

VISVESVARAYA TECHNOLOGICAL UNIVERSITY

BELGAUM



PAVEMENT DESIGN

(Subject Code: 18CV825)

LECTURE NOTES

(MODULE-1)

VIII-SEMESTER

NITESH

Assistant Professor, Dept. of Civil Engineering



AJIET

A J INSTITUTE OF ENGINEERING & TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING

(A unit of Laxmi Memorial Education Trust. (R))
NH - 66, Kottara Chowki, Kodical Cross - 575 006

Module -1

Introduction

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, favorable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the sub- grade. Two types of pavements are generally recognized as serving this purpose, namely flexible pavements and rigid pavements. This chapter gives an overview of pavement types, layers, and their functions, and pavement failures. Improper design of pavements leads to early failure of pavements affecting the riding quality.

Requirements of a pavement

An ideal pavement should meet the following requirements:

1. Sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil,
2. Structurally strong to withstand all types of stresses imposed upon it,
3. Adequate coefficient of friction to prevent skidding of vehicles,
4. Smooth surface to provide comfort to road users even at high speed,
5. Produce least noise from moving vehicles,
6. Dust proof surface so that traffic safety is not impaired by reducing visibility,
7. Should have good impervious surface, so that sub-grade soil is well protected, and
8. Should have long design life with low maintenance cost.
9. Pavement surface should be even along the longitudinal profile to enable the fast vehicles to move safely and comfortably at the design speed.
10. A pavement should be laid on well compacted subgrade free from any unfavorable moisture conditions.
11. A pavement should be free from any undulations which will increase the vertical oscillation in the fast-moving vehicle, increasing the fuel consumption and wear & tear of vehicle components which will result in increased vehicle operation cost.
12. To make the road surface more stable and non-yielding to allow the heavy wheel loads of road traffic to move with least possible rolling resistance.

Desirable Characteristics of a Pavement:

In order to fulfill the above function, the pavement has to have the following desirable properties:

- It should be structurally sound to withstand the heavy loads imposed on it.
- It should have sufficient thickness and composition such that the vehicles load is distributed to a safe value on the embankment on which it rests.
- It should have a strong and wear-resistant surface.
- It should be dust proof.
- It should have a smooth surface such that vehicles can travel at good speed comfortably and the wear and tear of vehicles is minimum.
- It should have a texture which is sufficiently rough to prevent skidding of vehicles.
- It should not generate high levels of sound.
- It should be sufficiently impervious to water such that the water does not reach the soil sub-grade.
- To sustain heavy wheel loads and to transfer the load stresses on a wide area of subgrade soil.
- It should have a long life, and the cost of maintaining it should be low.
- It should be economical to construct.
- It should be constructed well above the maximum level of ground water table to keep the subgrade relatively dry even during monsoon season.

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).

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).

In addition to these, composite pavements are also available. A thin layer of flexible pavement over rigid pavement is an ideal pavement with most desirable characteristics. However, such pavements are rarely used in new construction because of high cost and complex analysis required.

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 1).

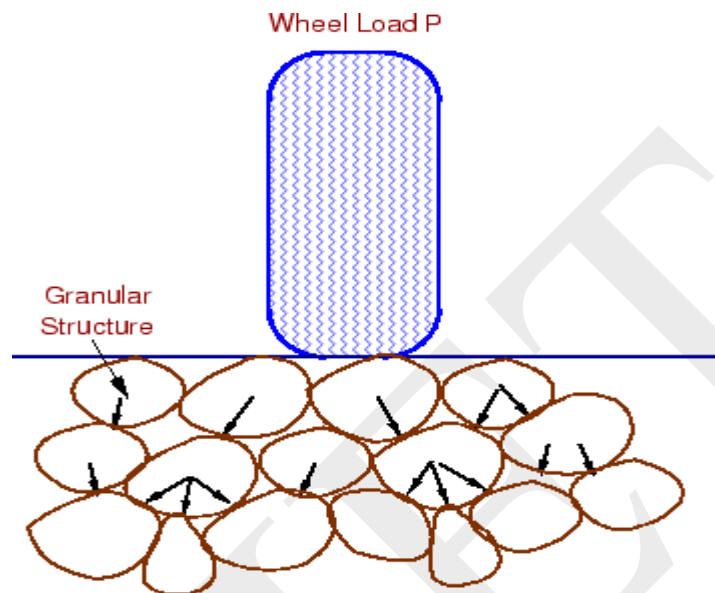


Figure 1: Load transfer in granular structure

Deflection on flexible pavement

The wheel load acting on the pavement will be distributed to a wider area, and the stress decreases with the depth. Taking advantage of these stress distribution characteristic, flexible pavements normally have many layers. Hence, the design of flexible pavement uses the concept of layered system. Based on this, flexible pavement may be constructed in a number of layers and the top layer has to be of best quality to sustain maximum compressive stress, in addition to wear and tear. The lower layers will experience lesser magnitude of stress and low-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). Flexible pavement layers reflect the deformation of the lower layers on to the surface layer (e.g., if there is any undulation in sub-grade then it will be transferred to the surface layer). In the case of flexible pavement, the design is based on overall performance of flexible pavement, and the stresses produced should be kept well below the allowable stresses of each pavement layer. However, lower layers will take lesser magnitude of stresses and there is no direct wear of wheel load. Therefore, lower quality materials with less cost can be used in lower layers. Life of flexible pavement ranges between 5 to 15 years and always requires frequent maintenance.

Types of Flexible Pavements

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

1. Conventional layered flexible pavement,
2. Full - depth asphalt pavement, and
3. 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 sub-grade. 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.

Typical layers of a flexible pavement

Typical layers of a conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub-grade (Figure 2).

Seal Coat:

Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.

Tack Coat:

Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water. It provides proper bonding between two layers of binder course and must be thin, uniformly cover the entire surface, and set very fast.

Prime Coat:

Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.

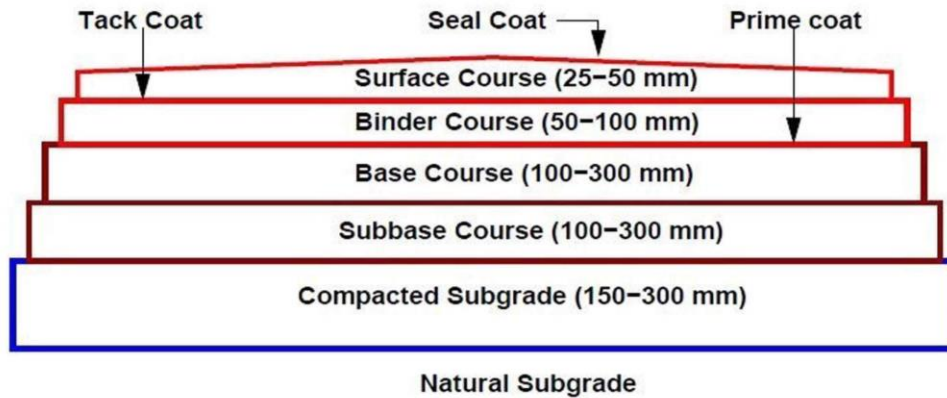


Figure 2: Typical cross section of a flexible pavement

Surface course

Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete (AC). The functions and requirements of this layer are:

- It provides characteristics such as friction, smoothness, drainage, etc. Also, it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade,
- It must be tough to resist the distortion under traffic and provide a smooth and skid-resistant riding surface,
- It must be water proof to protect the entire base and sub-grade from the weakening effect of water.

