Chapter 3

AN OVERVIEW OF DESIGN AND CONSTRUCTION PRACTICES OF RIGID PAVEMENTS

3.1 GENESIS AND HISTORY

It is widely believed that the origin of concrete pavements began in 1894 in Bellefontaine, Ohio, U.S.A. which is still in use! But according to Blanchard's American Highway Engineers' Handbook of 1919, cement concrete pavement was prepared in Scotland in 1879; however the pavement could not last long. A pavement section made of Portland cement grouted macadam was constructed in 1893 in New York City. In the early part of 20th century many concrete roads were constructed across the globe. It is probably in 1917 the dowel bars were used for the first time in the concrete roads of Virginia in USA. During this period many different configurations of slab cross sections, types of joints and reinforcement patterns for rigid pavements emerged. Design of Continuously Reinforced Concrete Pavements (CRCP) was introduced to eliminate joint stresses in the mid-1950s, which soon became very popular. Slipform paving technique was also introduced in 1950s which revolutionized the rigid pavement construction technology, where the manpower requirement was reduced by four-fold. In 1940s prestressed concrete pavements were introduced for airfield pavements. There were practical problems associated with prestressing like anchoring the slabs, buckling of slabs during release of stress and need of highly skilled labour, nevertheless, about a dozen of highways with prestressed concrete pavements were constructed in USA between 1970 and 1990.

Concrete pavement technology is continuously evolving and today the much of the emphasis is given to the use of eco-friendly materials in the pavement concrete and durability aspects of concrete roads.
The extreme scarcity of cement and the easy availability of bitumen led to an abandonment of concrete road construction in India for nearly 50 years, though the country constructed several cement concrete roads in the 1920s and 1930s. In 1980s cement was partially decontrolled due to which modernization of the cement industry and capacity enhancement took place. As a result of this, the interest in cement concrete pavement was revived in the late 1980s. It is because of this, the indigenous effort on the pavement concrete technology was almost non-existent and there was hardly any research in the field of pavement concrete technology in India. [88]. The capacity enhancement of National Highways qualitatively and quantitatively initiated by a NHDP under the aegis of NHAI gave the much needed thrust to the construction of rigid pavements in the beginning of new millennium.

### 3.2 TYPES OF RIGID PAVEMENTS

A typical rigid pavement consists of a granular subbase, a base course and a relatively thin concrete slab as wearing course. The base course may be any of these: Dry Lean Concrete (DLC), Paved Lean Concrete (LC), Porous Concrete (PC), and Asphalt Concrete (AC). Sometimes the base course is termed as subbase and the granular subbase is called Eventual Draining Layer.

![Figure 3.1 Typical rigid pavement](image)

Rigid pavements are broadly classified as plain, reinforced cement concrete and prestressed cement concrete pavements. Plain cement concrete pavements are used for low volume traffic roads or when the subbase, placed between slab and subgrade is
cement treated. The plain cement concrete pavements do not contain the dowel bars. Dowel bars, which reinforced cement concrete pavements carry, are generally made of mild steel and are circular in cross section. They are load-transfer devices and hence develop bending, shear and bearing stresses. Half the length of dowel bar is embedded in one slab and the other half in the adjacent slab but is kept free to move during expansion and contraction of slab. For the pavements with heavy vehicular traffic, dowel bars should be provided at the contraction joints. Reinforced concrete pavements also contain tie bars which are not load-transfer devices but are used to tie two slabs together. Continuous reinforced cement concrete pavements are the types of reinforced concrete pavements that contain no transverse joints (apart from construction and some expansion joints). They carry higher percentage of temperature reinforcement so that the cracks are held tightly closed. The last category of the concrete pavement is the prestressed cement concrete pavement. In case of prestressed cement concrete pavements the prestressing is achieved by placing a concrete slab under continuous compression in a manner similar to the prestressing of bridges or other structural members. The practical difficulties like anchoring of prestressed concrete slabs, buckling of the slabs upon release of the stress and construction of joints have restricted their widespread construction. The latest entries in the classification of rigid pavements are Ultra-thin White Topping (UTWT) and Rolled Concrete (RC) with surface dressing.

