Internal Assessment Test III – July 2021

Sub:	PAVEMENT DESIGN				Sub Code:	17CV833/15CV833	Branch:	CIVIL
Date:	18.07.2021	Duration:	90 min's	Max Marks:	50	Sem / Sec:	8/A & B	OBE

1 Write short notes on Falling weight deflectometer [04]

This involves three stages:

- Conduction of FWD
- Estimation of residual life of the pavement
- Design of overlay

Conduction of FWD

- A mass of weights is dropped from a pre-determined height onto a series of springs/buffers placed on top of a loading plate.
- The corresponding peak load and peak vertical

Estimation of residual life of the pavement

(i) The moduli of different layers are back calculated based on the deflection data.
(ii) The different thickness of layers are calculated from the core data collected. Accordingly, critical stresses and strains are computed.
(iii) Knowing the critical stresses and strains, the rutting life and fatigue life of pavement is estimated.
(iv) This is compared with the actual traffic and compared to estimate the residual life of the pavement.

Design of overlay

(i) Assume a trial thickness of overlay having high mechanical strength.
(ii) Here, pavement is analysed as a four layer system wherein top layer represents the overlay, the other three corresponds to the existing pavement layer
(iii) Critical stresses and strains are computed.
(iv) Knowing the critical stresses and strains, the rutting life and fatigue life of pavement is estimated.
(v) This is compared with the actual traffic and hence thickness of overlay is decided.

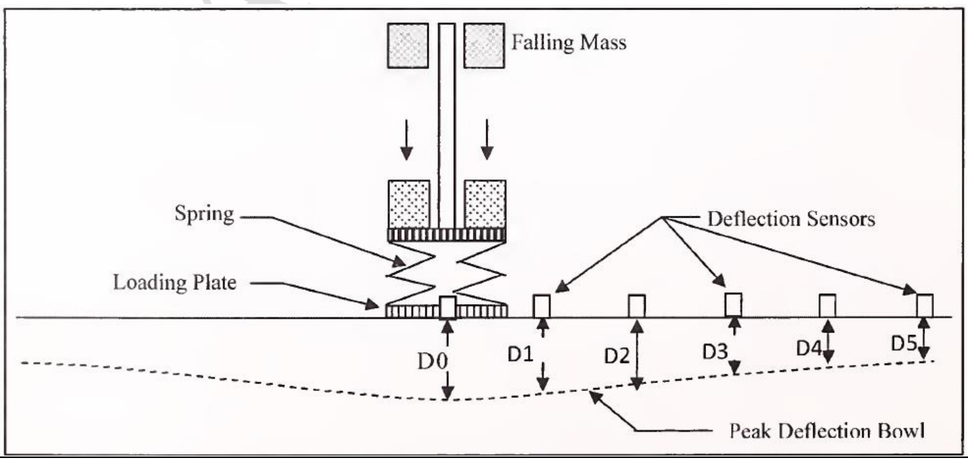

Figure – 1
Explanation –3

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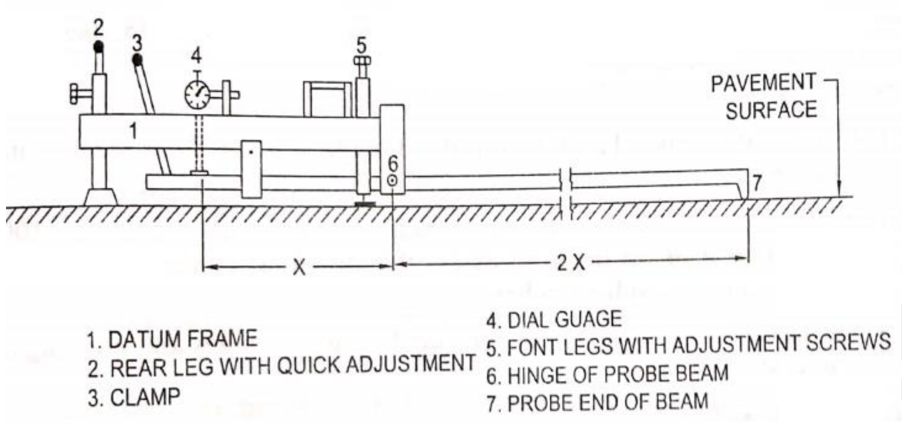
2	Explain step by step procedure for conducting Benkelman beam studies for evaluation of pavement surface condition.	[07]



