EXPERIENCE WITH NONDESTRUCTIVE STRUCTURAL EVALUATION OF AIRPORT PAVEMENTS

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Nondestructive testing (NDT) has become an accepted and highly requested procedure for evaluation of airport pavements. This paper describes recent improvements and additions that have been made to the NDT procedure described in Federal Aviation Administration Advisory Circular No. 150/5370-11. The improvements described allow the application of the method to composite pavements, present a method for determination of the radius of relative stiffness from deflection basin measurements, and give procedures for computation of overlay thickness requirements. NDT evaluation results from a number of portland cement concrete airport pavements are presented, and responses from airport operators as to the usefulness of the results are discussed.

Background

Nondestructive testing (NDT) of airfield pavements offers a rapid, economical method for pavement evaluation and overlay design with minimal effect to airport operations. The Federal Aviation Administration (FAA) began sponsoring research in the NDT method at the U. S. Army Engineer Waterways Experiment Station (WES) in 1972. From this research, an evaluation procedure was developed (1) that uses the WES 16-kip vibrator as the testing device (Figure 1). The WES 16-kip vibrator is an electrohydraulic vibratory device that applies a 66.7-kN (15-kip) peak load to the pavement surface.

The test used in developing the evaluation procedure is a dynamic load sweep from 0 to 66.7 kN (0 to 15 kips) at 15-Hz frequency. The parameter derived from this test is the dynamic stiffness modulus (DSM) of the pavement system (Figure 2). The procedure will be called the DSM procedure throughout this paper.

The FAA issued the Advisory Circular No. 150/5370-11 (2) in June 1976, outlining the DSM procedure and specifying the use. Since then, research at the WES has continued in the use of the NDT for pavement evaluation and overlay design.

Weiss (3) developed a procedure utilizing the DSM and the layered elastic theory to evaluate and design overlays for airport pavement. This procedure uses the nonlinear vibratory theory to predict the modulus of the subgrade. This modulus along with assumed values for the upper layers are used as input into a layered elastic procedure to predict the allowable gross aircraft load for a given number of operations.

A study was completed in the fall of 1980 (4) to develop an evaluation procedure for light aircraft pavements (those pavements supporting aircraft with gross loads of less than 13,607 kg (30,000 lb)). This procedure utilizes the deflection basin to predict modulus values of up to four layers in a pavement system. Only the modulus of the surface course is assumed. The procedure will predict the nonlinear

Figure 1. WES 16-kip vibrator.

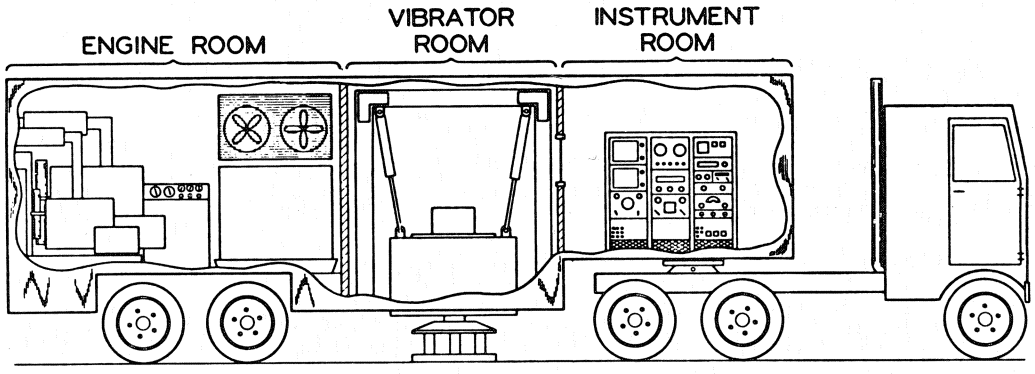
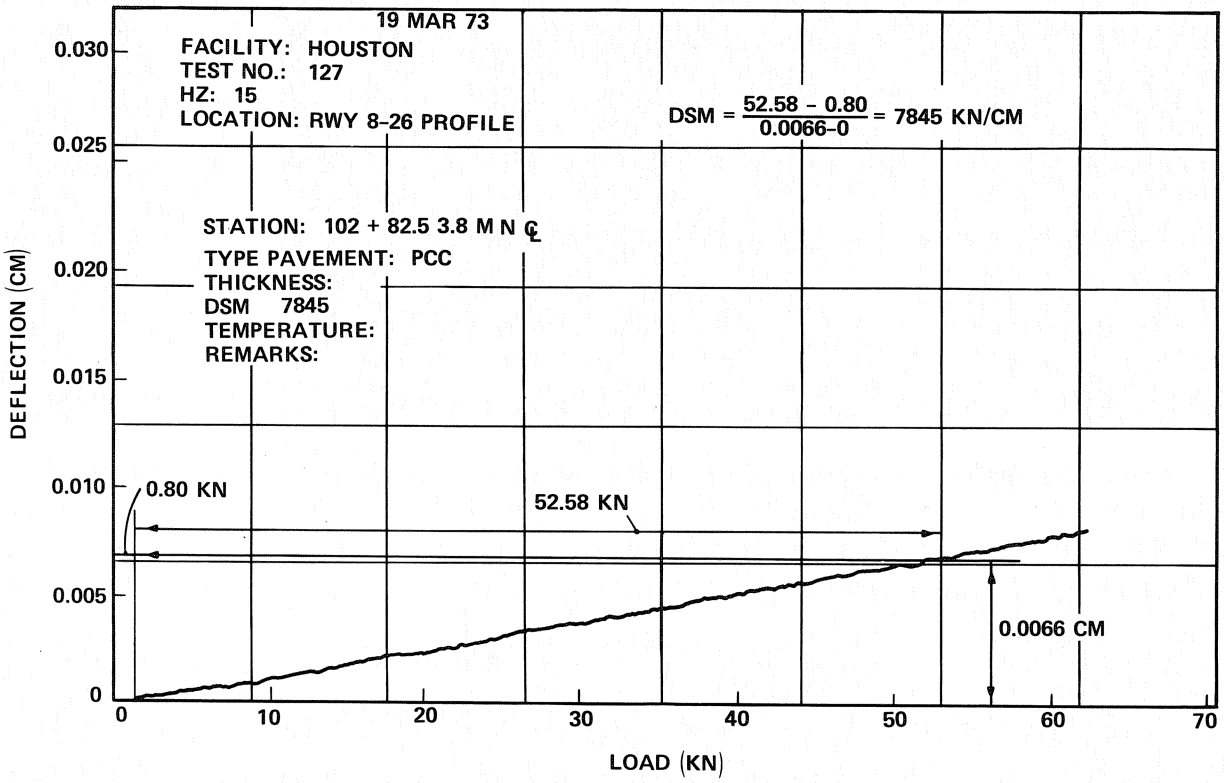


Figure 2. Typical deflection versus load data with DSM calculations for the WES 16-kip vibrator.



Note: 1 cm = 0.3937 in.; 1 kN = 0.225 kip.

stress-modulus characteristics of the subgrade. For rigid pavements, a limiting stress criteria of the portland cement concrete (PCC) is used to predict the allowable load.

Of the above procedures, only the DSM method has been widely used as an evaluation methodology since the Advisory Circular (2) was published. The purpose of this paper is to present the current state of the art in rigid airfield pavement evaluation with the WES 16-kip vibratory procedures used for evaluating the pavement structure and the load transfer across joints and designing overlays. Results of evaluations on several major airports will be presented with responses to the uses of this type of structural evaluation.

Nondestructive pavement evaluation relates the pavement structure at the time of test, i.e., the structural properties of the pavement system to the design aircraft loading characteristics and repetition level. It does not account for pavement roughness, skid characteristics, surface distress condition, or environmental factors, all of which could require pavement rehabilitation. Therefore, the NDT evaluation and the overlay design may not predict the total rehabilitation needs but only consider structural support deficiencies. But in this time when aircraft loads and repetition levels are increasing on civil airports and aircraft routes are being expanded to airports with pavements that were not designed to handle heavy modern aircraft, the NDT method offers an excellent solution for pavement evaluation.

New Developments in NDT on Rigid Airport Pavements

The FAA Advisory Circular (2) contains an evaluation procedure for rigid pavements for plain-jointed PCC pavements only. Methods have been developed to evaluate rigid pavements with asphalt overlays, to evaluate the load transfer characteristics of joints, and to design both rigid and flexible overlays for rigid pavements. This paper will not reproduce the complete evaluation procedure but will outline changes and improvements to the procedure given in the Advisory Circular. In the earlier procedure, the modulus of subgrade reaction k was determined from construction records. A procedure for measuring the radius of relative stiffness ℓ for use in a Westergaard analysis has since been developed. These new procedures will be presented in the following paragraphs.