### 3.3 STRESSES IN RIGID PAVEMENTS

The major portion of the load carrying capacity of the rigid pavement is derived from the concrete slab as the modulus of elasticity of concrete slab is much greater than that of the base or subbase materials; this mechanism is often termed as slab or beam action.
Wheel loads, temperature changes, changes in moisture and changes in volumes of base, subbase and subgrade are the causes for the stresses in the rigid pavements. The degree of continuity of subgrade also plays a vital role in deciding the magnitude of stresses. Hence the stresses in the rigid pavements are broadly categorized as wheel load stresses, stresses due to restrained temperature and moisture deformations, stresses due to volume changes of the supporting materials and stresses due to permanent deformations of the subgrade or loss of support through pumping, a condition where ejection of water and subgrade (or base) material through joints and cracks or at the pavement edge takes place due to deflection of the slab after accumulation of free water under the slab. The estimation of stresses by the mathematical analysis is based on certain assumptions regarding continuity and elasticity of the materials.

Westergaard’s equations are commonly used to estimate wheel load stresses [90]. These stress equations for the three typical regions of the cement concrete pavements in kg/cm\(^2\) are given by equations from 3.1 to 3.3.

Interior stress
\[ \sigma_i = (0.316 \frac{P_w}{h^2})[4\log_{10}(l_r/b_r) + 1.069] \]  
\[ \text{3.1} \]

Edge stress
\[ \sigma_e = (0.572 \frac{P_w}{h^2})[4\log_{10}(l_r/b_r) + 0.359] \]  
\[ \text{3.2} \]

Corner stress
\[ \sigma_c = (3 \frac{P_w}{h^2})\left[1 - \left(\frac{a_r \sqrt{2}}{l_r}\right)^{0.6}\right] \]  
\[ \text{3.3} \]

where, \( h \) = Slab thickness (cm), \( P_w \) = Wheel load (kg), \( a_r \) = Radius of wheel load distribution (cm),
$l_r =$Radius of relative stiffness (cm) and $b_r =$Radius of resisting section (cm).

$l_r = [E_c h^3/(12 K)(1 - \mu^2)]^{1/4}$

$b_r = (1.6a_r^2 + h^2)^{0.5} - 0.645 h$

(for $a_r \leq 1.724h$) and if $a_r > 1.724h$ then $b_r = a_r$

$K =$ Modulus of subgrade reaction (kg/cm$^3$)

The warping stresses in the three regions of a rigid pavement, expressed in kg/cm$^2$ are given by equations from 3.4 to 3.6

Interior stress

$\sigma_{wi} = 0.5E_c \alpha t \left[\left(C_x + \mu C_y\right)/(1 - \mu^2)\right]$ \hspace{1cm} 3.4

Edge stress

$\sigma_{we} = 0.5C_x E_c \alpha t \text{ or } \sigma_{we} = 0.5C_y E_c \alpha t,$ \hspace{1cm} 3.5

whichever is higher

Corner stress

$\sigma_{wc} = 0.333[E_c \alpha t (a_r/l_r)^{0.5}] / (1 - \mu)$ \hspace{1cm} 3.6

where

$E_c =$ Modulus of elasticity of concrete (kg/cm$^2$),

$\alpha =$ Thermal coefficient of concrete per °C,

$t =$ Temperature difference between top and bottom ends of slab in degree °C,

$\mu =$Poisson’s ratio for the material of the slab and $C_x$ and $C_y$ are the coefficients based on the ratios of $L_x/l_r$ and $L_y/l_r$

$L_x$ and $L_y$ are the dimensions of the slab along $x$ and $y$ directions (along the length and width of the slab) respectively.