Principle:

Benkelman beam is an apparatus used for measuring the surface deflection of the pavement when subjected to standard truck load. Pavement performance is related to the elastic deflection of the pavement under wheel loads. Knowing the rebound deflection and cumulative traffic in msa, overlay thickness is estimated. Elastic deflection depends upon subgrade soil type, moisture condition, pavement surface temperature, thickness and quality of pavement course. Here to measure deflection CGRA method is used i.e., rebound deflection is measured as and when load is removed from a point.

Procedure:

1. Beam plunger is brought in contact with the stem of the dial gauge. Initial reading of the dial gauge is noted.
2. Truck is driven to a distance of 2.7 m and the reading so observed is intermediate reading. The truck is moved to a further distance of 9 m and the reading so observed is the final reading.
3. Temperature of the bituminous surface is measured by making a hole and filling it with glycerol.
4. From the different readings, pavement deflection is calculated as follows:
   $D = 2(D_0 - D_f) \quad if\ D_i - D_f < 0.025\ mm$
   $D = 2(D_0 - D_f) + 2.91 \times 2\ (D_i - D_f) \quad if\ D_i - D_f < 0.025\ mm$
5. From the rebound deflection, characteristic deflection is estimated as
   $D_c = D + k\sigma,$
   where D is the mean deflection and k is a constant which is a measure of accuracy level and is dependent upon the importance of the roads. Accuracy 97.7 % indicate k = 2 which is relevant for NH and SH and accuracy 84% indicate k = 1
6. The obtained rebound deflection is corrected for temperature as follows:
   $D_{ct} = D_c \pm (35{\sim}t) \times 0.01$
   The term (35~t)×0.01 is positive if t < 35°C and negative if t > 35°C.
7. Rebound deflection corrected for temperature is corrected for moisture for subgrade type, plasticity index and type of rainfall. D_{ct} is multiplied with moisture correction factor to get the final rebound deflection.
8. The cumulative traffic is estimated in msa as
   $$N = \frac{365 \times [(1+r)^n - 1]}{r} \times A \times D \times F$$

	Where r is the growth rate , n is the design life, A is the anticipated traffic, D is the damage factor and F is the lane distribution factor. 9. Knowing the cumulative traffic and rebound deflection, overlay thickness in terms of BM can be obtained from nomograms. The overlay thickness can also be estimated using the equation, $h_0 = 550 \log_{10}\left(\frac{D_c}{D_a}\right) \text{mm}$ D_a – depends is the allowable deflection which is dependent on traffic $A = P(1+r)^{n+10}$ D_a (mm) / A (CVPD): 1 / 1500-4500; 1.25 / 450 – 1500; 1.5 / 150 -450 10. Thickness of any other layer can be estimated in terms of BM thickness as follows: 1BM = 1.5WBM/WMM/BUSG 1BM = 0.7 DBM/AC/SDC Minimum ovelay thickness = 50 mm BM and 50 DBM or 40 mm of BC	
	Principle -2 Estimation of rebound deflection – 2 Corrections -1 CSA estumation - 1 Overlay design-1	
3	Write step by step procedure for designing concrete pavement as recommended by IRC 58 2002.	[07]
	Salient features of the code are (i) Computation of flexural stress due to the placement of single and tandem axle loads along the edge (ii) Introduction of cumulative fatigue damage approach in the design (iii) Revision of criteria for design of dowel bars *Design steps for slab thickness:* 1. Stipulate design values ➢ The wheel loads considered are 10 t, 19 t and 24 t for single, tandem and tridem axle loads ➢ To account for heavy truck loads, Load Safety Factor is also considered. ➢ Design period considered is 30 years ➢ $N = \frac{365\times[(1+r)^n-1]}{r} \times A$ ➢ Edge stresses are assumed to be critical. In this its assumed that 25% of the vehicles move on the edges ➢ Design parameter is modulus of subgrade reaction k estimated using a plate of 75 cm diameter. $k_{75}=0.5\times k_{30}$ ➢ The flexural strength of concrete considered for the design is 4.5 MPa having E = 3×10^5 kg/cm^2 with Poisson's ratio of 0.15 ➢ Coefficient of thermal expansion is 10×10^{-6}/°C 2. Decide types and spacing of joints 3. Select a trial thickness 4. Compute repetitions of axle load during the design period	

