

AD-A145 039

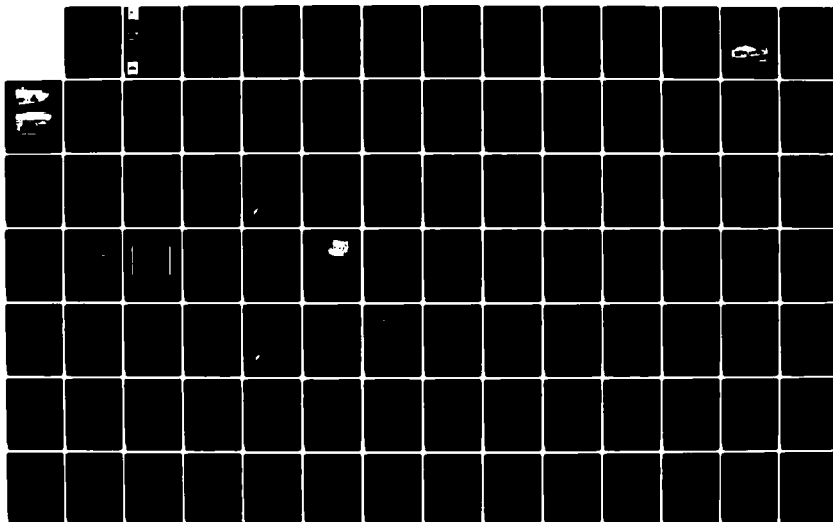
NONDESTRUCTIVE VIBRATORY TESTING AND EVALUATION
PROCEDURE FOR MILITARY RO..(U) ARMY ENGINEER WATERWAYS
EXPERIMENT STATION VICKSBURG MS GEOTE... D M COLEMAN
JUL 84 WES/MP/GL-84-9

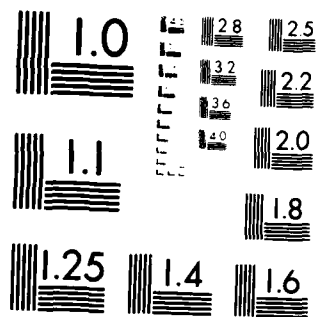
1/2

UNCLASSIFIED

F/G 13/2

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

12

MISCELLANEOUS PAPER GL-84-9

NONDESTRUCTIVE VIBRATORY TESTING AND EVALUATION PROCEDURE FOR MILITARY ROADS AND STREETS

by

David M. Coleman

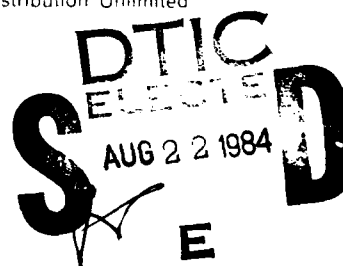
Geotechnical Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631
Vicksburg, Mississippi 39180



July 1984
Final Report

Approved For Public Release. Distribution Unlimited



Prepared for

Headquarters, US Army Facilities
Engineering Support Agency
Ft. Belvoir, Virginia 22060

84 08 20 161



US Army Corps
of Engineers

AD-A145 039

DTIC FILE COPY



Destroy this report when no longer needed. Do not
return it to the originator.

The findings in this report are not to be construed as an
official Department of the Army position unless so
designated by other authorized documents.

The contents of this report are not to be used for
advertising, publication, or promotional purposes.
Citation of trade names does not constitute an
official endorsement or approval of the use of such
commercial products.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper GL-84-9	2. GOVT ACCESSION NO. AD-A145039	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) NONDESTRUCTIVE VIBRATORY TESTING AND EVALUATION PROCEDURE FOR MILITARY ROADS AND STREETS		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) David M. Coleman		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Engineer Waterways Experiment Station Geotechnical Laboratory PO Box 631, Vicksburg, Mississippi 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Facilities Engineering Support Agency Ft. Belvoir, Virginia 22060		12. REPORT DATE July 1984
		13. NUMBER OF PAGES 131
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Highway pavements Pavement performance and evaluation Military facilities Road Rater 2008 Nondestructive testing Roads and streets pavements Overlays (pavements) Single-axle dual-wheel loads 18,000 lb		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A procedure for the nondestructive evaluation of military roads and streets is presented. Nondestructive testing is performed with the Road Rater 2008, an electrohydraulic vibrator which measures the load-deflection response of pavements. From the measured load-deflection response, the dynamic stiffness modulus (DSM) is calculated. Correlations of the DSM to the number of allowable passes of an 18,000-lb single-axle dual-wheel load, determined from conventional destructive testing and evaluation procedures, are used with existing analytical (Continued)		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. ABSTRACT (CONTINUED).

relationships to determine the number of allowable passes the pavement can support, and, if required, the overlay thickness.

This report also describes the testing equipment, testing techniques, data reduction procedures, and computational methodology used in developing the evaluation procedures. Detailed examples are presented in the Appendices to guide the users through the evaluation procedures for both flexible (AC) and rigid (PCC) highway pavements. An operator's guide describing the day-to-day maintenance and operation of the NODET is presented in Appendix C.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

PREFACE

The investigation reported herein was sponsored by the U. S. Army Facilities Engineering Support Agency (FESA), Fort Belvoir, Virginia, the U. S. Army Forces Command (FORSCOM), Fort McPherson, Georgia, and the U. S. Army Training and Doctrine Command (TRADOC), Fort Monroe, Virginia.

The study was conducted at the U. S. Army Engineer Waterways Experiment Station (WES) during the period 1 October 1979 to 30 September 1982 by the Pavement Systems Division (PSD) of the Geotechnical Laboratory (GL). Personnel of the PSD involved in this study were Messrs. D. R. Alexander, A. J. Bush III, D. M. Coleman, D. E. Elsea, P. S. McCaffrey, Jr., and T. P. Williams. The work was conducted under the supervision of Mr. R. W. Grau, Chief, Prototype Testing and Evaluation Unit (PT & EU), and Mr. J. W. Hall, Jr., Chief, Engineering Investigations, Testing, and Validation Group (EITVG) of the PSD. The work was under the general direction of Mr. A. H. Joseph, Chief, PSD (Retired); Dr. T. D. White, Chief, PSD; and Dr. W. F. Marcuson III, Chief, GL. This report was prepared by Mr. Coleman.

COL Tilford C. Creel, CE, was Commander and Director of WES during the study and preparation of this report. Mr. F. R. Brown was the Technical Director.

Accession For	
NTIS	☒
DTIC	☒
Unannounced	☐
Justification	
By _____	
Distribution _____	
Availability _____	
Dist	Avail for
A-1	10-11



CONTENTS

	<u>Page</u>
PREFACE	1
CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)	
UNITS OF MEASUREMENT	4
PART I: INTRODUCTION	5
Background	5
Purpose	5
Scope	6
PART II: NONDESTRUCTIVE TESTING EQUIPMENT	7
Description	7
Modifications to NODET	8
Accuracy Test and Calibration	8
PART III: DEVELOPMENT OF EVALUATION METHODOLOGY	11
Tests Conducted	11
Determination of Temperature and Seasonal Effects	12
Conclusions and Recommendations from Temperature Study	18
Flexible Pavement Evaluation Methodology	19
Rigid Pavement Evaluation Methodology	25
Composite Pavement Methodology	31
PART IV: NONDESTRUCTIVE EVALUATION AND OVERLAY DESIGN	
PROCEDURES	34
Preliminary Requirements	34
Data Collection	36
Data Reduction	41
Evaluation and Overlay Design Procedures	50
Presentation of Data	58
PART V: DISCUSSION	59
Limitations	59
Advantages	59
Possible Uses	59
Future Improvements and Modifications	60
PART VI: CONCLUSIONS AND RECOMMENDATIONS	61
Conclusions	61
Recommendations	61
REFERENCES	62
TABLES 1-12	
APPENDIX A: EXAMPLE EVALUATION AND OVERLAY DESIGN, FLEXIBLE	
PAVEMENTS	A1
Required Information and Test Data	A2
Evaluation of Existing Pavement, Section 1	A9

	<u>Page</u>
Evaluation of Existing Pavement, Section 2B	A11
Pavement Overlay Thickness Design, Section 2B	A11
APPENDIX B: EXAMPLE EVALUATION AND OVERLAY DESIGN, RIGID PAVEMENTS.	B1
Required Information and Test Data	B2
Evaluation of Existing Pavement, Section 2	B6
Pavement Overlay Thickness Design, Section 2	B8
APPENDIX C: INSTRUCTION MANUAL FOR THE NODET	C1
Background	C2
Purpose and Scope	C2
Digital Instrumentation System	C3
Operational Preparation	C8
Force Calibration	C10
Velocity Sensor Calibration	C11
Maintenance	C12
Step-By-Step Setup Checklist	C12
Instructions for Using the Bidirectional Distance- Measuring Instrument	C13
Installation and Troubleshooting	C17
APPENDIX D: SOIL AND PAVEMENT DATA USED IN DEVELOPMENT OF EVALUATION METHODOLOGIES	D1

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
degrees Fahrenheit	5/9	Celsius degrees*
feet	0.3048	metres
inches	25.4	millimetres
kips (force) per inch	175.1268	kilonewtons per metre
kips (mass)	4,448.222	newtons
miles (U. S. statute)	1.609347	kilometres
pounds (force)	4.448222	newtons
pounds (force) per square inch	6,894.757	pascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic inch	27,679.9	kilograms per cubic metre
square inches	6.4516	square centimetres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

NONDESTRUCTIVE VIBRATORY TESTING AND EVALUATION PROCEDURE FOR
MILITARY ROADS AND STREETS

PART I: INTRODUCTION

Background

1. Nondestructive pavement testing (NDT) has drawn the attention of pavement researchers and managers in recent years as a useful tool for evaluating the load-carrying capabilities, predicting the rehabilitation requirements, and estimating the remaining life of pavement systems. The maintenance, repair, and rehabilitation of the pavement network (roads, streets, airfields, and parking areas, etc.) at Army installations remains one of the highest expenditures of the Facilities Engineer. Indications are that these expenditures will continue to increase since the majority of the pavement systems at Army installations have exceeded their 10- to 20-year design life. The ability of the Facilities Engineer to predict maintenance, repair, or rehabilitation requirements before the pavements fail is important to the installation operations and will result in improved efficiency through proper allocation of available fundings.

2. The U. S. Army Engineer Waterways Experiment Station (WES) was requested by the Facilities Engineering Support Agency (FESA), the U. S. Army Forces Command (FORSCOM), and the U. S. Army Training and Doctrine Command (TRADOC) to develop the test techniques and analytical methodology for non-destructive evaluation and overlay design of Army roads and streets.

Purpose

3. This study was conducted to develop the test techniques and analytical methodology required to evaluate the load-carrying capacity of roads and streets and design pavement overlays using the Road Rater 2008, which is referred to as the NODET. Specific objectives were to:

- a. Evaluate NODET to determine the accuracy of the velocity sensors, the indicated vibrating frequencies, and the load applied to the pavement.
- b. Develop a field operation manual for the NODET.

- c. Verify the applicability of temperature adjustment factors developed for other testing devices for use with the NODET.
- d. Develop correlations between the NODET load-deflection relations and the allowable load-carrying capacity of the pavement; or between the NODET load-deflection relations and the elastic properties of the pavement.
- e. Develop step-by-step evaluation and overlay design procedures using these correlations for flexible, rigid, and composite pavements.
- f. Document the evaluation procedure in an interpretation manual that will guide the user in fully assessing the structural capacity of his pavements and provide the methodology for designing overlays to support the anticipated traffic.
- g. Develop a computer program to provide the user with a fast, accurate method of handling the data, correcting for temperatures, predicting allowable loads, and calculating the required overlays for the pavement system.

Scope

4. This report describes the NODET (commercial name: Road Rater 2008), modifications to the NODET made at WES, as well as the accuracy tests and calibrations performed. The development of the evaluation methodology is also explained. The nondestructive evaluation procedure is described in detail to instruct the user in evaluating highway pavements and designing overlays, where required. Examples of evaluations and overlay designs are given in Appendices A and B. An instruction manual for the NODET is included as Appendix C. Data used in the development of evaluation methodologies is included as Appendix D.

PART II: NONDESTRUCTIVE TESTING EQUIPMENT

Description

5. The NDT equipment used in this study was the Road Rater Model 2008. This device was purchased by FORSCOM then transferred to the FESA inventory, and is generally referred to as the NODET.

6. The NODET is an electrohydraulic (electronically controlled hydraulic force generator) nondestructive test device that applies a vibratory sinusoidal force to the pavement surface and measures the resulting deflection response. The force is measured with three load cells mounted on an 18-in.-diam* steel plate that contacts the pavement surface. Deflections are monitored with velocity transducers. These velocities are electronically integrated to produce deflections.

7. The NODET is housed in a tandem-axle trailer towed by a crew-cab pickup truck (Figure 1). A gasoline engine powers the hydraulic and electrical systems. The force-generating system consists of a 4000-lb reaction mass, three load cells, a hydraulic activator, and air springs for centering the reaction mass to provide for equal load distribution. The deflection



Figure 1. Model 2008 road rater nondestructive pavement test device (NODET)

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

measurement system consists of velocity transducers located in the center of the loading plate and at 18, 30, and 48 in. from the center of the plate. These transducers measure the velocity of the pavement surface movement which is then electronically integrated to read deflection in milli-inches (mils). Figure 2 shows the loading plate and velocity transducers.

8. The NODET digital instrumentation system console (Figure 3) contains all the instrumentation controls and readouts necessary for operation. It is located in the cab of the tow vehicle in a floor bracket just to the right of the driver. After the initial setup, all equipment operations and data collection can be controlled from this console. The data collected are automatically recorded by the printer located in the lower right corner of the console. These data include: identification number or test location, force, frequency, and the four measured deflections.

Modifications to NODET

9. Several modifications to the NODET were required to improve the accuracy and efficiency of operation. These included designing, constructing, and mounting a mechanism to lower and place the velocity sensors; installing an air compressor to supply air for the air bags; and mounting the control box and cables in the tow vehicle. To accurately determine the locations of the test points a bidirectional distance-measuring meter was installed in the tow vehicle. The instrumentation system console was modified to improve the method of field calibrating the force-generating system. A fan was added to the console to help cool the instrumentation. During accuracy testing of the velocity transducers, the NODET transducers did not perform within the required ranges and new transducers were installed.

Accuracy Test and Calibration

Force calibration

10. The force calibration of the NODET is very important for accurate pavement load and displacement measurements. The NODET was calibrated at WES by using three Baldwin Lima Hamilton (BLH) load cells sandwiched between two 18-in.-diam steel plates. The NODET loading plate was placed over this sandwich construction and operated at frequency ranges of 5 to 50 Hz at a 3000-lb

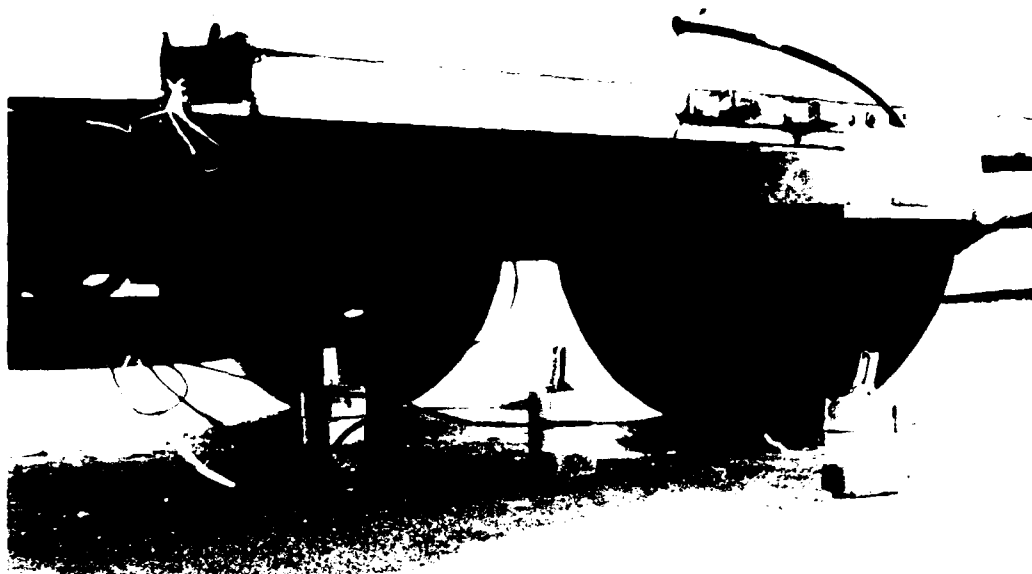


Figure 2. Load plate and velocity transducers.

