四、剛性鋪面之結構評估與回算

Readings: Training Course - Module 2C

◎Structural Evaluation

Nondestructive Deflection Testing (NDT)
Equipments, Concepts, and Procedures

◎ Introduction

※Factors to be considered:

Existing distress, structural components, NDT

※Existing distress (caused primarily by traffic loadings):

AC - alligator cracking > 10%
rutting > 1/2 in.
JPCP - cracked slabs > 10%
JRCP - deter. trans. cracks > 850 ft/lane-mile
deteriorated joints > 50%
CRCP - punchouts & patches > 10/lane-mile
steel ruptures > 10/lane-mile

※Material tests:

pavement types, thickness, conditions of different layers

※NDT: most reliable; detailed deflection studies

to ascertain causes of distress, to locate inadequate support or voids, to determine load transfer efficiency at joints and cracks

◎Deflection Measurement

stronger pavement => lower deflection
weaker pavement => higher deflection

◎Types of NDT Equipments:

Static deflection, Automated beam deflection, Steady-state dynamic deflection, Impulse deflection

※Static Deflection Device:

1. Benkelman Beam: Figure 5
   Need to make sure front supports are not within deflection basin
2. Plate Bearing
3. Curvature Meter

※Automated Beam Deflection Device:

1. La Croix Deflectograph
2. California Traveling Deflectometer

Technical Problems:

1. Reference point may be in the basin
2. Inadequately represent moving wheel load
3. cannot easily be used to determine load transfer across a joint or crack

※Steady-State Dynamic Deflection Device (**穩態動力撓度儀**)**：**

1. Dynaflect **動力撓度儀 - 台灣省公路局**
2. Road Rater, Model 2000, **道路評審儀- 高速公路局**
3. Cox Device
4. FHWA Cox Van (Thumper)

＊基本特性：

1. Static pre-load
2. Static-state sinusoidal vibration,

dynamic force generator
3. Peak-to-peak dynamic force < 2 * static force

＊Dynaflect **動力撓度儀：**

1. One of the first commercially available devices
2. Static load: 2,000~2,100 pounds
3. Limitation: 6 mph, up to 1,000 pounds peak-to-peak fixed frequency

＊Road Rater：Series 400B, 2000(**國內**),2008

1. Peak-to-peak loading 1,000-8,000 lbs
2. Load frequency: 5-70 cycles/sec
3. Technical limitation: limited load levels for lighter models, heavy static preload for heavier devices

※Impulse Deflection Device:

1. Resulting deflection closely simulates deflection caused by a moving wheel load (Note: static preloading may change paving materials' stress states (stress-sensitivity))
2. Pre-load = 8~18% of the max. impulse load 9,000 - 24,000 lbs (Figure 7)

＊Dynatest Falling Weight Deflectometer:

1. Model 8000 is the most widely used FWD device in the U.S.
2. loading plate diameter 11.8 in. (30 cm)
3. varying drop heights & weights 1,500 - 24,000 lbs

4. up to 7 sensors

∗KUAB FWD:

1. Two-mass falling weight system
2. Smoother rise of the force pulse
3. Dynamic force 2,698 - 35,000 lbs

∗Phonix FWD:

1. Dynamic force 2,248 - 11,240 lbs

※Summary Characteristics of NDT Devices:

See Figure 4 or Table 9.1 (Hudson)

◎Factors Influencing Deflections

※Loading Factors:

1. Impulse deflection equipment most closely simulates the deflection
2. Load-deflection relationship is not linear (Figure 8)
3. Recommendation: Use NDT produces loads approximate to those of heavy truck loads
4. “Correction” between different devices (static deflection > dynamic deflection) (Figure 9)
5. Special cautions and difficulties (stress-sensitive for static pre-load) (Figure 10)

※Pavement Factors:

Distressed areas, wheel paths, joints, corners, voids, random variations, etc. (Figure 12)

※Climatic Factors:

1. Higher AC surfacing temperature => higher deflection (Figure 13)
2. Higher PCC temperature => tighter joints & cracks => higher load transfer efficiency (LTE) => lower deflection
3. Thermal gradients:
   $\Delta T>0$ (day-time) => lower deflection
   $\Delta T<0$ (night-time) => higher edge or corner deflection
4. Seasonal variation: (Figure 14)

   ⛩ Time of the day & season of the year

   ⛩ Standard temperature (70 ^{o}F) & season, equivalent deflection based on locally developed procedures

◎Conducting NDT Field Survey

1. Temperature measurement
2. Deflection along the project length
3. More detailed intensive deflection if necessary

◎Special Test Procedures

※Deflection Profile: shape of deflection basin

1. Dynaflect Max. Deflection (DMD)
2. Surface Curvature Index (SCI=D1-D2)
3. Base Curvature Index (BCI=D1-D3)

※Utah Overlay Design Procedure (Figure 18)

※Load Transfer Efficiency (LTE) (Figure 19)

◎Interpretation of Structural Testing Data

Uniformity of the project

C 剛性鋪面之回算

C.1 剛性鋪面回算之介紹

資料來源：

林炳森、李泰明、吳元廷、鄒譽名，“路面評審儀應用於剛性路面之回算法”，中華民國第八屆鋪面工程學術研討會論文輯，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。

C.2 剛性鋪面回算之封閉型解法

資料來源：

Hall, K. T., “Performance, Evaluation, and Rehabilitation of Asphalt-Overlaid Concrete Pavements,” Ph.D. Thesis, University of Illinois, Urbana, Illinois, 1991, pp. 88-104.