Binder course

This layer provides the bulk of the asphalt concrete structure. Its chief purpose is to distribute load to the base course. The binder course generally consists of aggregates having less asphalt and doesn't require quality as high as the surface course, so replacing a part of the surface course by the binder course results in more economical design.

Base course

The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage. It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials.

Sub-Base course

The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure. If the base course is open graded, then the sub-base course with more fines can serve as a filler between sub-grade and

the base course. A sub-base course is not always needed or used. For example, a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered by a sub-base course. In such situations, sub-base course may not be provided.

Sub-grade

The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed. It should be compacted to the desirable density, near the optimum moisture content.

Functions of different layers of pavement:

1. Sub-grade or Formation:

- It is the finished and compacted surface of earthwork on which a road pavement rests.
- It may be provided in embankment or in cutting or at level grounds.
- It is compacted to its optimum density and moisture conditions.
- Finished with proper camber and gradient.
- Thickness and type of pavement depends on the power of sub-grade, because entire traffic load and pavement is taken up by the sub-grade.

Functions of Sub-grade:

- To bear ultimately the entire load of pavement including the traffic load transmitted through the pavement.
- To provide an adequate and uniform support to the road pavement.

2. Sub- Base Course:

- It is the layer of granular materials provided in between the sub-grade and the base course.
- It is provided as an additional layer when sub-grade is of poor quality.
- It consists of materials like burnt clinker, natural gravel or slag.

Functions of Sub-Base Course:

- To transmit the compressive stress on a wide area of sub-grade soil
- To improve the bearing capacity of sub-grade
- To improve the drainage capacity
- To prevent the action of capillary rise of sub-soil water
- To eliminate the frost heave in frost affected areas.

3. Base Course:

- It is a layer made of stable materials like boulders or gravel or bricks
- It is provided over the sub-base course, or immediately over the sub-grade in the absence of sub-base in a road pavement.
- This course or layer is considered as the most important and a major component of road pavement structure, because this layer can bear the impact of traffic wheel loads as transferred through the wearing course.
- In case of rocky sub-grade, this layer is not provided.

Functions of Base Course:

- To withstand the high intensity of compression stresses or flexural stresses due to wheel load.
- To withstand high shearing stresses imposed upon it due to the impact affect of traffic on wearing course.
- To act as the foundation for the road top layer.
- To transfer the wheel loads coming over the pavement surface safely to the sub-base course and sub-grade layers underneath.

4. Wearing Course or Surfacing:

- It is the top most layer of the road pavement.
- This course is directly exposed to traffic and heat.
- It may consist of one or more no. of layers in case of flexible pavement.
- Should have good impervious properties.
- Should act as weather resisting layer.
- Should be able to resist abrasive action of traffic

Functions of Wearing Course:

- To distribute the traffic load safely to the base course
- To act as an impervious layer so that the surface water could not find its access to base course
- To prevent dust nuisance
- To withstand abrasive effect of traffic
- To provide smooth riding surface.

Rigid pavements

Rigid pavements are made up of cement concrete, RCC or PSC and may or may not have base course between the pavement and subgrade. A cement concrete pavement can be laid directly over the subgrade soil if the soil is of gravel sand in nature.

Otherwise, it must be followed by the suitable sub base or base course. However,

cement concrete pavement cannot be laid directly over the subgrade soil if the soil is of fine clay or expanding in nature. Otherwise, this may result in other problems like mud pumping or frost heaving. The selection of base course between the concrete pavement and subgrade soil depends on the manner in which they distribute the load over the subgrade.

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 3. 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.

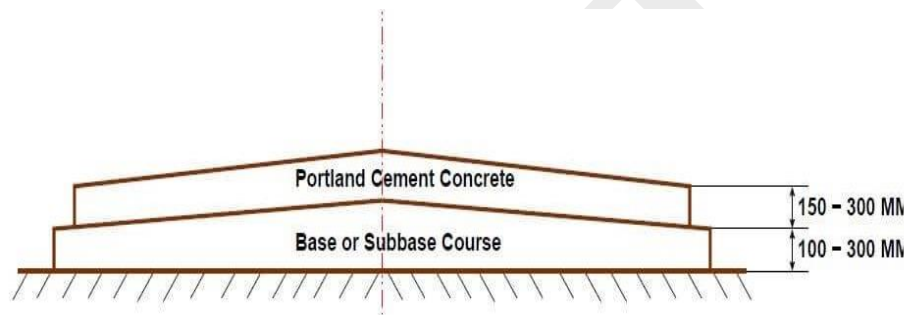


Figure 3: Typical Cross section of rigid pavement

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, assuming an elastic plate resting on viscous foundation.

Plate theory is a simplified version of layer theory that assumes the concrete slab as a medium thick plate which is plane before loading and to remain plane after loading. Bending of the slab is due to wheel load and temperature variation and the resulting tensile and flexural stress. Because of the slab action in rigid pavement, maximum tensile stress is developed due to the wheel loads and temperature variation. However, the rigid pavements do not deform to the shape of subgrade. Life of rigid pavement is around 25 to 30 years in general, or even it may extend upto 50 years.

Types of Rigid Pavements

Rigid pavements can be classified into four types:

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

Jointed Plain Concrete Pavement: These are 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 have 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. Reinforcement's help to keep the slab together even after cracks.

Continuous Reinforced Concrete Pavement: Complete elimination of joints is achieved by reinforcement.

Factors affecting design and performance of pavements or Design strategies of variables:

The various factors to be considered for the design of flexible pavements are given below:

- a) Wheel load
- b) Subgrade soil
- c) Climatic factors
- d) Environmental factors
- e) Pavement component materials

1. Wheel load: Total load influences the thickness requirements of flexible pavement. Higher the wheel load, thicker will be the pavement, provided other design factors remain same. Major amount of weight of a vehicle is transmitted through a rear axle on the pavement. In addition to the total load, tyre pressure and contact pressure are also to be considered in the design of pavements. Tyre pressure is due to the pressure of air in air tubes. A constant pressure between the pavement and tyre is different from tyre pressure. Tyre pressure does not control the thickness of pavement to any great extent, but they influence the regional quality of surface. Repetition of load has a direct influence on both types of pavements, i.e., for high repetitions, thick pavements are required.