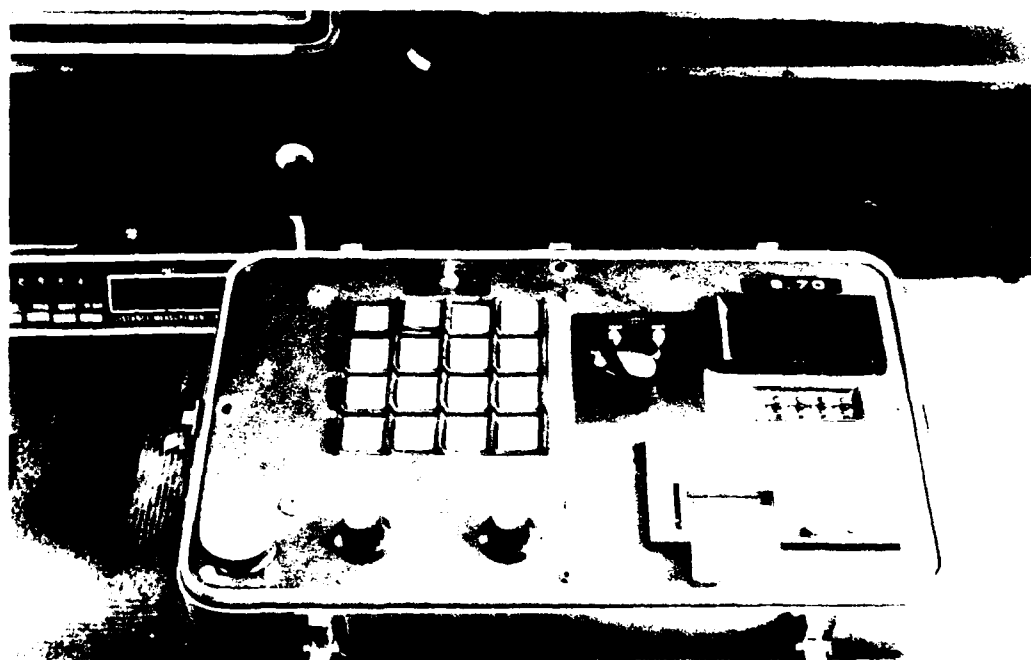


Figure 3. Control and data acquisition unit for the NODET

peak-to-peak load. The value for force calibration was established from this test and is used in the daily calibration check of the NODET, as discussed later.

Velocity transducer calibration

11. The velocity transducers are calibrated using a calibrated shake table. Each transducer is placed on the shake table and vibrated at known deflections. The NODET electronics are then adjusted to correctly read that deflection.

Field calibration checks

12. Methods were developed to check the NODET's calibration in the field. These methods are fully described in Appendix C.

13. The load cells and velocity transducers must be properly calibrated to provide accurate collection of pavement load and deflection data. Both the force calibration value and the velocity transducers should be checked at WES at regular intervals of 6 months or 600 operating hours, whichever comes first.

PART III: DEVELOPMENT OF EVALUATION METHODOLOGY

Tests Conducted

14. The development of the nondestructive evaluation methodology described in this report is based on correlating nondestructive test results with the load-carrying capability of pavements. The NODET was used to collect the nondestructive load-deflection data while conventional procedures for in situ measurement of pavement properties were used to determine the load-carrying capacity of the pavements.

15. Data for this study were collected at 58 different sites on three U. S. Army installations (Ft. Polk, Ft. Eustis, and WES) in the United States during the period March 1980 through April 1981 and at 20 different sites on 10 airfields located in the Republic of Korea during the period May through July 1982. The pavements selected for testing were generally free of major surface defects with relative strengths ranging from weak to strong. The pavements tested were not under the influence of frost or subsequent thaw. The facilities where data were collected are listed in Table 1.

Nondestructive testing

16. Before destructive testing was begun on the test pavements, a series of nondestructive tests were performed using the NODET operating at frequencies of 15, 20, and 25 Hz. Previous work with the NODET indicated that the equipment performed best and the force, velocity, and deflection output signals were nearest a sinusoidal wave at an operating frequency of 20 Hz. Only the 20-Hz data were used in development of the evaluation procedure; however, the additional data at 15- and 25-Hz data were collected to provide a comparison of the load-deflection outputs at different frequencies.

Destructive testing

17. The destructive testing consisted of the determination of conventional soil-pavement parameters through in-place and laboratory tests on samples of the various pavement elements. In-place tests consisted of California bearing ratio (CBR) or plate-bearing tests as well as density and moisture content measurements. The test methods used in obtaining data at the Ft. Eustis, Ft. Polk, and WES test sites are described in Hall and Elsea (1974). The small aperture test method for CBR determination was used at the Ft. Eustis, Ft. Polk, and WES test sites. The CBR of a pavement layer tested by the

small aperture method is based on a single measurement determined in a 6-in.-diam core hole. The moisture content was determined for each layer tested for CBR. Since the small-aperture-test method was used, in-place density determinations were not made. For rigid pavements, the modulus of soil reaction, k , of the pavement layer directly beneath the portland cement concrete (PCC) was determined by converting measured CBR values to k values as shown in Plate 4 of Hall and Elsea (1974). The data from the Korean airfields were obtained from conventional test pits. The CBR values measured on these flexible pavement sites and presented in this report are the average of three CBR tests performed on each pavement layer in these pits. In-place density and moisture content measurements were also performed at each test level. Plate-bearing tests were performed on the base course of the rigid pavements to determine the modulus of soil reaction, k . In-place density and moisture content determinations were also made on the base course in these test pits. Laboratory tensile splitting tests were performed on the PCC cores taken from each test site in accordance with ASTM C-496-71 (American Society for Testing and Materials 1980). The concrete tensile splitting strength was converted to flexural strength as described in Hall and Elsea (1974) using the empirical relationship developed by Hammitt (1971). Test procedures for the CBR, plate-bearing, density, and moisture content measurements made at the Korean test sites are given in Military Standard 621A (Department of Defense 1964).

Presentation of data

18. A summary of the physical property and nondestructive test data for each test site is presented in Tables 2, 3, and 4 for flexible, rigid, and composite pavements, respectively. Complete structural data from each test location are tabulated in Appendix D.

Determination of Temperature and Seasonal Effects

19. The stiffness, and therefore the deflection response, of pavements containing asphaltic concrete (AC) layers is directly related to the temperature of that asphalt layer. Presently most evaluation procedures using deflection measurements take into account the mean air temperature or some temperature-related factor so that pavements can be tested at varying temperatures and then adjusted to a common temperature for comparison purposes.

20. During the development of the dynamic stiffness modulus (DSM)

evaluation procedure for airfield pavements (Green and Hall 1975), it was realized that the measured stiffness of a pavement must be corrected in order to evaluate flexible pavements during varying temperatures. A temperature test section consisting of 4, 8, and 14 in. of asphalt was constructed and tested with nondestructive testing equipment at various temperatures. This research led to the development of a set of correction factor curves which were used to correct the DSM data to a common mean pavement temperature of 70° F. Later research* resulted in the modification of these curves into the DSM temperature correction factor curves presently used. These temperature correction factor curves are presented in Figure 4.

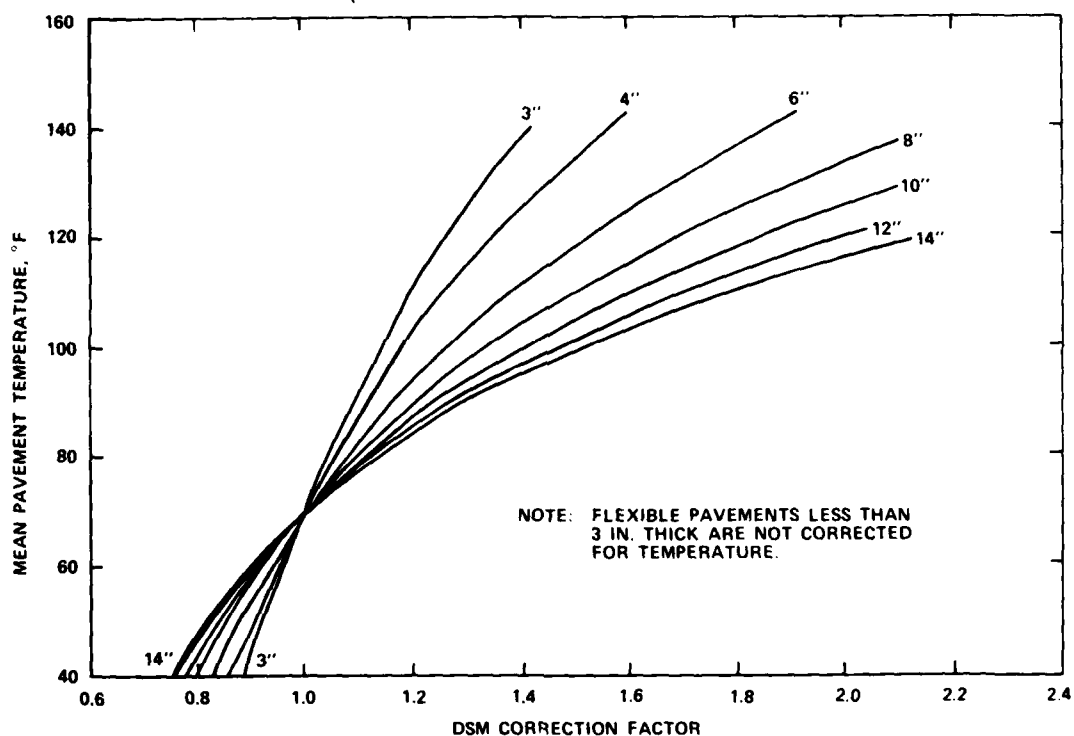


Figure 4. DSM temperature correction factor curves for flexible pavements

21. The applicability of these temperature correction factors to the NODET had not been verified. Therefore, a series of tests were conducted to determine if the DSM temperature correction factors that have been developed

* Bush, A. J. III. 1979 (Nov). "Correction Factors and Deflections Measured on Pavements Containing Asphaltic Concrete Layers," Memorandum for Record, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

for other pavement testing devices are applicable to the NODET.

Temperature effects testing

22. Five pavements with varying thicknesses of AC were selected to be tested during different seasons and at various temperatures. These pavements are designated W-1 through W-5 in Table 2 which shows the physical properties of the test pavements. The thickness of the asphalt layer in these pavements varied from 2.0 to 4.75 in.

23. Data collection was begun in August 1980 and continued through May 1981. The DSM was calculated from the NODET load-deflection data taken at 20 Hz using the equation:

$$DSM = \left(\frac{F_7 - F_5}{D_7 - D_5} \right) \times 1000 \quad (1)$$

where

DSM = dynamic stiffness modulus, kips/in.

F_7 = measured force at approximately 7.0-kip force, kips

F_5 = measured force at approximately 5.0-kip force, kips

D_7 = measured plate deflection under the 7.0-kip force, mils

D_5 = measured plate deflection under the 5.0-kip force, mils

Temperatures on the pavement surface were measured using an electronic digital thermometer. The mean pavement temperature (MPT) was calculated using the Asphalt Institute procedure as found in the Asphalt Institute Manual Series No. 17 (1969). This procedure requires that the maximum and minimum air temperatures for 5 days immediately preceding the day of test be known. Each of these daily air temperatures are averaged to obtain the mean daily air temperature. The mean daily air temperatures for the 5 days preceding the test are averaged to determine the "Previous 5-Day Mean Air Temperature." The measured pavement surface temperature at the time of the test and the previous 5-Day Mean Air Temperature are then summed to obtain the "Pavement Surface Plus 5-Day Mean Air Temperature." This "Pavement Surface Plus 5-Day Mean Temperature" is then used in Figure 5 (taken from the Asphalt Institute Manual Series No. 17, 1969) to determine the pavement temperature at the bottom and mid-depth of the AC layer. The MPT is then calculated as the average of the pavement temperatures at the surface, mid-depth, and bottom of the asphalt layer.

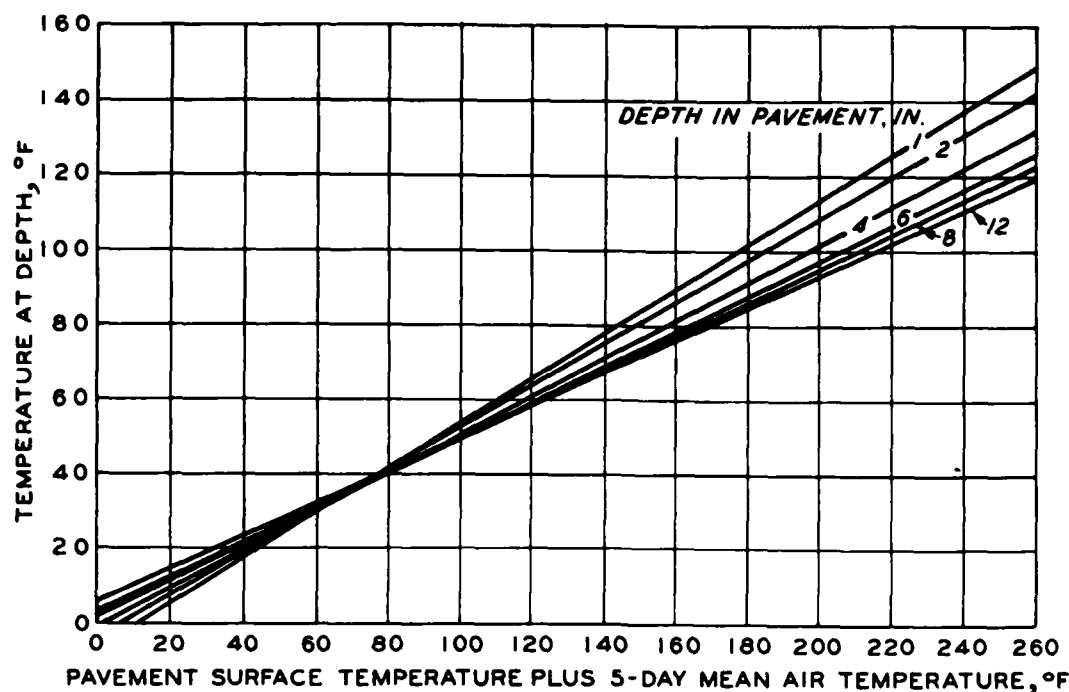


Figure 5. Prediction of pavement temperatures
for bituminous layers

Test results

24. The DSM-MPT data obtained at each test site are presented in Table 5. For each test site the measured DSM values were plotted versus MPT. When possible, a "best fit" line was drawn through these data and DSM values were determined from this line for 5-deg increments of MPT ranging from 40° F to 140° F. Using 70° F MPT as the common temperature to which all DSM data are corrected, DSM correction factors were determined from:

$$CF_T = \frac{DSM_{70}}{DSM_T} \quad (2)$$

where

CF_T = DSM correction factor for any MPT, T
 DSM_{70} = best-fit DSM from plot at 70° MPT
 DSM_T = best-fit DSM from plot at any MPT, T

