由面層撓度值回算鋪面彈性模數的初步研究

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OBJECTIVES

- Major Deficiencies of Traditional Backcalculation Procedures
  - Uniqueness Problem
  - Iterative but Time-consuming Calculation
  - Subjective Selection of Initial Trial Values and Input Data Ranges
  - Violation of the Specified Convergence Criteria
- Scope: A Two-Layer Elastic Pavement System

RESEARCH APPROACH

- Theoretical Investigation - Burmister (1943) and Scrivner's (1973) Deflection Equations
- Identification of Functional Forms
- Validation of the Dominating Dimensionless Variables Identified
- Development of a Backcalculation Database
- Development of Backcalculation Prediction Equations
- Validation of the Proposed Prediction Equations

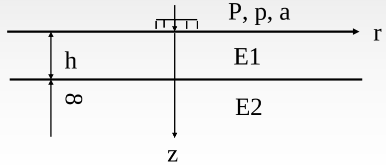
CLASSIFICATION OF BACK-CALCULATION PROCEDURES

- Existing:
  - Iterative Approach (BISDEF, ELSDEF, etc.)
  - Data Base Approach (MODULUS)
- Proposed: (A New Approach)
  - Integrate the Concept of Traditional Database Approach and Modern Regression Techniques
  - Strive to Develop Prediction Equations to Allow "DIRECT" Modulus Calculations

DEVELOPMENT OF TWO-LAYER ELASTIC THEORY

- Burmister (1943)
  - A Uniformly Distributed Circular Load

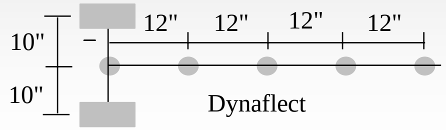
$$w=\frac{1.5pa}{E_2}F_w\ ,\quad F_w=f\left(\frac{h}{a},\frac{E_2}{E_1}\right)$$



DEVELOPMENT OF TWO-LAYER ELASTIC THEORY (continue ...)

- Scrivner (1973)
  - A Concentrated Load

$$\frac{4\pi E_1}{3P}wr=f\left(\frac{E_2}{E_1},\frac{r}{h}\right)$$



DYNAFLECT'S LOAD CONFIGURATION

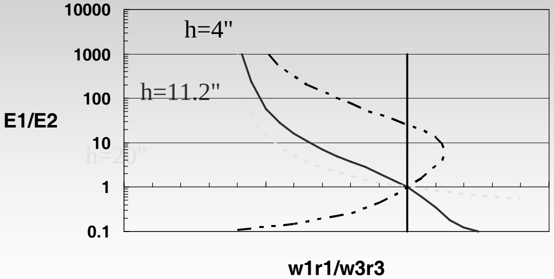
$$\frac{w_1r_1}{w_3r_3}=\frac{f_1\left(\frac{E_2}{E_1},\frac{r_1}{h}\right)}{f_3\left(\frac{E_2}{E_1},\frac{r_3}{h}\right)}=G\left(\frac{E_2}{E_1},\frac{r_1}{h},\frac{r_3}{h}\right)$$

- When r1, r3, and h are known ==>
- w1r1/w3r3 is a function of E2/E1

LIMITATIONS OF BACK-CALCULATION PROGRAMS

- Assume there exists a Unique Modulus Combination
- Iterative but Time-consuming Calculations
- Results Affected by:
  - Different Initial Trial Values
  - Data Ranges
  - Specified Error Tolerance
  - Limited Number of Iterations

Scrivner's Study (1973)



Dynaflect: a=1.41", P = 1000 lbs, r1=10", r3=26"

UNIQUENESS PROBLEM FOR BACKCALCULATION

w1r1/w3r3	h11.2"	h<11.2"
1	Unique	None / Two
<1	Unique	None / Two

DOMINATING MECHANISTIC VARIABLES (DIMENSIONLESS)

$$Y = \frac{4\pi E_1}{3P} w_1 r_1 = F\left(\frac{E_2}{E_1}, \frac{r_1}{h}, \frac{h}{a}\right)$$

$$\frac{w_1 r_1}{w_3 r_3} = F'\left(\frac{E_2}{E_1}, \frac{r_1}{h}, \frac{r_3}{h}, \frac{h}{a}\right)$$