Following are the important factors to be considered in the design:

- a) Max wheel load
- b) Contact pressure
- c) Dual or multiple loads and ESWL
- d) Repetition of loads
- e) Tyre pressure

There are various types of wheel load configurations indicating the way in which the loads of a given vehicle are applied on the pavement surface. In highways, maximum axle loads as specified by IRC is 8170kg with a maximum ESWL of 4085kg. In fact, the magnitude of vertical stress at any depth of a soil mass depends upon the surface pressure as well as total load. Tyre pressure is different from contact pressure.

Contact Pressure = Load on wheel/ Contact area or area of impression

If tyre pressure is low, contact pressure is greater than tyre pressure and contact area in this case is more and will produce lower stresses than actual.

An influence of tyre pressure is quite predominant in upper layers. It is maximum in upper

layers and decreases at greater depths. Because of high tyre pressure in upper layers, high qualities of materials are required in upper layers. However, total depth of pavement is not influenced by tyre pressure. Magnitude of stress on upper layer depends on total load and same tyre pressure.

Rigidity Factor (RF): As far as the distribution of wheel load on the pavement is considered, it is assumed that the load distributed is in the form of circle. But in real practice, by the measurement of impressions of tyres under different loads and pressures, it is found to be in elliptical shape.

A ratio of contact pressure to tyre pressure is known as Rigidity Factor (RF), given as:

$$\text{Rigidity Factor} = \text{Contact pressure} / \text{Tyre pressure}$$

This depends on the degree of tension developed in the walls of tyres.

$$\text{RF} = 1 \text{ for average tyre pressure of } 7\text{kg/cm}^2$$

$$\text{RF} > 1 \text{ for low tyre pressure}$$

Tyre pressure do not control the thickness of pavement to great extent, but they influence the required quality of surface and base. Total load also influences the thickness of rigid pavements. Tyre pressure affects the thickness of pavement to a lesser extent. Number of repetitions of loads also affects both types of pavements, that is, heavy pavements are required for more repetitions.

2. Subgrade Soil properties:

- a) Lower stability requires thicker pavement.
- b) Density
- c) Moisture content
- d) Soil structures
- e) Rate of load application
- f) Degree of confinement
- g) Permeability of soil

The properties of subgrade soil are important in deciding the thickness requirements of pavements. A subgrade with lower stability requires thicker pavement to protect it from traffic loads. In the design of pavements, two important points are to be considered – one is strength of soil, and another is volume change behavior under various loadings & climatic conditions. Strength of soil is affected by many factors like density, moisture content cause variations in strength and then volume of subgrade. These factors influence the design to a great extent. A permeability of soil influences the performance of drainage conditions.

3. Climatic Conditions:

- a) Rainfall intensity
- b) Moisture content
- c) Frost action, more in winter season, causes freezing

- d) Water in subgrade soil forms crystals which grows in size if water is supplied through capillary action
- e) Daily and seasonal variations in temperature, shrinkage, swelling.

Among the climatic factors, rainfall affects the moisture conditions in the subgrade and pavement layers. However, the effect of rainfall and frost action is taken into account. Rainfall causes variations in moisture content, in turn affects the strength and volume of soil subgrade as well as paving materials.

Frost action is predominant in cold climate regions, particularly in winter seasons. Frost action refers to the alternative freezing and thawing. The water held or stored in subgrade soil forms the crystals which grow in size if water is supplied through capillary action. This results in rising of pavement portion which is known as “Frost Heave”. The design of both flexible and rigid pavements is greatly influenced by daily and seasonal variations in temperature, shrinkage, swelling, freezing and thawing.

4. Environmental Factors:

Height of embankment, foundation, depth of cutting depends on,

- a) Depth of water table
- b) Pavement temperature

Environmental factors such as height of embankment and its foundation, depth of cutting, depth of sub surface water table, etc. affects the performance of pavement. Choice of the bituminous binder and the performance of bituminous pavement depend on variations in pavement temperature with the seasons in the region. Warping stresses in rigid pavements depends on the daily variations in temperature in the region and is the maximum difference in temperature between the top and bottom of pavement slab.

5. Pavement Component Materials:

Stress distribution characters of the pavement component layers depend on characteristics and properties of materials used. The fatigue behaviour of materials and durability under adverse conditions of weather should be given due considerations.

Fundamentals of Design of Pavement

Stresses in Flexible Pavements

- Distribution of vertical stress below a concentrated load takes the form of bell-shaped surface.
- Maximum stress occurs on the vertical plane passing through the point of application of load.
- Stress is minimum at shallow depth.
- In case of flexible pavements, load is distributed over an elliptical area.

Boussinesq’s Theory (Single Layer Theory)

In 1885, Boussinesq analysed the distribution of stresses in an ideal, elastic, homogeneous and isotropic solid obeying Hooke’s law and presented equations for horizontal and vertical stresses in such a material under a load. The vertical stress under a load at any horizontal section decreases from the maximum at the point located directly beneath the load to zero at a very large distance from this point.

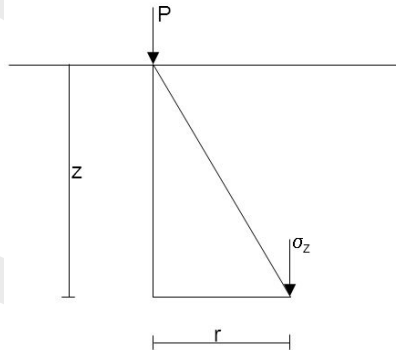
Assumptions of Boussinesq's Theory:

1. The soil mass is an elastic medium, for which the modulus of elasticity E is constant.
2. The soil mass is homogeneous, that is, all its constituent parts or elements are similar and it has identical properties at every point in it in identical directions.
3. The soil mass is isotropic, means, it has identical elastic properties in all directions through any point of it.
4. The soil mass is semi-infinite, means, it extends infinitely in all directions below a level surface.

Limitations of Boussinesq's Theory:

1. The assumption that soil is perfectly elastic and homogeneous is not true.
2. Soil may be elastic only upto a certain limit.
3. Pavement consists of a number of layers, each with its own modulus of elasticity.
4. Assumption of one constant property for the entire mass is not justified.
5. Assumption that the load is uniformly distributed may not be correct.

The following equations are based on Boussinesq's theory and are widely used to calculate stresses in soil mass.

Case 1: Point Load

Assume that soil is perfectly elastic, homogeneous and obey Hooke's law,

$$\sigma = e E$$

Where σ = stress, e = strain, E = modulus of Elasticity.

