CMR
INSTITUTE OF
TECHNOLOGY

Internal Assessment II- April 2018
Solutions

Sub: Pavement Design **Code:** 10CV833

Sem: VIII **Branch:** CIVIL

1. With a neat sketch, explain briefly the significance of design wheel load and contact pressure in pavement design.

Design Wheel loads:

Traffic loads:

The thickness design of flexible pavement primarily depends on the various factors associated with wheel loads of heavy vehicles. Higher magnitude of wheel load needs thicker pavement, provided other design factors are the same.

Factors to be considered:

- Maximum wheel load
- Contact Pressure
- Wheel Load Configuration - dual or multiple wheel load assembly
- Repetition of these loads
- Dynamic effects of Transient loads

Wheel Load and Contact Pressure:

The magnitude of the wheel load (P) and the loaded area (A) or the contact pressure (p) are to be taken into account for the analysis of stresses and the stress distribution within the pavement.

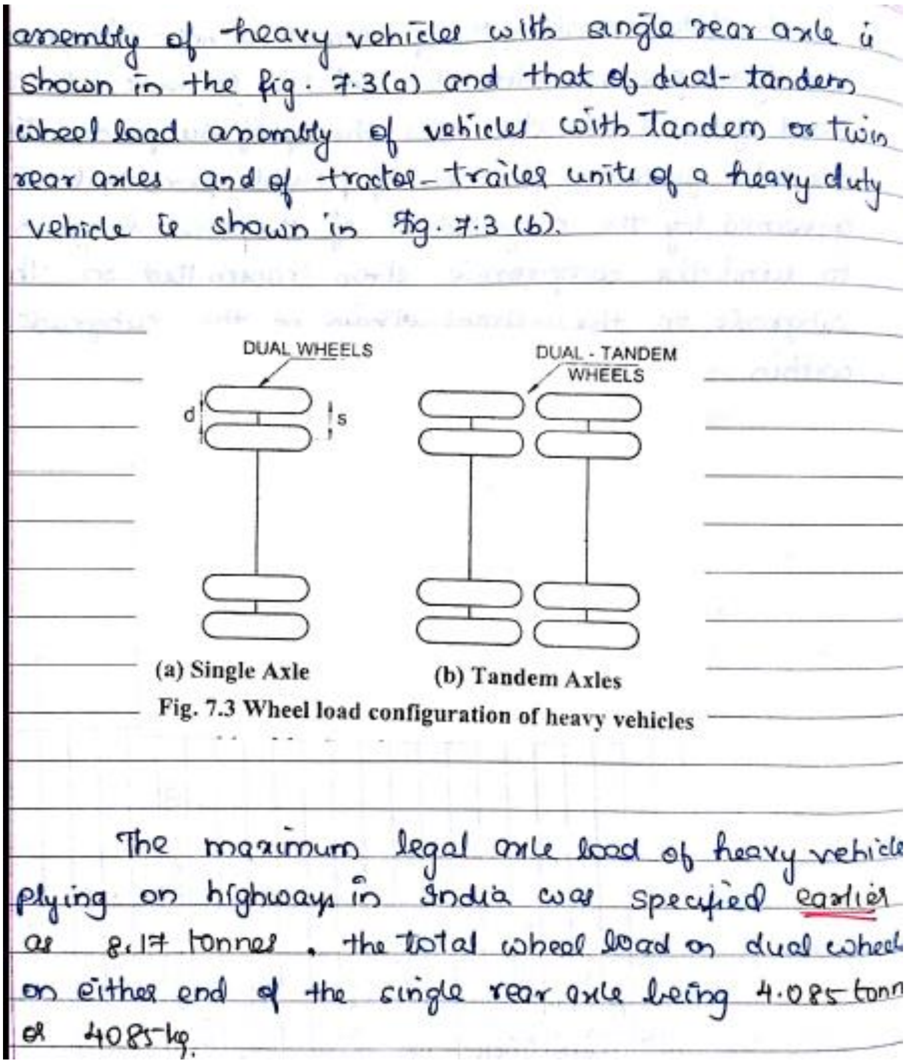
$$\text{Contact Pressure } p = \frac{\text{Load on Wheel}}{\text{Contact area of imprint}} = \frac{P}{A}$$

If the loaded area or the contact area, A of the wheel load is assumed to be circular in shape of radius 'a', then the relationship between the load P, loaded area A and contact pressure p, may be expressed as:

Wheel Load Configuration:

It is important to know the wheel load configuration or the manner in which the wheel loads of a heavy vehicles are applied on the pavement surface. This is because the total thickness of flexible pavement structure is influenced by the effective magnitude of load due to the wheel load assembly.

