is that if the PCP panels develop cracking over the long term due to traffic loading, the cracking can be expected to remain tight and not affect pavement serviceability.

e. Panel lifting, storage and shipping requirements: Panel lifting typically uses a four-point lifting method. The lifting anchors are embedded in each panel at four symmetrical points. It is calculated by lifting load calculation method.

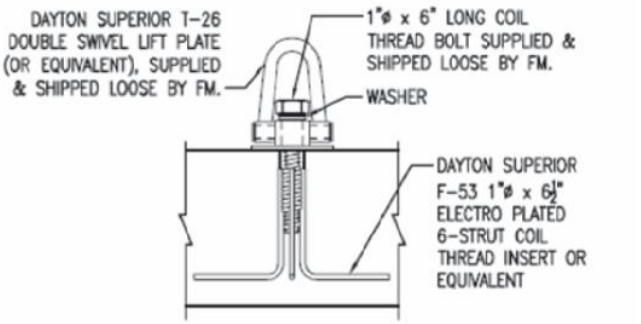

Fig 1 : Details of lifting anchors

f. Surface characteristics: The characteristics like ride smoothness, surface texture, tire noise while moving, co-efficient of friction between tires and pavement surface and safety due to erosion of pavement are included in surface characteristics. These characters are same as that for cast in place concrete. The controlled conditions of a precast plant also present the opportunity to imprint

textures that will provide a smooth ride and adequate friction.

V. ANALYSIS OF PAVEMENT

To accommodate a lane width of 3.5 m the size of pavement selected is 1.75m x 1.5m and 0.2m thick where 2 panels are placed so as to complete 1 complete lane. A horn-shaped dowel bas is provided in both longitudinal as well as lateral directions so as to transfer loads. This dowel bars also maintain the integrity of panels. The analysis of loads from vehicle and differential temperature are both taken into consideration for the purpose of design.

i) For the loads of vehicle by considering the worst case. (By SAFE modeling).

The loads on different roads are different and thus for design simplification the ranges of stresses in pavement. The ranges are as given below

SR. NO.	98th percentile single axle load (tonnes)	SR. NO.	98th percentile tandem axle load (tonnes)
1	10	1	12
2	12	2	18
3	14	3	24
4	16	4	28
5	18	5	32
6	20	6	36
7	22	7	40
8	24	8	44

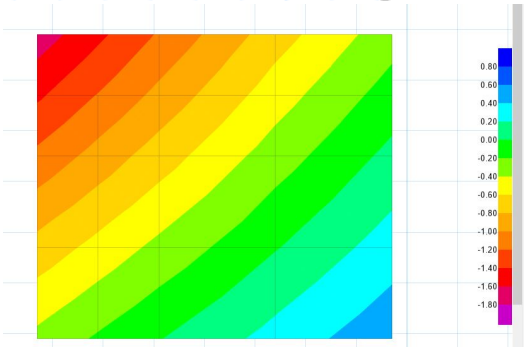

Fig 2 : Stresses due to edge stresses

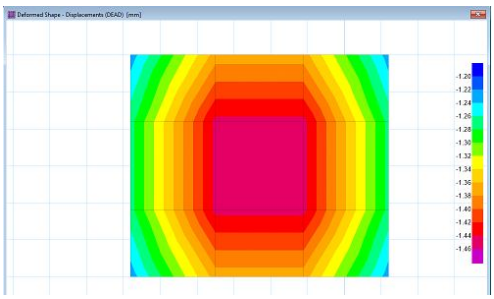

Fig 3 : Stresses due to centre stresses

ii) Temperature stresses in pavement is given by
Edge warping stress = (CEαT) / 2
Where, C =Bradbury's coefficient
E = Modulus of elasticity of concrete, kg/cm^2
α = coefficient of thermal expansion of concrete (10^{-5} per ºC)
T = Maximum differential temperature, ºC

VI. DESIGN OF PRECAST PANEL

i) Design of pavement slab: Steps for design in SAFE are given below

a) The geometry of slab with the exact dimensions are generated.
b) Materials like concrete and steel, slab and soil subgrade are defined.
c) Loads & support conditions are assigned to the slab geometry.
d) Selecting Run and Design which gives the required area of steel depending on which steel is provided at the bottom and top layers.
e) Calculation of spacing of reinforcement is same as that of slabs
f) Spacing of bars (s) = $\frac{\text{Area of bar} \times 1000}{\text{Area of steel required}}$

ii) Design for lifting forces when it is being fabricated in factory and transported at site. (By manual calculation)

1. Panel weight calculation (w)
   W= ρ x V
   =25 x(1.75 x 1.5 x 0.2)
   =13.125 KN
2. Adhesive forces between formwork and panel (H_a) depends on type of mould material.
   H_a= q x A
   = 2 x (1.75 x 1.5)
   =5.25 KN
   Where, q = Formwork adhesion factor.
   q = 1 kN/m² (for oiled steel mould).
   q = 2 kN/m² (for varnished timber mould). q = 3 kN/m² (for rough timber mould).
3. Dynamic factor (f)- When the movement of the precast unit is performed by lifting gear, dynamic forces that depend on the lifting gear used, appear

Lifting equipment	Lifting load coefficient f
Tower crane and fixed crane	1,2 *
Mobile crane	1,4 *
Lifting and transporting on flat ground	2 - 2,5
Lifting and transporting on uneven terrain	3 - 4

Fig 4 : table for Dynamic factor

4. Spread angle factor (z)- The cable angle ß is determined by the length of the suspending cable. It is recommend that, if possible, ß should be kept to ß ≤30°.
   z = 1/cos ß
   = 1/cos30 =1.16
5. Lifting force calculation (F)
   F = (f x z x w) / n = 9.52 KN
   Where, n = no. of anchors.

iii) Design of Dowel bars:

In this PCP we are providing a horn shaped dowel bars which are easy to install and maintain the integrity of precast panels through the ducts provided at the ends. After positioning the dowel bars at its position the duct is filled with HILTI grout as shown in fig 5.

Length	The recommended length is 50-60cm. However embedment of atleast 20-25 cm is needed on each side
Diameter	For slab thickness upto 250mm 32mm dia bars and that for250-400 mm 40mm dia bars are recommended.
Spacing	Typically 30cm spacing is provided. However, central portion does not contributes much so at that zone upto 40cm spacing can be provided

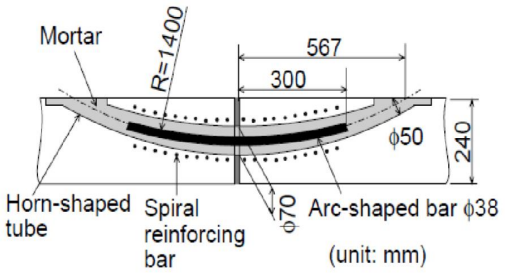

Fig 5 : Detail of Horn-shaped dowel bar

VII. RESULT AND CONCLUSION

The behavior of precast concrete pavement is same as that of caste in place pavement in terms of soil reaction . As the size changes the stresses in PCP changes.

a) The use of dowel bars for load transfer in longitudinal and transverse direction is effective in load transfer which results in increase in the stiffness at joints.
b) It also avoids failure due to mud pumping and remains even at joints , thereby increasing the quality of ride.
c) Due to use of reinforcement the flexural resistance of the pavement increases and cracks due to shrinkage, temperature difference are minimized.
d) The panel size being small is effective to transport and also placement is easier than conventional manufactured PCP.

VIII. ACKNOWLEDGEMENT

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