INFLUENCE OF DIFFERENT PARAMETERS ON CRITICAL STRESSES IN CONCRETE PAVEMENT

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Abstract
Concrete pavements are largely constructed and promoted by government in recent years in India. Concrete pavements are preferred over bituminous pavements due to its low life cycle cost, durability and low maintenance. Design of plain jointed concrete pavement depends on the stress ratio (i.e. ratio of flexural stress to flexural strength). Flexural stress calculation is influenced by many parameters like stiffness of soil subgrade, vehicle axle loads, environmental loads, location of load placement, load arrangement, tyre pressure, material properties of concrete, design period, repetition of loads and slab size. It is very important to estimate errorless response of pavement for given practical conditions. A study has been carried out on important parameters that affects the design of plain jointed concrete pavement. Study shows that finite element analysis should be done to obtain the critical flexural stresses as many widely used guidelines are based on many assumptions.

Key Words: Concrete pavement, flexural stress, edge stress, slab thickness, radius of relative stiffness, simplified approach

1. Introduction
Rigid pavements are mainly subjected to vehicle load and temperature load. Pavement response vary primarily with the effective modulus of subgrade reaction, location, panel size, material properties, slab thickness and axle load configurations.

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Other parameters have less influence on critical stresses as studied below.

2. Effect of Loading and Geometric Configurations of Axle Loads
Tyre pressure does not vary a lot, for most commercial highway vehicles tyre inflation pressures ranges from about 0.7 MPa to 1.0 MPa [1]. For the concrete slabs with the thickness higher than 200 mm are not affected significantly by the variation of tyre pressure [1].

Table 1
Loading and geometric configurations considered by IRC and PCA Guidelines [2]

| Parameter                      | IRC 58 (2015) | PCA (1984) |
|-------------------------------|---------------|------------|
| Slab length (mm)              | 4500          | 4572       |
| Slab width (mm)               | 3500          | 3667       |
| Modulus of elasticity (MPa)   | 30000         | 27579      |
| Poisson’s ratio               | 0.15          | 0.15       |
| Longitudinal axle spacing (mm)| 1300          | 1273       |
| Transverse wheel spacing (mm) | 1800          | 1833       |
| Distance between centre of dual wheel (mm) | 310 | 305 |
| Offset distance between outer face of wheel and slab edge (mm) | 0.00 | 102 |
| Contact area of single wheel (mm²) | 160 x 234 mm | 178 x 254 mm |

Vehicle axle loads considered by IRC 58 [1,3] and PCA [4] are single, tandem and tridem axles. Axle load configurations considered by IRC 58 [1,3] and PCA [4] guidelines are almost same. Table 1 shows loading and geometric configurations considered by IRC and PCA guideline for the calculation of flexural stresses in slab at edge.
3. Effect of Stiffness of Soil Subgrade

Pavements are supported on foundation soil/subbase and hence it is necessary to maintain uniform and good subgrade. In India, concrete slabs are mostly supported on dry lean concrete (DLC) layer.

It was observed by Roesler et al. [5] that for thin slab pavements, lower subgrade stiffness lead to large deformations. However, the effect of subgrade stiffness has minor influence on the slabs with thicker sections. Generally most of the concrete pavements are provided with thickness below 350 mm, and response of these pavements greatly affected by the K-value of the soil foundation. Finite Element (FE) analysis of concrete slab without shoulder and with shoulder shows that for vehicle axle loads, critical edge stresses decreases with the increase in the effective modulus of subgrade reaction. Regions where temperature loads are not critical and not considered in the design, subgrade with good stiffness function better. FE model considered for the analysis is shown in Fig. 1.

![Fig. 1: FE model of concrete slab with 80 kN (18 kip) single axle (dual wheel) load][2]

Analysis of plain concrete pavement is done using 2D area element. Four noded shell element is used to model concrete slab that combines separate membrane and plate-bending behavior. Each node has 6 degrees of freedom at connected joint that is, translation and rotation in x, y and z direction. To achieve best results, aspect ratio of element is maintained by refining mesh size near to unity. Effective subgrade stiffness is assigned at each node as per the mesh area using Winkler model theory. Results obtained from SAP 2000 (FE software) are validated with simplified approach [2] as well as PCA document [4]. Validation of the FE model with simplified approach [2] for single, tandem and tridem axle loads are shown in Table 2.

| Axle Type | Load (kN) | Thickness (mm) | Stress (MPa) | % Difference |
|-----------|-----------|----------------|--------------|--------------|
| Single    | 80        | 150            | 1.172        | 1.173        | -0.1        |
| Tandem    | 160       |                | 1.094        | 1.095        | -0.1        |
| Tridem    | 240       |                | 1.101        | 1.097        | 0.4         |

Variation in soil stiffness might be due to many reasons like compaction difference, variable soil density and moisture content. It is found that when temperature difference is applied along with the axle load on non uniform soil subgrade, it develops higher critical stresses than the stresses develop for uniform soil with lowest or largest subgrade stiffness.