◎常用的非破壞性試驗儀器：

動力撓度儀(Dynaflect)
路面評審儀(Road Rater)
衝擊荷重撓度儀(Falling Weight Deflectometer)

◎回算法之分類：

反覆計算法： BISDEF, CHEVDEF, WESDEF, ELSDEF
資料庫處理法： COMDEF, MODULUS

◎反覆計算法尚待解決之問題：

彈性模數值的解可能不唯一、回算結果受輸入資料範圍的影響甚巨、反覆運算的過程不僅耗費時間甚至可能不收斂

◎Westergaard (1926)**與**Losberg (1960)**之理論解**

1. **路基土壤為緊密液體**

$$w^{*} = \frac{\text{¢}k\text{a}^{2}}{P} = \frac{\text{¢}D}{P\text{a}^{2}} = f\left(\frac{a}{\text{a}}, \frac{r}{\text{a}}\right)$$

$$\text{a} = \text{a}_{k} = \sqrt[4]{\frac{Eh^{3}}{12(1-\text{«}^{2})k}}$$

$$D = \frac{Eh^{3}}{12(1-\text{«}^{2})}$$

2. **路基土壤為彈性固體**

$$w^{*} = \frac{\text{¢}C\text{a}}{2P} = \frac{\text{¢}D}{P\text{a}^{2}} = f\left(\frac{a}{\text{a}}, \frac{r}{\text{a}}\right)$$

$$\text{a} = \text{a}_{e} = \sqrt[3]{\frac{Eh^{3}(1-\text{«}_{s}^{2})}{6(1-\text{«}^{2})E_{s}}}$$

$$C = \frac{E_{s}}{(1-\text{«}_{s}^{2})}$$

其中:

w^{*} = **版之無因次撓度值**

D = **版之撓屈勁度**,[L^{4}]

C = **路基土壤常數**,[FL^{-2}]

r = **與載重中心點之徑向距離**,[L]

◎撓度盤區域面積(AREA) 的方法

Hoffman和Thompson (1981)對AREA的定義如下：(AREA的單位為長度，最大值為36) (Figure 25)

$$AREA = 6 * \left[1 + 2\left(\frac{d_{12}}{d_0} \right) + 2\left(\frac{d_{24}}{d_0} \right) + \left(\frac{d_{36}}{d_0} \right) \right]$$

其中:

d_0 = 載重中心點正下方之最大撓度值,[L]

d_i = 離載重中心點 i 處(12, 24, 36英吋)之撓度值,[L]

ERES 和Foxworthy (1985)依據不同之混凝土彈性模數值(E)、路基反力模數值(k)、與版厚度(h)，建立一系列之最大撓度值與AREA之關係圖，並利用內插圖解法反算出該系統之E值與k值。(Figure 26)

Homework #2:

Please perform a series of ILLI-SLAB runs to construct a graph of curves for backcalculation in a similar way.

◎ 回算之封閉型解與ILLI-BACK程式

Ioannides (1990)並指出在固定的載重半徑與量測固定徑向距離之撓度值情況下，AREA與相對勁度半徑有唯一的關係，並建立ILLI-BACK程式。

Hall (1991)進而利用FORTRAN之IMSL副程式庫，對於該封閉型解(含多種特殊之貝索函數Bessel Functions)直接積分，並利用SAS統計軟體推導出AREA與相對勁度半徑之迴歸關係式：(Fig. 4.1-4.2)

$$\ell_k = \left[\frac{\ln\left(\frac{36 - AREA}{1812.279133}\right)}{-2.559340}\right]^{4.387009}$$

$$\ell_e = \left[\frac{\ln\left(\frac{36 - AREA}{4521.676303}\right)}{-3.645555}\right]^{5.334281}$$

因此，由上述迴歸方程式即可利用已知AREA值推算出其相對勁度半徑值。再利用Westergaard內部撓度方程式之重新排序，即可由已知最大撓度值求解路基土壤之反力模數值：

$$k = \frac{P}{8 d_0 \ell_k^2}\left\{1 + \frac{1}{2\pi}\left[\ln\left(\frac{a}{2\ell_k}\right) + \gamma - 1.25\right]\left(\frac{a}{\ell_k}\right)^2\right\}$$

或利用Losberg內部撓度方程式之重新排序，即可由已知最大撓度值求解路基土壤之彈性模數值：

$$E_s = \frac{2P\left(1 - \mu_s^2\right)}{d_0 \ell_e}\left[0.19245 - 0.0272\left(\frac{a}{\ell_e}\right)^2 + 0.0199\left(\frac{a}{\ell_e}\right)^2 \ln\left(\frac{a}{\ell_e}\right)\right]$$

混凝土版之彈性模數值也可因此由版與路基土壤之相對勁度半徑公式直接求解而得。

Homework #3:

Please use Hall’s equation and the graph constructed in previous Homework #2 to compare both backcalculation procedures using the same example inputs.