25. The thickest pavement tested in this temperature study was at site W-1 which contained 4.75 in. of AC. The MPT-DSM plot for site W-1 is presented in Figure 6 and the best-fit DSM values and the calculated

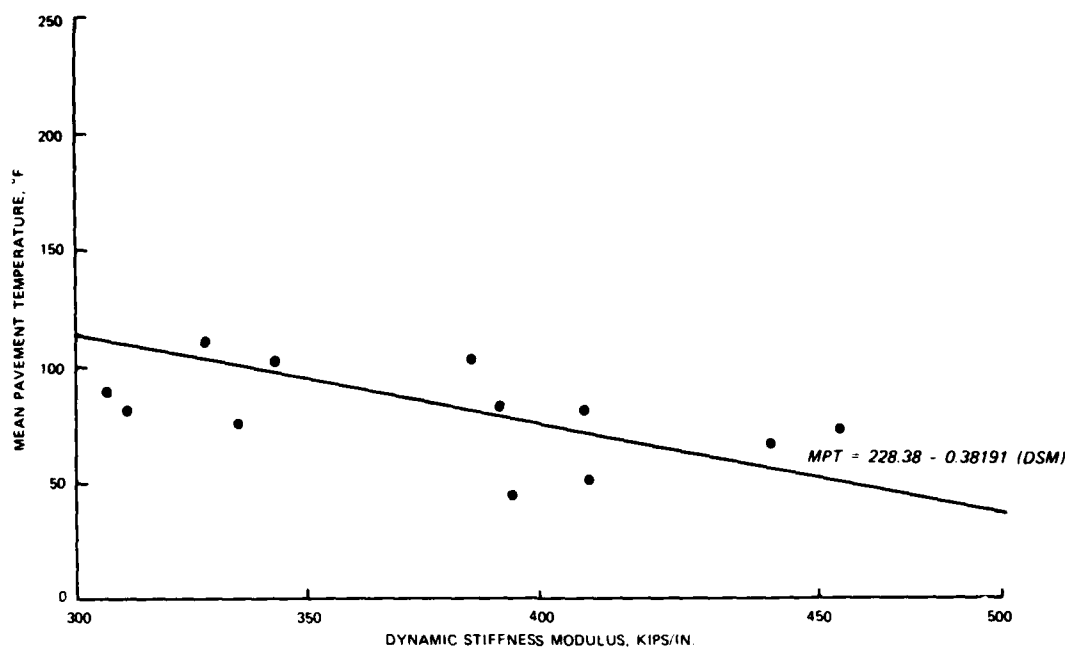


Figure 6. MPT versus DSM for site W-1

temperature correction factors are presented in Table 6. The NODET temperature correction factors from Table 6 along with the currently used WES temperature correction factors were then plotted versus MPT. As seen in Figure 7 these correction factor curves are nearly identical to about 90° F MPT where the NODET correction factor begins to become slightly larger than the WES correction factor. The maximum difference occurs at 140° F MPT where the NODET correction factor is 6 percent higher than the WES correction factor.

26. Site W-3 contained 3.0 in. of asphalt and was the second thickest pavement used in the temperature study. The MPT-DSM data for site W-3 from Table 5 are plotted in Figure 8. Using the best-fit line from Figure 8, the best-fit DSM was used to calculate the temperature correction factors. These best-fit DSM values and calculated temperature correction factors are presented in Table 6. The calculated NODET correction factors and the currently used WES correction factors are then plotted versus MPT in Figure 9. These correction factors agree very well with the NODET correction factors being almost identical to the WES correction factors presently in use.

27. Sites W-2, W-4, and W-5 contained less than 3 in. of asphalt. Plots of the MPT-DSM data for these sites from Table 5 showed considerable scatter and no real trend could be seen. Due to the large amount of variation in these

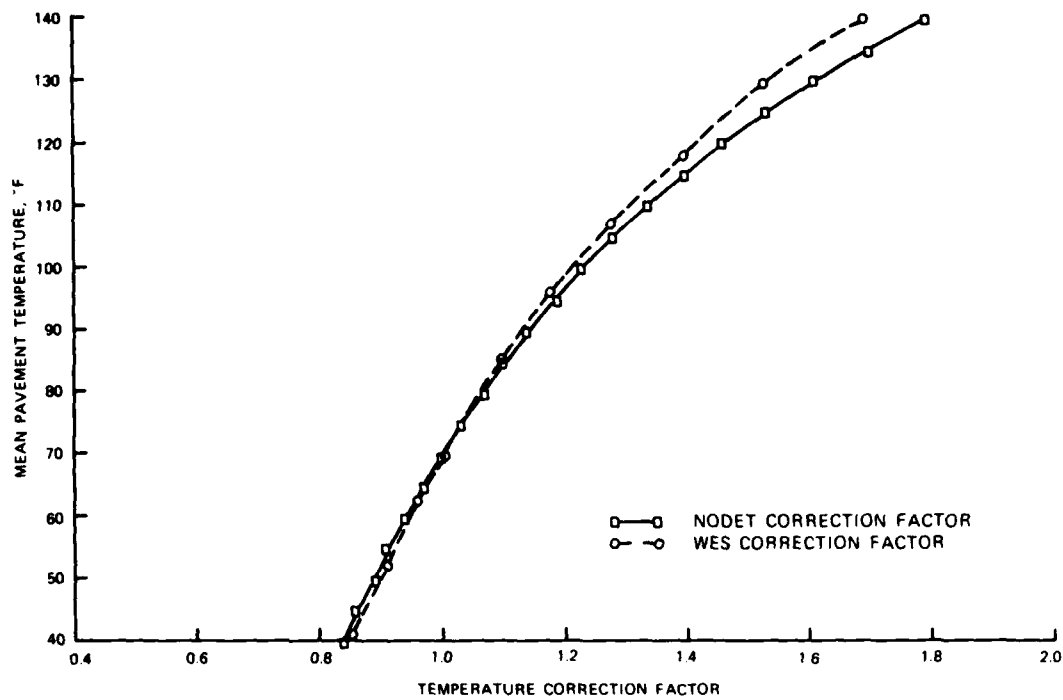


Figure 7. Comparison of NODET and WES correction factors for 4.75 in. of AC

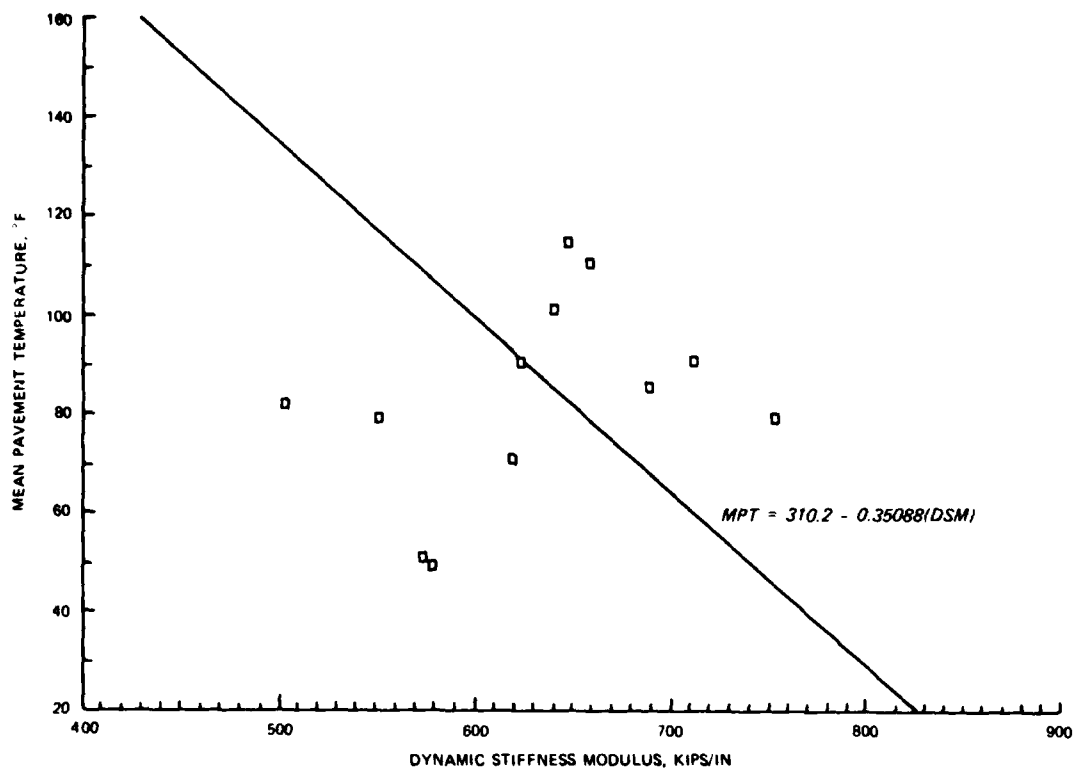


Figure 8. MPT versus DSM for site W-3

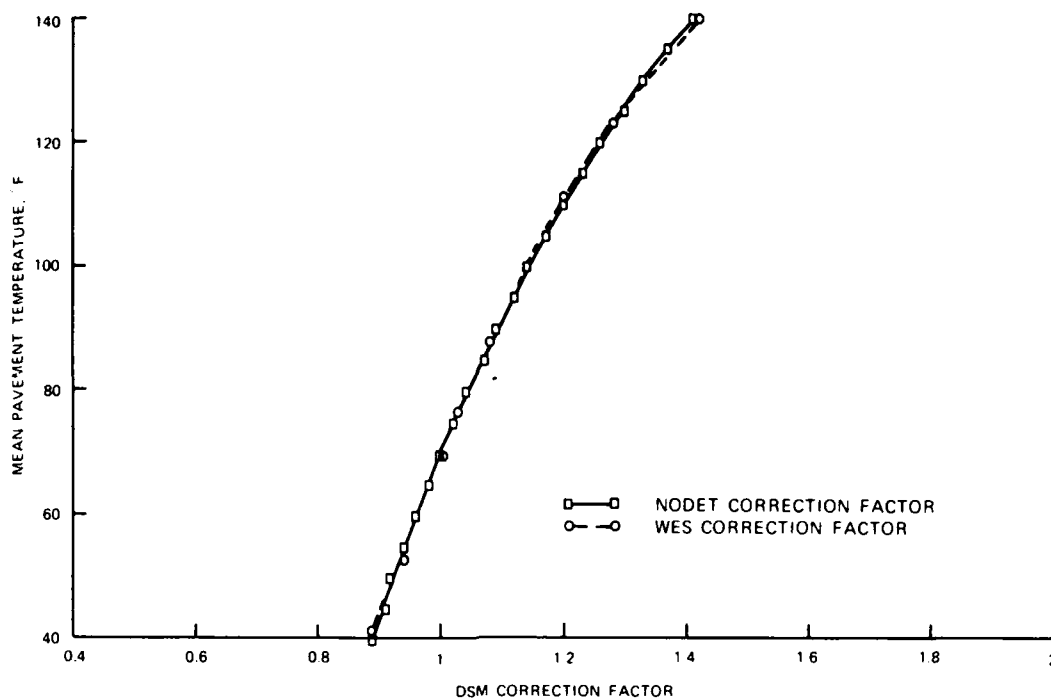


Figure 9. Comparison of NODET and WES correction factors for 3.0 in. of AC

data, no definitive relationship between MPT and DSM could be established. Previous experience with asphalt pavements less than 3 in. thick has shown that temperature changes have little significant effect on measured deflection values. This, along with other unmeasured values (such as strength changes due to moisture content, etc.), are a possible cause of the large amount of scatter in these data.

Conclusions and Recommendations from Temperature Study

28. Results of the temperature effects study indicate that the WES DSM correction factors presently in use (Figure 4) are applicable and should be used to correct DSM values obtained with the NODET to a common MPT of 70° F. Because temperature effects produce little significant change in the NODET deflection measurements when the AC thickness is less than 3 in., it is recommended that only those pavements with 3 in. or greater of AC surfacing be corrected for temperature effects.

Flexible Pavement Evaluation Methodology

29. The methodology described in the following paragraphs is used for the structural evaluation of flexible (AC) highway pavements and is based on the allowable load-carrying capability of the pavements. The major parameters affecting the structural performance of flexible pavements are pavement thickness, soil strength, number and configuration of wheels or axles, and number of load repetitions (U. S. Army Engineer Waterways Experiment Station 1951, 1961).

30. The nondestructive evaluation procedure described in Part IV uses a measurement of overall pavement rigidity in terms of the DSM. The DSM is a measurement of the rigidity of the total pavement system and not independent measurements of the major parameters listed above.

31. Development of the basic evaluation methodology for flexible highway pavements consisted of establishing a correlation between DSM and the allowable single-axle dual-wheel load. This correlation was developed by performing DSM tests on both highway and airfield pavements and correlating the results with the allowable load on a single axle determined from conventional evaluation procedures. After development of the DSM versus allowable load relationships for six different pass levels, the evaluation methodology was based on existing interrelationships between axle passes, vehicle operations, pavement thickness, soil strength, and axle load and configurations.

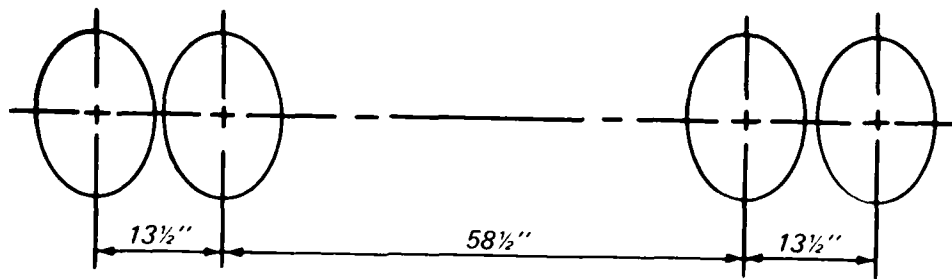
Basic load and wheel configurations

32. An 18,000-lb, single-axle, dual-wheel load (Figure 10) was selected as the basic load and wheel configuration in accordance with TM 5-822-5 (Headquarters, Department of the Army 1980).

Development of evaluation methodology

33. After collection of the data as described in paragraphs 15-17 the allowable single-axle load for a given pass level was calculated for each test site using the following procedure.

- a. Convert the pavement to an "Equivalent Thickness of Subbase," T_S , in inches, using the equivalency factors in Table 7.
- b. Using T_S from a above, determine the "Total Equivalent Pavement Thickness," T_{EQ} , in inches. The T_{EQ} is defined as a pavement section composed of: 3.5 in. of AC, 4.0 in. of 100 CBR crushed stone base, and a variable amount of subbase. The total equivalent pavement thickness is determined from:



DUAL WHEELS,
PNEUMATIC TIRES

CONTACT PRESSURE 70 PSI
CONTACT AREA 64.29 SQ IN.

Figure 10. Basic wheel configuration: 18,000-lb,
single-axle, dual wheels

$$T_{EQ} = 3.5 \text{ AC} + 4.0 \text{ base} + (T_S - 16.05) \text{ subbase}$$

$$T_{EQ} = 7.5 + (T_S - 16.05)$$

$$T_{EQ} = T_S - 8.55 \text{ in.} \quad (3)$$

Note that the 16.05 in. above is the result of converting the required 3.5 in. of AC (equivalency factor 2.3) and 4.0 in. of crushed stone (equivalency factor 2.0) to equivalent subbase. If T_S were less than 16.05 in. the equation for computing T_{EQ} would be

$$T_{EQ} = 3.5 + \frac{T_S - 8.05}{2.00} \quad (4)$$

- c. Calculate the load repetition factor, α , for the specified pass level from the equation

$$\alpha = 0.23 \log \left(\frac{\text{Passes}}{2.64} \right) + 0.15 \quad (5)$$

where Passes = the equivalent number of 18,000-lb axle loads on a single traffic lane during a 20-year period.