Determination of the Radius of Relative Thickness (ℓ)

The Hertz model of an infinite plate on an elastic foundation was used by Westergaard as a basis for calculating the stresses induced in concrete slabs on soil subgrades (5). The soil subgrade is assumed to behave in an analogous manner to a heavy fluid, providing vertical reaction proportional to the vertical displacement of the slab. The constant of proportionality is known as the coefficient of subgrade reaction k , has the same dimensions as density, and is assumed to be independent of the geometry of the load area.

Determination of k has been a weakness of the NDT evaluation procedure. In order to predict the allowable loads of multiple-wheel aircraft, k is determined from limited test pit data or assumed from known material properties. This assumption may not be valid in cases of varying moisture conditions, differences in compaction effort in construction and due to traffic, and variations in subgrade properties over the length of the feature evaluated.

A method of determining ℓ was developed that uses the deflection basin from the nondestructive measurement (6). The ℓ is defined by the formula

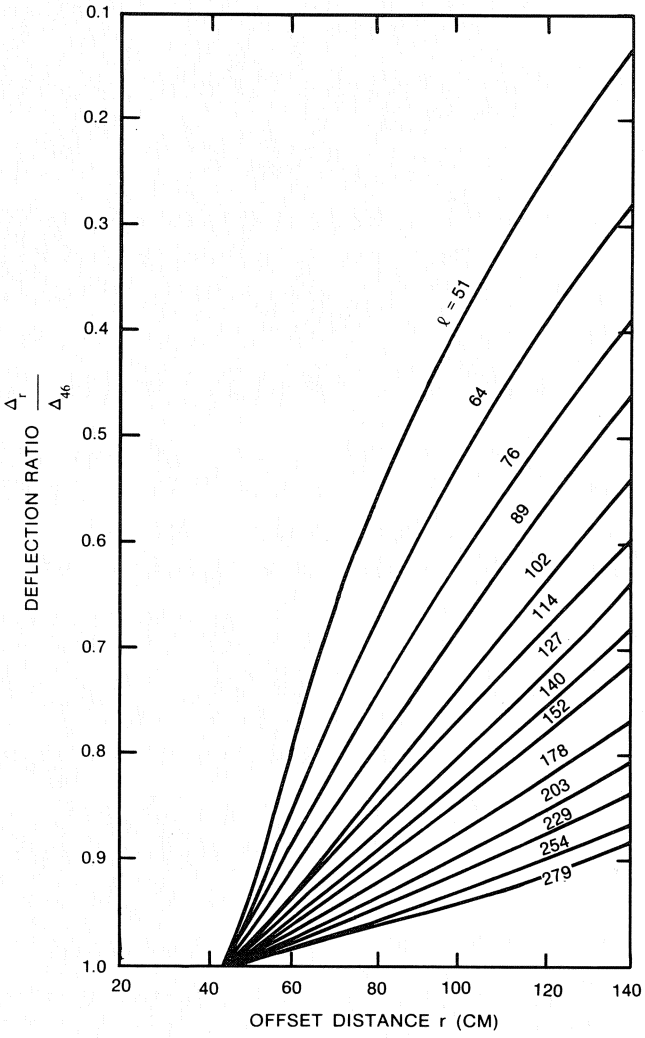
$$\ell = \left[\frac{Eh^3}{12(1-\nu^2)k}\right]^{1/4} \quad (1)$$

where ℓ = radius of relative stiffness, in centimetres; E = modulus of elasticity of concrete, in pascals; h = thickness of PCC slab, in centimetres; ν = Poisson's ratio of concrete; and k = modulus of soil reaction, in kilopascals/centimetre.

By using the deflections at distances from the applied load, ℓ can be computed theoretically (Figure 3). It was found that a better agreement to the ℓ calculated from measured values of k and H (test pit measurements) could be obtained, if offset distances of 46 cm (18 in.) and at least 132 cm (52 in.) from the center of the applied load were selected. The relationship between the computed ℓ from test pit measured data and the ℓ determined from NDT tests is presented in Figure 4.

This method offers a way of accounting for variations in pavement thickness as well as variations in subgrade support.

Figure 3. Relationships for ℓ using a deflection 46 cm (18 in.) from the applied load.



Note: 1 cm = 0.3937 in.

Evaluation of Load Transfer Across Joints

A study was conducted to evaluate drilled and grouted-in-place dowels for load transfer (7). The PCC pavements were instrumented with strain gages to measure load transfer when aircraft loads were applied to the edge of PCC slabs. An NDT evaluation was also performed on these joints using the WES 16-kip vibrator. The velocity transducers (electronically integrated to give deflection) were placed on either side of the joint at equal distances from the applied load (Figure 5). A comparison was obtained between the load transfer from strain gage measurements and the joint efficiency from NDT deflections (Figure 6). Percent load transfer is defined as the strain in the concrete on the unloaded slab divided by the sum of the strains on the loaded and unloaded sides multiplied by 100. Percent joint efficiency is defined as the vertical deflection of the surface of the concrete at "x" distance from the applied load and "y" distance from the joint on the unloaded side of the joint divided by the vertical deflection of the surface of the concrete at "x" distance from the applied load and "y" distance from the joint on the loaded side of the joint (see Figure 5) multiplied by 100.

$$\text{Joint efficiency} = \frac{D2}{D1} \times 100 \quad (2)$$

where D2 and D1 are deflections measured at equal distances "x" from the load and equal distances "y" from the joint, but D2 is across the joint from the load.

Evaluation of Rigid Pavements with Asphalt Overlays

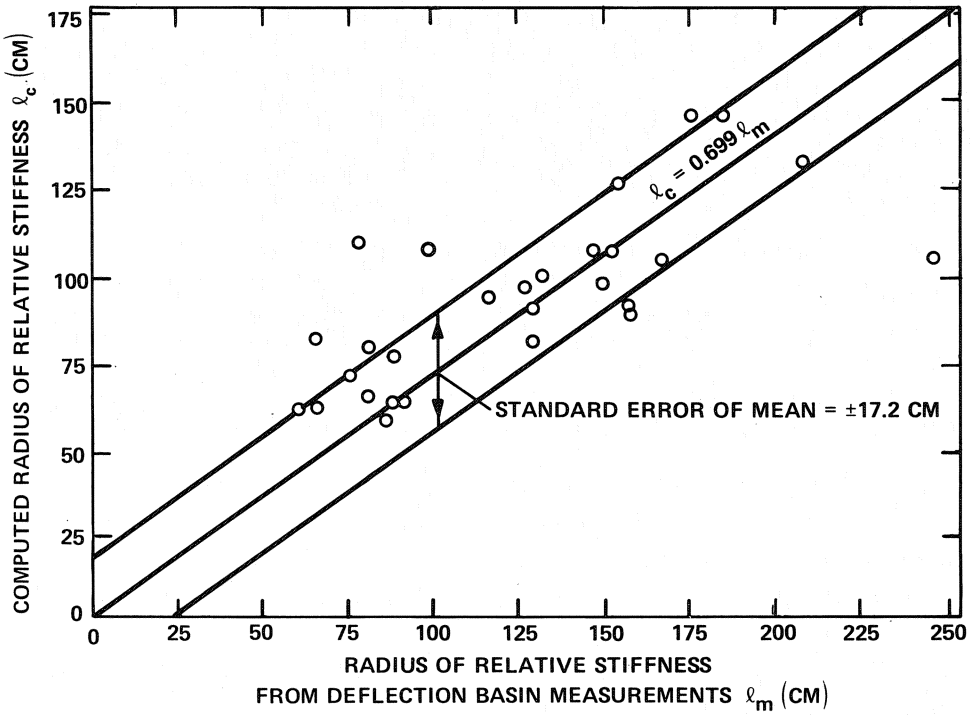
Evaluations of PCC slabs overlaid with different thicknesses of flexible pavement (asphaltic concrete (AC) or AC and base course) were conducted using the WES-16 kip vibrator (8) along with plate bearing tests performed in test sites at the NDT locations. The composite pavements were converted to an equivalent PCC slab by the formula

$$h_e = \frac{1}{F}(h + 0.4t) \quad (3)$$

where h_e = equivalent thickness of PCC; F = factor which projects the cracking that may be expected in existing PCC pavement as determined from Figure 7 (9); h = thickness of existing PCC slab; and t = thickness of AC overlay.

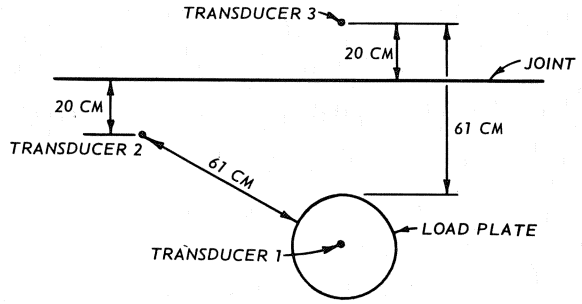
The allowable load for the equivalent slab was determined by the measured values of modulus of soil reaction k, flexural strength, and equivalent slab thickness. The allowable loads for different pavement sections were correlated to the measured DSM values, as shown in Figure 8. This correlation

Figure 4. Correlation between ℓ from deflection measurements (Δ_{132}/Δ_{46}) and ℓ computed from pavement properties.



