B 柔性鋪面之回算與結構評估

B.1 柔性鋪面之回算
(含BISDEF程式之使用介紹)

B.2 柔性鋪面之結構評估

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

B.1 柔性鋪面之回算
(含BISDEF程式之使用介紹)

STRUCTURAL CHARACTERIZATION OF PAVEMENT LAYERS AND DETERMINATION OF ALLOWABLE AIRCRAFT LOADS

1. BASIC APPROACH

The determination of the load-carrying capacity or the maximum allowable load for a given pavement requires the following major steps:

1. Measure pavement deflection basins at selected points throughout the pavement feature.

2. Backcalculate the elastic or resilient modulus of each pavement layer and the subgrade. Determine moduli for different seasons.

3. Use the elastic moduli and layer thicknesses in a structural model (such as the elastic layer program) to compute critical stresses and strains in the pavement under actual aircraft loadings for different seasons.

4. Use fatigue cracking and permanent deformation (rutting) prediction models to estimate the number of load applications to structural failure of the pavement for each aircraft type and varying gross aircraft loads. Use values for the load-carrying capacity for individual aircraft such as those shown in Figure 1. → Pass Damage

5. If several critical aircraft will regularly use the pavement, an analysis of the combined effect of all aircraft must be conducted using either the equivalent aircraft approach or a cumulative damage method, such as Miner's.

Prof. M. Darter
Civil Aviation Training
Jeddah, Saudi Arabia
1984

Module 2.8B

Structural Evaluation By NDT (Deflections)

CHAPTER 1 *

INTRODUCTION

1.1 General

Providing a quantitative basis for evaluating the pavement structural condition at any stage of its service life is one of the main objectives of flexible pavement Nondestructive Testing (NDT). A structural pavement evaluation is needed to:

1) Determine if a pavement structure is adequate to accomodate an anticipated change in mission (traffic),

2) Provide material properties for overlay design when the pavement is reaching its final serviceability, and

3) Develop rehabilitation recommendations and optimal maintenance strategies based on routine structural evaluation.

There is general agreement among pavement engineers and researchers that the measurement of the surface deflection basin provides valuable information for the structural evaluation of

* Ph.D. Thesis, Mario Hoffman, 1980. U. Illinois.

flexible pavements. To quantitatively interpret surface deflection measurements made during the load testing of pavements, the actual structure and its subgrade must be replaced by a mechanistic model(s).

The structural evaluation of a flexible pavement is, to an extent, an inverted design process. If the cross section and properties of the paving materials and support system are known, it is possible to compute the pavement response (stresses, strains, and displacements) for given loading conditions. In the evaluation process, the response of the pavement is observed and the material properties are backcalculated.

Among the different load responses, only surface deflections are easily measurable. Deflection is a basic response of the whole system to the applied load. It is frequently used as an indicator of the load carrying capacity of the pavement. Also, surface deflection measurements are rapid, relatively cheap, and nondestructive. All these factors make NDT attractive and useful.

The problem of evaluating a pavement is a complex one. The pavement structure is composed of various materials. The behavior of these materials under load is far from the ideal materials assumed in classical mechanics. Their properties vary diurnally, seasonally, and with repetitions of loading. In addition, the load-response characteristics of flexible pavements are stress and rate of loading dependent. All these factors must be fully understood and accounted for in the development of a methodology for structural evaluation.

1.2 Surface Deflections in Pavement Evaluation

Surface deflections have been used for many years as pavement performance indicators. In 1955, results from the WASHO Road Test established the values of 45 and 35 mils as limiting values of allowable maximum deflection under an 18 kip axle for flexible pavements in spring and fall respectively (1). Following the concept developed in the WASHO Road Test, many other investigators and agencies adopted and established their own limiting deflection criteria (2,3,4).