D_a (mm)	A (CVPD)
1	1500-4500
1.25	450 – 1500
1.5	150 -450

5. Calculate the flexural stresses and compute CFD
   - Stress ratio is the ratio of edge load stress and the flexural strength
   - For a given SR fatigue life is calculated as follows:

N = unlimited for SR < 0.45

$$N = \left[\frac{4.2577}{SR - 0.4325}\right]^{3.268} \quad \text{When } 0.45 \le SR \le 0.55$$

$$Log_{10} N = \frac{0.9718 - SR}{0.0828} \quad \text{for SR} > 0.55$$

   - The expected repetition, n is computed from the axle load survey data and CFD is calculated as

$$CFD = \sum_i \frac{n_i}{N_i}$$

6. If CFD is greater than 1, increase the thickness and repeat steps 1 to 5 till CFD is less than 1
7. Compute temperature stresses and estimate the critical combination of stresses by combining edge load stresses and temperature stresses and check if its less than flexural strength of the slab. Else, increase thickness and repeat steps 1 to 6.
8. Check for corner stresses.

Design steps for dowel bars:

Maximum bearing stress between the concrete and dowel bar is obtained from the equation as:

$$\sigma_{max} = \frac{KP_t}{4\beta^3 EI}(2 + \beta z)$$

Where

$$\beta = \sqrt[4]{\frac{kb}{4EI}}$$

β = relative stiffness of the bar embedded in concrete

K = modulus of dowel/concrete interaction (dowel support, $kg/cm^2/cm$)

b = diameter of the dowel, cm

z = joint width, cm

E = modulus of the elasticity of the dowel, kg/cm^2

I = moment of inertia of the dowel, cm^4

P_t = load transferred by a dowel bar.

calculation of the allowable bearing stress on concrete:

$$F_b = \frac{(10.16 - b)\, f_{ck}}{9.525}$$

Where

F_b = allowable bearing stress, kg/cm^2

b = dowel diameter, cm

f_{ck} = ultimate compressive strength (characteristic strength) of the concrete, kg/cm^2 (400 kg/cm^2 for M40 concrete)

Design steps for tie bars:

The area of steel required per metre length of joint may be computed using the following formula:

$$A_s = \frac{bfW}{S}$$

in which

A_s = area of steel in cm^2, required per m length of joint

b = lane width in metres

f = coefficient of friction between pavement and the sub-base/ base (usually taken as 1.5)

W = weight of slab in kg/m^2 and

S = allowable working stress of steel in kg/cm^2.

Principle -1
Design of slab - 4
Mention of dowel and tie bar design -2

4	Explain any four typical flexible pavement failures with neat sketches.	[08]

- Alligator cracking - Interconnected cracks caused by fatigue failure of the HMA surface under repeated traffic loading.
- After repeated loading, these longitudinal cracks connect forming many-sided sharp-angled pieces that develop into a pattern resembling the back of an alligator or crocodile.

Problem:	Possible causes:	Repair:
➢ Roughness ➢ Indicator of structural failure ➢ Cracks allow moisture infiltration into the base and subgrade ➢ Results in potholes and pavement disintegration if not treated	➢ Decrease in pavement load supporting characteristics due to water seepage ➢ Stripping on the bottom of the HMA layer ➢ Increase in loading ➢ Inadequate structural design ➢ Poor construction	➢ Localized fatigue cracking : Replace the area of poor subgrade and improve the drainage of that area and patch over the repaired subgrade. ➢ Large fatigue cracked areas – design of overlays

Bleeding:

	➢ Film of asphalt binder on the pavement surface... ➢ Creates a shiny, glass-like reflecting surface that can become sticky when dry and slippery when wet	

Problem:	Possible causes:	Repair:
➢ Loss of skid resistance when wet	➢ Excessive asphalt binder in the HMA ➢ Low HMA air void content	➢ Applying coarse sand to blot up the excess asphalt binder. ➢ Cutting off excess asphalt with a motor grader or removing it with a heater planer.