Note: 1 cm = 0.3937 in.

Figure 5. Location of load plate and deflection transducers for joint deflection tests.



Note: 1 cm = 0.3937 in.

Figure 6. Load transfer versus joint efficiency effect of relative positions of load and side of dowel.

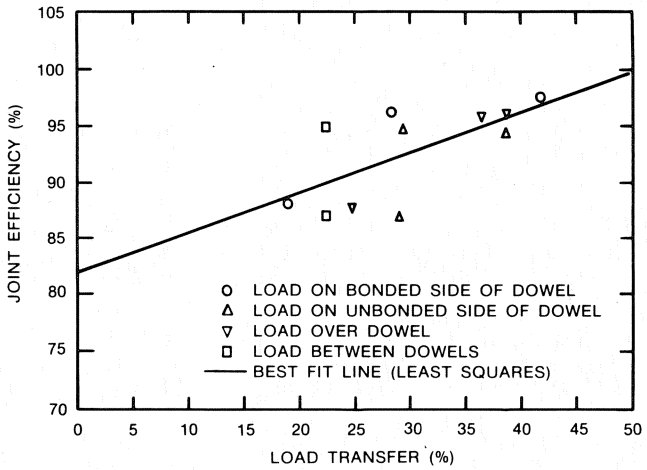
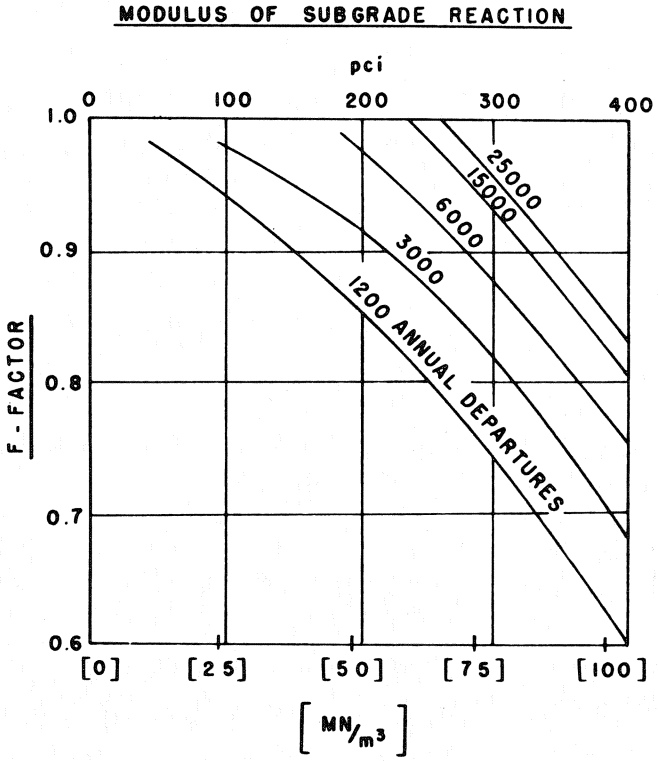
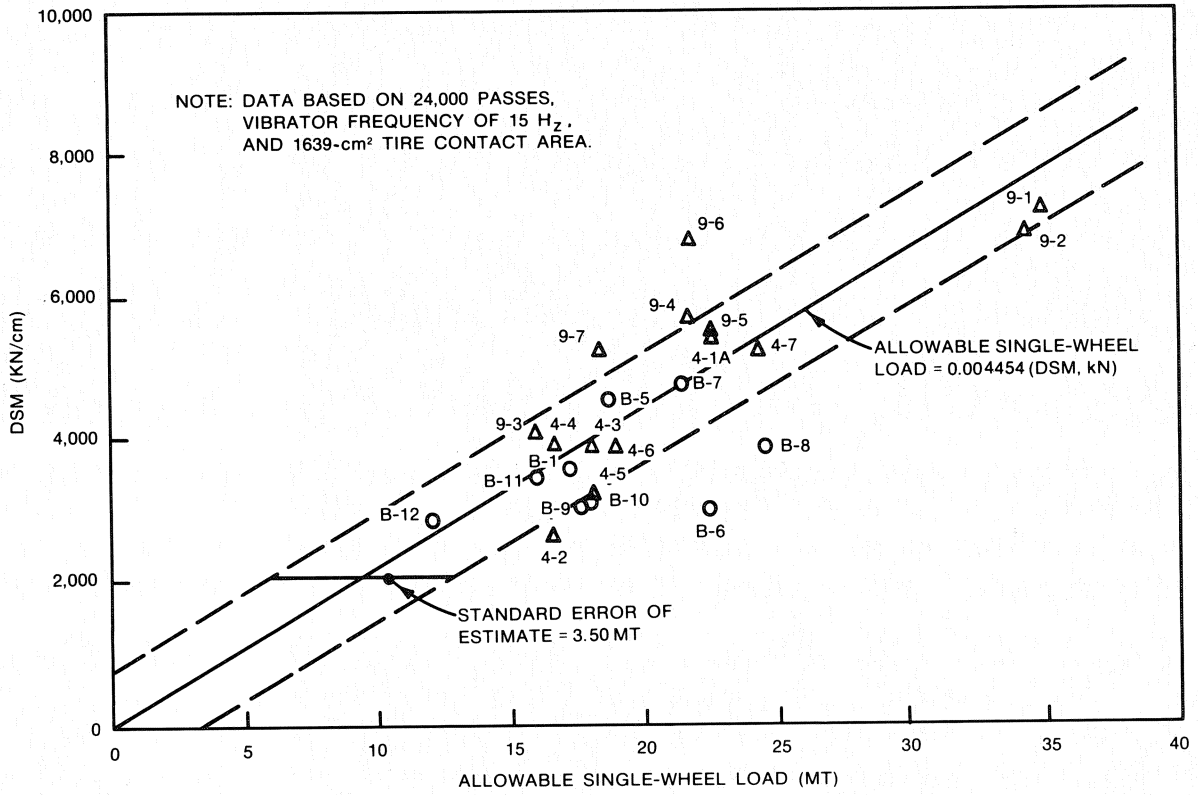


Figure 7. Graph of "F" factor versus modulus of subgrade reaction for different traffic levels.



Note: 1 MN/m^3 = 3.68 $lbf/in.^3$

Figure 8. The DSM versus allowable single-wheel load for the AC over PCC pavements.



Note: 1 kN/cm = 0.571 kip/in.; 1 cm^2 = 0.155 $in.^2$; 1 kN = 0.225 kip; and 1 MT = 2200 lb.

or the best-fit line is nearly identical to that for plain PCC pavement (where the allowable single-wheel load = 0.00484 x DSM). This obviously indicates that the equivalent slab approach to composite pavements is reasonable. The DSM tests were adjusted for temperature effects in the AC overlay through the use of Figure 9.

The procedure for evaluation of composite pavements is to convert the AC overlay and the PCC slab to an equivalent thickness of PCC and use the procedure given in the Advisory Circular (2) except that the allowable single-wheel aircraft load is given by PSWL = 0.004454 (DSM). Also, the radius of relative stiffness ℓ for composite pavement cannot be determined from deflection basin measurements. The subgrade modulus k can be estimated from the subgrade soil classification and Figure 10. Then ℓ can be computed as follows:

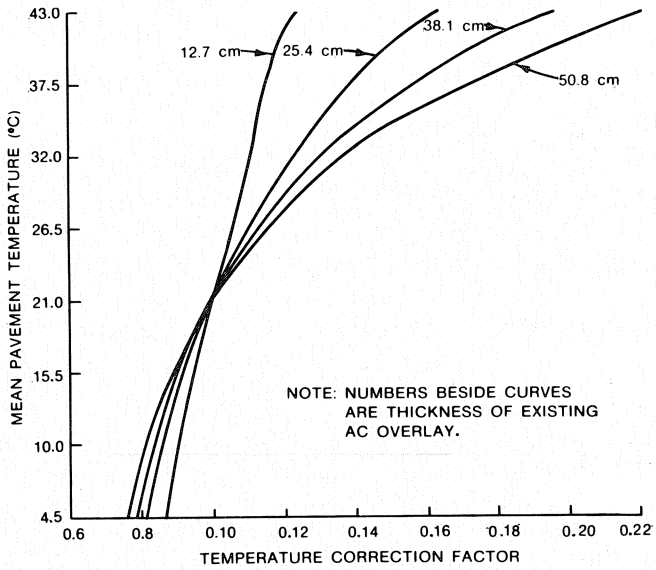
$$\ell = 39.34 \sqrt[4]{\frac{h_e^3}{k}} \qquad (4)$$

where h_e represents equivalent thickness of PCC obtained from equation 4. This equation for ℓ is for PCC with a modulus of elasticity of 27.6 x 10^6 kPa (4 x 10^6 $lbf/in.^2$) and Poisson's ratio of 0.2.