Subsequently, researchers related the limiting deflection criteria to traffic (5,6), and to combined traffic and thickness of the asphalt concrete layer (7,8). Limiting deflection criteria for different types of structures and traffic for both airport and highway pavements were developed (9,10,11,12). Correlations between surface deflections and the Present Serviceability Index derived from the AASHO Road Test were modified and incorporated into a pavement design method (14,15). Table 1.1 summarizes some typical limiting deflection criteria reported in the literature.

In the early 1950's, while developing light vibrators for wave propagation analysis of pavements, Shell investigators in Holland proposed a limited stiffness value of 1,100 kips/in to prevent cracking of the asphalt concrete pavement surface (16). The stiffness value, defined as the load required to produce a unit deflection, became especially popular in the field of airport pavement evaluation (12,17,18).

Parallel to the development of limiting deflection and stiffness criteria, researchers considered the curvature of the deflection basin, but few limiting curvature criteria were developed. Furthermore, there is no unique definition of curvature nor any established method for its measurement. Different geometric functions are used to describe the deflected shape of the pavement's surface: a circle (19), a sine curve (15), and a parabola (20). Criteria are reported for radius of curvature (19), the ratio between the size of the deflection basin and the maximum deflection (21), the "slope" of the deflection basin (22), and the product between the radius of curvature and the maximun deflection (20). Table 1.2 summarizes limiting stiffness and curvature criteria for pavement evaluation.

Once a limiting deflection criterion is established and adopted, the evaluation scheme is generally complemented by a method for the determination of the overlay required to reduce the measured deflections below a desired limit. The Asphalt Institute (5), the TRRL (10), and others have developed such methods that are widely used.

The limiting deflection and curvature criteria, developed over long years of observations, experience, and empirical correlations with performance indicators, proved to be unsatisfactory for pavements, materials, and environmental conditions different from those considered in the correlations. In the last 15 years, parallel to the development of mechanistic methods of pavement design, more emphasis has been placed on the development of more fundamental methods of pavement evaluation. Measured deflection basin parameters are used as input into a mechanistic pavement model and the model parameters are backcalculated. This is the main topic of this dissertation.

1.3 Statement of the Problem

A mechanistic method of pavement design generally starts with a component analysis of the different materials (laboratory testing of material specimens). The different components are then incorporated into a system (layered model), and the behavior of the whole system under load is analyzed (stresses, strains, deflections). In a mechanistic pavement evaluation method the system response is measured (surface deflections), the response is analyzed with the use of a layered model, and the material properties are backcalculated. The analogies and differences between a component and system analyses are illustrated in Figure 1.1.

The laboratory determination of the resilient modulus requires the interpretation of a "nondestructive test": a) The specimen is axially loaded, b) its deformation is measured, and c) the resilient modulus is calculated as the ratio between the deviator stress and the recoverable strain.

The backcalculation of material properties based on NDT interpretation is a "full-scale test": a) The specimen (the pavement) is loaded, b) its deflection basin is measured, and c) the material properties are backcalculated using a selected layered model. The analogies of both methods of test are evident.

The same concern excercised in laboratory procedures to simulate the repetitive nature and magnitude of traffic loadings applies to the load testing of pavements. The interpretation of a full-scale test imposes complications and difficulties compared with the relatively simple component testing at the laboratory. The obvious advantages of pavement NDT are:

1) Realistic loading simulating actual traffic loadings can be applied,

2) The complex interactions among different layers in the pavement are incorporated into the pavement "sample,"

3) The specimens (the layers) are loaded in a realistic three dimensional fashion (very difficult to reproduce in the lab),

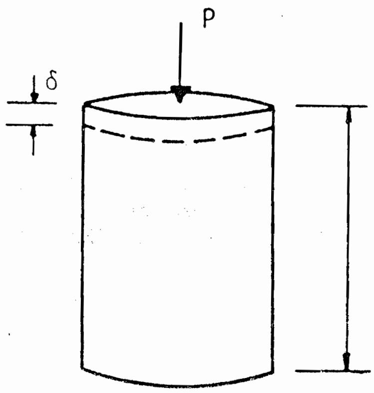
4) The backcalculated parameters represent the "layer material" rather than the "specimen material" at the lab,

