三、柔性鋪面之回算與結構評估

B 柔性鋪面之回算與結構評估

Table 1.1 - Limiting deflection criteria for pavement evaluation

Figure 1.1 - Component versus system analysis of pavement structures

Destructive Testing vs. NDT

B.1 柔性鋪面之回算

(含BISDEF程式之使用介紹)

◎ Determination of the Load-Carrying Capacity

Basic Approach :

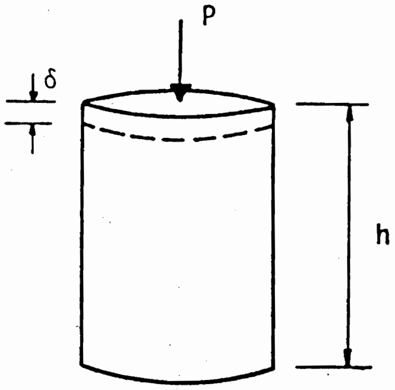
1. Measure pavement deflection basins
2. Backcalculate the layer modulus for different seasons
3. Compute critical stresses and strains for different seasons
4. Use fatigue cracking and permanent deformation (rutting) prediction models to estimate the allowable load repetitions (Figure 1 - Pass Damage)
5. Miner's cumulative damage method for the combined effect of various loads

◎ Basic Concepts for Flexible Pavements

※One-Layer Pavement：Boussinesq Theory

$$\Delta = 1.5\frac{pa}{E}$$ (➔ can be directly backcalculated)

Laboratory Testing of a Specimen

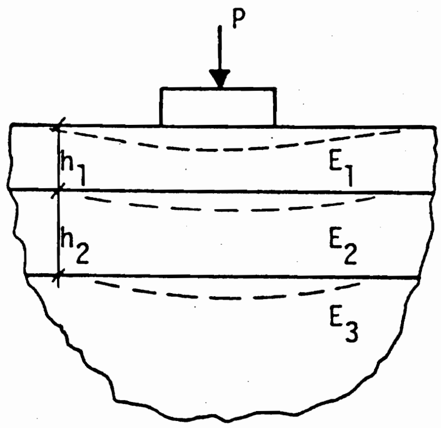


1. Apply axial load;
2. Measure axial deformation;
3. Compute "E" based on the ratio:

$$E = \frac{\text{Deviator Stress}}{\text{Recoverable Strain}}$$

Component Characterization → System Response

Full-Scale Testing of a Pavement



1. Apply NDT load;
2. Measure surface deflections;
3. Compute "E's" based on a Layered Model

System Response → Component Characterization

Figure 1.1 Component versus System Analysis of Pavement Structures

TABLE 1.1 Limiting Deflection Criteria for Pavement Evaluation

Reference	Deflection Criteria	Remarks
WAASHO (1)	Spring Δ_{max} = 45 mils Fall Δ_{max} = 35 mils	Conventional flexible pavements. Deflections measured under 18 kip axle.
Hveem (4)	$\Delta_{all} \leq$ 50 mils (1) $\Delta_{all} \leq$ 17 mils (2)	(1) Surface treatment; (2) AC layer thickness = 4 in. Deflections measured under 15 kip axle. Δ_{all} = allowable maximum deflection
Carneivo (3)	20 mils $\leq \Delta_{max} \leq$ 35 mils	Conventional flexible pavements. Benkelman beam deflections under 18 kip. axle, 80 psi tire pressure.
Whiffin et al (6)	20 mils $\leq \Delta_{max} \leq$ 30 mils (1) 5 mils $\leq \Delta_{max} \leq$ 15 mils (2)	(1) Asphalt concrete over granular base. (2) Asphalt concrete over cement treated base. Traffic volume considered. Benkelman beam deflections under 14 kip axle, 85 psi tire pressure.
State of California (8)	Δ_{all} = f(Tac,N)	Δall = Allowable maximum deflection Tac = Thickness of AC layer N = Number of repetitions of a 5 kip EWL Examples: Δ_{all} = 80 mils for Tac = 1.5 in. and N = 10,000 Δ_{all} = 37 mils for Tac = 1.5 in. and N = 10^6 Δ_{all} = 46 mils for Tac = 6 in. and N = 10,000 Δ_{all} = 22 mils for Tac = 6 in. and N = 10^6
Asphalt Institute (5)	Δ_{all} = f(DTN, Temp)	DTN = Design traffic number = average daily 18 kip axle loads Δ_{all} = Allowable maximum deflection (plus two standard deviations) Examples: Δ_{all} = 22 mils for DTN = 1000 Δ_{all} = 100 mils for DTN = 2 Benkelman Beam Deflections
Lister (7)	N = f($\Delta_{in.}$, pavement type)	N = Cumulative number of 18 kip axle repetitions $\Delta_{in.}$ = Initial Benkelman beam deflection (14 kip axle) Graphical relations between N and $\Delta_{in.}$ for different pavement types. For AC pavement with granular base layer: $\Delta_{in.}$ = 20 mils; N = 4.5×10^6 $\Delta_{in.}$ = 40 mils; N = 0.5×10^6
Nagumo et al (13)	$\log N = 0.179\Delta^2 - 1.117\Delta + 6.772$	N = Number of repetitions to failure of heavy loads (over 18 kip) Δ = Benkelman beam deflections
Joseph and Hall (11)	$\Delta = 1.1315/N^{0.233}$	Δ = Initial deflection (mils) under a given load N = Repetitions to failure of that load