- d. Calculate $T_{EQ}/(\alpha\sqrt{A})$

where

T_{EQ} = total equivalent pavement thickness from Step b

α = load repetition factor from Step c

A = tire contact area = 64.29 sq in.

- e. Using $T_{EQ}/(\alpha\sqrt{A})$ calculated in Step d, determine CBR/p from the CBR curve shown in Figure 11.

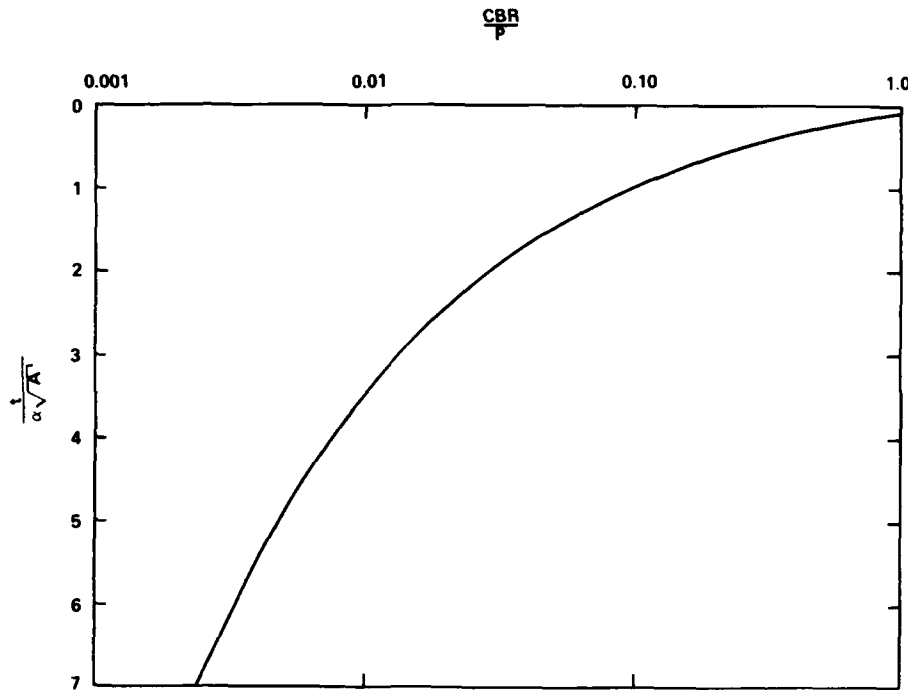


Figure 11. CBR curve

- f. Calculate the equivalent single-wheel load from the equation

$$P_{ESWL} = \frac{CBR}{\frac{CBR}{p}} \times A \quad (6)$$

where

P_{ESWL} = equivalent single-wheel load, lb

CBR = measured CBR at depth T_{EQ}

$\frac{CBR}{p}$ = value determined from CBR curve in Step e

A = tire contact area = 64.29 sq in.

The equivalent single-wheel load is defined as the load on a single wheel with the same contact area as one wheel of a multiple-wheel configuration that produces a maximum deflection equal to that beneath the multiple-wheel configuration.

- g. Convert the equivalent single-wheel load to the single axle, basic load configuration

$$P_{\text{axle}} = \frac{P_{\text{ESWL}}}{\text{percent ESWL}} \quad (7)$$

where

P_{axle} = axle load, lb

P_{ESWL} = equivalent single-wheel load, lb

percent ESWL = percent equivalent single-wheel load determined at depth T_{EQ} from Figure 12 expressed as a decimal.

34. The procedure outlined above was repeated for each flexible pavement test site for 10, 100, 1,000, 10,000, 100,000, and 1,000,000 passes of the basic axle configurations. The measured DSM values were then plotted versus the allowable axle load, as seen in the typical plot shown in Figure 13, and a statistical analysis performed to determine the best-fit curve that can be placed through the data. The DSM value corresponding to an 18,000-lb axle load was determined from this best-fit curve. The DSM corresponding to the 18,000-lb axle load for each pass level was then plotted versus passes as seen in Figure 14, and the best-fit line through the points was determined. From this plot the DSM versus allowable 18,000-lb Single-Axle Load Passes (ASALP) relationship is defined by the equation

$$\text{ASALP} = \text{antilog}[(0.0169 \text{ DSM}) - 0.2919] \quad (8)$$

35. From this relationship the number of allowable passes of an 18,000-lb single-axle dual-wheel load which a pavement will support can be determined from the DSM value for that pavement.

Summary of evaluation procedure

36. The flexible pavement evaluation procedure basically consists of determining the allowable number of standard axle load passes (ASALP) the pavement can carry (allowable passes), converting this amount to daily traffic number, then comparing that amount with the current daily traffic number. A summary of the evaluation procedure is presented in the following paragraphs, with detailed instructions for performing the data collection, evaluation, and overlay design given in Part IV.

37. The structural evaluation of a pavement section requires that

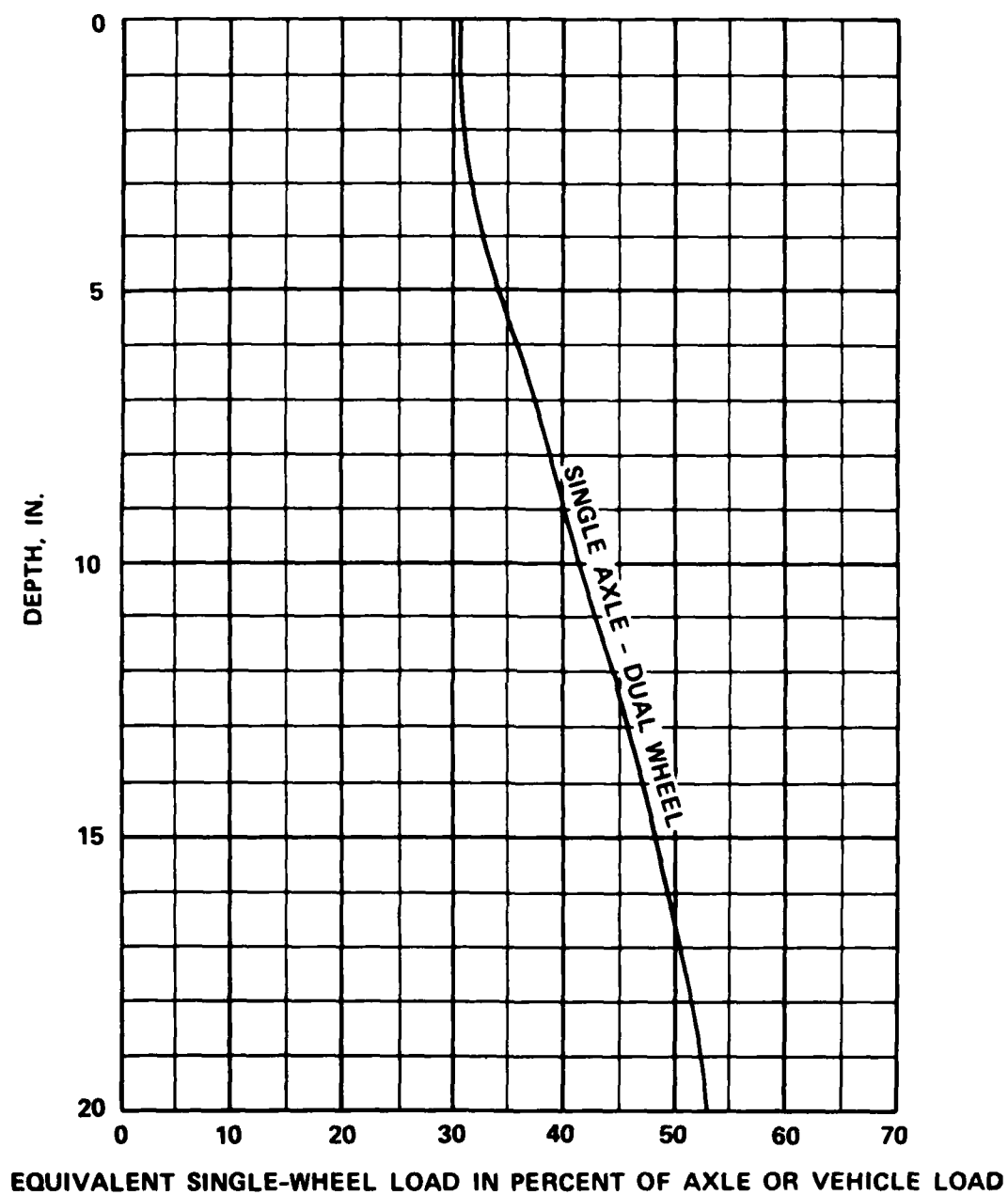


Figure 12. Percent ESWL curve for 18,000-lb single-axle, dual wheels

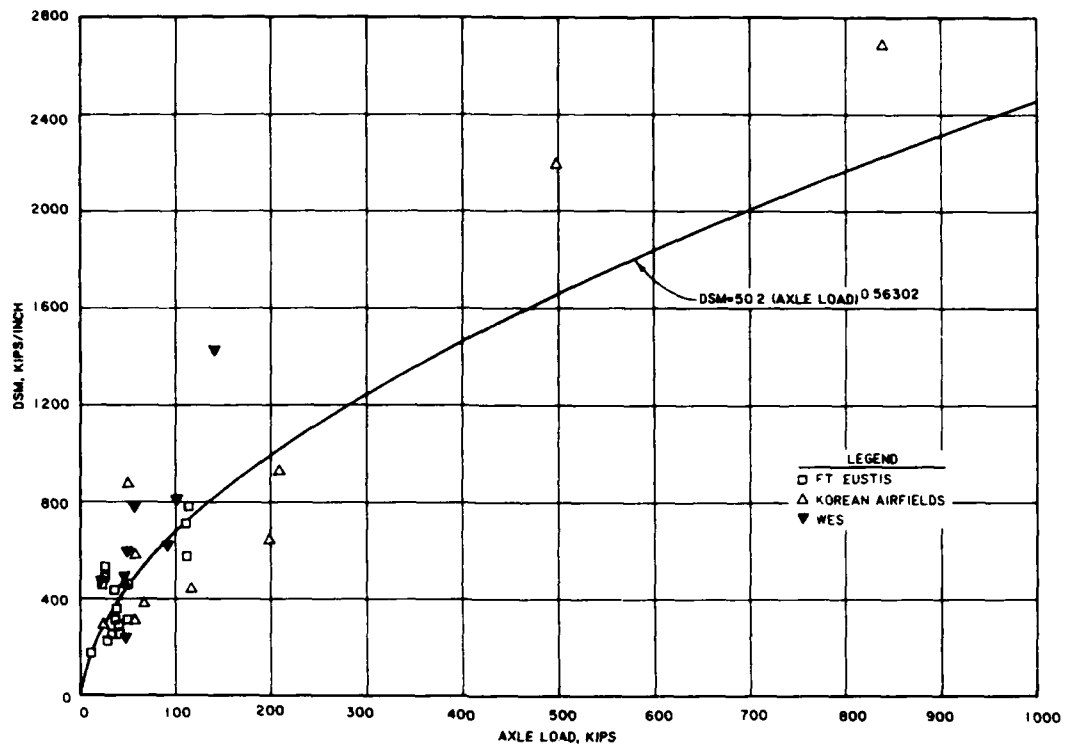


Figure 13. DSM versus axle load for 10,000 passes

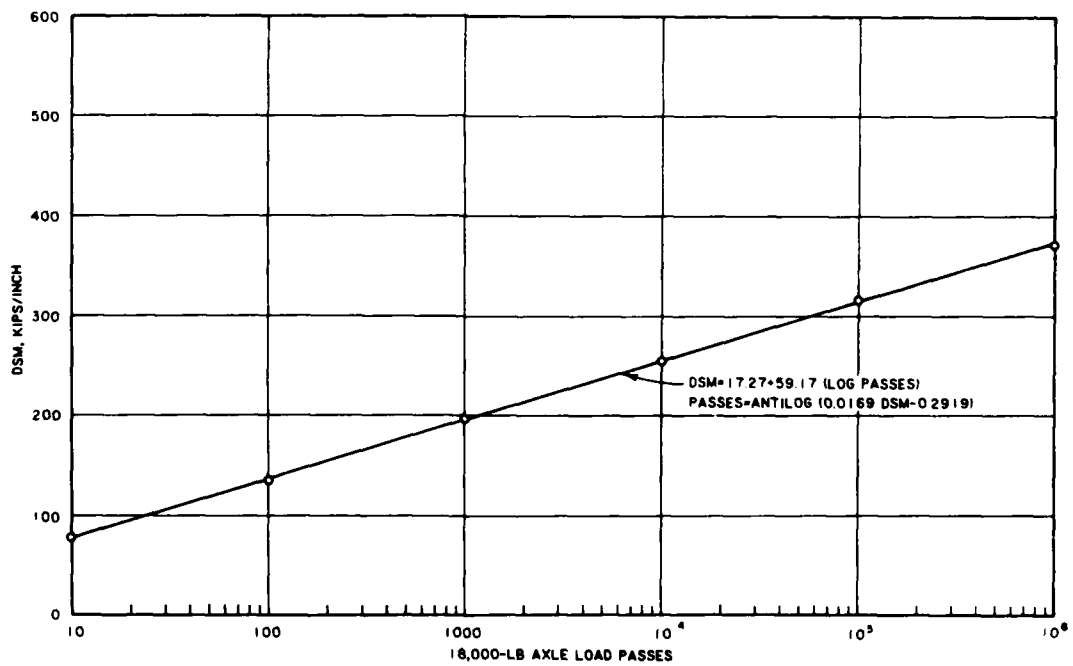


Figure 14. DSM versus 18,000-lb axle load passes

several things be known about the section before evaluation begins. This includes information on the pavement structure, current daily traffic, and estimated future traffic. Load deflection data are then collected with the NODET operating at 20-Hz frequency and 5,000- and 7,000-lb force. During this testing the pavement surface temperature should be measured at 1-hr intervals. On completion of the NDT the maximum and minimum air temperatures for 5 days preceding and each day during the testing should be obtained from the installation weather station.

38. After obtaining the NODET data, the DSM for each test is calculated and each of these DSM values is corrected for temperature effects to bring all of the tests to a common mean pavement temperature of 70° F. The corrected DSM values are then plotted to produce a DSM profile for each branch. From this DSM profile a representative DSM is determined for each section. For each section the ASALP is calculated from Equation 8. If the calculated number of allowable passes, in terms of daily traffic number (ADTN), is greater than the current daily traffic number (CDTN), the pavement is structurally adequate. The CDTN is determined from traffic data as described in paragraphs 51 and 52 and is the equivalent number of 18,000-lb single-axle load passes using a pavement each day. If the ADTN is less than the CDTN the section is structurally inadequate and some type of rehabilitation may be required. Step-by-step details of the flexible pavement evaluation and overlay design procedure are presented in Part IV.

Rigid Pavement Evaluation Methodology

39. Many parameters affect the load-carrying capacity of rigid pavements. The major parameters affecting the structural performance of rigid pavements include pavement thickness, concrete strength, strength of foundation, wheel or track configuration, and traffic volume during the design life.

40. The evaluation methodology for rigid or PCC pavements was developed in a manner similar to the flexible pavement methodology. As in the flexible pavement methodology, the DSM is used to measure the overall rigidity of the pavement system. However, in the rigid pavement procedure the radius of relative stiffness, l , a measure of the stiffness of a PCC slab relative to that of the subgrade, is also determined from the NODET data, as discussed later.

Basic load and wheel configuration

41. The basic load and wheel configuration used in the rigid pavement evaluation methodology is the 18,000-lb single-axle dual-wheel load as specified in TM 5-822-6 (Headquarters, Department of the Army 1977).