5) The layer materials can be tested under different seasonal and environmental conditions and at any time during the life of the pavement,

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
Carneiro (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

Laboratory Testing of a Specimen

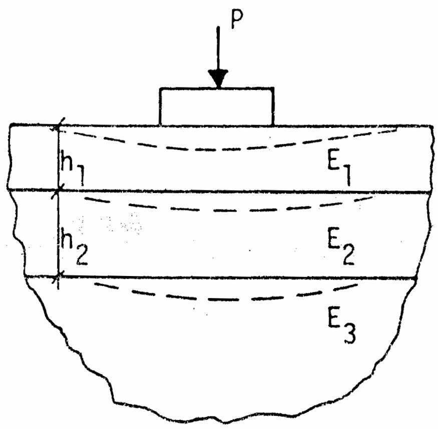


1. Apply axial load;
2. Measure axial deformation;
3. Compute "E" based on the ratio:

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

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

Figure 1. Allowable Gross Aircraft Loads for Outer Portion of Taxiway on B-727 Aircraft**

[A particular pavement presentation]

Pass Intensity Level	Passes	Coverages*	Allowable Loads, kips			
			Rutting Subgrade 0.5 in.	% Fatigue Cracking 50	25	10
I	50,000	15,385	120	134 x	130	120
II	15,000	4,615	150	170	165	155
III	3,000	923	> 190.5	> 190.5	> 190.5	>190.5
IV	500	154	> 190.5	> 190.5	> 190.5	>190.5

* P/C = 3.25

** Maximum loads acceptable for interior portion of taxiway for all Levels.

x Interpretation: This pavement section can handle about 50,000 passes of a B727 aircraft load at 134 kips before 50% fatigue cracking would develop.

2. BASIC CONCEPTS FOR FLEXIBLE PAVEMENTS

Pavement Characterization

One-layer pavements can be characterized using Boussinesq theory:

$$DEF = 1.5\ p\ a\ /\ E$$

where: DEF = measured deflection, ins. or cm
p = pressure on loading plate, psi or kg/sq.cm
a = radius of load plate, ins. or cm
E = modulus of elasticity of layer, psi or kg/sq.cm

Example-- A Falling Weight Deflectometer was used to measure the deflection directly on top of a compacted silty clay subgrade. The load and other information are as follows:

Load = 2000 pounds or 908 kg
Radius of plate = 5.9 ins or 15 cm.
Measured maximum deflection beneath plate = 0.025 ins. or 63.5 mm

Compute the E of the silty clay subgrade (Answer: 6474 psi or 455 kg/sq.cm).

Two-layer pavements can be characterized using two-layer elastic layer theory and a simple chart such as the one shown in Figure 2. The backcalculation of the elastic moduli of the two layers requires the measurement of the deflection basin at four uniformly spaced intervals of 0, 12, 24, and 36 in. (0, 30, 61, and 91 cm). The thickness of the upper layer must also be known. The curvature of the deflection basin is therefore measured, and can then be used to compute the E1 and E2. The "area" of the deflection basin is first computed according to the following formula:

$$AREA = 6\,(1 + 2D1/D0 + 2D2/D0 + D3/D0)$$

where: AREA = A value representing the stiffness of the pavement relative to the subgrade (ranges from 36 for a perfectly stiff pavement that does not bend, to 11.1 for a pavement which is as stiff as the subgrade).

D0,D1,D2,D3 = Measured deflections at 0, 12, 24 and 36 in. (0, 30, 61 and 91 cm) from the center of the loading plate.