※Two-Layer Pavement：

Uniformly spaced intervals of 0, 12, 24, and 36 in. (Falling Weight Deflectometer)

$$AREA = 6\left(1 + 2\frac{D_1}{D_0} + 2\frac{D_2}{D_0} + \frac{D_3}{D_0}\right)$$

AREA=11.1(stiff as subgrade) ~ 36(perfectly stiff)

D_0, D_1, D_2, D_3 = Measured deflection at 0, 12, 24, 36 in. from the center of the load

Steps: (in Figure 2)

1. Known AREA and layer thickness (t) -> E_1/E_2
2. Known AREA, t, and load (P) -> D_0E_2/P

➔ E_1 and E_2

※Three- and Four-Layer Pavement：

Elastic layer computer program, inputs required for backcalculation:

1. Layer thicknesses
2. Estimated E values and allowable upper and lower limits
3. Poisson's ratios for each layer (minor effect)
4. Deflection basin measurements

◎BISDEF Program Output

◎Typical Elastic Modulus Values

Homework #1: BISDEF Trials

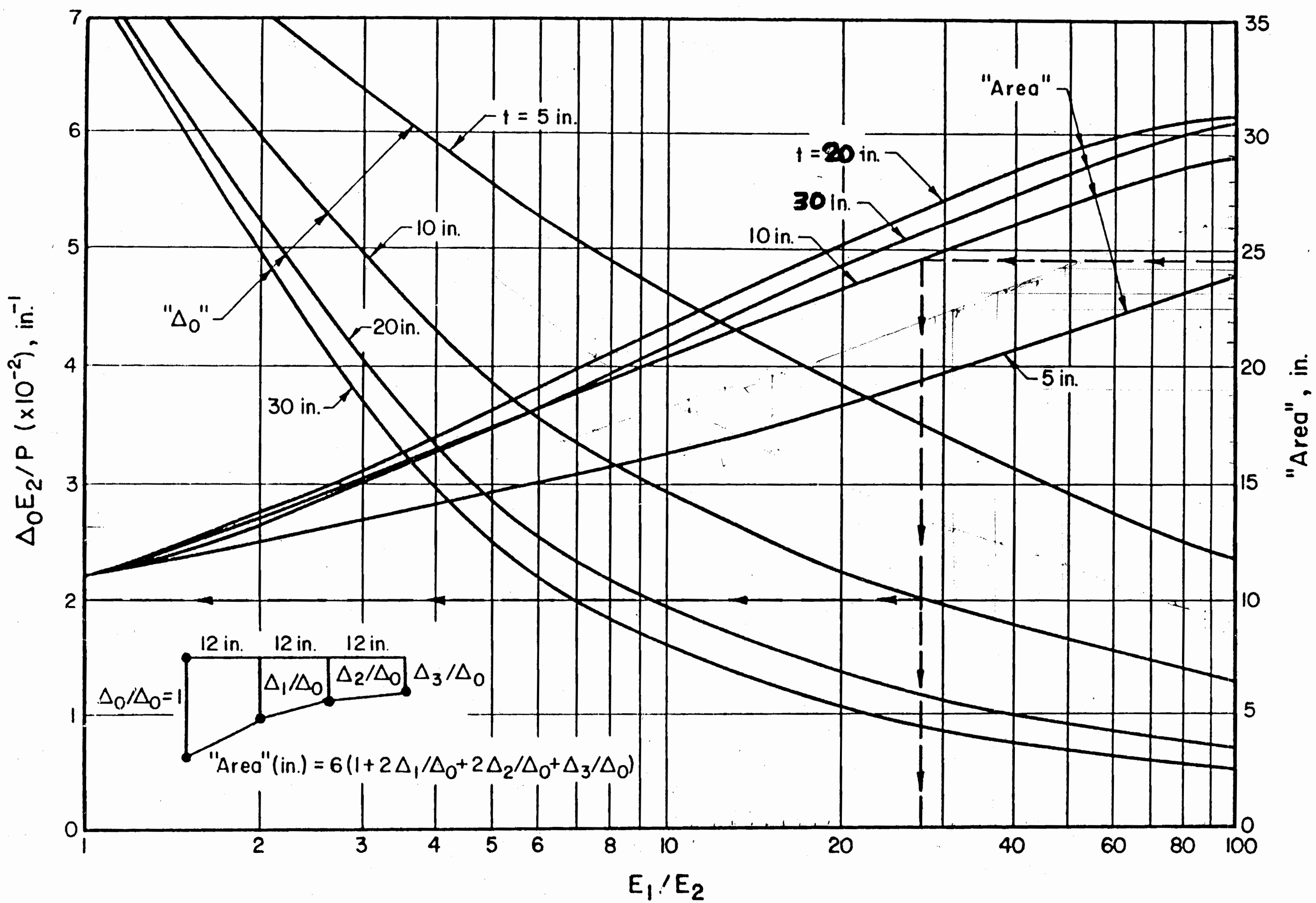


Figure 2. Variation of the "Area" and the Maximum Deflection Factor in a Two-Layer Linear Elastic Model.

B.2 柔性鋪面之結構評估

1. Measure deflection basins along the project (100 ft. or 300 - 500 ft. intervals)
   (a) Hihways: 9,000 lbs FWD loading
   (a) Airports: 24,000 lbs FWD loading
2. Measure AC surface temperature hourly
3. Plot a maximum deflection profile along the project and examine its uniformity
4. Backcalculate the layer moduli
5. Estimate each layer modulus for each season