Development of evaluation methodology

42. The evaluation methodology for rigid pavements involves establishing a relationship between DSM, ℓ , and passes of a standard axle load (SAL). The first step in developing this evaluation methodology was to modify the rigid pavement design chart from TM 5-822-6 to read passes of a SAL instead of design index. This modification, shown in Figure 15, amounted to constructing the Rigid Pavement Design Chart as described in "Development of Rigid Pavement Thickness Requirements for Military Roads and Streets" (Ohio River Division Laboratories 1961), replacing the rigid pavement design index with passes.

43. The next step was to develop the relationship between DSM, ℓ , and passes. This relationship should be such that both DSM and ℓ are used to determine the number of allowable passes. Several steps were involved in this development:

- a. Calculate the modulus of subgrade reaction, k , for a range of PCC slab thicknesses, h , from the equation

$$k = 341005.97 \frac{h^3}{\ell^4} \quad [\text{units: lb/cu in.}] \quad (9)$$

These calculations are made for radius of relative stiffness, ℓ , values ranging from 20 to 60 in. Equation 9 is a rearrangement of the radius of relative stiffness equation (Equation 10) (Ohio River Division Laboratories 1961) assuming the modulus of elasticity of concrete, E , to be 4×10^6 psi and Poisson's ratio of concrete, ν , to be 0.15.

$$\ell = \left[\frac{Eh^3}{12(1 - \nu^2)k} \right]^{1/4} \quad [\text{units: in.}] \quad (10)$$

- b. From each value of k determined above, along with its corresponding thickness, h , the interior stress in the slab under a 7,000-lb load and a 64.29-sq-in. area is calculated, along with the resulting deflection, using the Westergaard equations (Westergaard 1926).

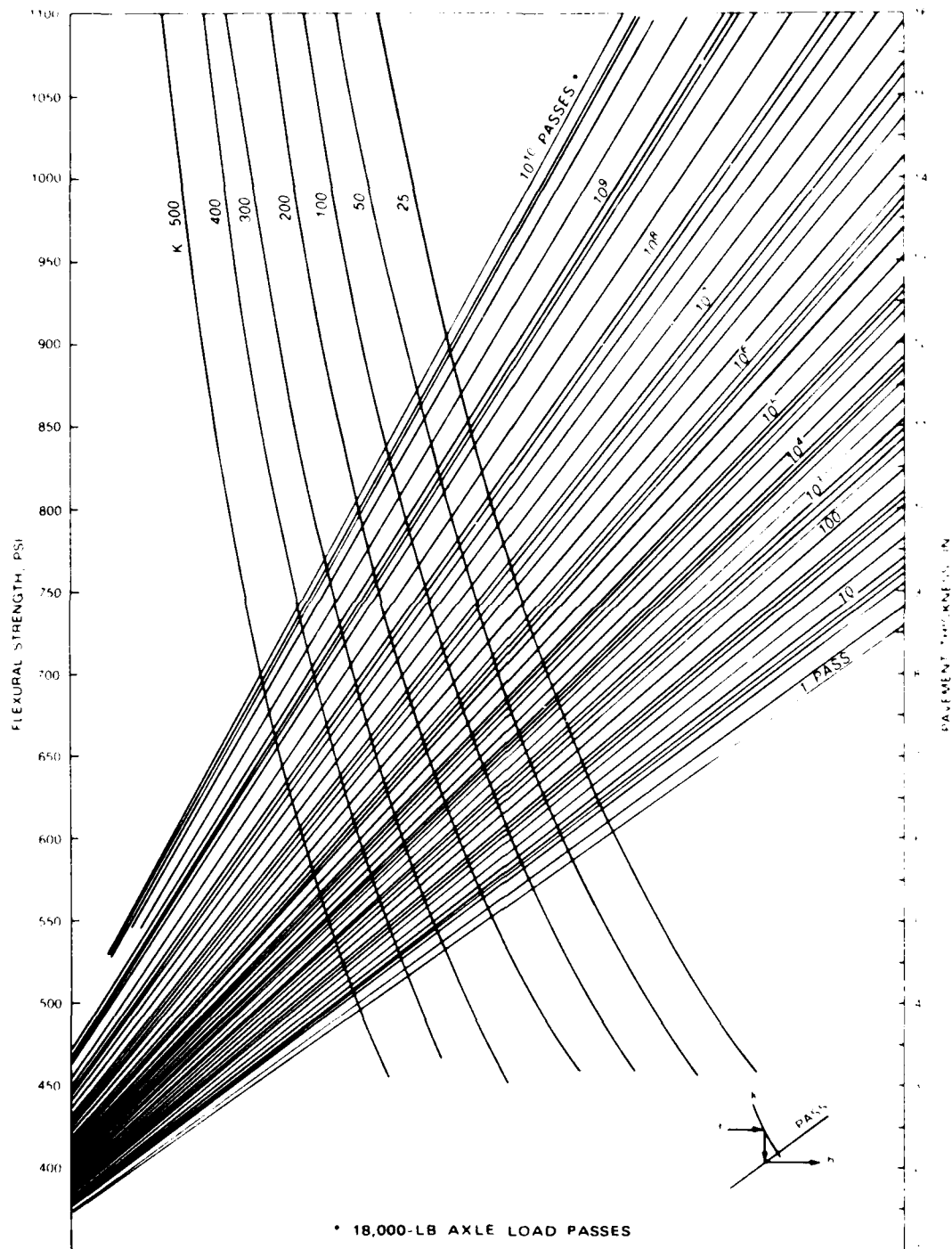


Figure 15. Rigid pavement design chart

- c. The deflections calculated in Step b above were divided into the 7,000-lb load to yield a theoretical DSM value. This computation is allowed because the load-deflection response of rigid pavements is linear.
- d. Assuming a flexural strength, R , of 700 psi and using the h and the k values from Step a the rigid pavement design chart (Figure 15) was used to determine the number of axle load passes corresponding to the assumed ℓ and theoretical DSM values.
- e. For each ℓ value the number of passes was plotted versus theoretical DSM to produce the curves shown in Figure 16. This plot provides the basic relationship between DSM and passes for use in the evaluation of rigid pavements.
- f. After development of the basic theoretical relationship a comparison of the results obtained using the basic theoretical relationship and results obtained from the destructive data was made. To perform this comparison the number of allowable passes was determined for each test site from the destructive test results (Table 3) using Figure 15. The number of allowable passes was then determined for each test site from Figure 16 using the DSM and radius of relative stiffness, ℓ , values calculated from the nondestructive test data presented in Table 3. Details of the DSM and ℓ value calculations will be discussed in Part IV. The logarithms of the allowable passes determined from the destructive test data were then plotted versus the logarithms of the allowable passes determined from the nondestructive test data as shown in Figure 17. A best-fit line through zero was calculated for these data points, and the relationship between the number of allowable passes calculated from destructive testing and the number of allowable passes determined from NDT was found to be

$$\log (\text{ASALP}_{\text{DEST}}) = 1.2 \log (\text{ASALP}_{\text{NDT}}) \quad (11)$$

Rewriting this expression eliminating the log terms, the relationship becomes

$$\text{ASALP}_{\text{DEST}} = (\text{ASALP}_{\text{NDT}})^{1.2} \quad (12)$$

where

$\text{ASALP}_{\text{DEST}}$ = allowable standard axle load passes determined from destructive testing

$\text{ASALP}_{\text{NDT}}$ = allowable standard axle load passes determined from nondestructive testing

- g. The basic theoretical relationship in Figure 16 was then modified to account for the difference in results obtained when NDT procedures are used. This modification consisted of increasing the number of axle load passes calculated in Step d by raising

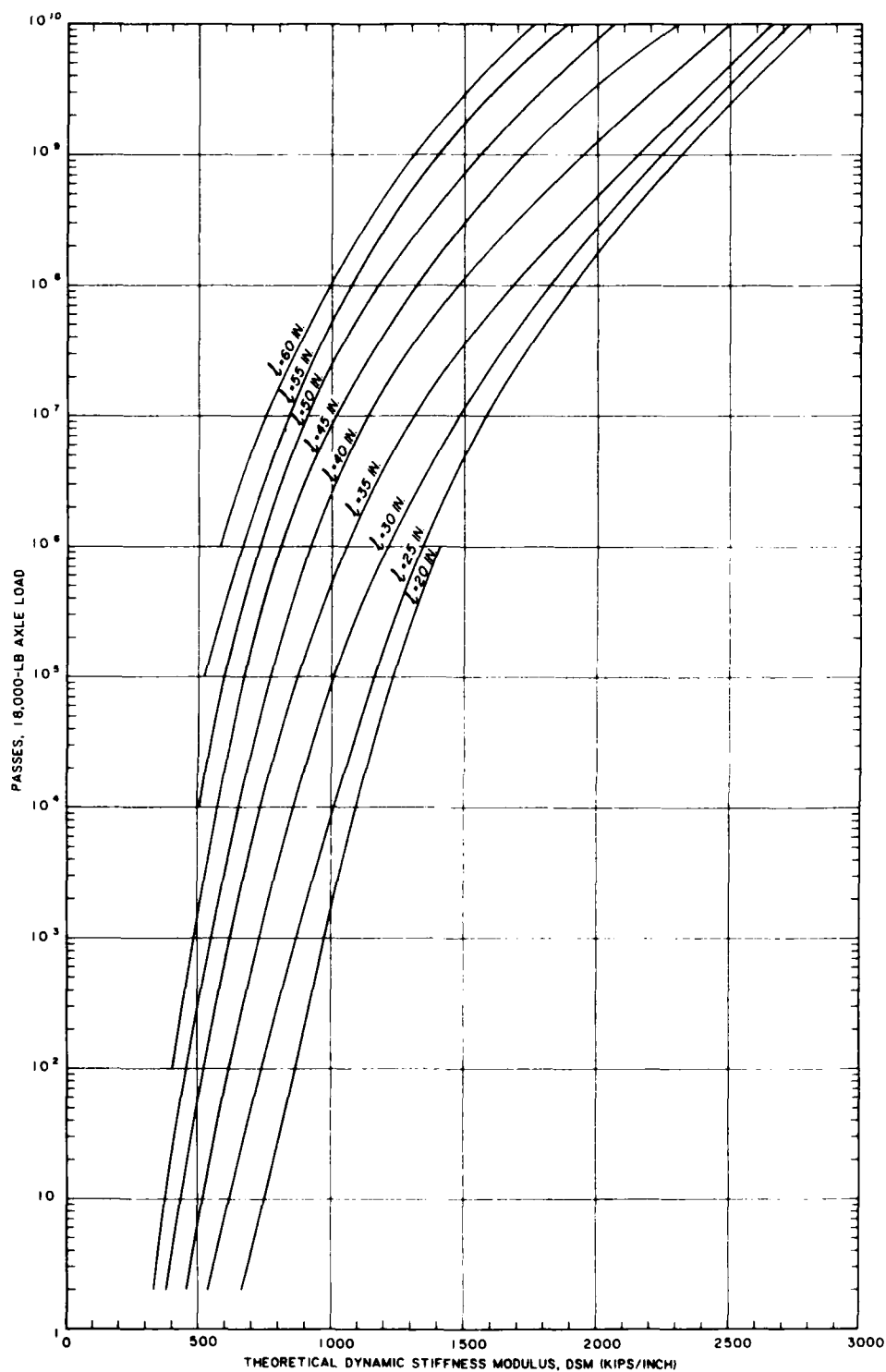


Figure 16. Passes-radius of relative stiffness-theoretical DSM relationship

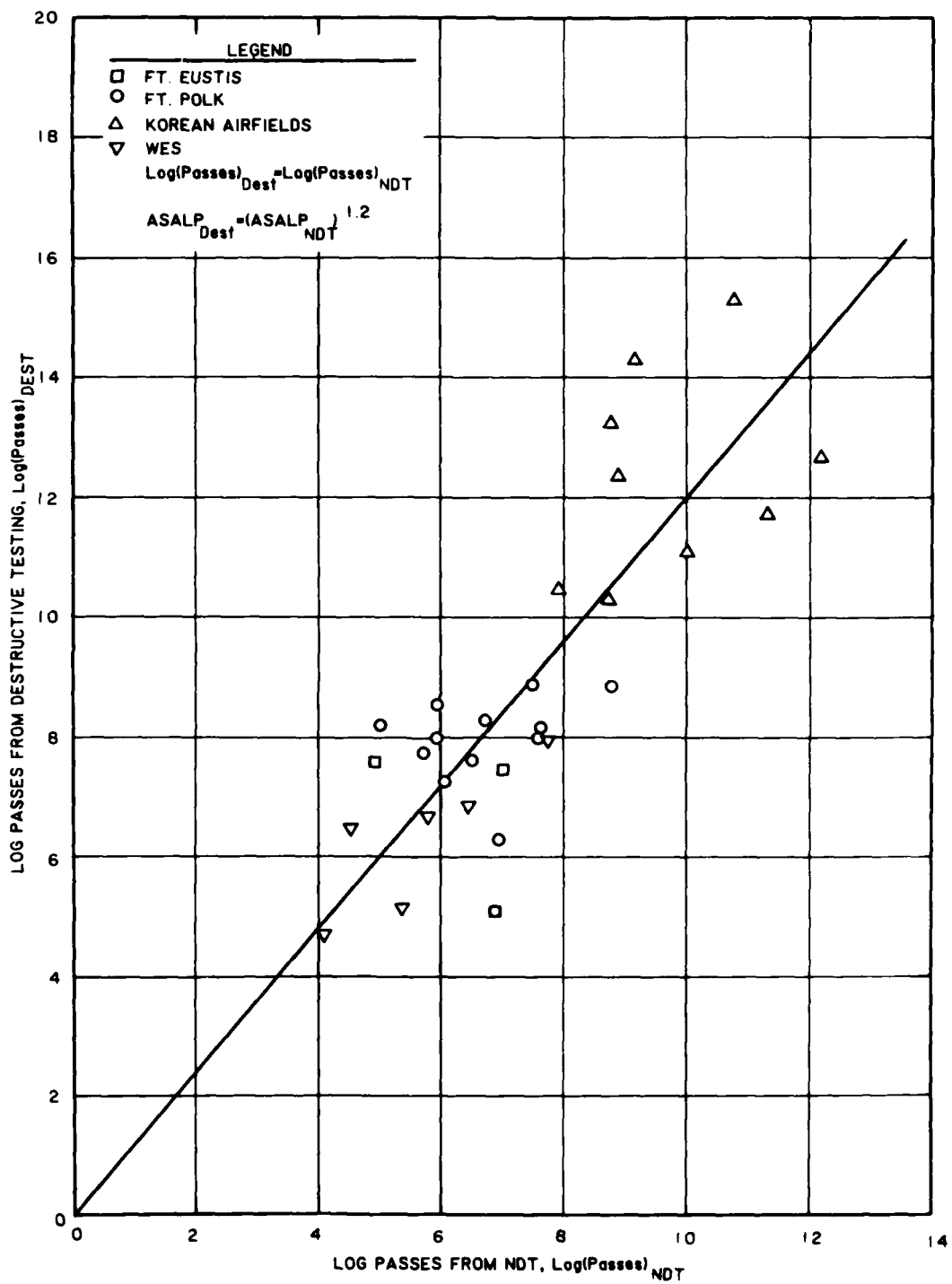


Figure 17. Relationship between destructive testing and NDT for rigid pavements

the number of passes to the 1.2 power. The increased passes were then replotted as in Step e to produce the rigid pavement NDT evaluation chart presented in Figure 18.

44. Using the NDT data obtained with the NODET and the rigid pavement NDT evaluation chart shown in Figure 18 the number of allowable passes of the standard axle can be determined.