Typical wheel load configuration of dual wheel load



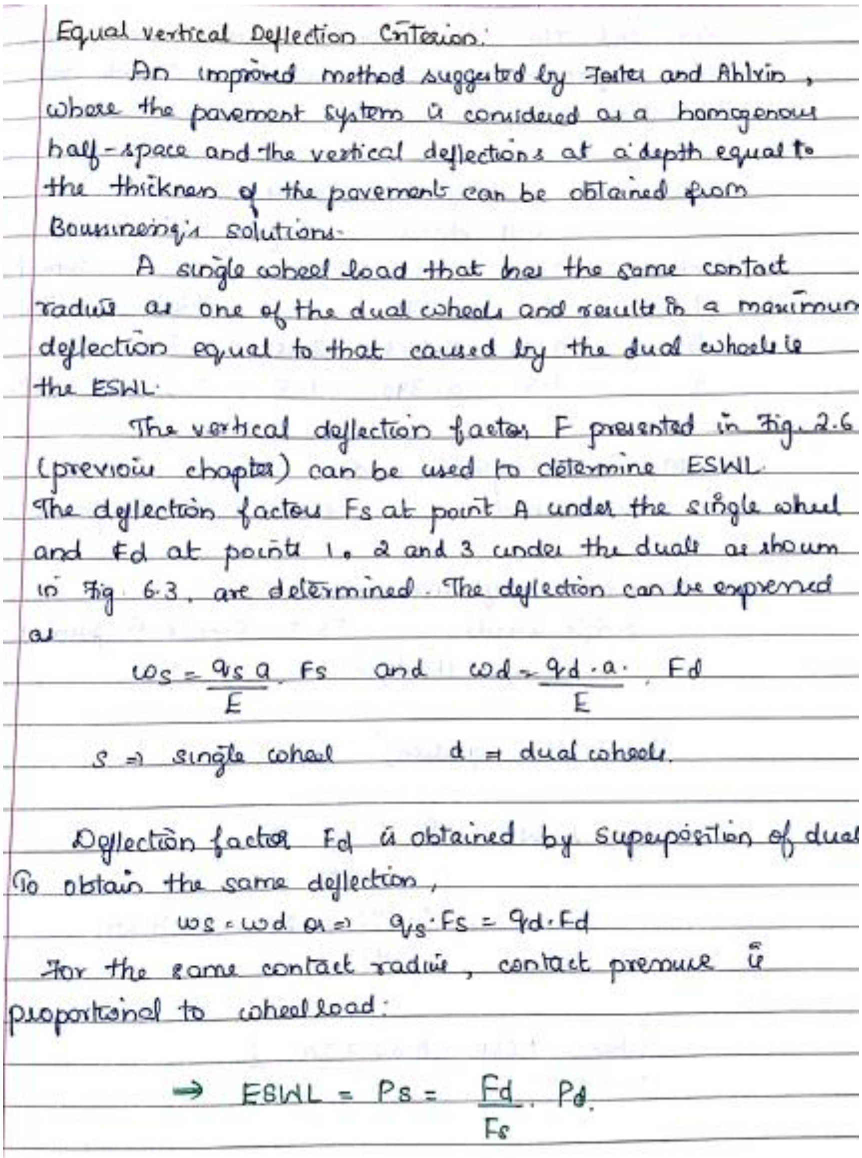
assembly of heavy vehicles with single rear axle is shown in the fig. 7.3(a) and that of dual-tandem wheel load assembly of vehicles with Tandem or twin rear axles and of tractor-trailer units of a heavy duty vehicle is shown in fig. 7.3 (b).

(a) Single Axle (b) Tandem Axles

Fig. 7.3 Wheel load configuration of heavy vehicles

The maximum legal axle load of heavy vehicle plying on highways in India was specified earlier as 8.17 tonnes. the total wheel load on dual wheel on either end of the single rear axle being 4.085 tonn or 4085 kg.