The frictional stress, expressed in kg/cm$^2$ is given by equation 3.7

$\sigma_f = [0.5 W L_s f]/10^4$ \hspace{1cm} 3.7
where

\[ W = \text{Unit weight of concrete (kg/m}^3\text{)}, \quad L_s = \text{Slab length and } f = \text{Coefficient of subgrade restraint} \]

The critical condition of the stress is obtained by the combination of load, warping and frictional stresses. Following combinations are generally tried:

At edge

Load stress + warping stress – frictional stress during summer

Load stress + warping stress + frictional stress during winter

At corner

Load stress + warping stress.

In reinforced concrete pavements the stresses in the dowel and tie bars are also significant. From the experience all over the world, it is found that only stress responsible for the performance of the joints of the dowel bars is the bearing stress in the concrete. Maximum bearing stress between the concrete and the dowel bar is obtained from equation 3.8

\[ \sigma_{\text{max}} = K_i P_t (2 + \beta z)/(4 \beta^3 E_d I) \]

where

\[ \beta = (K_i b_d / 4 E_d I)^{1/4} \]

\( \beta \) = Relative stiffness of the dowel bar, \( K_i \) = Modulus of dowel/concrete interaction (kg/cm\(^2\)/cm),

\( b_d \) = Diameter of the dowel bar (cm),

\( z \) = Joint width (cm),

\( E_d \) = Modulus of elasticity of the dowel (kg/cm\(^2\)),

\( I \) = Second moment of area of the dowel cross section (cm\(^4\)) and

\( P_t \) = Load transferred by the dowel bar.
Tie bar of a slab develops tensile stress which depends on the frictional force between the bottom of the adjoining slab and the soil subgrade.

3.4 DESIGN OF RIGID PAVEMENTS

There are several methods of pavement design, developed by various professional organizations based on their years of experience in design and construction. With this great diversity, the pavement design is more of an art than science [91]. The work of Westergaard in developing the analytical methods and research in the physical properties of pavement concrete is till date the greatest contribution in the field of rigid pavement analysis and design. The high-water mark of rigid pavement design was the development of design method for air field pavements by the Ohio River Division Laboratory of the U.S. Army Corps of Engineers. Some of the methods which have been acclaimed worldwide are Portland Cement Association (PCA) method, Corps of Engineers method, AASHTO method, Yield-line method, Load Classification Number (LCN) method and Federal Aviation Agency (FAA) method. To reflect the current knowledge on the subject of pavement design, the guidelines for the design of plain jointed rigid pavements were revised in India by Indian Road Congress [92]. The early approach to the design of rigid pavements by IRC was based on Westergaard’s analysis. The prominent features of the revised guidelines are estimation of flexural stress due to single and tandem axle loads along the edge, inclusion of cumulative damage concept and revision of design criteria for the design of dowel bars. The factors that govern the design are: single or tandem axle loads, repetition of the loads, tyre pressure and lateral placement characteristics of commercial vehicles.
3.5 CONSTRUCTION OF RIGID PAVEMENTS

While constructing, rigid pavements are always jointed. Basically there are four types of joints in rigid pavements namely, contraction joints, expansion joints, construction joints and hinge or warping joints. Contraction joints are provided to relieve tensile stresses the pavement develops due to contraction and warping. Stresses due to expansion are not relieved by contraction joints. The joints may contain dowel bars if the load transfer by grain interlock is doubtful. Expansion joints are constructed throughout the depth of the pavement slab to permit expansion. These joints are provided with some type of load transfer since there is no aggregate interlock at these joints. As expansion joints are highly vulnerable to pumping action, they are avoided by many highway construction agencies. Construction joints are generally butt type and contain dowel bars for load transfer. These joints are used to separate old and new construction. To control cracking along the centre line of the pavement, hinge or warping joints are used. Tie bars are used at these joints to tie the slabs together.

Slipform paving technology for pavements has reduced the manpower requirement and increased the speed of construction. It is a process where pavement concrete is consolidated in a desired geometric form and surface finished by pulling the forms continuously through and surrounding the plastic mass of concrete. The technique is usually adopted for larger pavement works and is ideally suited for very low-slump concrete so that the freshly laid concrete can hold its shape once the slipform paver has passed. It also gives uniform and smooth riding surface.