(Additional Reading: Huang’s Text Book P.456-459.)

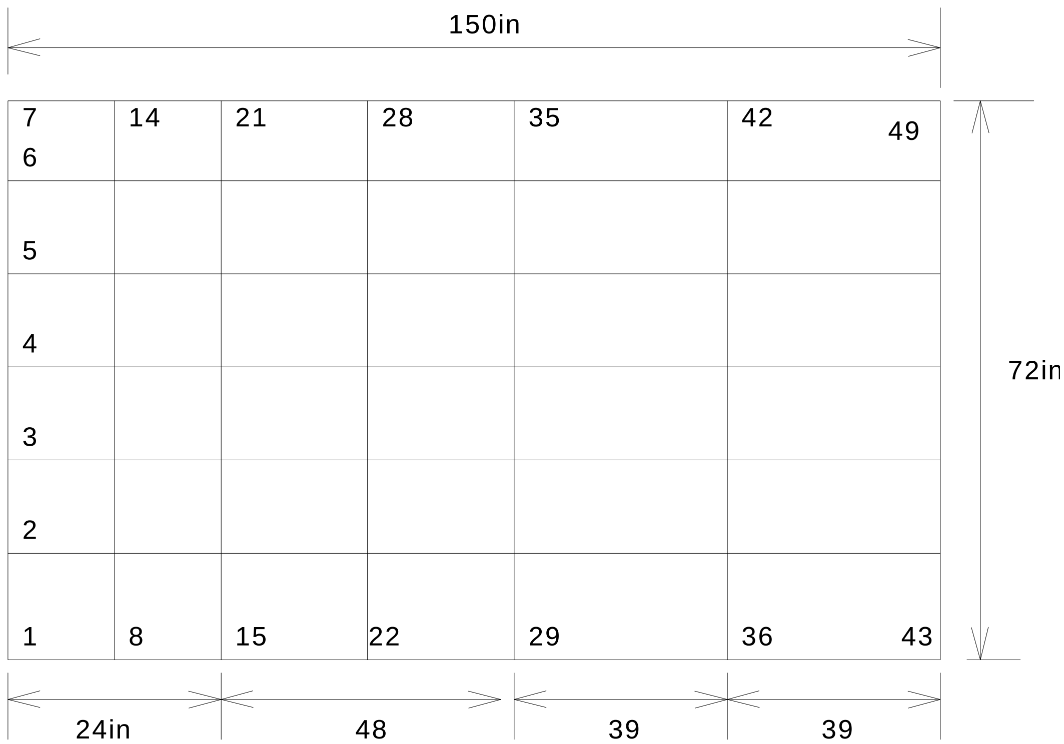
◎ C.3 ILLI-SLAB程式之使用手冊

資料來源：

Korovesis, G. T., “Analysis of Slab-on-Grade Pavement Systems Subjected to Wheel and Temperature Loadings,” Ph.D. Thesis, University of Illinois, Urbana, Illinois, 1990, pp. 305-334.

※ ILLISLABS**程式**Input **檔之範例：**

分析之狀態以雙軸對稱之中央荷重。在 Load = 9000 lbs，a = 5.9 in.**固定下，胎壓為常數等於**82.3 psi，**荷重區域之長度為**c = 10.46 in.，**因分析之狀態為雙軸對稱。所以取**1/2 c = 5.23 in.。



```
1
Slab Size h=10 K=100 E=3E6 infinite slabs p=9000lbs a=5.9
    1    3    0    0
    7
    7
    1    0   100.000
    6    1 0.05 0.05    1
000000  40
       0.0       12.0       24.0       48.0       72.0      111.0      150.0
       0.0       12.0       24.0       36.0       48.0       60.0       72.0
      10.0  3.00E+06       0.15      0.136       16.0  6.88E-06
     82.30        0.0       5.23        0.0       5.23
```

◎ C.4 對ILLI-SLAB使用者之建議

資料來源：

Ioannides, A. M., “Analysis of Slab-on-Grade for a Variety of Loading and Support Conditions,” Ph.D. Thesis, University of Illinois, Urbana, Illinois, 1984, pp. 187-188.

1. At least one node at the expected max. response location
2. $2a/h \leq 0.8$, finer mesh extends 2 times the loaded area, gradually increase the mesh size
3. “Winkler” model use option IST=6 is better than IST=7
4. Keep $2a/2b \cong 1$ extending to 2 times of radius of the loaded area; keep $2a/2b < 4\sim5$ elsewhere

※ILLI-SLAB for PC Version

(a) DOS conventional memory at least ≥ 550 KB (approximately)

(b) Keep at least 17 MB of hard disk space (depends on the size of the problem defined)

(c) ILSB89.EXE < INPUT.FIL > OUTPUT.FIL