Overlay design

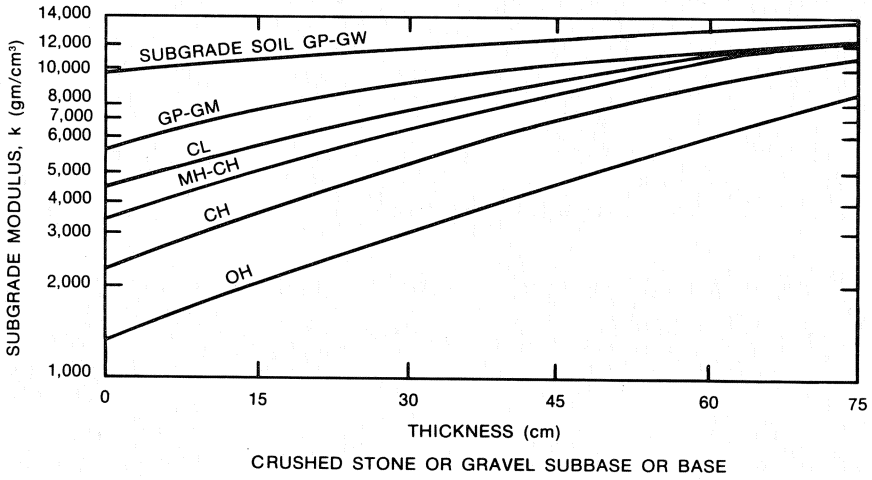
If in performing an NDT evaluation the evaluated aircraft load is less than the design maximum aircraft load, a required overlay thickness either flexible or rigid can be determined. The required thickness to support the given aircraft is computed in the following manner.

Figure 9. Temperature correction for DSM measurements on composite pavement.



Note: $1^{\circ}C = 5/9\ (F-32)$.

Figure 10. Subgrade modulus k versus subgrade soil type.



Note: 1 cm = 0.3937 in.; 1 gm/cm^3 = 0.036 lbm/in.^{3}.

Since the correlation was made between the allowable single-wheel load and the DSM, the existing flexural strength of PCC is determined by the following equation:

$$R = \sigma_e(1.3)(0.75) \quad (5)$$

in which R = flexural strength of PCC where 3450 $\leq R \leq$ 6200 kPa (899 lbf/in.^{2}); σ_e = computed edge stress of PCC slab subjected to 24,000 departures of a 1639-cm^2 (254-in.^{2}) single-wheel load; 1.3 = design factor based on repetitive loading and stresses; and 0.75 = load transfer factor (it is assumed that 25 percent of the load is transferred by the joint).

Flexural strength can also be determined by conducting splitting tensile strength tests on cores or beam tests taken from the pavement.

The design thickness can be obtained from the design curves presented in the FAA Advisory Circular No. 150/5320-6C (9) for the particular aircraft and the departure level that is projected for the pavement feature. Required overlays are calculated from the equations given below:

For asphalt overlay

$$t = 2.5(Fh_d - C_b h) \quad (6)$$

For PCC overlay without a leveling course

$$h_o = \sqrt[1.4]{(h_d)^{1.4} - (C_r h)^{1.4}} \quad (7)$$

For PCC overlay with a leveling course

$$h_{cl} = \sqrt{(h_d)^2 - (C_r h)^2} \quad (8)$$

where t = thickness of AC overlay required; F = factor determined from Figure 7; h_d = required total thickness of PCC for design aircraft and departure level; C_b = condition factor for base pavement ranging from 1.0 to 0.75 (9, pp. 106-107); h = thickness of existing rigid pavement; h_o = thickness of rigid pavement overlay required when leveling course is not used; C_r = condition factor for base pavement ranging from 1.0 to 0.75 (9, pp. 110-113); and h_{cl} = thickness of rigid pavement overlay required when leveling course is used.

Experience with NDT on Airport Pavements

The WES has performed routine evaluations at several civil airports using the WES 16-kip vibrator. For the earlier projects of this type, the WES performed both field tests and data analysis. In many of the later projects, the airport engineering staff or airport consultant has performed the data analysis. Results from the nondestructive evaluations at airports having PCC pavement where data analysis was performed by the WES are summarized in Table 1. It is rather difficult to determine the validity of the nondestructive evaluation recommendations for several reasons. Many airports for which the evaluations were made have not been able to fund the recommended overlay construction. Some airports followed the recommendations, but overlay pavements have not been in service long enough to make a performance assessment. A few airports found the nondestructive evaluation results to be contradictory to other studies and have, therefore, not followed the recommendations. The following paragraphs give some information about individual projects and how the results have been used.

Birmingham Municipal Airport (BMA)

The nondestructive evaluation of the BMA was performed during two time periods. Runway 5-23 was evaluated in July 1976, and the remaining pavements were evaluated in February 1977. The runway 5-23 was overlaid with AC pavement in general accordance with the recommendations during 1977, and the performance has been satisfactory. The other pavements have not been overlaid as yet.

Detroit City Airport (DCA)

The evaluation of the DCA resulted from anticipation that the Federal Express would begin an air service with the B-737 aircraft. The evaluation was made for that aircraft. The composite runway pavement was rated by the NDT evaluation as being structurally adequate. A portion of the apron,

Table 1. NDT evaluation results from fourteen airports.

Feature	Station (m)	Pavement Structure Layer 1 (cm)	Layer 2 (cm)	Layer 3 (cm)	Layer 4 (cm)	DSM (kN/cm)	Design Aircraft	Design Departure Level	Design Load (kN)	AGAL (kN)	Overlay Required AC (cm)
Birmingham Municipal Airport											
Birmingham, AL											
July 1976											
R/W 5-23	0+00-1+22	7.62 AC	26.2 PCC	10.9 Base	Subgrade	3,901	DC-10-10	5,100	1,837	1,401	27.2
R/W 5-23	13+17-15+00	30.5 AC	15.2 PCC	12.7 Base	Subgrade	3,567	DC-10-10	5,100	1,837	1,268	32.8
R/W 5-23	15+00-15+91	29.2 AC	24.1 PCC	10.2 Base	Subgrade	3,428	DC-10-10	5,100	1,837	1,063	46.7
R/W 5-23	15+91-17+74	30.5 AC	22.9 PCC	21.6 Base	Subgrade	4,628	DC-10-10	5,100	1,837	1,512	23.4
R/W 5-23	17+74-18+65	30.5 AC	22.9 PCC	15.2 Base	Subgrade	4,344	DC-10-10	5,100	1,837	1,384	30.5
R/W 5-23	18+65-22+04	12.7 AC	22.9 PCC	11.4 Base	Subgrade	3,284	DC-10-10	5,100	1,837	1,192	30.5
R/W 5-23	22+04-22+74	19.1 AC	21.6 PCC	11.4 Base	Subgrade	3,513	DC-10-10	5,100	1,837	1,259	29.7
R/W 5-23	22+74-25+18	20.3 AC	22.9 PCC	22.9 Base	Subgrade	3,956	DC-10-10	5,100	1,837	1,353	35.1
R/W 5-23	25+18-30+48	7.6 AC	20.3 PCC	12.7 Base	Subgrade	2,401	DC-10-10	5,100	1,837	916	47.0
Birmingham Municipal Airport											
February 1977											
R/W 18-36	0+00-14+63	8.4 AC	21.1 PCC	14.5 Slag	Subgrade	3,791	727-200	1,526	850	512	20.3
T/W A	0+00-1+21	9.7 AC	25.4 PCC	22.4 Base	Subgrade	5,612	DC-10-10	4,190	1,837	1,810	0
T/W A	18+29-19+51	25.4 AC	25.4 PCC	7.6 Base	Subgrade	6,396	DC-10-10	4,190	1,837	1,824	0
T/W E	0+00-6+10	5.1 AC	17.8 PCC	14.7 Base	Subgrade	4,070	727-200	1,526	850	569	7.6
T/W E	R/W 5-23-T/W A	27.9 AC	17.8 PCC	Subgrade	--	2,789	DC-10-10	3,143	1,837	1,668	7.6
T/W F	0+00-3+66	9.9 AC	17.3 PCC	10.2 Base	Subgrade	6,193	Fan Jet	890	133	133+	0
T/W G	0+00-2+29	5.1 AC	17.8 PCC	Subgrade	--	3,259	727-200	1,526	850	334	25.4
T/W L	0+00-1+52	11.4 AC	17.8 PCC	19.1 Base	Subgrade	4,300	RF-4	5,000	247	247+	0
Detroit City Airport											
Detroit, MI											
October 1978											
R/W 15-33	11+55-13+72	35.1 AC	10.4 P201	17.8 PCC	Subgrade	6,965	B-737	10/day	520	520+	0
Apron A		22.9 PCC	Subgrade	--	--	3,899	B-737	10/day	520	454	0
Apron A	Adjoining	27.9 PCC	Subgrade	--	--	2,462	B-737	10/day	520	276	22.9
Apron B		5.1 AC	17.8 PCC	Subgrade	--	1,051	B-737	10/day	520	338	5.1
Dress Regional Airport											
Evansville, IN											
May 1979											
R/W 4-22	25+76-27+28	16.5 AC	25.4 PCC	17.8 SM	CH	2,245	B-727-200	10,182	850	556	13.2
R/W 4-22	27+28-31+85	16.5 AC	20.3 PCC	17.8 SM	CH	1,805	B-727-200	10,182	850	445	19.8
R/W 4-22	31+85-32+92	25.4 AC	15.2 PCC	2.5 SM	CH	6,790	B-727-200	10,182	850	850	0
R/W 4-22	32+92-38+10	25.4 AC	15.2 PCC	2.5 SM	CH	3,432	B-727-200	10,182	850	850	0
R/W 4-22	38+10-50+20	25.4 AC	15.2 PCC	2.5 SM	CH	2,546	B-727-200	10,182	850	645	6.4
R/W 18-36	35+46-40+26	10.2 AC	15.2 PCC	CH	--	1,576	B-727-200	10,182	850	529	7.9
R/W 18-36	40+26-50+96	12.7 AC	15.2 PCC	CH	--	2,183	B-727-200	10,182	850	738	3.3
Fairfax Municipal Airport											
Kansas City, KS											
June 1976											
R/W 17-35	0+30-3+38	7.6 AC	20.3 PCC	Subgrade		1,488	DC-8	1,040	800	542	9.1
R/W 17-35	3+38-7+65	7.6 AC	15.2 PCC	Subgrade		1,790	DC-8	1,040	800	760	1.38
R/W 17-35	7+65-14+02	7.6 AC	15.2 PCC	Subgrade		1,266	DC-8	1,040	800	498	29.7
R/W 17-35	14+02-16+76	7.6 AC	15.2 PCC	Subgrade		1,762	DC-8	1,040	800	734	18.5
R/W 17-35	16+76-18+90	7.6 AC	15.2 PCC	Subgrade		1,338	DC-8	1,040	800	534	27.2
R/W 17-35	18+90-20+42	7.6 AC	15.2 PCC	Subgrade		974	DC-8	1,040	800	338	37.1
R/W 17-35	20+42-21+95	7.6 AC	15.2 PCC	Subgrade		2,531	DC-8	1,040	800	1,116	0.0
NS T/W	0+30-5+17	7.6 AC	20.3 PCC	Subgrade		876	DC-8	1,040	800	266	31.2
NS T/W	5+17-8+59	7.6 AC	15.2 PCC	Subgrade		1,038	DC-8	1,040	800	396	35.6
NS T/W	8+59-12+19	7.6 AC	15.2 PCC	Subgrade		1,313	DC-8	1,040	800	547	23.9
NS T/W	12+19-13+11	7.6 AC	15.2 PCC	Subgrade		2,329	DC-8	1,040	800	1,032	6.6
NS T/W	13+11-17+53	7.6 AC	15.2 PCC	Subgrade		1,473	DC-8	1,040	800	627	19.6
NS T/W	17+53-20+57	7.6 AC	15.2 PCC	Subgrade		991	DC-8	1,040	800	364	34.3
NS T/W	20+57-21+64	12.7 AC	15.2 PCC	Subgrade		2,457	DC-8	1,040	800	1,050	0.0
S Connect	0+30	7.6 AC	20.3 PCC	Subgrade		1,226	DC-8	1,040	800	440	19.3
N Connect	21+64	7.6 AC	15.2 PCC	Subgrade		1,821	DC-8	1,040	800	783	20.6
Apron		7.6 AC	15.2 PCC	Subgrade		1,234	DC-8	1,040	800	503	26.7

