PAVEMENT ANALYSIS AND DESIGN (ELECTIVE-II)
B.E. EIGHT SEMESTER
UNIT – 3

5) Highway pavement design: Flexible: North Dakota cone, CBR, IRC-37, Burmister, Triaxial (Kansas), AASHTO method of design.
6) Airfield pavement design.
5.1 HIGHWAY PAVEMENT DESIGN: FLEXIBLE: NORTH DAKOTA CONE

This method, similar to the CBR method, has been developed by the North Dakota State Highway Department. The method consists in finding out the in-situ bearing power of the sub-grade by means of a cone penetrometer, of the North Dakota Cone apparatus. The thickness is then found from the design curve.

The penetrometer (or North Dakota cone apparatus) consists essentially of a shaft with a sharp cone (half angle = 7045’) attached to one end. The movement of the shaft into the soil is measured with the help of a vernier. The shaft can be locked to the frame when necessary. A disc is fixed to the top of the shaft, over which weights can be fixed. The load carried by the shaft, during penetration into the soil, divided by the area of the cone at the surface level is termed as the cone bearing value q_c.

\[ q_c = \frac{Q}{\pi (\rho \tan 70^\circ 45')^2} = \frac{Q}{0.058 \rho^2} \]

Where \( q_c \) = bearing value (kg/cm²)
\( Q \) = load on cone (kg)
\( \rho \) = penetration (corrected) of cone (cm)

Fig. 1. North Dakota Curve.

The loads Q used in the test are 4.5, 9, 18 and 36 kg, inclusive of the weight of the shaft and cone. Theoretically, neglecting friction, the penetration under 4.5 kg is half the penetration under 18 kg. Actually, it is never so, because of the rounding of the tip of the cone. A correction is, therefore, added to or subtracted from all the readings so that the penetration \( \rho_9 \) under 9 kg becomes half of the penetration \( \rho_{36} \) under 36 kg.
5.2 CALIFORNIA BEARING RATIO METHOD

In this method, the CBR values are used to determine the total thickness of the flexible pavement and the thickness of various layers. Fig. 1.8 gives the design curves for different wheel loads and traffic conditions.

The design curves are based on the data collected on a large number of pavements which performed satisfactorily. The curves give the required thickness of construction above a material of a certain CBR value. As it is evident, the required thickness of construction above a material decreases as the CBR value increases.

The Indian Road Congress (IRC) has recommended the design chart. The chart is similar to one used in U.K. The soaked CBR value of the subgrade is evaluated and the volume of the traffic is estimated. The total thickness of the pavement is determined using the appropriate curve. Likewise, the CBR value of the sub-base material is used to determine the thickness of construction over the material. The thickness of the sub-base is equal to the total thickness of above the subgrade minus the thickness of construction above the sub-base. Likewise, the thickness of the base is determined.

The CBR method is based on strength parameter of the material and is, therefore, more rational than the group index method. The basic assumption in the method is that a layer of pavement is of pavement is of superior quality than the layer below it. The shortcoming of the method is that it gives the same total thickness above a material irrespective of the quality of the overlying layers.

![Diagram of CBR Design Chart](chart.png)

**Fig. 2.**
(a) **California Resistance value Method:**

The method uses the California Resistance value, called the R – value.

The R-value is determined by placing the specimen in the stabilometer and by applying the lateral and vertical pressures as specified. The R-value is given by

\[
R = 100 - \frac{100}{(2.5/D_2)(p_v/p_h - 1) + 1}
\]

where \(p_v\) = vertical pressure applied (1120 kN/m\(^2\)), \(p_h\) = horizontal pressure transmitted, \(D_2\) = displacement of stabilometer fluid required to increase the horizontal pressure from 35 kN/m\(^2\) to 700 kN/m\(^2\), measured in number of revolutions of the calibrated pump handle.

Hveem and Carmany (1948) gave the following expression for the total thickness of the pavement.

\[
t = \frac{KT (90 - R)}{C^{1/5}}
\]

where \(t\) = thickness (cm), \(K\) = numerical constant (= 0.166), \(T\) = traffic index, \(R\) = stabilometer resistance value, \(C\) = cohesiometer value, determined from the cohesiometer test.

The traffic index \(T\) has been empirically provided to estimate the traffic volume, as

\[
T = 1.35 (EWL)^{0.11}
\]

where EWL = equivalent wheel load.
5.3 BURMISTER METHOD

Burmister developed a method considering the pavement as a layered system. The Burmister theory is based on the following assumptions.

1) The material in each layer is homogeneous, isotropic and elastic.
2) The surface layer is infinite in the horizontal direction and finite in the vertical direction. The underlying layer is infinite in both directions.
3) The layers are in continuous contact.
4) The top layer is free of shearing stresses and normal stresses outside the loaded area.

