

## MODULE 4: Introduction to Pavement Design

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favourable light reflecting characteristics, and low noise pollution.

### Requirements of a pavement

The pavement should meet the following requirements:

- Sufficient thickness to distribute the wheel load stresses to a safe value on the sub grade soil
- Structurally strong to withstand all types of stresses imposed upon it
- Adequate coefficient of friction to prevent skidding of vehicles
- Smooth surface to provide comfort to road users even at high speed

### Types of pavements

The pavements can be classified based on the structural performance into two, flexible pavements and rigid pavements. In flexible pavements, wheel loads are transferred by grain-to-grain contact of the aggregate through the granular structure. The flexible pavement, having less flexural strength, acts like a flexible sheet (e.g. bituminous road). On the contrary, in rigid pavements, wheel loads are transferred to sub-grade soil by flexural strength of the pavement and the pavement acts like a rigid plate (e.g. cement concrete roads).

### Flexible pavements

Flexible pavements will transmit wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure (see Figure 19:1). The wheel load acting on the pavement will be distributed to a wider area, and the stress decreases with the depth. Taking advantage of this stress distribution characteristic the lower layers will experience lesser magnitude of stress and less quality material can be used. Flexible pavements are constructed using bituminous materials. These can be either in the form of surface treatments (such as bituminous surface treatments generally found on low volume roads) or, asphalt concrete surface courses (generally used on high volume roads such as national highways) pavement layer



The following types of construction have been used in flexible pavement:

- Conventional layered flexible pavement,
- Full depth asphalt pavement, and
- Contained rock asphalt mat (CRAM).

Conventional flexible pavements are layered systems with high quality expensive materials are placed in the top where stresses are high, and low quality cheap materials are placed in lower layers.

Full depth asphalt pavements are constructed by placing bituminous layers directly on the soil subgrade. This is more suitable when there is high traffic and local materials are not available.

Contained rock asphalt mats are constructed by placing dense/open graded aggregate layers in between two asphalt layers. Modified dense graded asphalt concrete is placed above the sub-grade will significantly reduce the vertical compressive strain on soil sub-grade and protect from surface water

### **Rigid pavements**

Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below. A typical cross section of the rigid pavement is shown in Figure below. Compared to flexible pavement, rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material.

Since there is only one layer of material between the concrete and the sub-grade, this layer can be called as base or sub-base course. In rigid pavement, load is distributed by the slab action, and the pavement behaves like an elastic plate resting on a viscous medium Rigid

pavements are constructed by Portland cement concrete (PCC) and should be analyzed by plate theory instead of layer theory,



## **Types of Rigid Pavements**

Rigid pavements can be classified into four types:

- Jointed plain concrete pavement (JPCP),
- Jointed reinforced concrete pavement (JRCP),
- Continuous reinforced concrete pavement (CRCP), and
- Pre-stressed concrete pavement (PCP).

**Jointed Plain Concrete Pavement** is plain cement concrete pavements constructed with closely spaced contraction joints. Dowel bars or aggregate interlocks are normally used for load transfer across joints. They normally has a joint spacing of 5 to 10m.

**Jointed Reinforced Concrete Pavement** Although reinforcements do not improve the structural capacity significantly, they can drastically increase the joint spacing to 10 to 30m. Dowel bars are required for load transfer. Reinforcements help to keep the slab together even after cracks. Continuous Reinforced Concrete Pavement Complete elimination of joints are achieved by reinforcement.

## **Factors affecting pavement design**

### **Traffic and loading**

Traffic is the most important factor in the pavement design. The key factors include contact pressure, wheel load, axle configuration, moving loads, load, and load repetitions.

### **Contact pressure**

The tire pressure is an important factor, as it determines the contact area and the contact pressure between the wheel and the pavement surface. Even though the shape of the contact area is elliptical, for sake of simplicity in analysis, a circular area is often considered.

## **Wheel load**

The next important factor is the wheel load which determines the depth of the pavement required to ensure that the subgrade soil is not failed. Wheel configuration affects the stress distribution and deflection within a pavement. Many commercial vehicles have dual rear wheels which ensure that the contact pressure is within the limits. The normal practice is to convert dual wheel into an equivalent single wheel load so that the analysis is made simpler.

## **Axle configuration**

The load carrying capacity of the commercial vehicle is further enhanced by the introduction of multiple axles.

## **Moving loads**

The damage to the pavement is much higher if the vehicle is moving at creep speed. Many studies show that when the speed is increased from 2 km/hr to 24 km/hr, the stresses and deflection reduced by 40 per cent.

## **Repetition of Loads**

The influence of traffic on pavement not only depends on the magnitude of the wheel load, but also on the frequency of the load applications. Each load application causes some deformation and the total deformation is the summation of all these.

## **Environmental factors**

Environmental factors affect the performance of the pavement materials and cause various damages. Environmental factors that affect pavement are of two types, temperature and precipitation.

## **EQUIVALENT SINGLE WHEEL LOAD**

To carry maximum load within the specified limit and to carry greater load, dual wheel, or tandem assembly is often used. Equivalent single wheel load (ESWL) is the single wheel load having the same contact pressure, which produces same value of maximum stress, deflection, tensile stress or contact pressure at the desired depth. The procedure of finding



the ESWL for equal stress criteria is provided below. This is a semi-rational method, known as Boyd and Foster method, based on the following assumptions:

- Equalancy concept is based on equal stress;
- Contact area is circular;
- Influence angle is 45 degree; and
- Soil medium is elastic, homogeneous, and isotropic half space.