2. (a) Describe the procedure of calculating ESWL by equal deflection criteria.
   Equivalent Deflection Criteria
   (Foster & Ahlvin)



Equal vertical Deflection Criterion:

An improved method suggested by Foster and Ahlvin, where the pavement system is considered as a homogenous half-space and the vertical deflections at a depth equal to the thickness of the pavements can be obtained from Boussinesq's solutions.

A single wheel load that has the same contact radius as one of the dual wheels and results in a maximum deflection equal to that caused by the dual wheels ie the ESWL.

The vertical deflection factor F presented in Fig. 2.6 (previous chapter) can be used to determine ESWL. The deflection factor Fs at point A under the single wheel and Fd at points 1, 2 and 3 under the duals as shown in Fig 6.3, are determined. The deflection can be expressed as

$$w_s = \frac{q_s a}{E} \cdot F_s \quad \text{and} \quad w_d = \frac{q_d \cdot a \cdot}{E} \cdot F_d$$

s ⇒ single wheel   d ⇒ dual wheels.

Deflection factor Fd is obtained by superposition of dual. To obtain the same deflection,

$$w_s = w_d \text{ or } \Rightarrow q_s \cdot F_s = q_d \cdot F_d$$

For the same contact radius, contact pressure is proportional to wheel load:

$$\Rightarrow \text{ESWL} = P_s = \frac{F_d}{F_s} \cdot P_d.$$

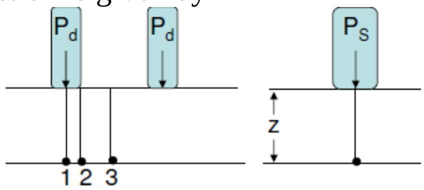
The general equation for deflection is given by

$$\Delta = \frac{pa}{E} F$$

$$\therefore \Delta \, \alpha \, P$$

$$\text{i.e., } \frac{P_S}{P_d} = \frac{\Delta_S}{\Delta_d}$$

$$\therefore \quad P_S = P_d \frac{\Delta_S}{\Delta_d}$$



Δ_S = max (Δ_1, Δ_2, Δ_3)

Δ_d = maximum deflection due to P_d

(b) State the assumptions and limitations in Boussinesq's theory

Assumptions of Boussinesq's theory:

a.For soil, the soil mass is elastic, isotropic, homogeneous and semi-infinite.

b. The soil is weightless.

c. The load is vertical, concentrated acting on the surface.

d. Hooke's Law is applied, it is mean that there is a constant ratio between stress and strain.
e. Poisson's ratio is assumed as 0.5
f. Area of contact is assumed as circular and the pressure is assumed to be uniformly distributed over the area.

Limitations of Boussinesq's theory:
a. Soil mass is never elastic, isotropic, homogeneous and semi-infinite.
b. The soil is having a distinct unit weight and cannot be considered as weightless.
c. The load is never vertical and will not be acting concentrated on the surface.
d. Hooke's Law is not applicable because soil mass is never linear.
e. Poisson's ratio cannot be assumed as 0.5
f. Area of contact is assumed as circular only for simplicity, which is not true, and the pressure cannot be assumed to be uniformly distributed over an area.

3. A plate bearing test conducted with 30 cm diameter plate on subgrade yielded a pressure of 2.26 kg/cm^2 at 0.25 cm deflection. The test when conducted on a base course of 22.5 cm yielded a pressure of 7.53 kg/cm^2 at 0.25 cm deflection. Design the pavement section by Burmister's approach for a contact pressure of 8.85 kg/cm^2 having radius of contact area of 15 cm.

Plate load test on subgrade:

$\Delta_1 = 0.25\,cm \quad p = 2.26\,kg/cm^2 \quad a = 15\,cm, \quad F_2 = 1$

$$\Delta_1 = \frac{1.18 \cdot p \cdot a \cdot F_2}{E_2} \Rightarrow E_2 = \frac{1.18 \times 2.26 \times 15 \times 1}{0.25} = 160\,kg/cm^2$$

Plate load test on base course:

$\Delta_1 = 0.25\,cm \quad p_1 = 7.53\,kg/cm^2 \quad a = 15\,cm, \quad F_2 = ?$

$E_2 = 160\,kg/cm^2$

$$\Delta_1 = \frac{1.18 \cdot p_1 \cdot a \cdot F_2}{E_2} \Rightarrow \frac{0.25 \times 160}{1.18 \times 7.53 \times 15} = F_2$$