Vertical Stress due to a point load is given by:

$$(\sigma_z) = \frac{3P}{2\pi z^2} \frac{1}{\left[1 + \left(\frac{r}{z}\right)^2\right]^{\frac{5}{2}}}$$

Where, P = point load

z = depth from surface

r = radial distance from the axis of loading

σ_z = vertical stress

Case 2: Uniformly distributed load over a circular area

Vertical stress due to the uniformly distributed circular area:

$$(\sigma_z) = p \left(1 - \left[\frac{1}{1 + \left(\frac{a}{z}\right)^2} \right]^{\frac{3}{2}} \right) \text{ or } (\sigma_z) = p \left[1 - \frac{z^3}{(a^2 + z^2)^{3/2}} \right]$$

Where, p = surface pressure

z = depth at which σ_z is calculated

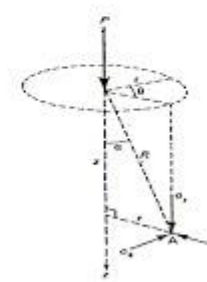
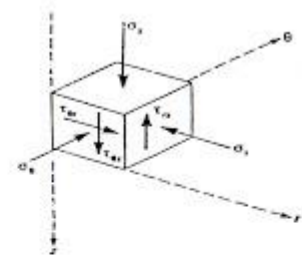
a = radius of loaded area

Boussinesq’s Influence Factor (K_B or I_p)

- This is a function of r/z ratio, which is dimensionless
- Influence factors for shear stress can be calculated by multiplying the factor (K_B or I_p) by the ratio r/z.
- Therefore, to find the vertical stress at any point at a radial distance r and depth z below the loaded point, find the influence factor for r/z ratio and then multiply it by Q/z^2 to get the vertical stress.

r/z	I_p	r/z	I_p	r/z	I_p	r/z	I_p
0.00	0.4775	0.50	0.2733	1.00	0.0844	1.50	0.0251
0.02	0.4770	0.52	0.2625	1.02	0.0803	1.55	0.0224
0.04	0.4756	0.54	0.2518	1.04	0.0764	1.60	0.0200
0.06	0.4732	0.56	0.2414	1.06	0.0727	1.65	0.0179
0.08	0.4699	0.58	0.2313	1.08	0.0691	1.70	0.0160
0.10	0.4657	0.60	0.2214	1.10	0.0658	1.75	0.0144
0.12	0.4607	0.62	0.2117	1.12	0.0626	1.80	0.0129
0.14	0.4548	0.64	0.2024	1.14	0.0595	1.90	0.0105
0.16	0.4482	0.66	0.1934	1.16	0.0567	2.00	0.0084
0.18	0.4409	0.68	0.1846	1.18	0.0539	2.20	0.0058
0.20	0.4329	0.70	0.1762	1.20	0.0513	2.40	0.0040
0.22	0.4243	0.72	0.1681	1.22	0.0489	2.60	0.0028
0.24	0.4151	0.74	0.1602	1.24	0.0465	2.80	0.0021
0.26	0.4054	0.76	0.1527	1.26	0.0443	3.00	0.0015
0.28	0.3954	0.78	0.1455	1.28	0.0422	3.20	0.0011
0.30	0.3849	0.80	0.1386	1.30	0.0402	3.40	0.0009
0.32	0.3742	0.82	0.1320	1.32	0.0383	3.60	0.0007
0.34	0.3632	0.84	0.1257	1.34	0.0365	3.80	0.0005
0.36	0.3521	0.86	0.1196	1.36	0.0348	4.00	0.0004
0.38	0.3408	0.88	0.1138	1.38	0.0332	4.50	0.0002
0.40	0.3295	0.90	0.1083	1.40	0.0317	5.00	0.00014
0.42	0.3181	0.92	0.1031	1.42	0.0302	6.00	0.00006
0.44	0.3068	0.94	0.0981	1.44	0.0288	7.00	0.00003
0.46	0.2955	0.96	0.0933	1.46	0.0275	8.00	0.00001
0.48	0.2843	0.98	0.0887	1.48	0.0263	10.00	0.00000

$$\sigma_z = \frac{P}{z^2} I_p \quad \tau_{rz} = \frac{P}{z^2} I_p \frac{r}{z}$$



Stresses due to a point load

Influence factors (I_p) for vertical stress due to a point load.

Burmister’s Theory – Stresses in Layered Systems:

In 1943, Donald M. Burmister developed a method of analyzing a two-layered soil system which resembled a flexible pavement having its top layer stiffer than its bottom layer. Later in 1945, he extended the method to include three-layered system. As an

important outcome of Burmister's numerical solutions, the flexible pavement thickness design method was developed for airfield pavements.

Assumptions of Burmister's Theory:

1. Every layer material is homogenous, isotropic and ideally elastic. They are characterized by a unique elastic modulus and Poisson's ratio.
2. A pavement consists of two layers. The elastic modulus value of the top layer is more than the bottom layer (i.e., $E_1 > E_2$).
3. The layers are weightless and infinite in the horizontal direction.
4. The top layer has finite thickness (h) but the bottom layer is infinitely thick.
5. The top layer is in full contact with the bottom layer.
6. The interface between these layers is rough and there is no loss of transfer of applied stress from the top layer to the bottom layer.
7. There will be no shear and normal stresses outside the loaded area.
8. The applied stress is uniform over a circular area.

Deflection equations given by Burmister for a two-layered system are as follows:

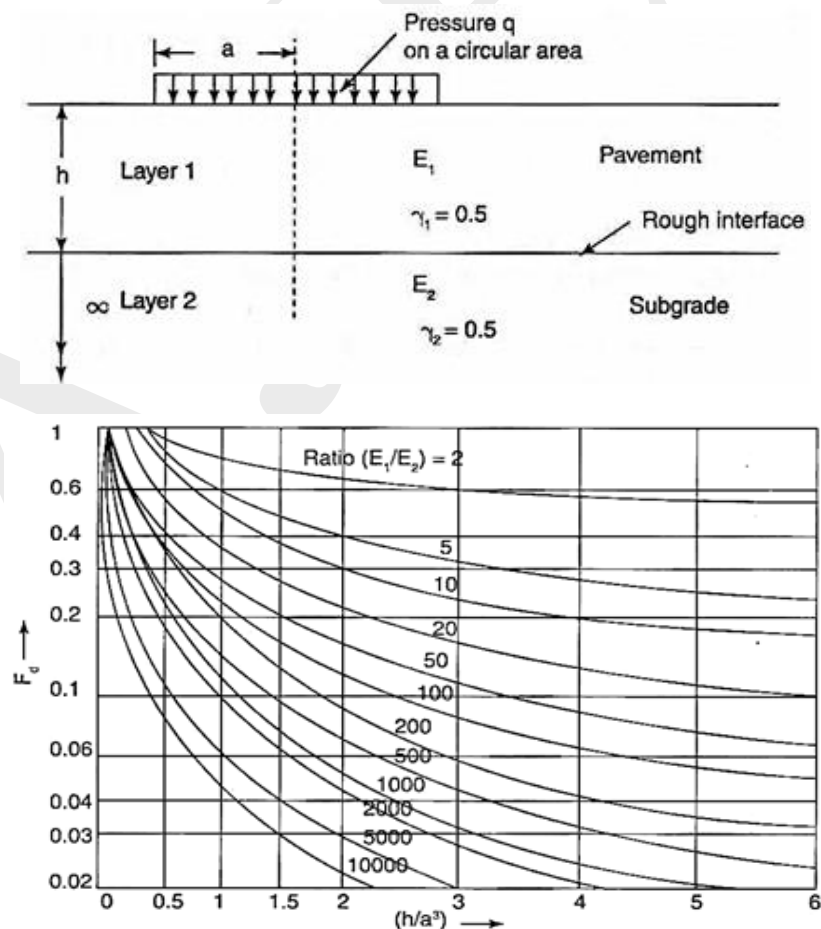
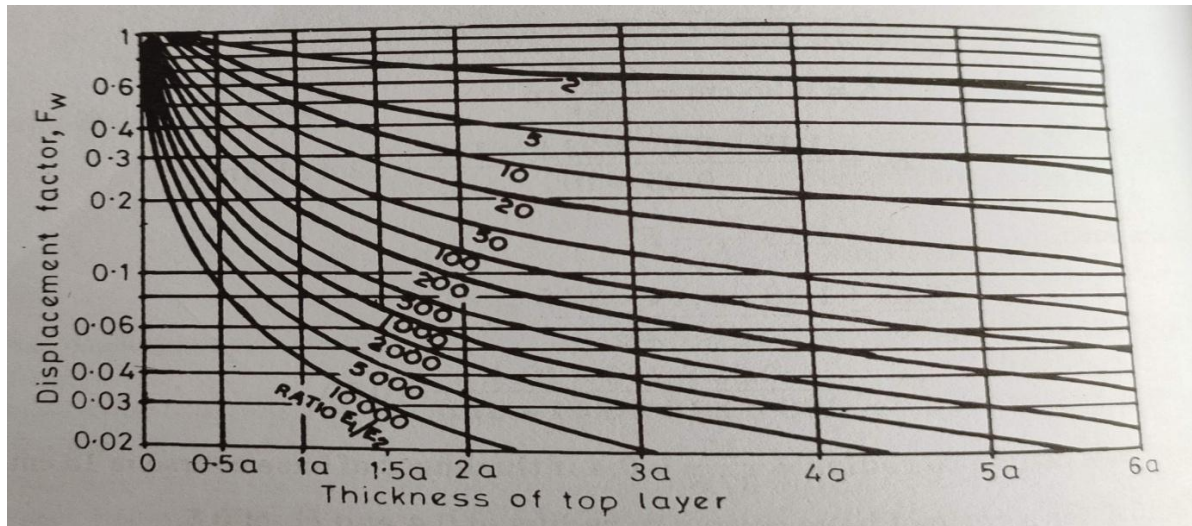


FIG. 7.12 Burmister's two-layered system: F_d vs (h/a)



Surface deflection under the flexible pavement:

$$\Delta = \frac{1.5 p a}{E_2} \times F_w$$

Surface deflection under the rigid pavement:

$$\Delta = \frac{1.18 p a}{E_2} \times F_w$$

Where, Δ = vertical deflection at surface (when $z=0$)

p = uniform pressure on circular plate

a = radius of the circular plate

E_2 = elastic modulus of subgrade

F_w = displacement factor, depends on ratios of $\left(\frac{E_1}{E_2}\right)$ and $\left(\frac{h}{a}\right)$

E_1 = elastic modulus of the top layer

h = thickness of the top layer

Difference between flexible and rigid pavements:

Flexible pavement	Rigid pavement
Design depends on the wheel load and also on the no. of repetitions of wheel load.	Design depends on wheel load and strength of concrete.
Life of pavement is 5 to 10 years.	Life of pavement is more, around 25-30 years
More maintenance works.	Maintenance work is very less.
Initial cost is low.	Initial cost is high.
Joints are not required.	Joints are very much essential.
Moderate skill and less supervision are required.	High skill and more supervision are required.
Repair work is easy.	Repair work is difficult.
Easy to lay and locate or repair underground pipes below the pavement	Difficult to lay and locate or repair underground pipes below the pavement.
The flexible pavement can be opened soon after the construction.	Rigid pavement requires minimum of 28 days of curing after the construction which will delay the utilization of the road and hence affect the traffic.
Less durable	More durable.
Stresses are not developed due to changes in temperature.	Stresses are developed due to changes in temperature.
They develop more corrugations.	Do not develop corrugations.
Suitable for all types of traffic.	They become noisy when heavy wheeled traffic is in use.
Maintenance cost is high.	Maintenance cost is less.
Overall pavement thickness is more.	Overall thickness is less.
Load distribution is based on layered system.	Load carries by slab itself.

Difference between Highway Pavement and Airfield Pavement:

Highway pavement	Airfield pavement
Width of pavement depends upon no. of lanes and no. of lanes depends on the traffic intensity.	Width of pavement depends upon the class of airport, type of area in operation and standard clearance values.
Width of 2 lane highway is 7.0m	Width of airport pavement varies between 13 to 60m.
Weight of truck is maximum of 60-80 tonnes	Gross weight of an aeroplane ranges between 80 to 250tonnes.
Design wheel load is about 5.1 tonnes.	Design wheel load is around 50 tonnes.
Tyre proof pressure is about 4 to 7 kg/cm ² .	Tyre proof pressure is about 25 to 30kg/cm ² .
In highway, pavements are not subjected to impact load.	Airport pavements are subjected to different types of impacts during landing and take-off.
No. of repetitions of wheel loads are more.	No. of repetitions of wheel loads are less.

Highways are generally made of asphalt and rarely made of concrete.	All runways are made of concrete.
Overall pavement thickness is less	Overall pavement thickness is more.
Traffic load on highway pavement is concentrated at edges of the pavements.	Traffic load is concentrated at the centre of pavement.
Compaction required is less than airfield and airports.	Need more compaction as weight of planes landing has a much greater force than highways.

Problems:

1. Calculate the intensity of vertical pressure due to a point load of 4200kg at a depth of 4m from the surface and a distance of 2m from the axis of loading.