6. Compute critical strains for different seasons
7. Compute the expected or "allowable" number of load applications to "failure" using an AC fatigue model and a subgrade permanent deformation model

Corps of Engineers:

$$\log_{10} N_{ac} = -\left[5.01 * \log_{10} TSTRAIN + 2.6651 * \log_{10}\left(\frac{E_{ac}}{14.22}\right) + 0.392\right]$$

$$N_{sg} = \left(\frac{0.005511}{VSTRAIN}\right)^{6.527}$$

Where:
TSTRAIN = tensile strain at the bottom of the AC layer;
E_{ac} = elastic modulus of the AC layer, psi;
VSTRAIN = vertical strain on the top of the subgrade;
N_{ac} and N_{sg} = allowable load applications.

CE 421

FLEXIBLE PAVEMENT STRUCTURAL EVALUATON

USING BACKCALCULATED MODULI

1. Measure deflection basins at representative locations along the project (e.g., 100 ft. intervals or less for projects less than one mile, and 300 to 500 ft. intervals for longer projects). Set FWD loading as close as possible to wheel load of design or critical vehicle. For highways, use 9-kips. For airports use maximum (normally 24-kips). Also, run lighter and heavier loads (if possible) so that the extent of load or stress sensitivity can be determined.

Do not normally place the load plate on cracks. However, it may be desirable to obtain some deflections on alligator cracks or other prominent cracks to later determine the extent of deterioration at those locations.