Summary of rigid pavement evaluation procedure

45. The rigid pavement evaluation procedure basically consists of determining the number of allowable passes the pavement will carry (ASALP), converting the ASALP to the Allowable Daily Traffic Number (ADTN), then comparing the ADTN with the Current Daily Traffic Number (CDTN). The NODET load-deflection data obtained at 20-Hz frequency and the 5,000- and 7,000-lb force levels provide the information to calculate the DSM and ℓ values for each test. The DSM is calculated from the NODET load-deflection data using Equation 1. The radius of relative stiffness ℓ of a rigid pavement is obtainable through deflection basin measurements (Bush 1979). The radius of relative stiffness, ℓ , is determined from Figure 19 which gives the relationship between a ratio of deflections measured at points 18 and 48 in. from the center of the load plate at a load of 7 kips and ℓ . The calculated DSM and ℓ values are plotted in profile form and a representative DSM and ℓ for each section is determined. The number of allowable passes for each section is then determined from Figure 18, converted to daily traffic number (ADTN), and compared with the Current Daily Traffic Number (CDTN) to determine the structural adequacy of the pavement section. Step-by-step details of the rigid pavement evaluation and overlay design procedure are presented in Part IV.

Composite Pavement Methodology

46. Although data were collected on composite (AC over PCC) pavements (Table 4), no definite relationships correlating the NODET DSM data to conventional evaluation procedures for these pavements could be established. Therefore no evaluation methodology for composite pavement evaluation using the NODET is presented.

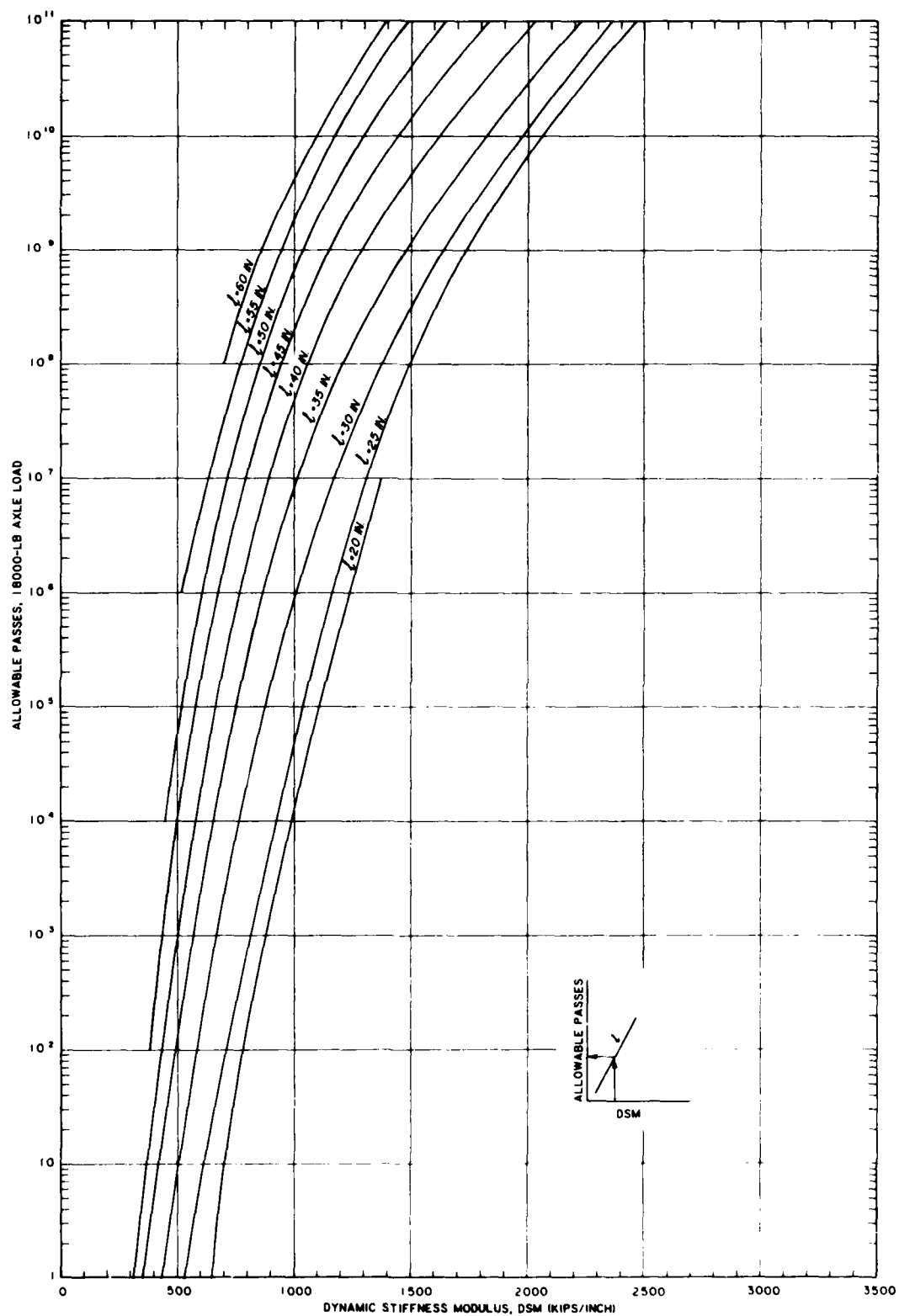


Figure 18. Rigid pavement NDT evaluation chart

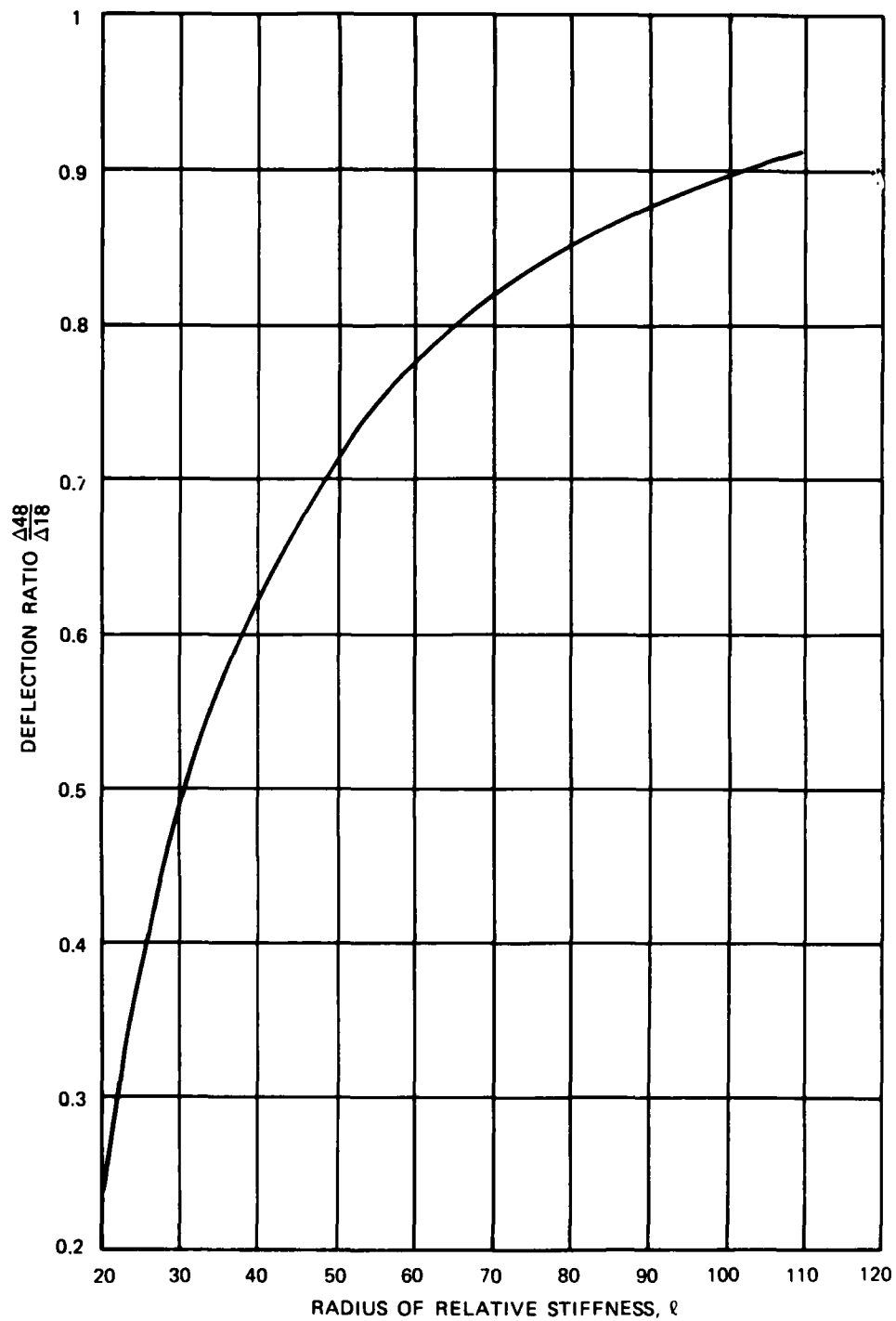


Figure 19. Deflection ration versus radius of relative stiffness

PART IV: NONDESTRUCTIVE EVALUATION AND OVERLAY DESIGN PROCEDURES

Preliminary Requirements

47. Before beginning data collection with the NODET, certain data must be obtained. These include determining the pavement structure, daily traffic number, and an estimate of the amount of traffic that will use the pavement in the future. If it has not been done previously the pavement network should be divided into branches and sections as outlined in TM 5-623 (Headquarters, Department of the Army 1982). Station numbers should also be assigned within the branches.

Determination of pavement structure

48. Both the flexible and rigid pavement evaluation procedures require that the type and thickness of each material in the pavement system be known. This information can often be obtained from existing facility records such as "as-built" drawings or maintenance records. In areas where information on the pavement structure is incomplete, out-of-date, or nonexistent, it will be necessary to determine the pavement structure by coring the pavements. This information should be updated when any rehabilitation, such as placement of an overlay or recycling, is performed or other changes in pavement structure occur.

Determination of current daily traffic and future traffic

49. Before the structural evaluation of a pavement can be performed, the current daily traffic must be known and an estimate of the future traffic expected to use the pavements must be made. The current daily traffic can be determined from existing records of recent traffic-volume studies or by conducting a traffic-volume study. The future traffic can be estimated from traffic-volume studies which include vehicle classification counts as described in "Transportation and Travel, Traffic Engineering Study Reference (Headquarters, Military Traffic Management Command 1976).

Conversion to the standard axle load

50. In this evaluation procedure all traffic should be in terms of passes of the 18,000-lb single-axle dual-wheel load or Standard Axle Load (SAL). Traffic data which are not in this form, such as design index (DI) or vehicles/day for each vehicle classification, must be converted to passes of the SAL as shown in the following paragraphs.

51. Conversion from DI to standard axle load passes. Often traffic data will be in terms of the DI. For flexible pavements the DI is an index representing all traffic expected to use the pavement during its life. It is based on typical magnitudes and compositions of traffic reduced to equivalents in terms of repetitions of an 18,000-lb single-axle dual-wheel load. The number of passes of the standard axle load corresponding to each flexible pavement DI is given in Table 8. For rigid pavements, the rigid pavement design index is used which is different from the DI used for flexible pavements. Table 9 gives the number of equivalent SAL passes corresponding to each of the rigid pavement DI's, along with a range of equivalent passes for each index (Ohio River Division Laboratories 1961). To convert from DI to SAL passes, simply find the DI in the appropriate table and read the number of equivalent SAL passes. The DI is based on a 20-year pavement life and the daily traffic number (DTN) can be obtained by dividing the number of SAL passes for a given DI by 7,300 which is the number of days in 20 years.

52. Conversion from vehicles/day for each classification to standard axle load passes. To aid in evaluating vehicular traffic, TM's 5-822-5 and 5-822-6 (Headquarters, Department of the Army 1980, 1977) divide the various vehicles into six groups as shown in Table 10. If the axle load (or gross load for forklift trucks and track vehicles) is known for the vehicles, Table 11 is used to determine the equivalent operations factor as a function of vehicle group and load. The number of equivalent SAL passes per day is then calculated for each vehicle and the equivalent SAL passes are summed to determine the number of equivalent SAL passes/day. In some cases the traffic-volume data will contain only the number of vehicles/day for each group. If this is the case, the equivalent operations factors listed in Table 12 should be multiplied by the number of vehicles/day to obtain the number of equivalent SAL passes per day for each group. The number of equivalent SAL passes for each vehicle group is then summed to obtain the number of equivalent SAL passes/day which is the CDTN. The equivalent operations factors presented in Table 12 were determined from plots of equivalent operations factor versus load for each group. These plots are based on the data presented in Table 11. The equivalent operations factors for each group in Table 12 are the equivalent operations factors corresponding to 75 percent of the maximum load for that group.

Dividing streets into branches and sections

53. All pavements to be evaluated should be divided into manageable segments. TM 5-623 provides an excellent method for dividing the pavements into branches and sections. A branch is any identifiable part of the pavement network that is a single entity and has a distinct function such as an individual street or parking lot. A section is a subdivision of a branch that contains consistent characteristics in regard to pavement structure, construction history, traffic, and pavement condition. Division of the pavements into sections based on pavement structure and traffic is required to complete the evaluation of the pavement. These sections will also provide permanent references allowing the same sections to be tested repeatedly in later years. These sections can be further subdivided based on the results of the NDT, as discussed in paragraph 73.

Data Collection

Equipment setup and preparation

54. The procedures for preparing the NODET for data collection are detailed in Appendix C. These preparations include: attaching the control cables to the NODET and instrumentation control box, attaching the velocity transducers in their proper positions, system warmup, air spring pressurization, and force calibration. Upon completion of these preparations, data collection is ready to begin.

Data collection

55. Test locations. For roads and streets on military installations, data should be collected at 100-ft intervals on opposite sides of the center line. On flexible pavements, the test should be conducted in the outside wheel path of each lane. On rigid pavements, tests should be conducted at the center of the slab nearest the 100-ft distance.

56. The simplest and safest method for collecting the data is to test one lane of a street at 200-ft intervals going with the flow of traffic. The electronic distance measuring equipment in the tow vehicle is used to determine the station numbers of the test. When reaching the end of the branch the distance-measuring device should be put on HOLD, the NODET turned around, and the opposite lane tested at 200-ft intervals offset 100 ft from the last test performed in the adjacent lane. Care should be taken to reverse the

distance-measuring equipment and release the HOLD button after turning the NODET around so the stationing of the test locations will be consistent. Typical test patterns for roads and streets are shown in Figure 20.

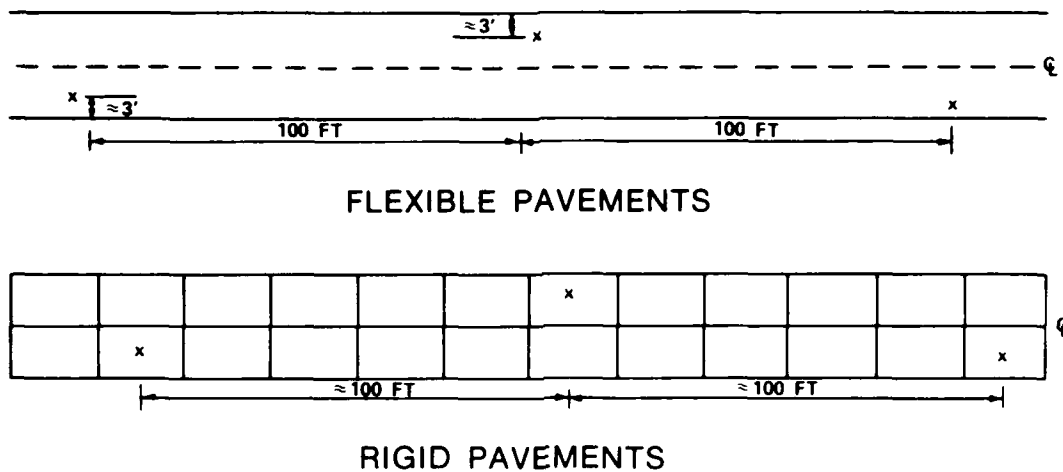


Figure 20. Typical test patterns

57. In parking areas containing curbs, tests should be conducted in the wheel paths of the traffic lanes. In small parking areas where the 100-ft test spacing is not practical, the test should be spaced to obtain at least three tests per parking area. On large motorpools and open parking areas, tests should be conducted in a grid pattern to provide uniform coverage of the area. However, tests should not be spaced further than 200 ft apart.