Typical values of AREA for different pavements placed over a soft subgrade are as follows:

Pavement/Soft Subgrade	AREA
Surface Treatment	11 - 15
Weak Flexible Pavement	16 - 20
Stiff Flexible Pavement	21 - 25
Concrete Slab	29 - 32

Other factors which must be known are the maximum deflection (MDEF), the total load on the plate (P), and the thickness of the pavement layer (t). The chart shown in Figure 2 is then entered as illustrated and the E1/E2 ratio determined, followed by the determination of the following ratio:

$$MDEF\ E2\ /\ P\ (x\ 10^{-2})$$

Once this is known, E2 and E1 are computed.

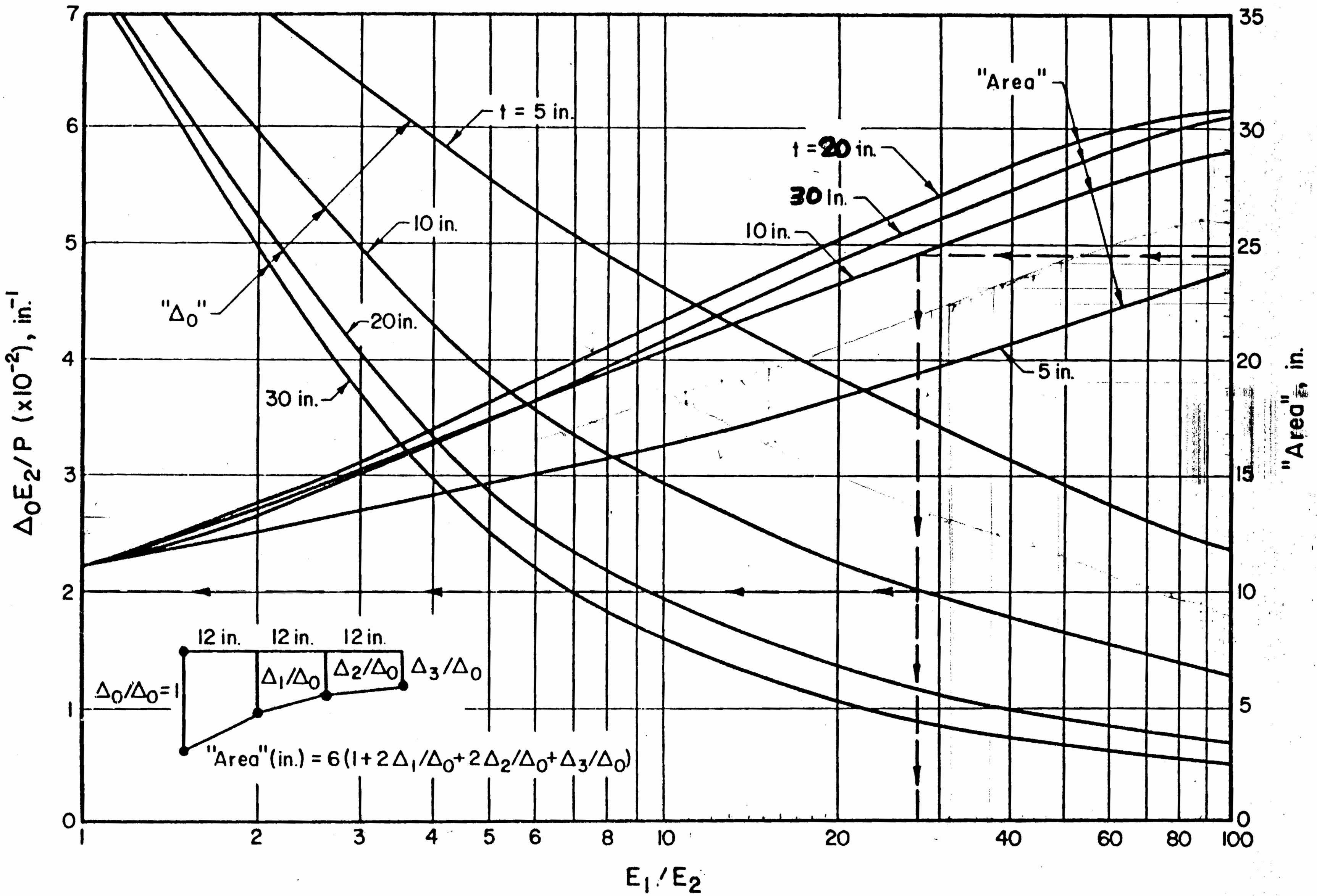


Figure 2. Variation of the "Area" and the Maximum Deflection Factor in a Two-Layer Linear Elastic Model.