2. Measure AC surface temperature hourly throughout the testing period by drilling a 2 inch deep hole, filling with oil or water, and inserting a thermometer. Measure deflections at one or more points each hour for use as reference points to adjust other deflections if temperature changes significantly.

3. Plot a maximum deflection profile along the project and examine the profile for uniformity (adjust the maximum deflection for uniform temperature). If there exists obvious variation along the project, it may be desirable to divide the project length into different design or evaluation sections. The reason for differences in deflections for the different sections should be determined (e.g., change in pavement thickness or soil type).

4. Back-calculate modulus of layers and subgrade for each test location using an elastic layered based computer program (ELSDEF OR BISDEF).

Do not average deflection basins back-calculate for the average basin. Look for a few points of erronous data where something may of happened to the deflection reading and delete if too far out (bad data always exists for some reason).

Determine the mean AC stiffness modulus for each design section at the field measurement temperature.

5. Estimate each pavement layer modulus value for each season (or month) under consideration.

AC stiffness varies greatly with temperature and must be adjusted for each seasonal period. Adjust the mean backcalculated AC stiffness modulus (at the field temperature) to the estimated pavement temperature for each major season (or month) over the year. Mean monthly air temperatures for the Champaign area are given in Figure 1 and an approximate relationship between mean monthly air temperature and AC layer temperature is given in Figure 2. Use the general shape of the graph in Figure 3 to adjust the stiffness modulus measured in the field at a given temperature to the mean pavement layer temperature for each month obtained from Figure 2. Assume that the slope of the stiffness modulus versus temperature is constant to make this adjustment.

Unstabilized granular base and subbase and fine grained subgrade soil modului may also need to be adjusted for seasonal conditions based upon expected frost and moisture conditions. An example of this is shown in Figure 4 for the central Illinois area.

6. Compute critical strains in pavement layers for each month over a year for each aircraft or truck under consideration using the elastic layered program. For highway evaluation, the 18-kip equivalent single axle load is normally used as the standard. However, the entire range of axle weights could be used, but this may require adjustment of subgrade and granular base moduli for lighter and heaver axle loads due to stress sensitivity.

7. Compute the expected or "allowable" number of load applications to "failure" using an AC fatigue model and a subgrade permanent deformation model for each month (denoted by N_i). Two reasonable models are given that were developed by the Corps of Engineers, and have been used successfully for consulting work.

Asphalt Concrete:

$$\log_{10}(COV) = -\left(5.0 \log_{10} TSTRAIN + 2.665 \log_{10}(Eac/14.22) + 0.392 \right)$$

Where: COV = number of coverages to unknown amount of fatigue cracking
TSTRAIN = tensile strain in the AC layer
Eac = stiffness modulus of the AC layer, psi

Fine Grained Subgrade

$$COV = (0.005511 / VSTRAIN)^{6.527}$$

where: COV = number of coverages to 0.5 ins. of rutting
VSTRAIN = vertical strain on fine grained subgrade

8. Compute past damage (and future damage if desired to determine if pavement can withstand future loadings over some time period) using Miner's accumulated hypothesis:

$$DAMAGE = \sum n_i / N_i$$

where: n_i = no. of axle or gear loads for the ith month actually applied to the pavement at a given load magnitude.

N_i = no. of axle or gear loads for the ith month allowable to "failure" computed from fatigue or permanent deformation models.

If more than one axle or gear load is used, this summation must be repeated for each and the total damage summed for all axle or gear loads.

8. Compute pass damage
Damage = $\Sigma (n_i / N_i)$
9. Develop a table of results (total pass damage)
10. Computed past damage vs. expected pavement condition
11. Assess remaining life of the existing pavement

B.3由面層撓度值回算鋪面彈性模數的初步研究

資料來源：

陳建桓、李英豪，"由面層撓度值回算鋪面彈性模數的初步研究"，中華民國第八屆鋪面工程學術研討會論文輯(已接受)，台北國際會議中心，中原大學，中華民國八十四年十二月六日至八日。

B.4 BISAR程式之使用介紹

Needed Correction:

Vertical load should be input in pound per square inch (psi) instead of pound (lb)!!!