$F_2 = 0.30$

From Burmister's Two layer deflection factor chart for

$$\frac{h}{a} = \frac{22.5}{15} = 1.5, \quad F_2 = 0.30, \quad \frac{E_1}{E_2} = ?\ 20$$

$$\Rightarrow E_1 = 20 \times E_2 \Rightarrow 20 \times 160 = 3200\,kg/cm^2$$

c) Design wheel load (for flexible plate)

$p_2 = 8.85\,kg/cm^2$ radius $a = 15\,cm$

~~8.85~~ $$\Delta = \frac{1.5\,p_2 \cdot a_2}{E_2} \cdot F_2$$

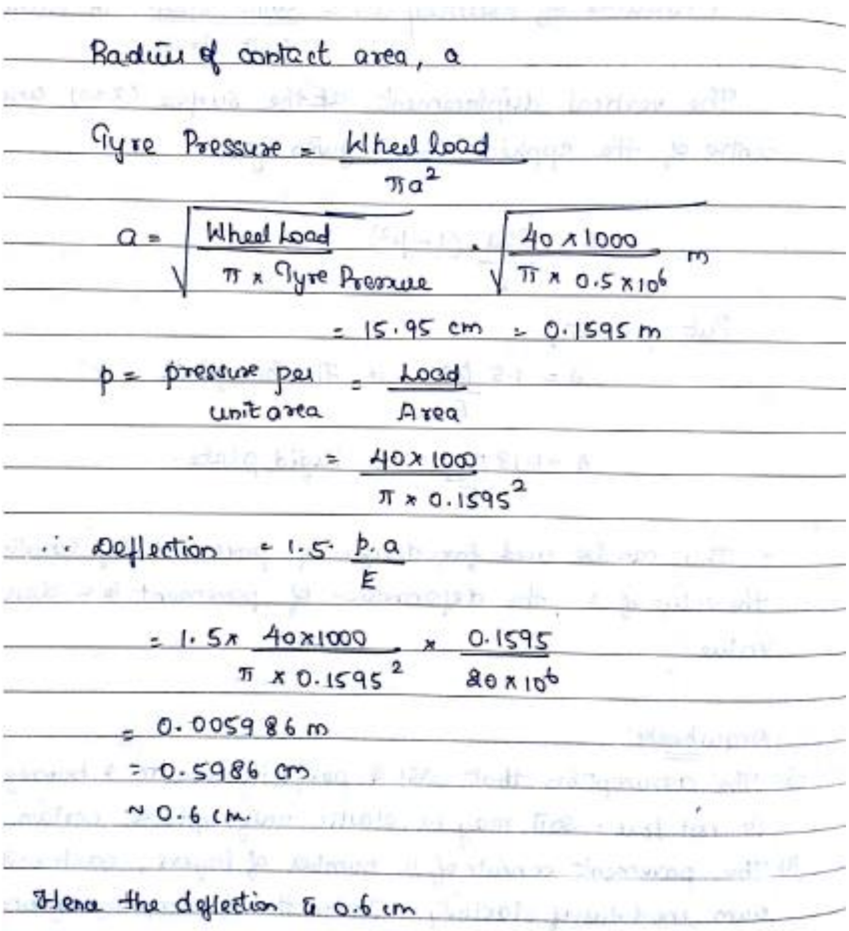
$$0.5 = \frac{1.5 \times 8.85 \times 15}{160} \times F_2 \Rightarrow 0.40$$

$$F_2 = 0.4, \quad \frac{E_1}{E_2} = 20 \Rightarrow \frac{T}{a} = 0.9$$

$$\Rightarrow T = 0.9 \times 15 = 13.5\,cm$$

Hence the pavement thickness should be 13.5 cm

4. (a) 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 is equal to 20 MN/m^2.



Radius of contact area, a

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

$$a = \sqrt{\frac{\text{Wheel Load}}{\pi \times \text{Tyre Pressure}}} = \sqrt{\frac{40 \times 1000}{\pi \times 0.5 \times 10^6}}\ m$$

$$= 15.95\ cm = 0.1595\ m$$

$$p = \text{pressure per unit area} = \frac{\text{Load}}{\text{Area}}$$

$$= \frac{40 \times 1000}{\pi \times 0.1595^2}$$

$$\therefore \text{Deflection} = 1.5 \frac{p.a}{E}$$

$$= 1.5 \times \frac{40 \times 1000}{\pi \times 0.1595^2} \times \frac{0.1595}{20 \times 10^6}$$

$$= 0.005986\ m$$

$$= 0.5986\ cm$$

$$\sim 0.6\ cm.$$

Hence the deflection is 0.6 cm

(b) Describe the procedure of calculating ESWL based on Boussinesq's theory.