—FWD—EXAMPLE OUTPUT—

Date: 10071992 Temp: 78 F
Roadway: PARKING LOT
Time: 2:00 PM

Load Radius [a] =6 in
r's=0 12 24 36 48 60 72

SHUNTVAL in VOLTS: 7.18336
STEP: 6

BURRELL St.

Station FIRST TEST				
DEMO FOR PROF. DARTER				
Ld.(lbs)	→ 6231	5854	8907	9020
Df1(mil)	21.2	20.2	31.3	31.5
Df2(mil)	13.4	12.9	20.2	20.4
Df3(mil)	7.8	7.6	12.0	12.1
Df4(mil)	4.8	4.8	7.6	7.6
Df5(mil)	3.1	3.1	5.0	5.0
Df6(mil)	2.3	2.3	3.6	3.7
Df7(mil)	1.8	1.7	2.8	2.8
Area(in)	19.4	19.6	19.8	19.8
dsm(kpi)	294	289	285	286
DSM(kpi)	281			

Station FIRST TEST				
DEMO FOR PROF. DARTER				
Ld.(lbs)	12648	12696	15964	15934
Df1(mil)	44.2	44.5	55.9	56.4
Df2(mil)	28.8	29.0	36.4	36.9
Df3(mil)	17.2	17.2	21.8	22.0
Df4(mil)	10.9	11.0	13.8	13.8
Df5(mil)	7.1	7.2	8.9	9.0
Df6(mil)	5.1	5.1	6.3	6.3
Df7(mil)	3.8	3.9	4.8	4.8
Area(in)	20.0	19.9	20.6	20.0
dsm(kpi)	286	285	286	282
DSM(kpi)	270			