4. Effect of Material Properties

Modulus of elasticity of concrete changes with grade of concrete. Concrete with higher characteristic compressive strength also shows higher modulus of elasticity [7,8]. Concrete with characteristic compressive cylinder strength 12 MPa and 70 MPa shows modulus of elasticity 27000 and 41000 MPa respectively as per Eurocode 2 [8]. Widely used guidelines [1,3,4] consider a constant modulus of elasticity for the determination of critical edge stress. [1,3,4] methods can not use the advantage of higher modulus of elasticity. However simplified approach [2] provide flexibility to consider different modulus of elasticity as this method primarily depends on the value of radius of relative stiffness thus provide realistic and better solution.

5. Effect of Axle Load Placement

Edge location in the slab is considered critical in the design of concrete slab. Axle loads may be placed at the extreme edge location of slab, it will give higher edge stresses due to stress concentration below load. However, PCA [4] suggest axle loads are placed at 4 inches (10.2 cm) away from the edge. IRC 58 [1] does not suggest any offset for placement of wheel on edge.

![Fig. 2: FE model with single axle load at an offset of 4 inch][2]
### Table 3
Comparison of critical stresses for loading with and without offset

| Thickness inch (mm) | K pci (MPa/m) | PCA | FEM At 100 mm from edge | FEM At Edge (without offset) | IRC 58 2015 | Westergaard's Regression Eq | Charts |
|---------------------|---------------|-----|-------------------------|-----------------------------|-------------|-----------------------------|--------|
| 4 (101.6)           | 50 (13.55)    | 5.69| 5.43                    | 7.05                        | 9.44        | 10.06                       | 10.41  |
| 4 (101.6)           | 200 (54.20)   | 4.37| 3.97                    | 5.37                        | 7.72        | 10.11                       | 9.43   |
| 4 (101.6)           | 700 (189.70)  | 3.34| 2.93                    | 4.07                        | 6.23        | 7.79                        | 7.35   |
| 9.5 (241.3)         | 50 (13.55)    | 1.69| 1.62                    | 1.95                        | 2.26        | 1.51                        | 1.80   |
| 9.5 (241.3)         | 200 (54.20)   | 1.31| 1.27                    | 1.58                        | 1.95        | 1.59                        | 1.65   |
| 9.5 (241.3)         | 700 (189.70)  | 1.04| 0.95                    | 1.23                        | 1.66        | 1.29                        | 1.22   |
| 14 (355.6)          | 50 (13.55)    | 0.99| 0.82                    | 0.98                        | 1.17        | 0.49                        | 0.85   |
| 14 (355.6)          | 200 (54.20)   | 0.76| 0.72                    | 0.87                        | 1.02        | 0.59                        | 0.77   |
| 14 (355.6)          | 700 (189.70)  | 0.61| 0.57                    | 0.71                        | 0.89        | 0.56                        | 0.60   |

6. Effect of Slab Size

Plain jointed concrete pavement always constructed continuous and then saw cut joints are made by using saw cutting machine to form aggregate interlock joint. These joints are cut to 1/3rd to 1/4th depth from top of the slab. After application of repeated loads, this develops a gradually increasing crack. Slab is devided into panels of rectangular shape and devided by saw cut joints.

Widely used guidelines [1,3,4] use fixed size of 3.5 m x 4.5 m. Practically it is found that slab sizes are selected by the designers. When panels with different size are analysed, it is found that critical edge stress shows large variation in critical edge stresses.

Bradbury's temperature stress coefficients depend on length and width of the slab. Guidelines consider size effect while determining critical edge stress for temperature difference but not when subjected to axle load. Slabs with size more than 3.5 m x 4.5 m provides stresses on higher side and hence can be considered for the design of pavement for most of the cases. In few L/W ratios with specific radius of relative stiffness show higher stresses in shorter slabs than standard (3.5 m x 4.5 m).

Load transfer mechanism is also an important factor which will affect the design of concrete pavement. Critical stresses developed for jointed plain concrete pavement with tied concrete shoulder are less than that develop for slab without shoulder. Load transfer at the joint is better when slab is provided with shoulder. However, this parameter is not included in this study.

It is important to account all these design parameters while designing the concrete pavement when the parameters considered does not meet the guidelines assumption.
7. Conclusions

Following are the broad conclusions from the study of different design parameters and its effect on critical stresses in plain jointed plain concrete pavement.

- For the regions where temperature loads are considered along with axle loads on non-uniform soil subgrade, it produces higher critical stresses than the stresses develop for uniform soil with lowest or largest subgrade stiffness.
- Axle load placement at edge without any offset creates large amount of stresses than the loads placed with some offset.
- Slab size affects critical stresses even if temperature stresses are neglected. It is general assumption that shorter slabs have smaller critical stress value than that of standard size. However, from the study it is observed that for some cases shorter slabs may also develop large amount of critical stress.

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