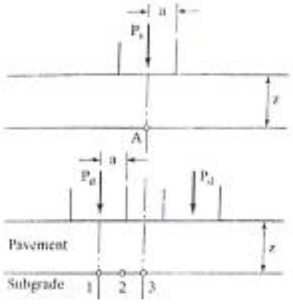


FIGURE 6.3
Location of maximum vertical stress or deflection on subgrade.

The above Fig 6.3(a) shows a pavement of thickness ~~g~~ 'z' under single and dual wheels that have the same contact radius 'a'. The maximum subgrade stress under a single wheel occurs at point A with a stress factor of σ_z/q_s, where q_s is the contact pressure under a single wheel. The location of the maximum stress under dual wheels (unknown) can be determined by comparing the stresses @ three points:

point 1 = centre of one tyre.
point 3 = centre between two tyres
point 2 = midway between points 1 and 3.

The stress factor @ each point is obtained by superposition of the two wheels, and the maximum stress factor σ_z/q_d is found, where q_d is the contact pressure under dual wheels.

To obtain the same stress,

$$q_s\left(\frac{\sigma_z}{q_s}\right) = q_d\left(\frac{\sigma_z}{q_d}\right)$$

For the same contact radius, contact pressure is proportioned to wheel load or

$$\frac{P_s}{P_d} = \frac{\sigma_z/q_d}{\sigma_z/q_s}$$

in which P_s is the single wheel load (which is the ESWL to be determined) and P_d is the load on each of the duals.

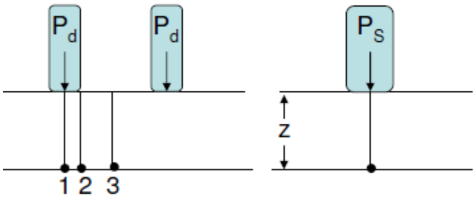
In one layer system, the vertical stress sz at the axis of symmetry at a depth z is given by

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

$$\text{i.e.,}\quad \sigma_z = \frac{P}{\pi a^2}\left[1 - \frac{z^3}{\left(a^2 + z^2\right)^{3/2}}\right]$$

$$\therefore\ \sigma_z\ \alpha\ P \text{ for a constant } a$$

$$\text{i.e.,}\quad \frac{P_d}{P_S} = \frac{\sigma_{zd}}{\sigma_{zs}}$$



- σ_{zs} is the maximum of stresses at 1, 2 and 3
- σ_{zd} is the maximum stress due to P_d

5. Briefly explain the 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 tyre pressure is an important factor, as it determine 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 affect the stress distribution and deflection within a pavemnet. 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 depend 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. Although the pavement deformation due to single axle load is very small, the cumulative effect of number of load repetition is significant. Therefore, modern design is based on total number of standard axle load (usually 80 kN single axle).

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 and they are discussed below:

Temperature

The effect of temperature on asphalt pavements is different from that of concrete pavements. Temperature affects the resilient modulus of asphalt layers, while it induces curling of concrete slab. In rigid pavements, due to difference in temperatures of top and bottom of slab, temperature stresses or frictional stresses are developed. While in flexible pavement, dynamic modulus of asphaltic concrete varies with temperature. Frost heave causes differential settlements and pavement roughness. Most detrimental effect of frost penetration occurs during the spring break up period when the ice melts and subgrade is a saturated condition.

Precipitation

The precipitation from rain and snow affects the quantity of surface water infiltrating into the subgrade and the depth of ground water table. Poor drainage may bring lack of shear strength, pumping, loss of support, etc.

6. Calculate the ESWL of a dual wheel assembly carrying 2044kg each for a pavement thickness of 150mm, 200mm and 250mm. Centre to centre spacing is 270mm and distance between the walls of the tyres is 110mm. (Solve by both Normal Graph and interpolation method)

Given:

$P = 2044$ kg. $S = 270$ mm $d = 110$ mm.

$2P = 4088$ kg. $2S = 540$ mm $\frac{d}{2} = 55$ mm

Points X and Y which are (P, d/2) and (2P, 2S) respectively are plotted on a log-log graph between ESWL and pavement thickness.