Where  $P$  is the wheel load,  $S$  is the center to center distance between the two wheels,  $d$  is the clear distance between two wheels, and  $z$  is the desired depth.

### **Equivalent single axle load**

Vehicles can have many axles which will distribute the load into different axles, and in turn to the pavement through the wheels. A standard truck has two axles, front axle with two wheels and rear axle with four wheels. But to carry large loads multiple axles are provided. Since the design of flexible pavements is by layered theory, only the wheels on one side needed to be considered. On the other hand, the design of rigid pavement is by plate theory and hence the wheel load on both sides of axle need to be considered. Legal axle load.

### **Repetition of axle loads:**

The deformation of pavement due to a single application of axle load may be small but due to repeated application of load there would be accumulation of unrecovered or permanent deformation which results in failure of pavement.

## **IRC method of design of flexible pavements**

### **Design traffic**

The method considers traffic in terms of the cumulative number of standard axles (8160 kg) to be carried by the pavement during the design life. This requires the following information:

1. Initial traffic in terms of CVPD
2. Traffic growth rate during the design life
3. Design life in number of years
4. Vehicle damage factor (VDF)
5. Distribution of commercial traffic over the carriage way.

### **Initial traffic**

Initial traffic is determined in terms of commercial vehicles per day (CVPD). For the structural design of the pavement only commercial vehicles are considered assuming laden weight of three tones or more and their axle loading will be considered. Estimate of the initial daily average traffic flow for any road should normally be based on 7-day 24-hour classified traffic counts (ADT). In case of new roads, traffic estimates can be made on the basis of potential land use and traffic on existing routes in the area.

### **Traffic growth rate**

Traffic growth rates can be estimated

- (i) By studying the past trends of traffic growth, and
- (ii) By establishing econometric models. If adequate data is not available, it is recommended that an average annual growth rate of 7.5 percent may be adopted.

### **Design life**

For the purpose of the pavement design, the design life is defined in terms of the cumulative number of standard axles that can be carried before strengthening of the pavement

is necessary. It is recommended that pavements for arterial roads like NH,SH should be designed for a life of 15 years, EH and urban roads for 20 years and other categories of roads for 10 to 15 years.

### **Vehicle Damage Factor**

The vehicle damage factor (VDF) is a multiplier for converting the number of commercial vehicles of different axle loads and axle configurations to the number of standard axle-load repetitions. It is defined as equivalent number of standard axles per commercial vehicle. The VDF varies with the axle configuration, axle loading, terrain type of road, and from region to region. The axle load equivalency factors are used to convert different axle load repetitions into equivalent standard axle load repetitions. For these equivalency factors refer IRC: 37 2001. The exact VDF values are arrived after extensive field surveys.

### **Vehicle distribution**

A realistic assessment of distribution of commercial traffic by direction and by lane is necessary as it directly affects the total equivalent standard axle load application used in the design. Until reliable data is available, the following distribution may be assumed.

- **Single lane roads:** Traffic tends to be more channelized on single roads than two lane roads and to allow for this concentration of wheel load repetitions, the design should be based on total number of commercial vehicles in both directions.
- **Two-lane single carriageway roads:** The design should be based on 75 % of the commercial vehicles in both directions.
- **Four-lane single carriageway roads:** The design should be based on 40 % of the total number of commercial vehicles in both directions.
- **Dual carriageway roads:** For the design of dual two-lane carriageway roads should be based on 75 % of the number of commercial vehicles in each direction. For dual three-lane carriageway and dual four-lane carriageway the distribution factor will be 60 % and 45 % respectively.

## **Rigid pavement design**

### **Wheel load stresses - Westergaard's stress equation**

The cement concrete slab is assumed to be homogeneous and to have uniform elastic properties with vertical sub-grade reaction being proportional to the deflection. Westergaard developed relationships for the stress at interior, edge and corner regions, denoted as  $\sigma_i$ ;  $\sigma_e$ ;  $\sigma_c$  in kg/cm<sup>2</sup> respectively and given by the equation.

where  $h$  is the slab thickness in cm,  $P$  is the wheel load in kg,  $a$  is the radius of the wheel load distribution in cm,  $l$  the radius of the relative stiffness in cm 29.1 and  $b$  is the radius of the resisting section in cm

### **Temperature stresses**

Temperature stresses are developed in cement concrete pavement due to variation in slab temperature. This is caused by

- (i) Daily variation resulting in a temperature gradient across the thickness of the slab
- (ii) Seasonal variation resulting in overall change in the slab temperature. The former results in warping stresses and the later in frictional stresses.

### **Warping stress**

The warping stress at the interior, edge and corner regions, denoted as  $\sigma_{ti}$ ;  $\sigma_{te}$ ;  $\sigma_{tc}$  in kg/cm<sup>2</sup> respectively and given by the equation



### **Frictional stresses**

The frictional stress  $\alpha f$  in kg/cm<sup>2</sup> is given by the equation.

Where  $W$  is the unit weight of concrete in kg/cm<sup>2</sup> (2400),  $f$  is the coefficient of sub grade friction (1.5) and  $L$  is the length of the slab in meters.

### **Combination of stresses**

The cumulative effect of the different stress give rise to the following thee critical cases

**Summer, mid-day:** The critical stress is for edge region given by  $\alpha_{critical} = \alpha_e + \alpha_{te} - \alpha f$

**Winter, mid-day:** The critical of stress is for the edge region given by  $\alpha_{critical} = \alpha_e + \alpha_{te} + \alpha f$

**Mid-nights:** The critical of stress is for the corner region given by  $\alpha_{critical} = \alpha_c + \alpha_{tc}$