58. Data collection procedure. The data used in this NDT evaluation procedure are obtained with the NODET operating at 20-Hz frequency and dynamic force levels of 5,000 and 7,000 lb.

59. After equipment setup, warmup period, and force calibration, the NODET is ready to begin the data collection. The procedure for collecting data at a test location is:

- a. Stop the NODET with the load plate over the desired test location.
- b. Set test number in the thumbwheel located on the instrumentation control console.
- c. Check the operating frequency by pressing the FREQ switch on the control console (Figure 21). The panel meter should read 20.0. If the frequency is not set at 20 Hz the frequency control potentiometer (frequency knob) should be adjusted until the panel meter reads 20 Hz.

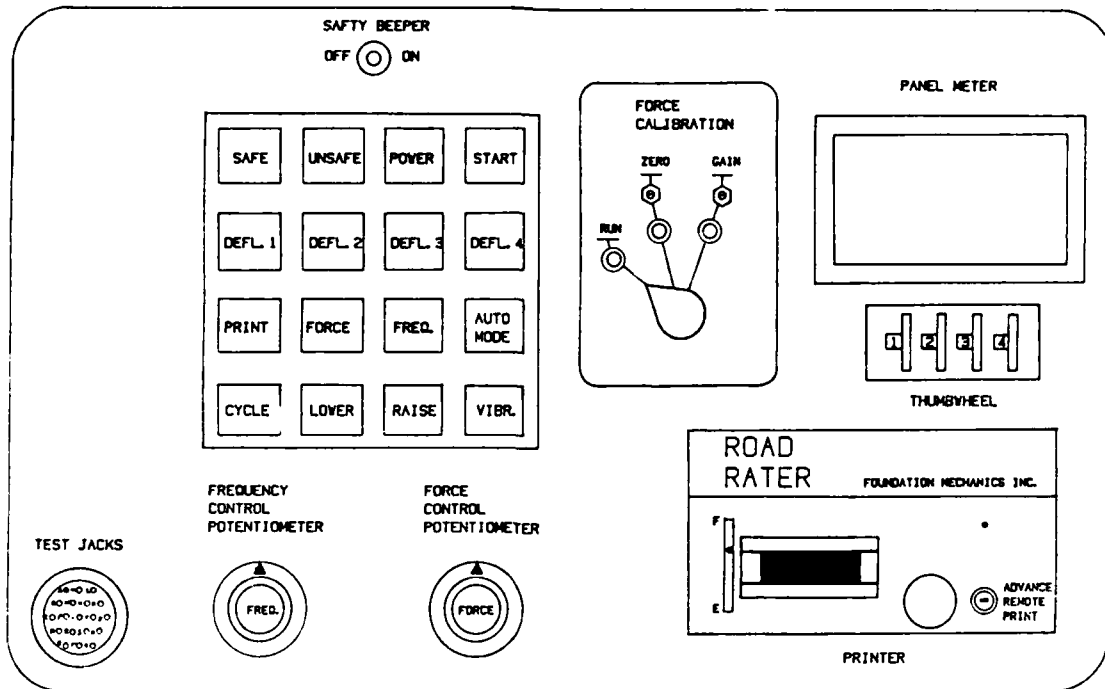


Figure 21. Layout of the control console

- d. Press the SAFE switch to engage the operating functions. This switch should now glow continuously green.
- e. Press and hold the LOWER switch to lower the force generator to the pavement. When the force generator is fully lowered, release the switch.
- f. Press the FORCE switch to display the force value on the panel meter.
- g. Press the VIBR switch to activate the hydraulic vibrator.
- h. Using the force control potentiometer (force knob), adjust the dynamic force to 5,000 lb. At this time the panel meter should read 5.00; however, some fluctuation of the meter on the order of ± 0.05 is to be expected.
- i. Press the PRINT switch to record the test numbers, frequency, force, and deflections at this force level.
- j. Increase the dynamic force to 7,000 lb (panel meter reading 7.00) by rotating the force knob clockwise approximately two full turns.
- k. Press the PRINT switch to record these data.
- l. Release the VIBR switch to deactivate the hydraulic vibrator.
- m. Press the SAFE switch to raise the force generator and render all functions inactive. This switch should now be flashing green, indicating the force generator is fully elevated before the NODET is moved.

60. A record of the test number, test location (branch, section, station number, etc.), and time should be kept in a fieldbook or other permanent record. A typical fieldbook setup is shown in Figure 22.

[illegible]

61. NODET output. The digital printer contained in the instrumentation system control console provides a permanent record of the test data on paper tape. The printout format is shown in Figure 23.

39

7	001.7
6	003.2
5	004.9
4	008.6
3	020.0
2	05.00
1	0063

Function	Channel Number	Units	Data
I. D. Number	1	--	0063
Force	2	Kips, peak-to-peak	05.00
Frequency	3	Hertz	020.0
Deflection (center of plate)	4	Mils, peak-to-peak	008.6
Deflection (18-in. offset)	5	Mils, peak-to-peak	004.9
Deflection (30-in. offset)	6	Mils, peak-to-peak	003.2
Deflection (48-in. offset)	7	Mils, peak-to-peak	001.7

Figure 23. NODET printout format

7	001.4
6	000.0
5	003.6
4	006.4
3	020.0
2	04.99
1	4001

a. Channel with all zero readings

7	002.5
5	007.6
4	012.9
3	020.0
2	07.00
1	2001

b. Missing channel

7	001.3
6	005.6
5	003.5
4	006.4
3	020.0
2	05.00
1	0008

c. False deflection reading

4	444.4	4	454.5
4	444.4	4	454.5
4	444.4	4	454.5
4	444.4	4	454.5
4	444.4	4	454.5
4	44.44	2	5.01
4	4444	1	0126

d. Malfunctions caused by heat

Figure 24. Typical data errors

deflection data contain a reading higher than the reading that is next closest to the plate (Figure 24c) there is some problem with that velocity sensor. The sensor may be on a rock, crack, or other object causing a false reading to be produced. The sensor giving the false reading should be visually checked and any foreign objects underneath the transducer removed before the test is rerun.

63. The NODET printer is sensitive to high temperatures and will malfunction if the instrumentation control console is not kept cool. Temperatures greater than approximately 90° F in the area of the instrumentation console may result in malfunctions such as those seen in Figure 24d. Large fluctuations in the panel meter force readings that will not stabilize and/or large discrepancies between the panel meter force reading and tape output can also be caused by excessive heat. To prevent this malfunction from occurring the cab of the tow vehicle should be kept cool.

64. Large fluctuations in the panel meter force readings that will not stabilize may result from uneven pressure in the air bags or loss of pressure in one or more of the bags. If these fluctuations occur and cannot be attributed to heat, the pressure in the air bags should be checked and adjusted if necessary.

65. If there is any doubt as to the validity of the data recorded on the tape, each value of force, frequency, and deflection can be checked independently by depressing the appropriate switch on the instrumentation console and reading the resulting value on the panel meter. Should the automatic printer stop working for any reason, testing can continue with the data being recorded manually.

66. Pavement temperature measurements. When collecting NDT data on asphaltic concrete or composite pavements, the pavement surface temperature should be measured and recorded at 1-hr intervals. To obtain these data the thermometer probe is attached to the pavement, as shown in Figure 25, and shielded from direct sunlight until the temperature reading peaks. This value is then recorded along with the time and location in the fieldbook shown in Figure 22.

Data Reduction

DSM calculation

67. After completing the data collection the next step is to calculate the DSM for each test location. To simplify this procedure the data should be tabulated onto the NDT data sheets; sample sheets are shown in Figures 26 and 27. Figure 26 is the data sheet for recording flexible pavement data; while the rigid pavement data are recorded on the data sheet shown in Figure 27.

68. The DSM is then calculated using the equation

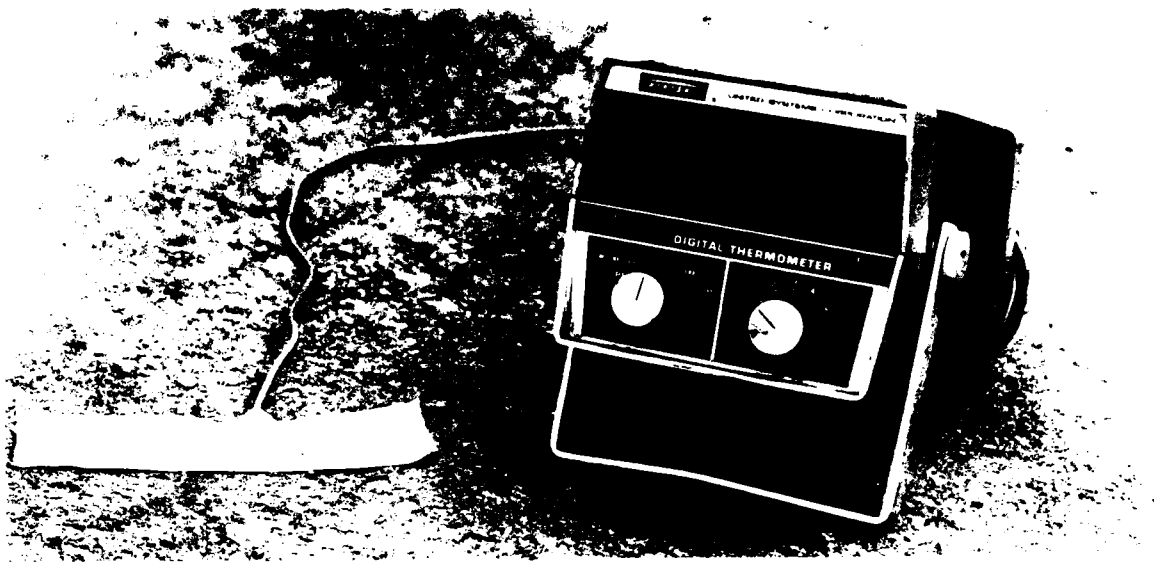


Figure 25. Typical setup for pavement temperature measurements

$$DSM = \left(\frac{F_7 - F_5}{D_7 - D_5} \right) \times 1000 \quad (1 \text{ bis})$$

where

DSM = dynamic stiffness modulus, kips/in.

F_7 = measured force at approximately 7.0-kip force, kips
(channel 2)

F_5 = measured force at approximately 5.0-kip force, kips
(channel 2)

D_7 = measured plate deflection under the 7.0-kip force, mils
(channel 4)

D_5 = measured plate deflection under the 5.0-kip force, mils
(channel 4)

The calculated DSM is then recorded in proper column of the appropriate data sheet.

Flexible pavements:
correction for temperature effects

69. The DSM's measured on flexible pavements must be corrected to a mean pavement temperature of 70° F. This correction is necessary because the stiffness of pavements containing AC layers is directly related to the temperature of that AC layer. Therefore, for a DSM measured at one pavement temperature to be comparable to DSM's measured at other pavement temperatures, the

DSM values should be corrected to a common mean pavement temperature. The correction factors used in correcting the measured DSM values to the common mean pavement temperature of 70° F for flexible pavements are presented in Figure 28 and the DSM correction factors for AC over PCC pavements are presented in Figure 29.

70. To correct the measured DSM, the DSM correction factor is determined from Figure 28 using the mean pavement temperature and thickness of the asphalt layer. The mean pavement temperature is calculated using the Asphalt Institute method as described in paragraph 23 and Figure 30. The correction factor obtained is then multiplied by the measured DSM to obtain the temperature corrected DSM.

Radius of relative stiffness calculation

71. For rigid pavements the radius of relative stiffness ℓ should be determined from the NODET data. The radius of relative stiffness is determined at the 7.0-kip-force level using the deflections measured at 18 and 48 in. from the center of the plate, and Figure 31. The deflection ratio Δ_{48}/Δ_{18} is calculated, then used in Figure 31 to determine ℓ . The NODET data sheet for rigid pavements (Figure 27) contains columns for recording the deflection ratio and ℓ value to simplify the calculations.

Selecting representative DSM values

72. To aid in determining the representative DSM value to use in evaluating a pavement section each corrected DSM value should be plotted in profile form. The best results are obtained when each DSM measured on a branch or street is plotted along the length of the branch or street. The locations of the pavement sections should be noted along the bottom of the profile.

73. Although a pavement section may supposedly be of the same type and construction, it should be subdivided and treated as more than one group when the DSM values measured in one area differ greatly from those measured in another area of the same section.

74. The DSM value assigned to a pavement group or section should be the statistical mean corrected DSM for the group ($\bar{X}$) minus one standard deviation (S). A minimum of three test points should be taken in each section.