- Identified through Theory for any NDT Devices
- Validated through Series of BISAR Runs

Validation of Variable (h/a)

h/a	h in.	a in.	r1 in.	r3 in.	w1 mil	w3 mil	w1r1 /w3r3
2.5	5	2	7.5	15	3.9 9	3.1 6	0.631
2.5	8	3.2	12	24	2.4 9	1.9 8	0.629
2.5	14	5.6	21	42	1.4 2	1.1 3	0.628

Note: r1/h=1.5, r3/h=3, E2/E1=100,
E1=500,000 psi, E2=5,000 psi, P=1,000 lbs

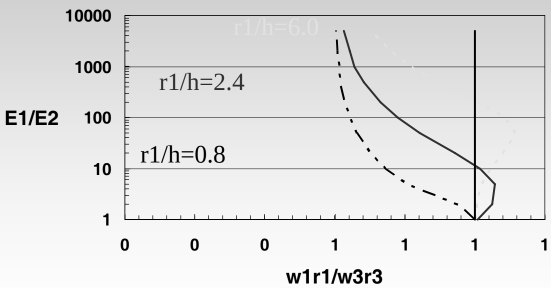
A BACKCALCULATION DATABASE

- Based on Four Dimensionless Variables Identified
- E1/E2 = 1, 2, 5, 10, 20, 50, 100, 200, 500, 1000, 2000, 5000
  r1/h = 0.8, 1.2, 1.8, 2.4, 3.6, 4.8, 6.0
  r3/h = 1.2, 1.8, 2.4, 3.6, 4.8, 6.0, 7.2
  h/a = 0.8, 1.3, 2.5, 3.5, 5.0
  (r1>r3, P = 2400 lbs, E2 = 1000 psi, h = 10 in.)
- FORTRAN Programs Written for Batch Processing
- Total of 1680 Data Sets

USE OF THE DATABASE

- Advantages:
  - "DIMENSIONLESS" Variables
  - Covers Almost All Data Ranges
  - Save Unnecessary Iterative Computation Time
- A Computer Program, Look-up Tables or Figures for Linear Interpolation
- "DIRECT" Calculation is Possible if "Uniqueness" is Guaranteed.

h/a=1.3, r1/r3=0.6



PROJECTION PURSUIT REGRESSION

- "Projection" (PPR) Algorithm by Friedman and Stuetzle, 1981
- Capable of Modeling Variable Interactions
- Model the Response Surface as a Sum of Nonparametric Prediction Functions of Explanatory Variables Using Local Smoothing Techniques

"PROJECTION" (PPR) ALGORITHM

$$y = \bar{y} + \sum_{m=1}^{M_0} \beta_m \phi_m \left(a_m^T x \right) + \varepsilon$$

Minimizing the Mean Squared Residuals:

$$E\left[\varepsilon^2\right] = Minimum$$

TWO-STEP MODELING APPROACH

- Use PPR Algorithm to Break down the Multi-Dimensional Response Surface into a Sum of Several Smooth Projected Curves, Which Are Graphically Representable in Two Dimensions
- Use Traditional Linear and Nonlinear Regressions to Model Each Projected Curves Individually

PROPOSED PREDICTION EQUATIONS FOR "DIRECT" CALCULATION - E1/E2

$$\log_{10}\left(\frac{E_1}{E_2}\right) = f\left(\frac{w_1 r_1}{w_3 r_3}, \frac{h}{a}, \frac{r_1}{h}, \frac{r_3}{h}, \frac{r_1}{r_3}, \frac{r_1}{a}, \frac{r_3}{a}\right)$$

Statistics and Limits:

$$N = 1247,\ R^2 = 0.995,\ SEE = 0.064,\ CV = 2.8\%$$

$$1 \le \frac{E_1}{E_2} \le 5000,\ 0.8 \le \frac{r_1}{h} \le 6.0,\ 1.2 \le \frac{r_3}{h} \le 7.2$$

$$0.8 \le \frac{h}{a} \le 5.0,\ \frac{w_1 r_1}{w_3 r_3} \le 1.0,\ r_1 > r_3$$

PROPOSED PREDICTION EQUATIONS FOR "DIRECT" CALCULATION - E1

$$\log\left(\frac{4\pi E_1}{3P} w_1 r_1\right) = f\left(\log\left(\frac{E_1}{E_2}\right), \frac{h}{a}, \frac{r_1}{h}, \log\left(\frac{E_1}{E_2}\right) * \frac{r_1}{h}, \frac{r_1}{a}\right)$$