(Continued)

Table 1 (continued).

Feature	Station (m)	Pavement Structure Layer 1 (cm)	Layer 2 (cm)	Layer 3 (cm)	Layer 4 (cm)	DSM (kN/CM)	Design Aircraft	Design Departure Level	Design Load (kN)	AGAL (kN)	Overlay Required AC (cm)
Godman Army Airfield											
Ft. Knox, KY											
October 1979											
NS R/W	0+00-1+83	5.1 AC	15.2 PCC	Subgrade	--	2,669	C-130	500	689	454	13.2
NS R/W	15+39-15+85	8.9 AC	15.2 PCC	Subgrade	--	2,768	C-130	500	689	587	9.1
NW-SE R/W	8+84-10+36	15.2 PCC	Subgrade	--	--	1,536	C-130	500	689	463	11.9
NW-SE R/W	10+36-10+97	15.2 PCC	Subgrade	--	--	1,536	C-130	500	689	449	13.0
NW-SE R/W	10+97-13+41	15.2 PCC	Subgrade	--	--	2,189	C-130	500	689	600	3.6
T/W D	0+00-5+18	5.1 AC	15.2 PCC	Subgrade	--	1,320	C-130	500	689	414	22.6
T/W D	5+18-8+23	5.1 AC	15.2 PCC	Subgrade	--	2,024	C-130	500	689	632	9.7
T/W D	8+23-9+75	8.9 AC	15.2 PCC	Subgrade	--	2,809	C-130	500	689	689	0
T/W A		5.1 AC	15.2 PCC	Subgrade	--	1,544	C-130	500	689	485	17.0
N&S Apron	Extensions	3.8 AC	15.2 PCC	Subgrade	--	1,963	C-130	500	689	614	9.7
Original Apron		3.8 AC	12.7 PCC	Subgrade	--	947	C-130	500	689	289	35.6
Keesler Air Force Base											
Biloxi, MS											
June 1979											
Apron 1	Drain	15.2 PCC	Subgrade	--	--	1,769	C-130	1,045	689	534	13.5
Apron 2	Drain 1	30.5 PCC	Subgrade	--	--	5,784	C-130	1,045	689	689	0
Apron 2	No drain	30.5 PCC	Subgrade	--	--	6,941	C-130	1,045	689	689	0
Apron 2	Drain 2	30.5 PCC	Subgrade	--	--	4,959	C-130	1,045	689	689	0
Apron 3	Drain 2	22.9 PCC	Subgrade	--	--	2,488	C-130	1,045	689	618	2.54
Lambert-St. Louis International											
St. Louis, MO											
July 1977											
R/W 12L-30R	0+00-2+26	35.6 PCC	Subgrade	--	--	6,894	L 10-11	18,000	1,828	1,828	0
R/W 12L-30R	2+26-6+10	35.6 PCC	Subgrade	--	--	5,766	L 10-11	18,000	1,828	1,760	7.6
R/W 12L-30R	6+10-10+70	35.6 PCC	Subgrade	--	--	6,241	L 10-11	18,000	1,828	1,828	0
R/W 12L-30R	10+70-15+00	35.6 PCC	Subgrade	--	--	5,766	L 10-11	18,000	1,828	1,760	7.6
R/W 12L-30R	15+00-17+13	35.6 PCC	15.2 AC Base	Subgrade	--	7,689	L 10-11	18,000	1,828	1,828	0
R/W 12L-30R	17+13-18+90	35.6 PCC	15.2 AC Base	Subgrade	--	5,766	L 10-11	18,000	1,828	1,760	7.6
R/W 12L-30R	18+90-20+73	35.6 PCC	15.2 AC Base	Subgrade	--	6,741	L 10-11	18,000	1,828	1,828	0
R/W 12R-30L	0+00-5+79	15.2 AC	33.0 PCC	Subgrade	--	6,242	L 10-11	18,000	1,828	1,672	12.7
R/W 12R-30L	5+79-8+38	15.2 AC	30.5 PCC	Subgrade	--	7,920	L 10-11	18,000	1,828	1,828	0
R/W 12R-30L	8+38-11+89	15.2 AC	30.5 PCC	Subgrade	--	6,242	L 10-11	18,000	1,828	1,672	11.4
R/W 12R-30L	11+89-15+24	15.2 AC	33.0 PCC	Subgrade	--	5,164	L 10-11	18,000	1,828	1,361	20.3
R/W 12R-30L	15+24-19+05	15.2 AC	35.6 PCC	Subgrade	--	7,239	L 10-11	18,000	1,828	1,828	0
R/W 12R-30L	19+05-20+57	15.2 AC	35.6 PCC	Subgrade	--	8,741	L 10-11	18,000	1,828	1,828	0
R/W 12R-30L	20+57-24+20	15.2 AC	35.6 PCC	Subgrade	--	6,242	L 10-11	18,000	1,828	1,650	12.7
R/W 12R-30L	24+20-30+48	15.2 AC	35.6 PCC	Subgrade	--	7,239	L 10-11	18,000	1,828	1,828	0
Billings Logan International Airport											
Billings, MT											
October 1976											
Term. Apron	North	27.9 PCC	Subgrade	--	--	9,455	DC-10-40	2,600	1,708	1,708	0
Term. Apron	West	38.1 PCC	10.2 Cr. Stone	Subgrade	--	6,553	DC-10-40	2,600	1,708	1,708	0
Los Angeles International Airport											
Los Angeles, CA											
August 1977											
R/W L-25R	0+00-1+52	38.1 PCC	10.2 P-209	45.7 P-154	Subgrade	6,864	DC-10-10	31,850	1,824	1,356	--
R/W 7L-25R	1+52-14+94	30.5 PCC	10.2 P-209	45.7 P-154	Subgrade	4,728	DC-10-10	31,850	1,824	1,041	--
R/W 7L-25R	15+84-22+13	25.4 PCC	7.6 AC	22.9 SC	Subgrade	4,696	B-747	17,600	3,225	2,535	10.2
R/W 7L-25R	25+15-25+91	40.6 PCC	15.2 Comp Soil	30.5 SC	Subgrade	4,553	B-747	1,760	3,225	2,500	7.6
Ontario International Airport											
Ontario, CA											
August 1977											
R/W 7-25	15+24-26+82	10.2 AC	25.4 PCC	Subgrade	--	3,905	DC-10-10	14,000	1,824	1,188	7.6
R/W 7-25	33+22-45+72	17.8 AC	20.3-15.2-20.3 PCC	Subgrade	--	2,215	DC-10-10	14,000	1,824	743	20.3

(Continued)

Table 1 (continued).