The displacement equation given by Burmister can be written as, assuming \( \mu_s = \mu_p = 0.50 \),

\[
\Delta = 1.5 \frac{paF_2}{E_s} \quad \text{for flexible plates}
\]

\[
\Delta = 1.18 \frac{paF_2}{E_s} \quad \text{for rigid plates}
\]

and

where \( p \) = uniform pressure, \( a \) = radius of plate, \( F_2 \) = deflection factor, and \( E_s \) = modulus of the soil.

Fig. 1.11 gives the values of the deflection factor \( F_2 \). It depends upon the ratio of the modulus of the subgrade \( (E_s) \) and the modulus of pavement layer \( E_p \). The ratio \( (h/a) \) is equal to the thickness of the base layer divided by the radius of the load. It may be noted that for a single layer, \( h = 0 \) and \( E_s/E_p = 1.0 \) and hence \( F_2 = 1.0 \) and the solution reduces to Boussinesq’s settlement equation.

The design procedure can be summarized as under.

1) Determine \( E_s \) by conducting a plate bearing test on a 30 cm diameter plate over the subgrade.

\[
E_s = \frac{1.18 pa}{\Delta}
\]

2) Calculate \( F_2 \) by conducting a plate bearing test on the pavement,

\[
F_2 = \frac{\Delta \times E_s}{1.18 pa}
\]

3) For the computed value of \( F_2 \) and the given value of \( (h/a) \) ratio, determine \( E_s/E_p \) from fig. 1.11.

4) Determine the contact radius of the design load, as

\[
a = \sqrt{\frac{p}{\pi p}}
\]

where PP = design load and \( p \) = tyre pressure.

5) Compute the new value of \( F_2 \) for the design deflection the \( h/a \) ratio from 1.11.

\[
F_2 = \frac{\Delta \times E_s}{1.5 pa}
\]

6) Determine \( h \) from the \( h/a \) ratio.
5.4 TRIAXIAL TEST METHOD

The triaxial test is used to determine the shear strength of soil.

The triaxial test method for the design of flexible pavement is based on the Boussinesq’s concept for homogeneous elastic single layer.

According to Boussinesq’s concept

\[ z = \frac{3P}{2\pi E\Delta} - \alpha^2 \]

According to triaxial test method it is

\[ T = \frac{3P}{2\pi E_s\Delta} - \alpha^2 \]

where,

- \( T \) = Pavement thickness, (cm),
- \( P \) = wheel load (Kg),
- \( E_s \) = modulus of elasticity of subgrade from triaxial test results (Kg/cm²)
- \( A \) = radius of contact (cm)
- \( s \) = design deflection

The triaxial compression test is conducted on a soil specimen under a lateral pressure of 140 kN/m² and the value of the modulus of elasticity is determined from the stress-strain curve.

The thickness of the pavement in cm can be determined using the formula given by the Kansas Highway Dept.

\[ t = \sqrt\frac{(3Pxy)^2}{2\pi E\Delta} - \alpha^2 \]

where \( P \) = wheel load (kN), \( E \) = modulus of elasticity (kN/cm²), \( x \) = traffic coefficient (0.5 to 2.0), \( y \) = saturation coefficient (= 0.5 to 1.0), \( a \) = area of contact (cm²), \( \Delta \) = design deflection (= 0.25 cm).

If pavement and subgrade are considered as two layers, then stiffness factor will be \( (E_s/E_p)^{1/3} \).
The pavement thickness is modified for the stiffness factor. Then pavement thickness is given by

\[ t = \sqrt{\frac{3Pxy}{2\pi E_s^2}} - a^2 \left( \frac{E_s}{E_p} \right)^{1/3} \]

The relation between pavement layers of thickness \( t_1 \) and \( t_2 \) and modulus of elasticity \( E_1 \) and \( E_2 \) is given by

\[ \frac{t_1}{t_2} = \left( \frac{E_2}{E_1} \right)^{1/3} \]

### 5.5 AASHO Sub Grade Soil Classification

AASHO (American Association of State Highway Officials): In this method of classification soils are classified into seven groups. A1 to A7. A1, A2, and A3 are granular soil with percentage passing No.200 (75 μ) sieve less than 35 %. A4 to A7 soils are fine grained or silty clay soils with percentage passing NO. 200 (75μ) sieve more than 35%. A1 soil are well graded, mixture of stone, gravel, coarse sand, fine sand and non-plastic or slightly plastic soils binder. The soils of this group are subdivided into A-1-a and A-1-b.

- **A-1-a** = consists of stone fragments or gravels
- **A-1-b** = consists of coarse sand

A2 soils include a wide range of granular soils ranging from A1 to A3 groups with 35% fines form A4, A5, A6, A7 groups. So based on fines contents, the soils of A2 groups are sub-divided into subgroups A-2-4, A-2-5, A-2-6, and A-2-7.

A3 soils consist of uniformly graded medium or fine sand similar to beach sand or desert blown sand. Poorly graded fine sand of stream deposits with some coarse sand and gravel are also included in this group.

A4 soils are silty soils, non-plastic or moderately plastic in nature with liquid limit and plasticity index valued less than 40 and 10 respectively.