Corrugation cracking-

➢ A form of plastic movement in the form of corrugations or an abrupt wave (shoving) across the pavement surface.
➢ The distortion is perpendicular to the traffic direction.
➢ Usually occurs at points where traffic starts and stops (corrugation) or areas where HMA abuts a rigid object (shoving).

Problem:	Possible causes:	Repair:
➢ Ro ug hn ess	➢ An unstable (i.e. low stiffness) HMA layer ➢ Poor mix design ➢ Poor HMA manufacturing ➢ Lack of aeration of liquid asphalt emulsions ➢ Excessive moisture in the subgrade	➢ Remove the distorted pavement and patch. ➢ Remove the damaged pavement and overlay

Patching- A patch is considered a defect no matter how well it performs

Problem:	Possible causes:	Repair:
Roughness	➢ Previous localized pavement deterioration that has been removed and patched ➢ Utility cuts	➢ Patches are themselves a repair action. ➢ The only way they can be removed from a pavement's surface is by either a structural or non-structural overlay.

	Any 4 cause - 2 markss each = 1 mark	
5	The design thickness of a cc pavement is 26 cm, considering a design axle load (98th percentile load) of 12000 kg on single axle load and M40 concrete with characteristic compressive strength of 400 kg/cm^2, radius of relative stiffness 62.2 cm, elastic modulus of dowel: steel 2 × 10^6 kg/cm^2, modulus of dowel concrete interaction 41500 kg/cm^3 and joint width 1.8 cm, design the dowel bars for 40% load transfer edge loading. Take diameter of dowel bar = 3 cm, spacing =25 cm.	[08]

f_{ck}=400 kg/cm^2

b = 3 cm

s = 25 cm

Allowable bearing stress on concrete = $F_b = \frac{(10.16-b)\times f_{ck}}{9.525}$

$$F_b = \frac{(10.16-3)\times 400}{9.525} = 300.68\ kg/cm^2$$

EI =$(2\times10^6\times\pi\times3^4)/64$=7952156 kgcm^2

Relative stiffness of the bar, $\beta = \sqrt[4]{\frac{kb}{4EI}} = \sqrt[4]{\frac{41500\times3}{4\times7952156}} = 0.25$

$$P_t\left[1+\left[\frac{62.2-25}{62.2}\right]+\left[\frac{62.2-25\times2}{62.2}\right]\right] = 0.4\times6000$$

$P_t[1+0.598+0.196] = 2400$

Or Pt = 1337.79 kg

Maximum bearing stress developed $= \sigma_{max} = \frac{kP_t\,(2+\beta z)}{4\beta^3 EI}$

$\sigma_{max} = \frac{41500\times1337.79\,(2+0.25\times1.8)}{4\times0.25^3\times7952156} = 273.67\ kg/cm^2 < 300.68\ kg/cm^2$.

Hence the dowel bar system provided is adequate and hence safe.

Estimation of F_b, β, P_t, σ_{max} alongwith final statement - 2×4 = 8

6 Existing black top pavement was tested using Benkelman beam. The observations recorded at a pavement temperature of 43ºC are given below. Compute the thickness of bituminous concrete overlay taking allowable deflection as 1.25 mm, factor of subgrade moisture as content as 2 and accuracy 84%. (Hint: Accuracy 97.7 % indicate k = 2, accuracy 84% indicate k = 1). [08]
1.46, 1.52, 1.56, 1.76, 1.96, 1.74, 1.68, 1.74, 1.96, 1.42, 1.56, 1.62 mm

xi	1.46	1.52	1.56	1.76	1.96	1.74	1.68	1.74	1.96	1.42
$(xi-mean)^2$	0.04202 5	0.02102 5	0.01102 5	0.00902 5	0.08702 5	0.00562 5	0.00022 5	0.00562 5	0.08702 5	0.06002 5