Feature	Station (m)	Pavement Structure Layer 1 (cm)	Layer 2 (cm)	Layer 3 (cm)	Layer 4 (cm)	DSM (kN/cm)	Design Aircraft	Design Departure Level	Design Load (kN)	AGAL (kN)	Overlay Required AC (cm)
Robert Gray Army Airfield											
Ft. Hood, TX											
February 1979											
R/W 15-33	29+26-30+78	33.0 PCC	Subgrade	--	--	6,608	C-141	5,000 cov	1,437	1,437	0
R/W 15-33	30+78-32+31	38.1 PCC	Subgrade	--	--	7,519	C-141	5,000 cov	1,437	1,437	0
Parallel T/W	26+90-31+09	38.1 PCC	Subgrade	--	--	11,184	C-141	5,000 cov	1,437	1,437	0
North Apron	0+00-3+82	33.0 PCC	Subgrade	--	--	7,113	C-141	5,000 cov	1,437	1,437	0
North Warm-up	0+00-1+83	15.2 AC	40.1 PCC	Subgrade	--	7,219	C-141	5,000 cov	1,437	1,437	0
Sherman Army Airfield											
Ft. Leavenworth, KS											
August 1979											
R/W 15-33	0+00-0+97	11.4 AC	16.5 PCC	Subgrade	--	921	C-141	78	1,437	738	11.2
R/W 15-33	16+26-18+01	13.5 AC	15.2 PCC	27.4 Base	Subgrade	2,133	C-141	78	1,437	1,437	0
North T/W	3+87-5+09	12.7 AC	15.2 PCC	3.8 Grav	Subgrade	1,117	C-141	78	1,437	930	6.1
South T/W		10.2 AC	14.0 PCC	2.5 Grav	8.9 Lean CL	1,117	C-141	78	1,437	979	5.1
Apron T/W		10.2 AC	15.2 PCC	8.9 Lean CL	13.4 Cinders	627	C-141	78	1,437	979	5.1
Apron		5.1 AC	16.5 PCC	Subgrade	--	1,117	C-141	78	1,437	547	14.0
Spokane International Airport											
Spokane, WA											
October 1976											
R/W 3-21	-2+35- -0+69	33.0 PCC				7,267	DC-8	15,670	1,557	1,557	0
R/W 3-21	-0+69-1+86	30.5 PCC				5,866	DC-8	15,670	1,557	1,557	0
R/W 3-21	1+86-4+49	30.5 PCC				5,936	DC-8	15,670	1,557	1,557	0
R/W 3-21	4+49-7+28	30.5 PCC				6,619	DC-8	15,670	1,557	1,557	0
R/W 3-21	7+28-10+21	30.5 PCC				6,654	DC-8	15,670	1,557	1,557	0
R/W 3-21	10+21-13+12	30.5 PCC				4,272	DC-8	15,670	1,557	1,183	15.0
R/W 3-21	13+12-16+03	30.5 PCC				3,922	DC-8	15,670	1,557	1,181	18.0
R/W 3-21	16+03-18+96	30.5 PCC				3,800	DC-8	15,670	1,557	1,094	17.8
R/W 3-21	18+96-23+20	30.5 PCC				5,113	DC-8	15,670	1,557	1,490	6.4
R/W 3-21	23+20-24+99	33.0 PCC				6,916	DC-8	15,670	1,557	1,557	0
Term. Apron	Southwest of Term.	30.5 PCC				6,636	DC-8	15,670	1,557	1,557	0
T/W N	R/W 3/21-SW Pad	15.2 PCC				6,164	DC-8	15,670	1,557	1,557	0
T/W L	0+37-1+74	33.0 PCC				7,022	DC-8	1,600	1,557	1,557	0
T/W L	2+13-11+74	33.0 PCC				7,057	DC-8	1,600	1,557	1,557	0
T/W A	0+69-2+51	33.0 PCC				6,006	DC-8	1,600	1,557	1,557	0
T/W J	0+13-1+48	33.0 PCC				9,946	DC-8	1,600	1,557	1,557	0
T/W P	0+52-3+63	15.2 PCC				7,564	DC-8	1,600	1,557	1,557	0
T/W P	0+62-4+59	15.2 PCC				5,796	DC-8	1,600	1,557	1,557	0
T/W P	4+59-9+05	15.2 PCC				6,794	DC-8	1,600	1,557	1,557	0
R/W 7-25	15+22-17+48	17.8 AC	15.2 PCC			2,276	DC-8	1,600	1,557	738	20.3
R/W 7-25	17+93-24+59	7.6 AC	15.2 PCC			2,206	DC-8	1,600	1,557	738	15.2
T/W N	0+00-4+45	7.6 AC	15.2 PCC			3,257	DC-8	1,600	1,557	1,179	10.2
Gen Avia. Ramp	Entire Ramp	7.6 AC	15.2 PCC			4,132	DC-8	1,600	1,557	1,526	5.1
Standiford Field											
Louisville, KY											
December 1976											
R/W 1-19	0+00-3+05	35.6 PCC	25.4 PCC	30.5 AGG		16,249	727-200	1,100	850	850	0
R/W 1-19	3+05-5+58	35.6 PCC	22.9 PCC	30.5 AGG		14,498	727-200	9,600	850	850	0
R/W 1-19	5+58-8+41	35.6 PCC	22.9 PCC	30.5 AGG		13,185	727-200	9,600	850	850	0
R/W 1-19	8+41-11+52	35.6 PCC	27.9 Cem Base	27.9 AGG	122 Stab Subbase	10,961	727-200	9,600	850	850	0
R/W 1-19	11+52-13+72	71.1 AC	15.2 PCC	1.3 AC	15.2 PCC	16,740	727-200	9,600	850	850	0
R/W 1-19	13+72-16+70	35.6 PCC	15.2 AC	15.2 PCC/ 1.3 AC	15.2 PCC	11,434	727-200	9,600	850	850	0
R/W 1-19	16+70-20+60	35.6 PCC	15.2 AC	15.2 PCC/ 1.3 AC	15.2 PCC	17,282	727-200	9,600	850	850	0
R/W 1-19	20+60-23+77	35.6 PCC	15.2 AC	15.2 PCC/ 1.3 AC	15.2 PCC	12,747	727-200	8,500	850	850	0
R/W 11-29	0+00-3+51	10.2 AC	15.2 PCC	1.3 AC	15.2 PCC	2,171	727-200	8,500	850	178	76.2
R/W 11-29	3+51-7+99	10.2 AC	15.2 PCC	1.3 AC	15.2 PCC	2,276	727-200	12,000	850	200	73.7

(Continued)

Table 1 (concluded).