Solution: At 4m depth and distance 2m from the axis of loading: $z = 4\text{m}$ and $r = 2\text{m}$

$$\text{Vertical stress due to a point load } (\sigma_z) = \frac{3P}{2\pi z^2} \frac{1}{\left[1 + \left(\frac{r}{z}\right)^2\right]^{\frac{5}{2}}}$$

$$= \frac{3 \times 4200}{2\pi \times 4^2} \frac{1}{\left[1 + \left(\frac{2}{4}\right)^2\right]^{\frac{5}{2}}}$$

$$= 71.74 \text{ kg/m}^2$$

2. A semi- infinite soil mass is subjected to stress under a circular plate having a 15cm radius. The load intensity over the plate is 4000kg. Calculate the vertical stress in the soil under the axis of the circular plate at 2cm depth.

Solution: Intensity of pressure over plate = $4000 / (\pi \times 15^2) = 5.66 \text{ kg/cm}^2$

$$\text{Vertical stress under the centre of the circular area } (\sigma_z) = p \left(1 - \left[\frac{1}{1 + \left(\frac{a}{z}\right)^2} \right]^{\frac{3}{2}} \right)$$

$$= 5.66 \left(1 - \left[\frac{1}{1 + \left(\frac{15}{2}\right)^2} \right]^{\frac{3}{2}} \right)$$

$$= 5.64 \text{ kg/cm}^2$$

3. Design the thickness of a flexible pavement by Burmister's two-layer analysis for a wheel load of 40kN and a tyre pressure of 0.5MN/m^2 . The Modulus of Elasticity of the pavement material is 150MN/m^2 and that of the subgrade is 30MN/m^2 . The value of F_w , the displacement factor can be taken from graph.

Solution: Radius of circular area, a is given by

$$\text{Tyre pressure} = \frac{\text{Wheel load}}{\pi a^2}$$

$$\text{Therefore, } 0.5 \times 10^6 = \frac{40 \times 1000}{\pi a^2}$$

Therefore, $a = 15.95\text{cm}$, say 16cm

Select a thickness of pavement of $2a$, i.e., 32cm

$$\frac{E_1}{E_2} = \frac{150}{30} = 5$$

From fig, for $\frac{E_1}{E_2} = 5$, and pavement thickness of $2a$

$$F_w = 0.43$$

$$\begin{aligned} \Delta &= F_w \frac{1.5 p a}{E_2} \\ &= 0.43 \times \frac{1.5 \times 0.5 \times 10^6 \times 0.16}{30 \times 10^6} \\ &= 0.00172\text{m} = 0.172\text{cm} \end{aligned}$$

4. Calculate the rebound surface deflection on a single layer pavement under a wheel load of 40kN with a tyre pressure of 0.8 MPa . The effective elastic modulus of sub-grade may be taken as 40 MPa and Poisson's ratio of the soil as 0.5 .

Solution:

Tyre Pressure = wheel load/ tyre contact area

$$= \text{wheel load} / \pi a^2$$

$$\begin{aligned} \text{Radius of tyre contact area, } a &= \sqrt{\frac{\text{wheel load}}{\pi \times \text{tyre pressure}}} \\ &= \sqrt{\frac{40 \times 10^3}{\pi \times 0.8 \times 10^6}} = 0.126\text{m} \end{aligned}$$

$$\text{Intensity of pressure, } p = \text{load} / \text{area} = \frac{40 \times 10^3}{\pi \times (0.126^2)} = 801990.14 \text{ N/mm}^2$$

If a flexible plate considered, rebound surface deflection,

$$\Delta_s = \frac{1.5 p a}{E} = \frac{1.5 \times 801990.14 \times 0.126}{40 \times 10^6} = 0.00378\text{m}$$

5. A circular load of radius 15cm with uniform contact pressure of 7.0kg/cm^2 is applied on the surface of a homogeneous elastic mass. Determine the vertical stress under the centre of

the load at a depth of 45cm from the surface.

Solution: Pressure $p = 7.0 \text{ kg/cm}^2$, radius $a = 15\text{cm}$, depth of layer $z = 45\text{cm}$

$$\begin{aligned}\text{Vertical stress } \sigma_z &= p \left[1 - \frac{z^3}{(a^2 + z^2)^{3/2}} \right] \\ &= 7 \left[1 - \frac{45^3}{(15^2 + 45^2)^{3/2}} \right] \\ &= 1.023 \text{ kg/cm}^2\end{aligned}$$

6. Calculate the deflection at the surface of a pavement due to a wheel load of 40kN and a tyre pressure of 0.5 MN/m^2 . The value of E of the pavement and subgrade may be assumed to be uniformly equal to 20 MN/m^2 .

Solution:

Tyre Pressure = wheel load/ tyre contact area

$$= \text{wheel load} / \pi a^2$$

$$\begin{aligned}\text{Radius of tyre contact area, } a &= \sqrt{\frac{\text{wheel load}}{\pi \times \text{tyre pressure}}} \\ &= \sqrt{\frac{40 \times 10^3}{\pi \times 0.5 \times 10^6}} = 0.1595\text{m}\end{aligned}$$

$$\text{Intensity of pressure, } p = \text{load} / \text{area} = \frac{40 \times 10^3}{\pi \times (0.1595^2)} = 500482.32 \text{ N/mm}^2$$

If a flexible plate considered, rebound surface deflection,

$$\Delta_s = \frac{1.5 p a}{E} = \frac{1.5 \times 500482.32 \times 0.1595}{20 \times 10^6} = 0.005986 \text{ m}$$

7. Find the intensity of vertical pressure at a point 3m directly below 25kN point load acting on a horizontal ground surface. What will be the vertical pressure at a point 2m horizontally away from the axis of loading and at same depth of 3m? Use Boussinesq's equation.

Solution:

Case i: $P = 25\text{kN}$, $z = 3\text{m}$, $r = 0$

$$\begin{aligned}\text{Vertical stress due to a point load } (\sigma_z) &= \frac{3P}{2\pi z^2} \frac{1}{\left[1 + \left(\frac{r}{z}\right)^2\right]^{\frac{5}{2}}} \\ &= \frac{3 \times 25}{2 \times \pi \times 3^2} \frac{1}{\left[1 + \left(\frac{0}{3}\right)^2\right]^{\frac{5}{2}}} \\ &= 1.33 \text{ kN/m}^2\end{aligned}$$

Case ii: $P = 25\text{kN}$, $z = 3\text{m}$, $r = 2\text{m}$

$$\begin{aligned}\text{Vertical stress due to a point load } (\sigma_z) &= \frac{3P}{2\pi z^2} \frac{1}{\left[1 + \left(\frac{r}{z}\right)^2\right]^{\frac{5}{2}}} \\ &= \frac{3 \times 25}{2 \times \pi \times 3^2} \frac{1}{\left[1 + \left(\frac{2}{3}\right)^2\right]^{\frac{5}{2}}} \\ &= 0.53 \text{ kN/m}^2\end{aligned}$$

8. A circular area 6m in diameter, carries uniformly distributed load of 10kN/m^2 . Determine the vertical stress at a depth of 2m, 4m and 8m.