X coordinates (P, d/2) = (2044, 110/2)

= (2044, 55)

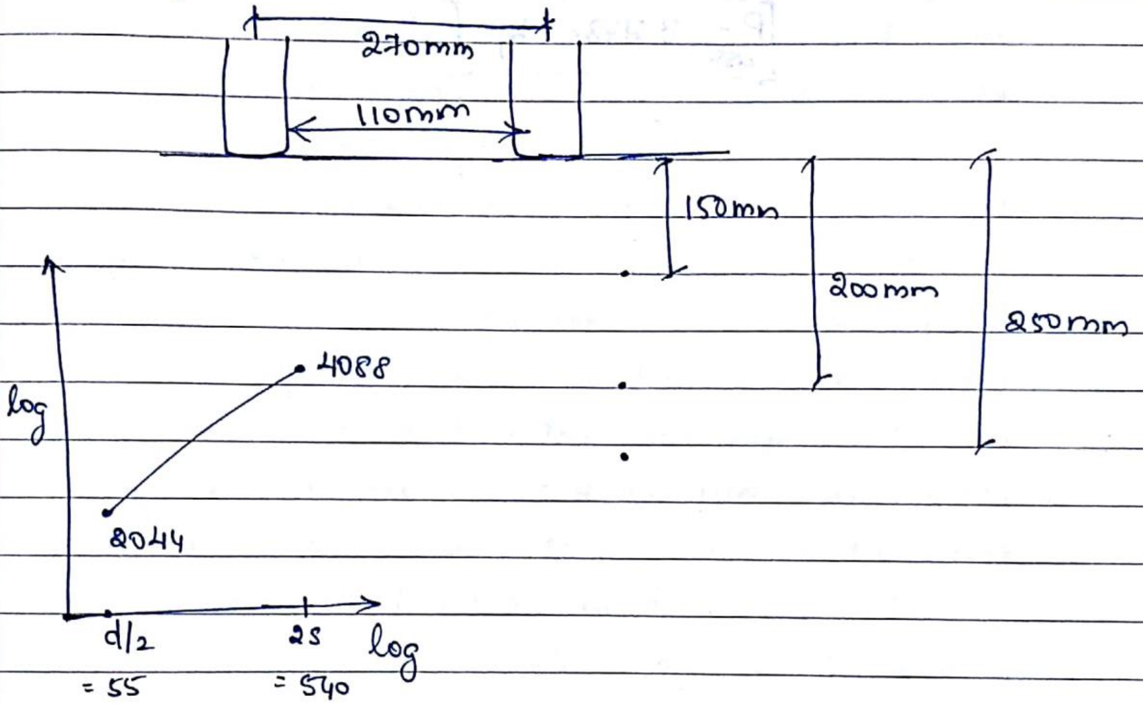
Y coordinates (2P, 2S) = (4088, 540)

are plotted on the log scale. The points X and Y are joined by a straight line.

On the X axis, points corresponding to pavement thickness of 150, 200 and 250 mm are marked and vertical lines are drawn from these points to intersect the line XY. Horizontal lines are now drawn from these points on line XY to meet the Y axis, to obtain the ESWL values @ the desired depths/ pavement thickness values. The ESWL values thus obtained are.

Thickness, mm	ESWL, kg
150	2760
200	8000
250	3230

By interpolation method,



SOLUTION:

$\log d/2 = 1.74$ $\quad \log(2044) = 3.310$

$\log 2S = 2.73$ $\quad \log(4088) = 3.612$

$\log 150 = 2.176$

$\log 200 = 2.301$

$\log 250 = 2.398$

By interpolation,

for 150 mm depth = $\frac{2.73-1.74}{2.176-1.74} = \frac{3.612-3.310}{x-3.310}$

$\frac{0.99}{1.436} = \frac{0.302}{x-3.310} \Rightarrow x = 3.443 \Rightarrow \boxed{P_{150} = 2773.32\,kg}$

For 200mm depth,

$$\frac{0.99}{0.302} = \frac{2.301 - 1.74}{x - 3.31}$$

$$x = 3.481$$

$$\boxed{P_{200} = 3026.91}$$

For 250mm depth,

$$\frac{0.99}{0.302} = \frac{2.398 - 1.74}{x - 3.31}$$

$$\boxed{\begin{array}{l} x = 3.511 \\ P_{250} = 3243.4 \text{ kg} \end{array}}$$