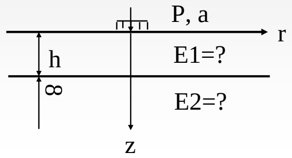
Statistics and Limits:

$$N = 420,\ R^2 = 0.999,\ SEE = 0.033,\ CV = 1.9\%$$

$$1 \le \frac{E_1}{E_2} \le 5000,\ 0.8 \le \frac{r_1}{h} \le 6.0,\ 0.8 \le \frac{h}{a} \le 5.0$$

VALIDATION - A NUMERICAL EXAMPLE

- A Two-Layer System
  - h=10 in, P=3,000 lbs, a=7.69 in
  - NDT Devices, r1=36 in, r3=60 in
- BISAR
  - If E1=1.0 Mpsi, E2=5.0 Kpsi Known
  - ==> w1=0.00386 in, w3=0.0028 in
- Backcalculation
  - (1) BISDEF Trials
  - (2) Proposed Approach



BISDEF TRIALS

E1 Start Mpsi	E2 Start Kpsi	E1 Range Mpsi	E2 Range Kpsi	E1 Mpsi	E2 Kpsi	Within Toler-ance*
0.5	3	0.1~	1~50	1.61	4.71	Y, N
1.61 etc.	4.71 etc.	0.1~	1~10	ERR	ERR	-
1.1	4.0	0.8~1.5	1~8	0.98	5.28	Y, N

* - Absolute Sum of % Difference
  - Change in Modulus Values

THE PROPOSED APPROACH

(1) Use for "Direct" Calculation

Dimensionless Variables:

h/a = 1.3, r1/h = 3.6

r3/h = 6.0, w1r1/w3r3 = 0.827

Use of the Prediction Models:

==> log(E1/E2) = 2.28826, E1/E2 = 194.2

==> log(Y) = 2.2475, Y = 176.8068

==> E1 = 911,259 psi, E2 = 4,692 psi

THE PROPOSED APPROACH

(2) Use as a Pre-Processor

Assist in Selection of Initial Trial Values,

Data Ranges to Speed Up the Convergence

E1 Start Mpsi	E2 Start Kpsi	E1 Range Mpsi	E2 Range Kpsi	E1 Mpsi	E2 Kpsi	Within Toler-ance*
0.91	4.69	0.1~1.2	1~12	0.98	5.13	Y, Y

CONCLUSIONS

- Discussed the "Uniqueness" Problem and Short Comings of Traditional Approach
- Proposed an Alternative Approach Using Database and Modern Regressions
- Identified Dominating Dimensionless Variables for More Complete Coverage
- Strive to Develop Prediction Equations to Allow "DIRECT" Modulus Calculations

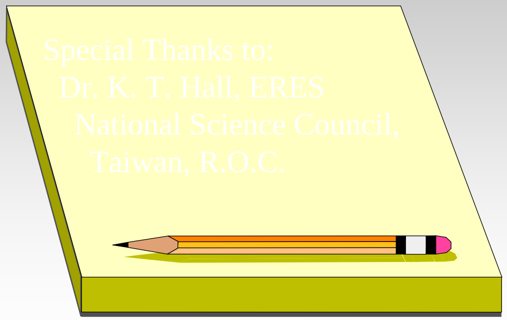
CONCLUSIONS (continue ...)

- Tentative Applications:
  - A Calculator, a Spreadsheet, or a Computer Program for "Direct" Modulus Calculations (Instantly)
  - A Pre-Processor of Traditional Backcalculation Programs
  - In-field Modulus Determinations and NDT Data Checking
- Obtain More Accurate and Consistent Results

LOOKING AHEAD ...

- Further Improve the Prediction Accuracy
- Investigate a Three- or Four-Layer System
- Must also Assure "Uniqueness" of Solutions
- Possible Use of Local Regression Techniques or Any Database Search Algorithms
- Lots of Research Remain to be Done!

ACKNOWLEDGMENTS



THANKS FOR YOUR ATTENTION!

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