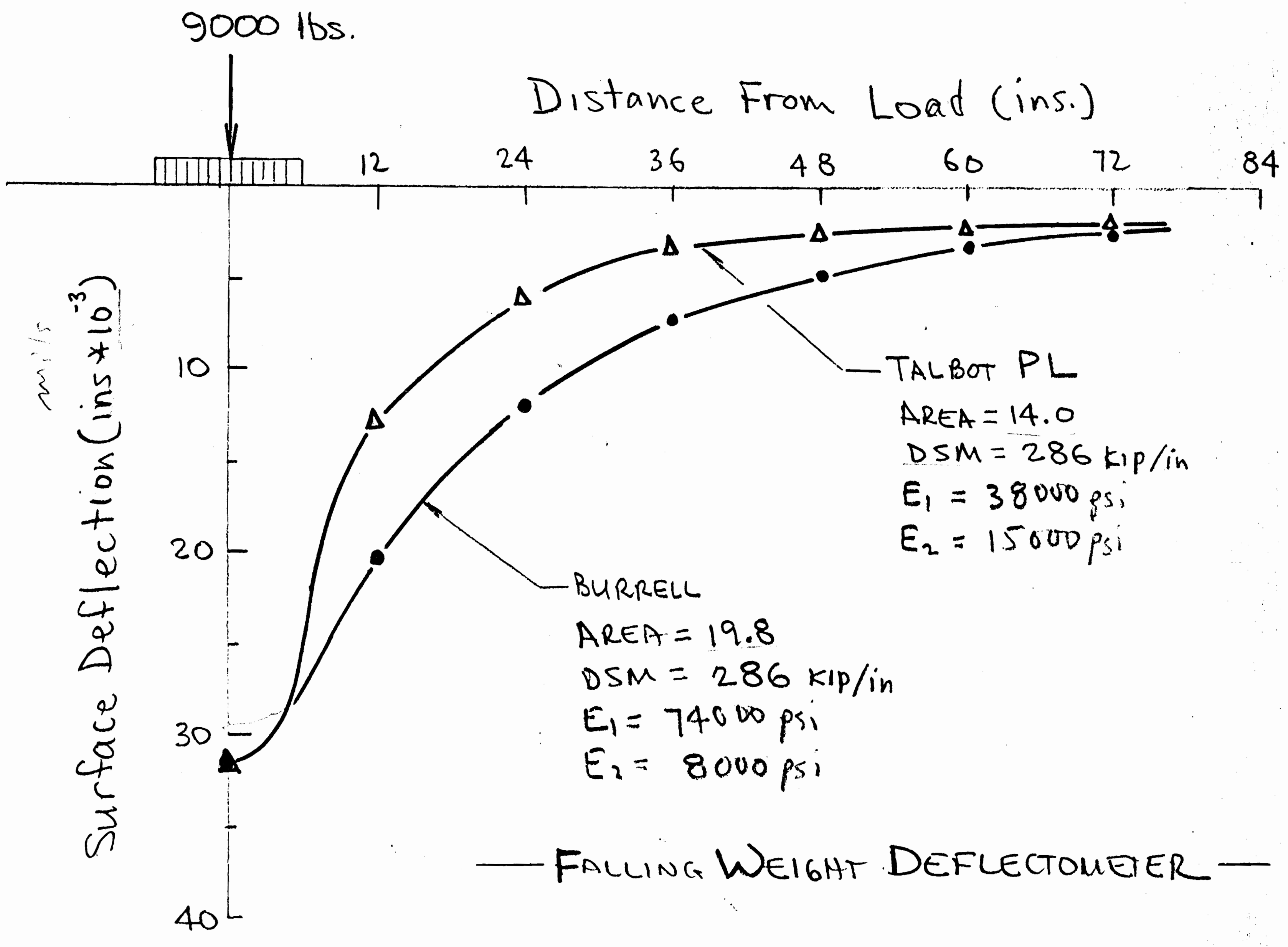
SHUNTVAL in VOLTS: 7.18092
STEP: 6

PARK LOT

Station FIRST TEST				
DEMO FOR PROF. DARTER				
Ld.(lbs)	6515	6634	9718	9119
Df1(mil)	23.4	21.8	33.0	31.8
Df2(mil)	9.0	8.7	13.3	13.1
Df3(mil)	4.3	4.3	6.0	6.1
Df4(mil)	2.6	2.7	3.8	3.8
Df5(mil)	2.0	2.1	2.9	2.9
Df6(mil)	1.9	1.8	2.5	2.5
Df7(mil)	1.4	1.4	2.0	2.3
Area(in)	13.5	13.9	13.7	14.0
dsm(kpi)	278	305	294	296
DSM(kpi)	247			

Station FIRST TEST				
DEMO FOR PROF. DARTER				
Ld.(lbs)	12371	12359	15376	15478
Df1(mil)	44.3	44.3	57.4	51.0
Df2(mil)	18.8	18.9	24.5	24.9
Df3(mil)	8.7	8.8	11.1	11.3
Df4(mil)	5.3	5.3	6.6	6.7
Df5(mil)	3.9	4.0	4.9	5.0
Df6(mil)	3.5	3.5	4.3	4.5
Df7(mil)	3.0	2.9	3.6	3.7
Area(in)	14.2	14.2	14.1	15.3
dsm(kpi)	279	279	268	303
DSM(kpi)	462			

EXAMPLE RESULTS – TWO LAYER ANALYSIS



— FALLING WEIGHT DEFLECTOMETER —

Example-- A two-layer pavement consisting of an asphalt concrete layer over a silty clay subgrade was tested with the Falling Weight Deflectometer and the following results obtained:

Asphalt concrete layer = 7.5 in. (19 cm)
Load = 9216 pounds or 4184 kg
Radius of plate = 5.9 ins. or 15 cm.
Measured deflection basin

Distance from Plate Center		Deflection	
0 ins.	(0 cms.)	0.0278 ins.	or 0.7061 mm
12	(30)	0.0186	0.4724
24	(61)	0.0104	0.2642
36	(91)	0.0058	0.1473

Compute the E1 of the asphalt concrete and the E2 of the subgrade using the AREA concept and Figure 2. (Answer: E1 = 116,150 psi or 8165 kg/sq.cm, and E2 = 10,100 psi or 710 kg/sq.cm.

Three- and four-layer pavements can be analyzed using an elastic layer computer program that begins with an assumed E for each layer and then iterates the E's of each layer until the measured deflection basin matches well with the computed deflection basin. The program developed by the Corps of Engineers will be demonstrated herein. This program can be used with good results as long as the engineer has a basic knowledge of the typical stiffnesses of different materials and can apply judgement in the analysis process.

All of the assumptions inherent in elastic layer theory are involved in this backcalculation procedure. Inputs required to backcalculate the moduli are as follows:

1. Layer thicknesses
2. Estimated E values for each layer and allowable upper and lower limits
3. Poisson's ratios for each layer (they have very little effect)
4. Deflection basin measurements at four locations

The computer program will then go through an iteration process by changing the moduli of the layers until the error between measured deflections and computed deflections is within a few percent. Three to five iterations are normally adequate, with a typical CPU time between 3 and 15 seconds.

Example-- A three-layer runway pavement has been tested with a Falling Weight Deflectometer and the following data obtained for a test site:

Pavement structure: 3 in (7.6 cm) asphalt concrete
12 in (30.4 cm) granular base
Silty clay subgrade
FWD Load = 16,182 pounds (7347 kg)
Radius of load plate = 5.9 in (15 cm)
Measured deflection basin:

Distance	Deflection	
0 ins. (0 cms.)	0.074 ins.	(188 mm)
12 ins. (30)	0.044	(112)
24 ins. (61)	0.024	(61)
36 ins. (91)	0.015	(38)

Starting values assumed for E's:
- Asphalt concrete = 200,000 psi (14,060 kg/sq.cm)
- Granular base = 15,000 psi (1,055 kg/sq.cm)
- Silty clay subgrade = 10,000 psi (703 kg/sq.cm)

Allowable range of E's:
- Asphalt concrete = 100,000 to 1,000,000 psi (7,030 to 70,300 kg/sq.cm)
- Granular base = 10,000 to 60,000 psi (703 to 4,218 kg/sq.cm)
- Subgrade = 5,000 to 30,000 psi (352 to 2,109 kg/sq.cm)

Results by iteration using the elastic layer theory backcalculation program for this problem are as follows:

Iteration	E Modulus (psi)	Deflection Basin -- ins. D0	D1	D2	D3
	Measured =	0.074	0.044	0.024	0.015
1 ASSUMED VALUES	200,000 AC 15,000 Base 10,000 Subgrade	0.075	0.036	0.018	0.012
2	496,277 AC 13,785 Base 8,202 Subgrade	0.071	0.042	0.023	0.015
3 FINAL	529,162 AC 12,261 Base 7,949 Subgrade	0.074	0.044	0.024	0.015

The resulting E values are very well within typical resilient repeated load laboratory tests for these materials and the final computed deflection basin matches the measured basin very closely.

BISDEF OUTPUT

An example run using the BISDEF PC program is given on the next page. This batch program uses BINPUT for entering data into a fixed format file that is then run by BISDEF. This program was developed by the CORPS of Engrs.