Feature	Station (m)	Pavement Structures: Layer 1 (cm)	Layer 2 (cm)	Layer 3 (cm)	Layer 4 (cm)	DSM (kN/cm)	Design Aircraft	Design Departure Level	Design Load (kN)	AGAL (kN)	Overlay Required AC (cm)
				Standiford Field (Continued)							
R/W 11-29	7+99-10+24	Varies AC	15.2 PCC	1.3 AC	15.2 PCC	-	727-200	12,000	850	--	74 to 0
R/W 11-29	10+70-11+89	Varies AC	15.2 PCC	1.3 AC	15.2 PCC	-	727-200	12,000	850	--	0 to 48
R/W 11-29	11+89-15+09	17.8 AC	17.8 PCC	10.2 AGG	--	3,695	727-200	12,000	850	289	48.3
R/W 11-29	15+09-18+44	10.2 AC	25.4 PCC	20.3 AGG	--	4,536	727-200	12,000	850	378	40.6
R/W 11-29	18+44-20+57	10.2 AC	25.4 PCC	20.3 AGG	--	4,325	727-200	12,000	850	378	40.6
R/W 11-29	20+57-22+10	10.2 AC	30.5 PCC	20.3 AGG	--	5,603	727-200	3,200	850	623	16.8
R/W 6-24	0+00-0+76	Varies AC	15.2 PCC	1.3 AC	15.2 PCC	--	727-200	24,000	850	--	76.2 to 68.5
R/W 6-24	0+76-3+96	15.2 PCC	1.3 AC	15.2 PCC	--	2,189	727-200	24,000	850	200	68.5
R/W 6-24	3+96-6+55	15.2 PCC	1.3 AC	15.2 PCC	--	2,189	727-200	24,000	850	200	68.5
R/W 6-24	6+55-9+99	Varies AC	15.2 PCC	1.3 AC	15.2 PCC	--	727-200	24,000	850	--	68.5 to 0
R/W 6-24	9+60-12+04	Varies AC	15.2 PCC	1.3 AC	15.2 PCC	--	727-200	24,000	850	--	0 to 43.2
R/W 6-24	12+04-14+17	15.2 PCC	1.3 AC	15.2 PCC	--	3,537	727-100	24,000	850	311	43.2
T/W G	0+00-1+22	Varies AC	25.4 PCC	30.5 AGG	--	--	727-200	1,100	850	--	7.6
T/W G	1+22-4+42	25.4 PCC	30.5 AGG	--	--	5,743	727-200	1,100	850	801	7.6
T/W G	4+42-7+77	25.4 PCC	30.5 AGG	--	--	5,726	727-200	1,100	850	801	7.6
T/W G	7+77-11+43	25.4 PCC	30.5 AGG	--	--	3,484	727-200	1,100	850	423	30.5
T/W G	11+89-13+11	5.1 AC	25.4 PCC	30.5 AGG	--	2,994	727-200	1,700	850	334	43.2
T/W G	13+72-18+44	10.2 AC	25.4 PCC	30.5 AGG	--	3,099	727-200	4,300	850	267	61.0
T/W G	18+44-22+86	10.2 AC	25.4 PCC	30.5 AGG	--	5,393	727-200	2,100	850	645	15.7
T/W G	23+47-24+99	10.2 AC	25.4 PCC	30.5 AGG	--	6,251	727-200	2,100	850	778	7.6
T/W A	0+00-3+51	27.9 AC	17.8 PCC	1.3 AC	15.2 PCC	4,325	727-200	24,000	850	334	55.9
T/W A	3+51-7+92	27.9 AC	17.8 PCC	1.3 AC	15.2 PCC	6,234	727-200	24,000	850	712	30.5
T/W A	7+92-13+41	27.9 AC	17.8 PCC	1.3 AC	15.2 PCC	6,426	727-200	24,000	850	712	27.9
T/W A	5+64-10+21	27.9 AC	20.3 PCC	15.2 AGG	--	5,516	727-200	24,000	850	445	35.6
T/W B North	0+00-3+23	10.2 AC	20.3 PCC	10.2 AGG	--	4,973	727-200	2,100	850	445	24.6
T/W B South	0+00-3+23	10.2 AC	20.3 PCC	10.2 AGG	--	4,500	727-200	710	850	512	21.3
E. Ramp T/W	0+00-2+29	17.8 PCC	--	--	--	2,416	727-200	710	850	311	38.1
E. Ramp T/W	2+29-4+57	17.8 PCC	--	--	--	1,681	727-200	710	850	200	58.4
E. Ramp T/W	4+57-8+53	7.6 AC	20.3 PCC	10.2 AGG	--	4,693	727-200	710	850	445	22.6
T/W D	0+00-1+98	10.2 AC	20.3 PCC	10.2 AGG	--	6,111	727-200	710	850	850	0
T/W C	0+00-3+51	10.2 AC	30.5 PCC	20.3 AGG	--	6,093	727-200	3,200	850	756	8.9
T/W C	3+51-6+16	10.2 AC	30.5 PCC	20.3 AGG	--	5,516	727-200	3,200	850	623	17.8
T/W C	6+52-9+14	10.2 AC	30.5 PCC	20.3 AGG	--	8,440	727-200	3,200	850	850	0
T/W E	0+00-0+76	Varies AC	20.3 PCC	10.2 AGG	--	--	727-200	710	850	--	7.6 to 38.1
T/W E	0+76-3+14	5.1 AC	20.3 PCC	10.2 AGG	--	2,714	727-200	710	850	334	38.1
T/W E	3+14-4+72	20.3 PCC	10.2 AGG	--	--	1,996	727-200	710	850	222	61.0
South Apron	-	30.5 PCC	20.3 AGG	--	--	6,093	727-200	24,000	850	667	14.5
Cargo Apron	-	17.8 AC	25.4 PCC	20.3 AGG	--	6,846	727-200	3,300	850	801	7.6
Cargo Apron	-	35.6 PCC	20.3 AGG	--	--	5,551	727-200	3,300	850	623	17.78
Term. Apron	-	33.0 PCC	25.4 AGG	--	--	6,059	727-200	620	850	850	0
Term. Apron	-	25.4 PCC	20.3 AGG	--	--	4,097	727-200	3,300	850	512	21.1
Term. Apron	West 1/3	25.4 PCC	10.2 AGG	--	--	2,994	727-200	6,700	850	311	61.0
Term. Apron	Middle 1/3	25.4 PCC	10.2 AGG	--	--	2,591	727-200	6,700	850	245	63.5
Term. Apron	East 1/3	25.4 PCC	10.2 AGG	--	--	2,259	727-200	6,700	850	200	66.0
Term. Apron	Southwest 1/2	25.4 PCC	22.9 AGG	--	--	6,199	727-200	3,400	850	823	7.6
Term. Apron	Southeast 1/2	25.4 PCC	22.9 AGG	--	--	4,290	727-200	3,400	850	436	25.4
Term. Apron	West 1/2	30.5 PCC	20.3 AGG	--	--	8,755	727-200	11,000	850	850	0
Term. Apron	East 1/2	30.5 PCC	20.3 AGG	--	--	6,934	727-200	11,000	850	778	7.6

Note: 1 m = 3.28 ft; 1 cm = 0.3937 in.; 1 kN/cm = 0.571 kip/in.; 1 kN = 0.225 kip.

however, required additional pavement thickness. The Federal Express did not begin the air service; therefore, the recommendations of the evaluation have not been implemented.

Dress Regional Airport (DRA)

The airport staff at the DRA feel that the NDT evaluation accurately predicted the structural capacity of the pavements based on their performance observations.

Fairfax Municipal Airport (FMA)

This general aviation airport was tested during the same time period (June 1976) that tests were conducted at the Kansas City International Airport (results from Kansas City not presented in this paper). The FMA pavements were of concern because one DC-8 aircraft per week was using the field. The NDT results showed that the pavement was not capable of supporting the DC-8, but the operations were continued without any upgrading of the pavement. Within approximately 3 to 6 months after the evaluation, the runway began a rapid deterioration and in a short time became nearly unusable.

Godman Army Airfield (GAA)

The evaluation of the GAA resulted from a mission requiring 500 operations of the C-130 aircraft and the need to know the effects of the mission on the airfield pavements. As a result of the NDT evaluation, a 12.7-cm (5-in.) overlay was placed on taxiway A, the first 183 m (600 ft) of the runway was closed to the C-130's, and only the apron extension pavements were used for the mission. The evaluation of the GAA was highly praised for its timeliness and cost savings.

Keesler Air Force Base (KAFB)

The primary purpose of the evaluation at KAFB was to locate possible voids beneath the PCC slabs on the parking apron. Experience has shown that the DSM tests can be used to identify voids. The data

collected at KAFB were used to determine the allowable aircraft loads and overlay requirements. As yet, the recommended overlays have not been constructed.

Lambert-St. Louis International Airport (LSIA)

A controversy arose over the results at the LSIA. As the airport consultant began to implement the recommended overlay, a question about the subgrade support called for additional study. The NDT evaluation had used the deflection basin to compute the radius of relative stiffness ℓ. This value of ℓ was used in the following formula to determine a k of approximately 810 kPa/cm (300 lbf/in.^{3}):

$$k = \frac{Eh^3}{12(1-\nu^2)\ell^4} \qquad (9)$$

where k = modulus of subgrade reaction, in kilopascals/centimetre; h = slab thickness, in centimetres; E = modulus of elasticity, in pascals; and ν = Poisson's ratio. Plate bearing tests had shown much lower k values, but the validity of the plate tests was also questioned, and a compromise k value of 540 kPa/cm (200 lbf/in.^{3}) was used. Construction of the overlay was performed using slightly greater thicknesses than originally recommended by the NDT evaluation.

Billings Logan International Airport (BLIA)

The BLIA implemented the NDT evaluation recommendations in a slightly different manner. Through the construction of new pavement facilities, traffic volumes were reduced on the structurally inadequate facilities such as the AC taxiway TB east of the terminal. The only PCC pavements were the apron pavements, and these rated structurally adequate. A 7.6-cm (3-in.) AC overlay is planned for AC taxiways A and B in accordance with the evaluation results. The BLIA staff feel that the pavement performance has so far agreed with the NDT evaluation.