Mean = 1.665 Standard deviation = 0.176249

Characteristic deflection = 1.665+1×0.176 = 1.841 mm

Correction for temperature = 1.841 – (43 - 35) × 0.01 = 1.761 mm

Correction for moisture = 2 ×1.761 = 3.522 mm

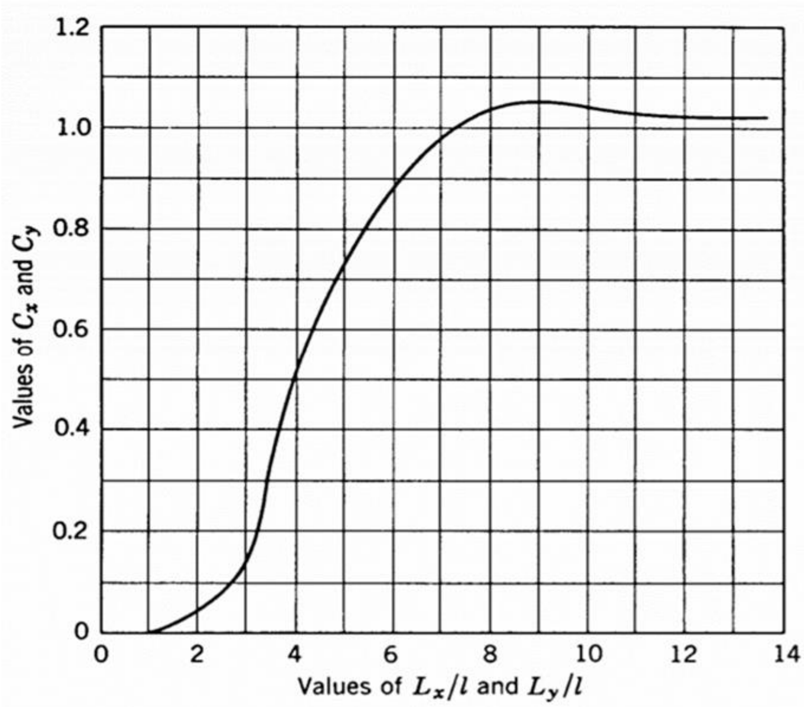
Overlay design $=550\log_{10}\left(\frac{D_c}{D_a}\right) = 550\log_{10}\left(\frac{3.522}{1.25}\right)$=247.4 mm

Mean, standard deviation – 2

Characteristic deflection, correction for temperature, moisture – 1+2+1

Overlay design -2

7 Calculate the warping stresses at interior, edge and corner regions in a 28 cm thick cement concrete pavement with transverse joints at 5.5 m interval and longitudinal joints at 3.5 m interval. Modulus of subgrade reaction is 0.75 N/mm^2. Temperature differential if 0.08°C/cm slab thickness. Take tyre pressure is 0.55 N/mm^2 for a wheel load of 51,000 N. [08]
$e = 10\times10^{-6}$ per °C, $E = 0.3\times10^5 = N/mm^2$ and μ = 0.15.



Lx= 5.5 m
Ly=3.5 m

$$l = \left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4} = \left[\frac{3\times 10^5 \times 28^3}{12\times 7.5\times(1-0.15^2)}\right]^{1/4} = 93.02\ cm$$

Lx/l= 550/93.02 = 5.9 ; Ly/l = 350/93.02 = 3.76

Cx = 0.89 ; Cy = 0.46

$$\text{Warping stress at interior } = Ste = \frac{Eet}{2}\left[\frac{C_x+\mu C_y}{1-\mu^2}\right]$$

$$= \frac{3\times 10^5\times 10\times 10^{-6}\times 0.08\times 28}{2}\times\left[\frac{0.89+0.15\times 0.46}{1-0.15^2}\right]$$

St_i = 3.29 N/cm^2

$$\text{Warping stress at edge} = Ste = \frac{C_x Eet}{2}$$

$$= \frac{0.89\times 3\times 10^5\times 10\times 10^{-6}\times 0.08\times 28}{2} = 2.99\ N/cm^2$$

a = 171.8 mm

$$\text{Warping stress at corner} = Stc = \frac{Eet}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

$$= \frac{3\times 10^5\times 10\times 10^{-6}\times 0.08\times 28}{3(1-0.15)}\times\sqrt{\frac{171.8}{93.02}}$$

$$Stc = 3.58\ N/cm2$$

Calaculation of l, Cx and Cy – 4

	Caulculation of warping stresses for different location - 4	

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