* # ** # ** # ** # ** # ** # ** # ** # ** # ** # *

P R O B L E M   N U M B E R = 1

* # ** # ** # ** # ** # ** # ** # ** # ** # ** # *

3-Layer Runway Pavement

DEFLECTION READINGS IN MILS

****

POSITION NUMBER	1	2	3	4
DEFLECTIONS	74.00	44.00	24.00	15.00
WEIGHTING FACTOR:	0.0135	0.0227	0.0417	0.0667

NUMBER OF VARIABLE LAYERS AND TARGET DEFLECTIONS = 3

VARIABLE LAYER NO	SYSTEM LAYER NO	VALUE OF MAXMUM MODULUS	VALUE OF MINIMUM MODULUS
1	1	1000000.0	100000.0
2	2	60000.0	10000.0
3	3	30000.0	5000.0

INITIAL PAVEMENT PARAMETERS

****

LAYER NUMBER	CALCULATION METHOD	YOUNG'S MODULUS	POISSON'S RATIO	THICKNESS	INTERFACE SPRINGCOMPL
1	ROUGH	0.2000E+06	0.3500E+00	0.3000E+01	0.0000E+00
2	ROUGH	0.1500E+05	0.4000E+00	0.1200E+02	0.0000E+00
3		0.1000E+05	0.4500E+00		

LOAD INFORMATION

****

LOAD NUMBER	NORMAL STRESS	SHEAR STRESS	RADIUS OF LOADED AREA	LOAD - POSITION X	LOAD - POSITION Y	SHEAR DIRECTION
1	0.1479E+03	0.0000E+00	0.5900E+01	0.0000E+00	0.0000E+00	0.0000E+00

DEFLECTIONS COMPUTED FOR INITIAL MODULUS VALUES

POSITION	OFFSET	DEFLECTION	MEASURED	DIFFERENCE	% DIFF.
********	******	**********	********	**********	*******
1	0.00	75.2409	74.0000	-1.2409	-1.7
2	12.00	35.8979	44.0000	8.1021	18.4
3	24.00	18.1959	24.0000	5.8041	24.2
4	36.00	11.9746	15.0000	3.0254	20.2
			ABSOLUTE SUM:	18.1725	64.4437
			ARITHMETIC SUM:		61.0899
			AVERAGE:	4.5431	16.1109

************************BISDEF OUTPUT SUMMARY***********************

PREDICTED E'S FOR ITERATION NO.: 2

PREDICTED E DISREGARDING BOUNDRY CONDITIONS

LAYER NO.	MODULUS
*********	**********
1	526905.
2	12253.
3	7945.

DEFLECTIONS COMPUTED FOR FINAL MODULUS VALUES

POSITION	OFFSET	DEFLECTION	MEASURED	DIFFERENCE	% DIFF.
********	******	**********	********	**********	*******
1	0.00	73.8465	74.0000	0.1535	0.2
2	12.00	44.1808	44.0000	-0.1808	-0.4
3	24.00	23.5897	24.0000	0.4103	1.7
4	36.00	15.2249	15.0000	-0.2249	-1.5
			ABSOLUTE SUM:	0.9696	3.8275
			ARITHMETIC SUM:		0.0067
			AVERAGE:	0.2424	0.9569

FINAL MODULUS VALUES
****

LAYER NO.:	1	2	3
MODULUS:	526905.	12253.	7945.

ABSOLUTE SUM OF % DIFF. WITHIN TOLERANCE

CHANGE IN MODULUS VALUES NOT WITHIN TOLERANCE

TYPICAL ELASTIC MODULUS VALUES

MATERIAL	TYPICAL VALUE-psi	TYPICAL RANGE-psi
Fine Grain Soil	8000	3000-15000
Coarse Grain Soil	20,000	15000 - ~~30000~~ 60,000
Granular Base	30,000	20,000-60,000
Cement Stab. Base	1,000,000	500,000-2,000,000
Asphalt Concrete	500,000 (70°F) 1,500,000 (40°F) 100,000 (100°F)	200,000-800,000
Portland Cement Concrete	5 million	3-10 million