A5 soils are also silty soils with plasticity index less than 10% but with liquid limit greater than 40%. These include highly compressible or elastic soils.

A6 soils are plastic clays, having high values of plasticity. Index greater than 10% and low values of liquid limit below 40%. They have high volume change properties with moisture content.

A7 soils are also cloyed soils but values of liquid and plastic limits are high. These soils have low permeability.

The AASHO design procedure [AASHO, 1993] was developed based on the findings of the AASHO road test [Highway Research Board, 1962]. Following parameters are required for design.

a) Resilient modulus for the subgrade.
b) Cumulative ESAL’s for the design life of the pavement.
c) Drainage coefficient for unbound material.
d) Reliability level.
e) Overall standard deviation.
f) Serviceability.
g) Modulus of subgrade reaction.
h) Elastic modulus of concrete.
i) Modulus of rupture of concrete.
j) Load transfer factors.
The parameters used in AASHTO method are:

a) CBR.
b) Resiliency factor.
c) Traffic in terms of ESAL.
d) Thickness equivalency factor.

These parameters yield a structural number or total thickness of pavements. The determination of the individual layer thickness is achieved using the thickness equivalent factor and the most practical layer for construction.

**AASHO GUIDE**

The 1986-1993 AASHO guide made many modifications in the procedures. The principle modification to AASHO concrete pavement design are:

a) Drainage Coefficient: - To allow for changes in thickness requirement due to differences in drainage properties, pavement layers, and subgrade, a drainage coefficient $C_d$ was included in the design. Setting $C_d = 1$ for conditions at the AASHO road test. The percentage of time during the year that the pavement structure would be exposed to moisture levels approaching saturation can be estimated from the annual rainfall and the prevailing drainage condition.

b) Determination of the design K-value as a function of subgrade resilient modulus, rigid layer, base thickness and elastic modulus erodability and seasonal variation in soil.

c) Load Transfer Coefficient: - Load transfer coefficient $J$ is a numerical index developed from experience and stress analysis. Addition of corner stress adjustment I-factor values as a function of pavement joint, load transfer, shoulder type.

A reliability adjustment applied to the design ESAL input instead of using a factor of safety on the modulus of rupture.

**5.6 AIRFIELD PAVEMENT DESIGN**

Aircraft Considerations:

- Load (95% main landing gear, 5% nose gear)
- Landing gear type and geometry
  a) Single gear aircraft
  b) Dual gear aircraft
  c) Dual tandem gear aircraft
  d) Wide body aircraft – B-747, B-767, DC-10, L-1011
- Tire pressure: 75 to 200 psi (515 to 1,380 kPa)
- Traffic volume

**AC 150/5320-6D**

The standard CBR procedure was originally developed for a single wheel load and was “expanded” in 1945 to address dual wheel gears and tandem gears by the “Equivalent Single Wheel Load” (ESWL).
## Equivalent Single Wheel Load (ESWL)

\[ \text{Load} = \text{ESWL} \]

- **Design Procedure**
  - Forecast annual departures.
  - Select design aircraft that requires the thickest pavement.
  - Transform other aircrafts to equivalent departures of design aircraft.

- **Determination of Design Aircraft**
  - The required pavement thickness for each aircraft type should be checked using the appropriate design curve and the forecast number of annual departures for that aircraft.
  - The design aircraft is the aircraft type that produces the greatest pavement thickness.
  - The design aircraft is not necessarily the heaviest aircraft in the forecast.

- **Conversion of Equivalent Annual Departure of Design Aircraft**

\[ \log R_1 = \log R_2 \cdot \sqrt[\text{W}_2 / W_1] \]

- **Principles of Rigid Airport Pavement Design**
  - Based on Westergaard analysis of edge loaded slabs (modified to simulate a jointed edge condition) Determine k value for rigid pavement.
  - Concrete flexural strength.
  - Gross weight of design aircraft.

- **Subbase Requirements**
  - A minimum thickness of 4 in. subbase
  - Types of subbase courses
- Item P-154: subbase course
- Item P-208: aggregate base course
- Item P-209: crushed aggregate base course
- Item P-211: lime rock base course
- Item P-304: cement treated base course - Item P-306: econocrete subbase course
- Item P-401: plant mix bituminous pavements Stabilized subbase (aircraft weight > 100,000 lbs)
- Item P-304: cement treated base course
- Item P-306: econocrete subbase course - Item P-401: plant mix bituminous pavement

Concrete Flexural Strength
- Design strength of 600 to 650 psi is recommended for most airfield applications.
- Strength at 28 days.
- 5% less than the test strength used for thickness design.

Effect of Subbase on $K$
- Well-Graded Crushed Aggregate.

Effect of Subbase on $K$
- Bank-Run Sand & Gravel (PI<6)
Effect of Subbase on K
- Stabilized Subbase

![Graph showing the effect of subbase on K for different subgrades.](image-url)