Solution: $a = 3\text{m}$, $p = 10\text{kN/m}^2$

$$\text{Vertical stress } (\sigma_z) = p \left(1 - \left[\frac{1}{1 + \left(\frac{a}{z}\right)^2} \right]^{\frac{3}{2}} \right)$$

$$\text{At } z = 2\text{m}, (\sigma_z) = 10 \left(1 - \left[\frac{1}{1 + \left(\frac{3}{2}\right)^2} \right]^{\frac{3}{2}} \right)$$

$$\sigma_z = 8.29 \text{ kN/m}^2$$

$$\text{At } z = 4\text{m}, (\sigma_z) = 10 \left(1 - \left[\frac{1}{1 + \left(\frac{3}{4}\right)^2} \right]^{\frac{3}{2}} \right)$$

$$\sigma_z = 4.88 \text{ kN/m}^2$$

$$\text{At } z = 8\text{m}, (\sigma_z) = 10 \left(1 - \left[\frac{1}{1 + \left(\frac{3}{8}\right)^2} \right]^{\frac{3}{2}} \right)$$

$$\sigma_z = 1.79 \text{ kN/m}^2$$

9. Calculate the intensity of vertical pressure due to a point load of 6400kg at a depth of 6m from the surface and a distance of 3m from the axis of loading.

Solution: $z = 6\text{m}$, $r = 3\text{m}$, $P = 6400\text{kg}$

$$\begin{aligned}\text{Vertical stress due to a point load } (\sigma_z) &= \frac{3P}{2\pi z^2} \frac{1}{\left[1 + \left(\frac{r}{z}\right)^2\right]^{\frac{5}{2}}} \\ &= \frac{3 \times 6400}{2 \times \pi \times 6^2} \frac{1}{\left[1 + \left(\frac{3}{6}\right)^2\right]^{\frac{5}{2}}}\end{aligned}$$

$$= 48.58 \text{ kg/m}^2$$

10. A circular area 10m in diameter, carries uniformly distributed load of 20kN/m². Determine the vertical stress at a depth of 6m.

Solution: d = 10m, a = 5m, z = 6m, p = 20kN/m²

$$\begin{aligned} \text{Vertical stress } \sigma_z &= p \left[1 - \frac{z^3}{(a^2 + z^2)^{3/2}} \right] \\ &= 20 \left[1 - \frac{6^3}{(5^2 + 6^2)^{3/2}} \right] \\ &= 10.93 \text{ kN/m}^2 \end{aligned}$$

11. A semi-infinite soil mass is subjected to stress under a circular plate having a 20cm radius. The load intensity over the plate is 5000kg. Calculate the vertical stress in the soil under the axis of the circular plate at 5cm depth.

Solution: a = 20cm, P = 5000kg, z = 5cm

Intensity of pressure over plate = 5000 / (π x 20²) = 3.97 kg/cm²

$$\begin{aligned} \text{Vertical stress } \sigma_z &= p \left[1 - \frac{z^3}{(a^2 + z^2)^{3/2}} \right] \\ &= 3.97 \left[1 - \frac{5^3}{(20^2 + 5^2)^{3/2}} \right] \\ &= 3.91 \text{ kg/cm}^2 \end{aligned}$$

12. Calculate the intensity of vertical pressure due to a point load of 4500kg at a depth of 5m from the surface and a distance of 4m from the axis of loading.

Solution: z = 5m, r = 4m, P = 4500kg

$$\begin{aligned} \text{Vertical stress due to a point load } (\sigma_z) &= \frac{3P}{2\pi z^2} \frac{1}{\left[1 + \left(\frac{r}{z} \right)^2 \right]^{5/2}} \\ &= \frac{3 \times 4500}{2 \times \pi \times 5^2} \frac{1}{\left[1 + \left(\frac{4}{5} \right)^2 \right]^{5/2}} \\ &= 24.95 \text{ kg/m}^2 \end{aligned}$$

13. Plate bearing tests were conducted using 30cm diameter plate on soil subgrade and over

a base course of thickness 45cm. The pressure yielded at 0.5cm deflection on the subgrade and base course were 1.25 kg/cm² and 8.0 kg/cm² respectively. Design the thickness requirement of flexible pavement for a wheel load of 5100kg with tyre pressure of 7.0kg/cm² for an allowable deflection of 0.5cm using Burmister's two-layer deflection factor chart.

Solution:

a) Plate load test on subgrade or single layer

$\Delta_1 = 0.5\text{cm}$, $p = 1.25 \text{ kg/cm}^2$, $a = 30/2 = 15\text{cm}$, $F_w = 1$ (test on subgrade/ single layer)

$$\Delta_1 = \frac{1.18 p a}{E_2} \times F_w$$

$$0.5 = \frac{1.18 \times 1.25 \times 15}{E_2} \times 1$$

$$E_2 = 44.25 \text{ kg/cm}^2$$

b) Plate load test on base course of thickness 45cm

$\Delta_1 = 0.5\text{cm}$, $p = 8 \text{ kg/cm}^2$, $a = 30/2 = 15\text{cm}$, $h = 45\text{cm}$, $E_2 = 44.25 \text{ kg/cm}^2$

$$\Delta_1 = \frac{1.18 p a}{E_2} \times F_w$$

$$0.5 = \frac{1.18 \times 8 \times 15}{44.25} \times F_w$$

$$F_w = 0.156$$

From Burmister's Two-layer Deflection Factor Chart, for $h/a = 45/15 = 3$, $F_w = 0.156$, the ratio $(E_1/E_2) = 50$.

c) Design wheel load (flexible plate)

$P_2 = 5100\text{kg}$, $p_2 = 7.0 \text{ kg/cm}^2$, radius of circular load $a_2 = \sqrt{\frac{5100}{\pi \times 7}} = 15.22\text{cm}$

$E_2 = 44.25 \text{ kg/cm}^2$, $\Delta = 0.5\text{cm}$

$$\Delta = \frac{1.5 p_2 a_2}{E_2} F_w$$

$$0.5 = \frac{1.5 \times 7 \times 15.22}{44.25} F_w$$

$$F_w = 0.138$$

From Burmister's two-layer deflection factor chart, using curve for $(E_1/E_2) = 50$ and $F_w = 0.138$

Ratio of pavement thickness h to radius of wheel load $(h/a_2) = 2.5$

Therefore, design thickness of flexible pavement,

$$\begin{aligned} h &= 2.5 a_2 \\ &= 2.5 \times 15.22 \\ &= 38.05 \text{ cm.} \end{aligned}$$

14. Plate bearing tests were conducted with a 75cm dia plate on soil subgrade and a granular base. The stress noticed, when the deflection was 0.25cm on the subgrade soil, was 0.07 MN/m². On the base course, the same plate yielded 0.25cm deflection under a stress of 0.14 MN/m². Design the pavement for an allowable deflection of 0.5cm under a wheel load of 40kN and a tyre pressure of 0.5 MN/m².