Los Angeles International Airport (LAIA)

The NDT evaluation results have been used as the basis for overlay design on runway 25R at LAIA.

O'Hare International Airport (OIA)

Nondestructive testing has been performed at the OIA each year since 1975 on six runways and two major taxiways. Much of the pavement at the OIA is continuously reinforced concrete and does not fit the evaluation methodology. Two runways, 9L and 4L, are plain jointed PCC and were evaluated by the NDT procedures. Overlay thicknesses recommended by the 1975 evaluation were constructed and retested after construction in 1976. Figures 11 and 12 show the actual overlay constructed, as compared with the recommended overlay, and also compare the evaluated allowable load after construction with the design load for each of the two runways. Note that when the recommended thicknesses were constructed on runway 9L, the evaluated load became greater than the design load. The full recommended overlay was not built on runway 4L, but the evaluated load was then about equal to the design load. This indicates a degree of conservatism in the NDT evaluation procedure.

The NDT procedure has been performed at the OIA each year since 1975 in order to monitor any changes in pavement strength and to evaluate joint efficiency. Test results at the pavement joints and tests over instrumented pavement sections are being used in a research study by Dr. Ernest Barenberg, University of Illinois.

Ontario International Airport (OA)

The NDT evaluation of runway 25 at the OA resulted in further study as to overlay versus reconstruction of that runway. The NDT evaluation is being relied upon heavily in the design of that project.

Robert Gray Army Airfield (RGAA)

The PCC pavements at the RGAA are in excellent condition and were rated as structurally adequate for the C-141 aircraft.

Sherman Army Airfield (SAA)

Purpose of the NDT evaluation at the SAA was to determine load-carrying capacity of existing pavements. According to the Facilities Engineers Office at Ft. Leavenworth, the results compared favorably with results from an evaluation based on core borings. No overlay is scheduled for the near future.

Spokane International Airport (SIA)

Following the recommendations of the NDT evaluation, runway 3-21 at the SIA was overlaid with AC in 1977 and, to date, is serving well. The only distress noted is about the 15 transverse cracks, but these are considered to be shrinkage cracks caused by the -29°C (-20°F) winter temperatures.

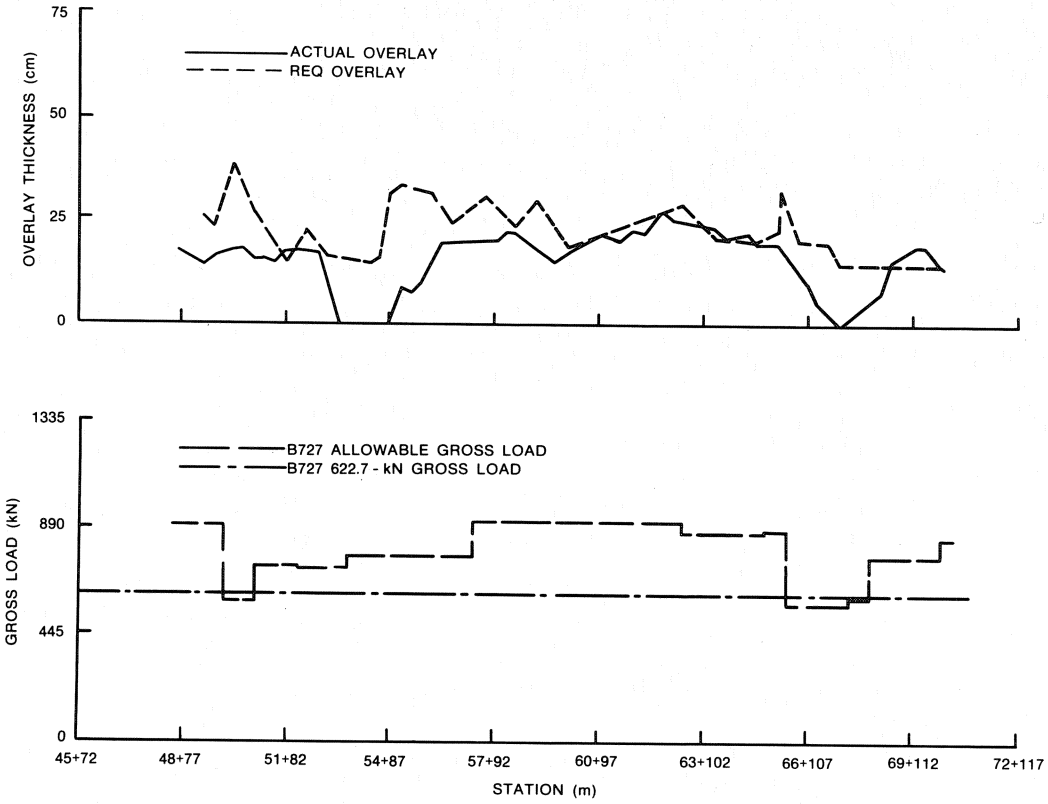
Standiford Field Airport (SFA)

Results of the NDT evaluation on some pavements at the SFA, particularly the composite pavements, were not in complete agreement with other more conventional studies. Therefore, the NDT recommendations have not been followed precisely. The airport engineers report that the results of the NDT were in "ballpark" agreement with conventional destructive testing, and the NDT results have been found very valuable in analyzing the SFA pavement conditions and previous overlay designs.

Conclusions

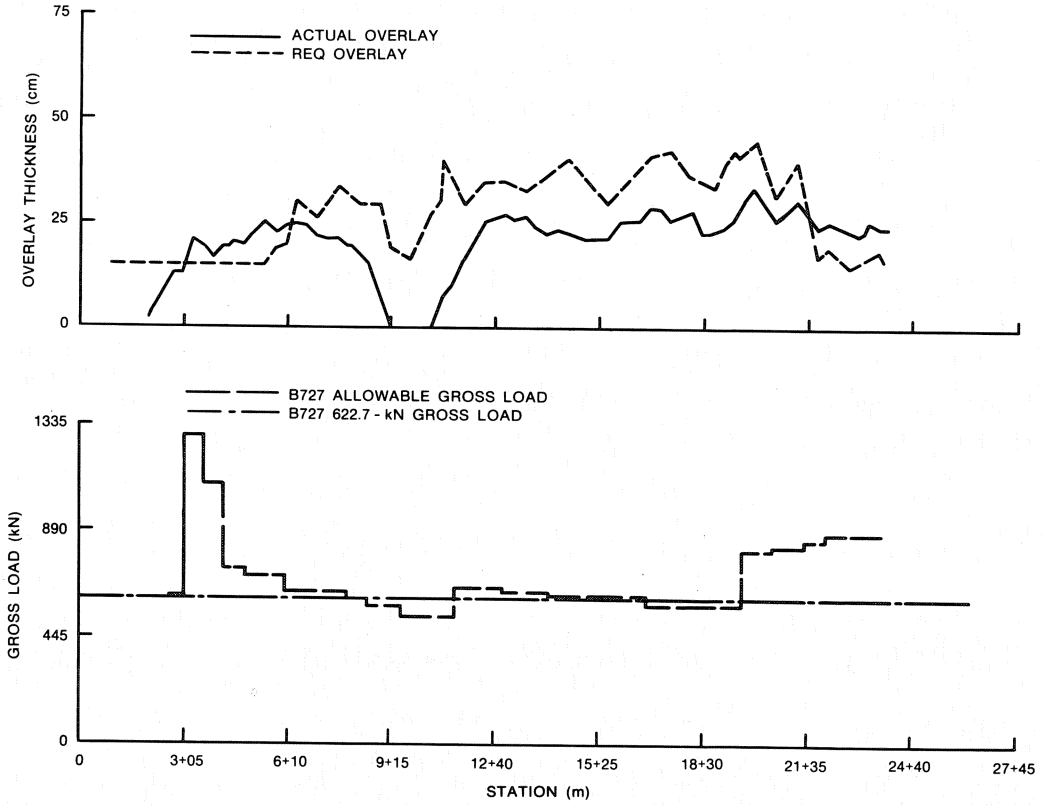
The nondestructive test and evaluation procedure has found wide acceptance for determining the structural support requirements of airport pavements. New developments described in this paper enhance the application of the procedure and extend its use beyond that outlined in the FAA Advisory Circular (2). The evaluation procedure has been used at numerous airports with mixed response as to its validity, although the general sentiment is that the DSM method gives valid, realistic results. The test method is highly praised for its rapid testing with no destruction to the pavement, its ability to operate during periods of least traffic, the quick availability of results, and the cost savings.

Figure 11. NDT evaluation of runway 9L at O'Hare International Airport.



Note: 1 cm = 0.3937 in.; 1 m = 3.28 ft; 1 kN = 0.225 kip.

Figure 12. NDT evaluation of runway 4L at O'Hare International Airport.



Note: 1 cm = 0.3937 in.; 1 m = 3.28 ft; 1 kN = 0.225 kip.

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