Solution:

Since the plate bearing test results are given, the values of the Modulus of Elasticity, E, can be calculated individually for the subgrade and the base.

For the subgrade,

$$\begin{aligned} \Delta &= \frac{1.18 p a}{E_2} \times F_w & a &= 75/2 = 37.5 \text{ cm} = 37.5/100 = 0.375\text{m,} \\ 0.0025 &= \frac{1.18 \times 0.07 \times 0.375}{E_2} \times 1 & \Delta &= 0.25/100 = 0.0025\text{m} \\ E_2 &= \frac{1.18 \times 0.07 \times 0.375}{0.0025} \times 1 \\ E_2 &= 12.39 \text{ MN/m}^2 \end{aligned}$$

For the base,

$$\begin{aligned} \Delta &= \frac{1.18 p a}{E_2} \times F_w \\ 0.0025 &= \frac{1.18 \times 0.14 \times 0.375}{12.39} \times F_w \\ F_w &= 0.5 \end{aligned}$$

Ratio of base course to radius = 15/37.5 = 0.4, if thickness of base course is 15cm.

From fig., for a ratio of base course to radius of 0.4 and F_w of 0.5.

$$E_2/E_1 = 1/100, E_1 = E_2 \times 100 = 1240 \text{ MN/m}^2$$

$$\begin{aligned} a &= \sqrt{\frac{\text{wheel load}}{\pi \times \text{tyre pressure}}} \\ &= \sqrt{\frac{40 \times 10^3}{\pi \times 0.5 \times 10^6}} \end{aligned}$$

$$= 0.16 \text{ m}$$

Deflection under wheel load,

$$\Delta = \frac{1.5 p a}{E_2} \times F_w$$

$$0.005 = \frac{1.5 \times 0.5 \times 10^6 \times 0.16}{12.4 \times 10^6} \times F_w$$

$$F_w = 0.52$$

From fig., for $F_w = 0.52$, $E_2/E_1 = 1/100$

$$\frac{\text{Pavement thickness}}{\text{Radius}} = 0.4$$

$$\text{Pavement thickness} = 0.4 \times 16 = 6.4 \text{ cm}$$

15. Determine the required thickness of an airfield flexible pavement based on Burmister's theory using the following Plate Load Test (PLT) data and other input parameters:

Diameter of plate used = 75cm

Pressure observed at 1.25mm deflection when the plate load test is conducted on the sub-grade = 0.82 kg/cm².

Pressure observed at 1.25mm deflection when the plate load test is conducted on a base course of 16cm thickness = 2.1 kg/cm².

Design wheel load = 23000kg, Tire pressure = 15kg/cm²

a) If allowable deflection = 0.125cm and (b) If allowable deflection = 0.50cm.

Solution:

i) Determination of the elastic modulus of the sub-grade from a plate load test conducted on the sub-grade.

$$\text{Deflection, } \Delta = \frac{1.18 p a}{E_2} \times F_w$$

$$0.125 = \frac{1.18 \times 0.82 \times 37.5}{E_2} \times 1$$

$$E_2 = 290.28 \text{ kg/cm}^2$$

ii) Determination of the elastic modulus of the granular layer from the results of a plate load test conducted on a granular layer.

$$\text{Deflection, } \Delta = \frac{1.18 p a}{E_2} \times F_w$$

$$0.125 = \frac{1.18 \times 2.1 \times 37.5}{290.28} \times F_w$$

$$F_w = 0.3$$

$$\text{Ratio of } h/a = 16/37.5 = 0.426$$

$$\text{Therefore, } \frac{E_1}{E_2} = 200, E_1 = 200 E_2$$

$$= 200 \times 290.28$$

$$= 58056 \text{ kg/cm}^2$$

iii) Design of flexible pavement

$$\text{Tyre Pressure} = \text{wheel load} / \text{tyre contact area}$$

$$= \text{wheel load} / \pi a^2$$

$$\text{Radius of tyre contact area, } a = \sqrt{\frac{\text{wheel load}}{\pi \times \text{tyre pressure}}}$$

$$= \sqrt{\frac{23000}{\pi \times 15}} = 22.09 \text{ cm}$$

$$\text{Deflection, } \Delta = \frac{1.5 p a}{E_2} \times F_w$$

a) If allowable deflection = 0.125cm

$$0.125 = \frac{1.5 \times 15 \times 22.09}{290.28} \times F_w$$

$$F_w = 0.073$$

Find the value of h/a based on the ratio of $E_1/E_2 = 200$

$$h/a = 2.79$$

$$h = 2.79 a$$

$$= 2.79 \times 22.09$$

$$= 61.63 \text{ cm}$$

Therefore, for the base course, provide a thickness of 62cm.

b) If allowable deflection = 0.50cm

$$0.50 = \frac{1.5 \times 15 \times 22.09}{290.28} \times F_w$$

$$F_w = 0.292$$

Find the value of h/a based on the ratio of $E_1/E_2 = 200$

$$h/a = 0.36$$

$$h = 0.36 a$$

$$= 0.36 \times 22.09$$

$$= 7.95 \text{ cm}$$

Therefore, for the base course, provide a thickness of 8cm.

REVIEW QUESTIONS

1. What are the desirable characteristics of a pavement?
2. Explain the typical layers of a flexible pavement.
3. Draw neat sketch of cross section of a flexible pavement and describe the functions of each layer.
4. Compare the salient features of flexible and rigid pavement.
5. Explain the factors affecting the design of pavement.
6. Differentiate between highway and airfield pavement.
7. Explain the assumptions and limitations of Boussinesq's theory
8. Explain the assumptions and limitations of Burmisters's theory
9. A plate load test was carried out on subgrade using 300mm diameter plate and corresponding to a deflection of 5mm, the load sustained on the plate per unit area was 0.08N/mm^2 . The test was repeated on base course of thickness 300mm and unit load sustained was 0.45N/mm^2 at the same deflection. Find
 - i. Elastic modulus of subgrade and the ratio of E_p/E_s
 - ii. What should be the thickness of base course as to sustain wheel load of 50kN and contact pressure of 0.6N/mm^2 so that maximum deflection does not exceed 5mm.