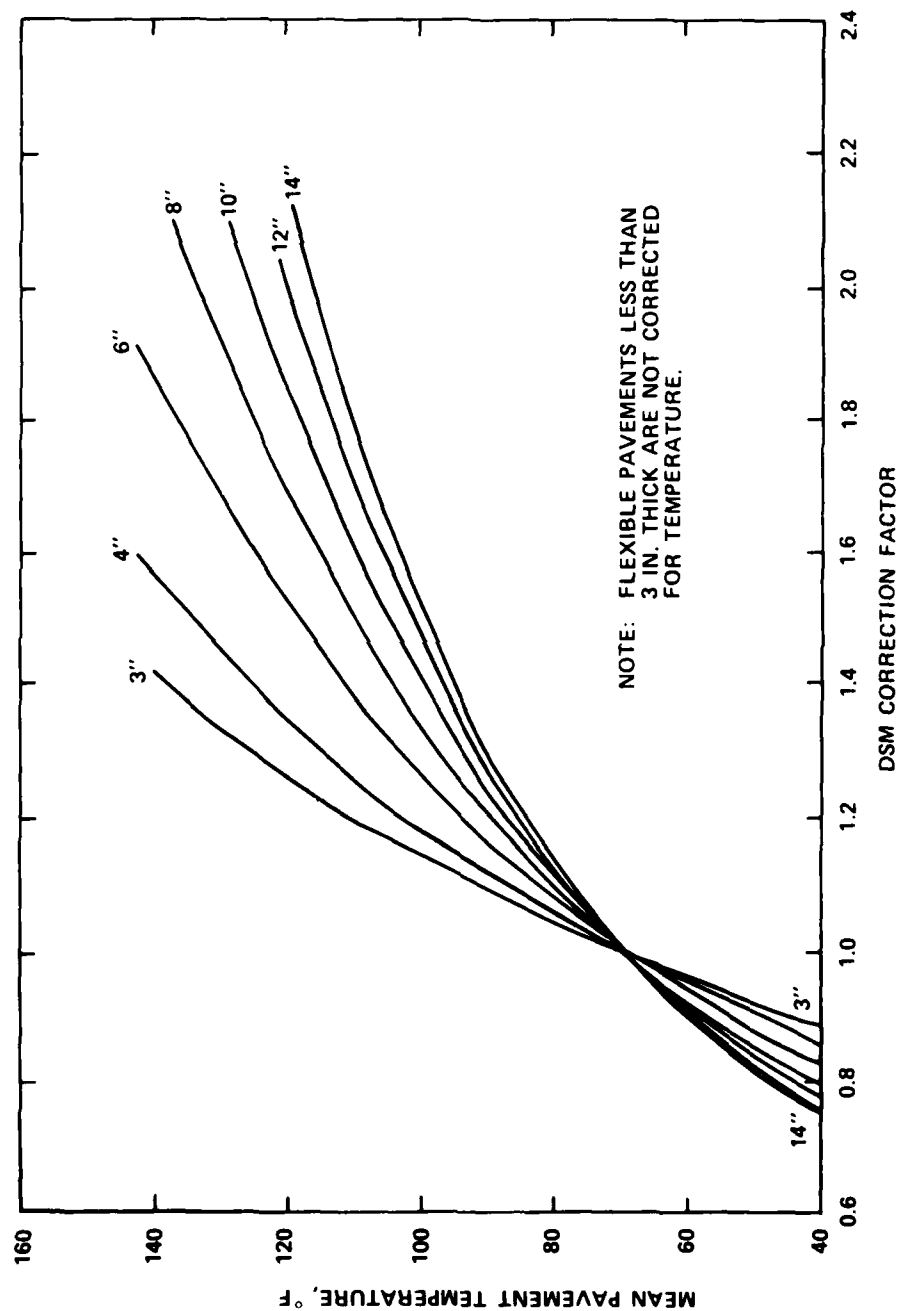


Figure 28. DSM temperature correction factor curves for flexible pavements

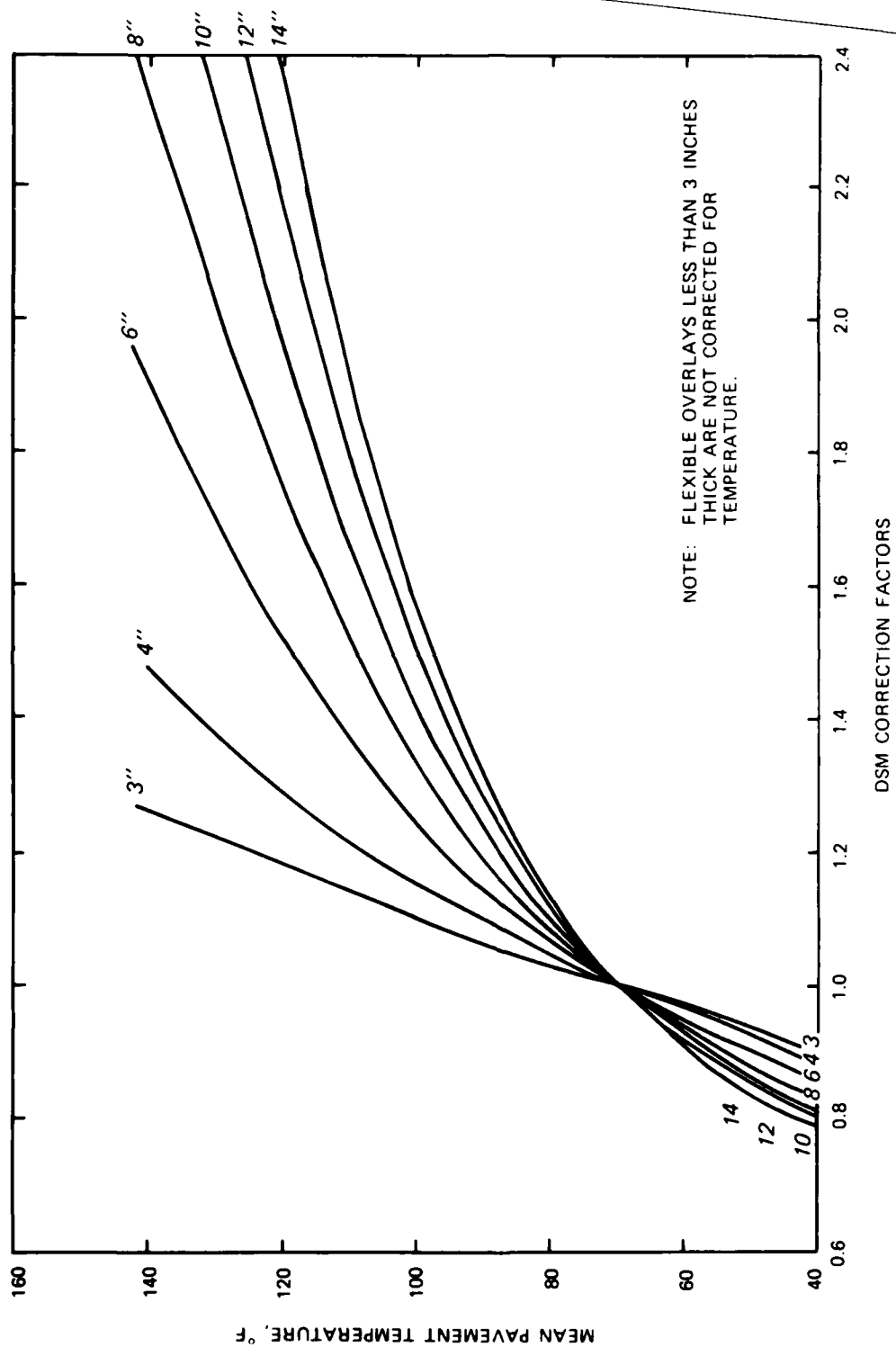


Figure 29. DSM temperature correction factor curves for asphalt over Portland cement concrete pavements

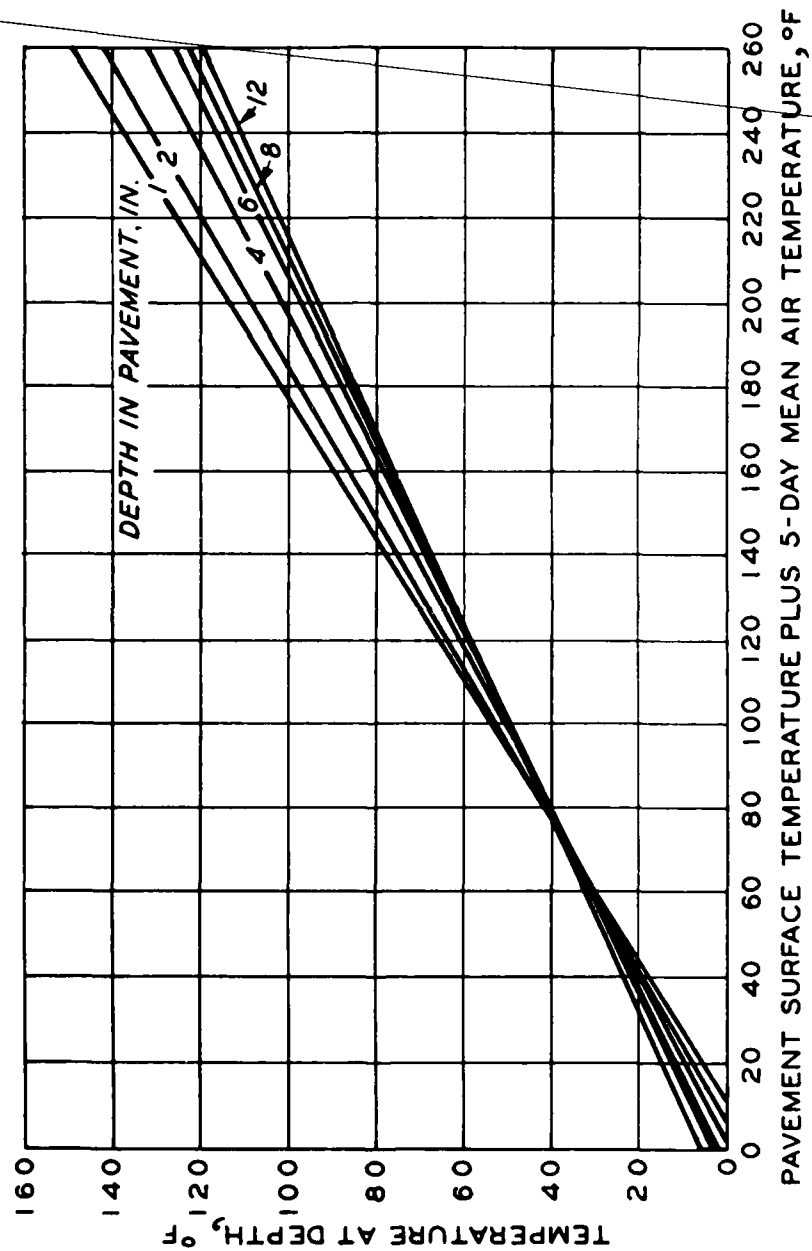


Figure 30. Prediction of pavement temperatures for bituminous layers

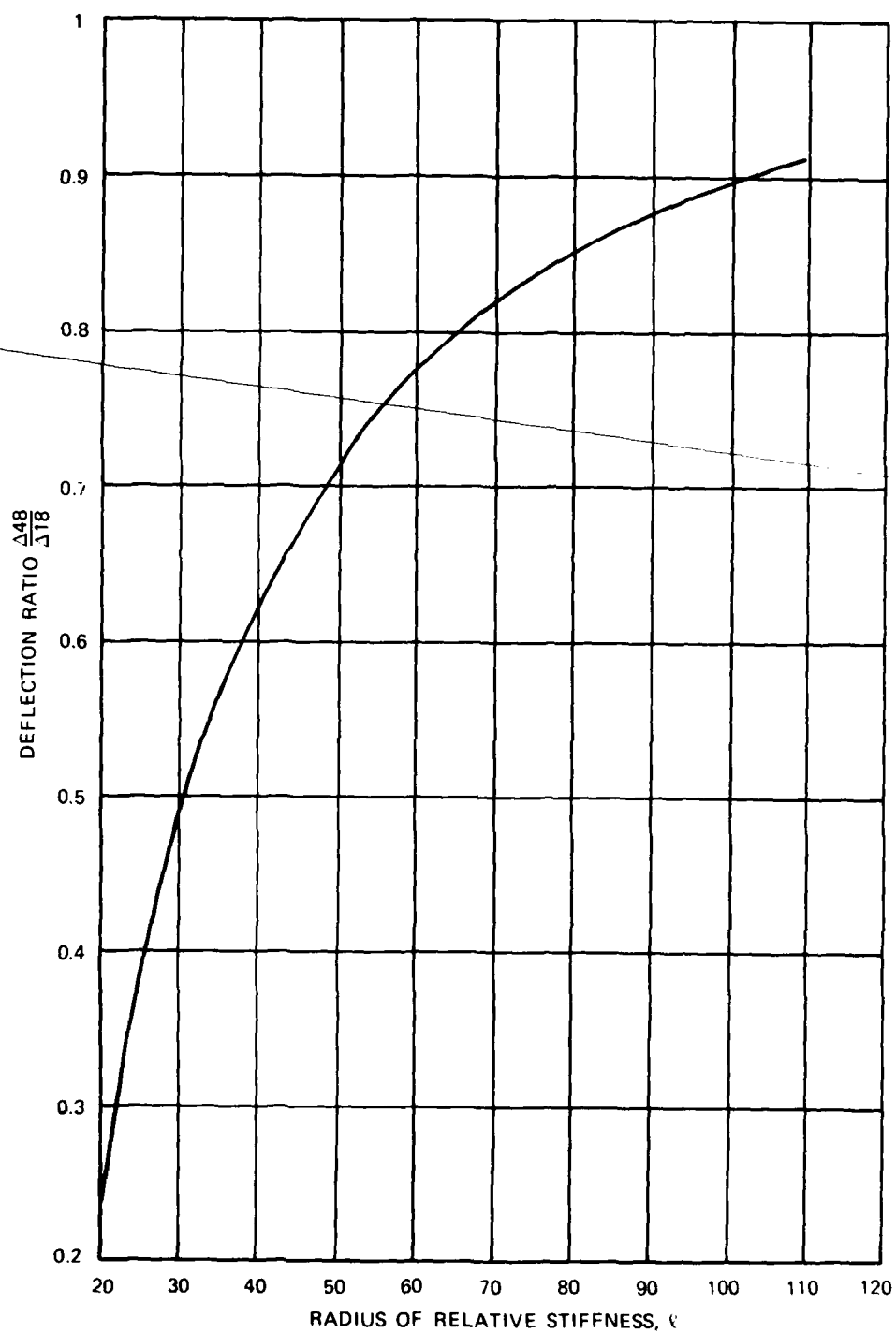


Figure 31. Deflection ratio versus radius of relative stiffness

Evaluation and Overlay Design Procedures

Flexible pavements

75. Evaluation procedure. After determining the representative DSM of the pavement section we are ready to evaluate the section. The steps in the evaluation procedures are:

- a. Determine the number of (ASALP) from Equation 8.

$$\text{ASALP} = \text{antilog}[0.0169(\text{DSM}) - 0.2919] \quad (8 \text{ bis})$$

- b. Convert the allowable passes to allowable daily traffic number (ADTN) by dividing the number of allowable passes by 7,300, which is the number of days in a 20-year period. The ADTN is therefore the allowable average number of daily 18,000-lb axle load passes based on a 20-year period.
- c. Compare the allowable DTN (ADTN) obtained in Step b with the current DTN (CDTN). Is the ADTN greater than the CDTN?

Yes - The pavement is structurally adequate.

No - The pavement is not structurally adequate.

Caution must be used in interpreting the evaluation results. The evaluation is based on conditions existing at the time the NDT was performed and does not take into account strength changes resulting from frost or freeze/thaw effects or from extreme dry or wet periods.

76. Overlay design procedure. If the pavement is not structurally adequate, some type of rehabilitation is required. One type of rehabilitation is to overlay the existing pavement. The amount of overlay required to support the expected future traffic can be determined from the previously obtained NDT results. The steps in determining the required overlay thickness are:

- a. Determine the total equivalent thickness, T_{EQ} , of the pavement section:
- (1) Convert the existing pavement section to an equivalent thickness of subbase, T_S , using the equivalency factors in Table 7. T_S is determined by multiplying the layer thickness by the proper equivalency factor to convert each layer to thickness of equivalent subbase, then summing each thickness to determine the total, T_S .
 - (2) Using T_S , determine the total equivalent pavement thickness, T_{EQ} , which is composed of 3.5 in. of AC, 4.0 in. of 100 CBR crushed stone base, and a variable amount of granular subbase. The T_{EQ} is determined from

$$T_{EQ} = 3.5 \text{ AC} + 4.0 \text{ base} + (T_S - 16.05) \text{ subbase}$$

$$T_{EQ} = 7.5 + (T_S - 16.05)$$

$$T_{EQ} = T_S - 8.55 \text{ in.} \quad (3 \text{ bis})$$

Note that the 16.05-in. equivalent subbase is the result of converting the required 3.5-in. of AC (equivalency factor = 2.3) and 4.0-in. of crushed stone base (equivalency factor = 2.0) to equivalent subbase. If T_S were less than 16.05 in., the equation for computing T_{EQ} would be

$$T_{EQ} = 3.5 + \frac{T_S - 8.05}{2.00} \quad (4 \text{ bis})$$

- b. Enter the flexible pavement design curves (Figure 32) with the number of allowable passes (ASALP) computed from Equation 8 and determine the subgrade CBR at the equivalent thickness, T_{EQ} .
- c. Reenter the design curves (Figure 32) with the estimated future traffic and move vertically to the subgrade CBR value determined in Step b above then horizontally to determine the thickness required, T_r .
- d. Determine the amount of asphaltic concrete overlay required:

$$t_o = \frac{T_r - T_{EQ}}{2.30} \quad (13)$$

where

t_o = overlay required, in.

T_r = required thickness (from c)

T_{EQ} = equivalent thickness (from a)

77. A complete example of the pavement evaluation and overlay design procedure is presented in Appendix A.

Rigid pavements

78. Evaluation procedure. After completing the data reduction the steps in evaluating rigid pavements are:

- a. Determine the number of allowable passes of the standard axle load from Figure 33.
 - (1) Enter with the representative DSM for the pavement section.

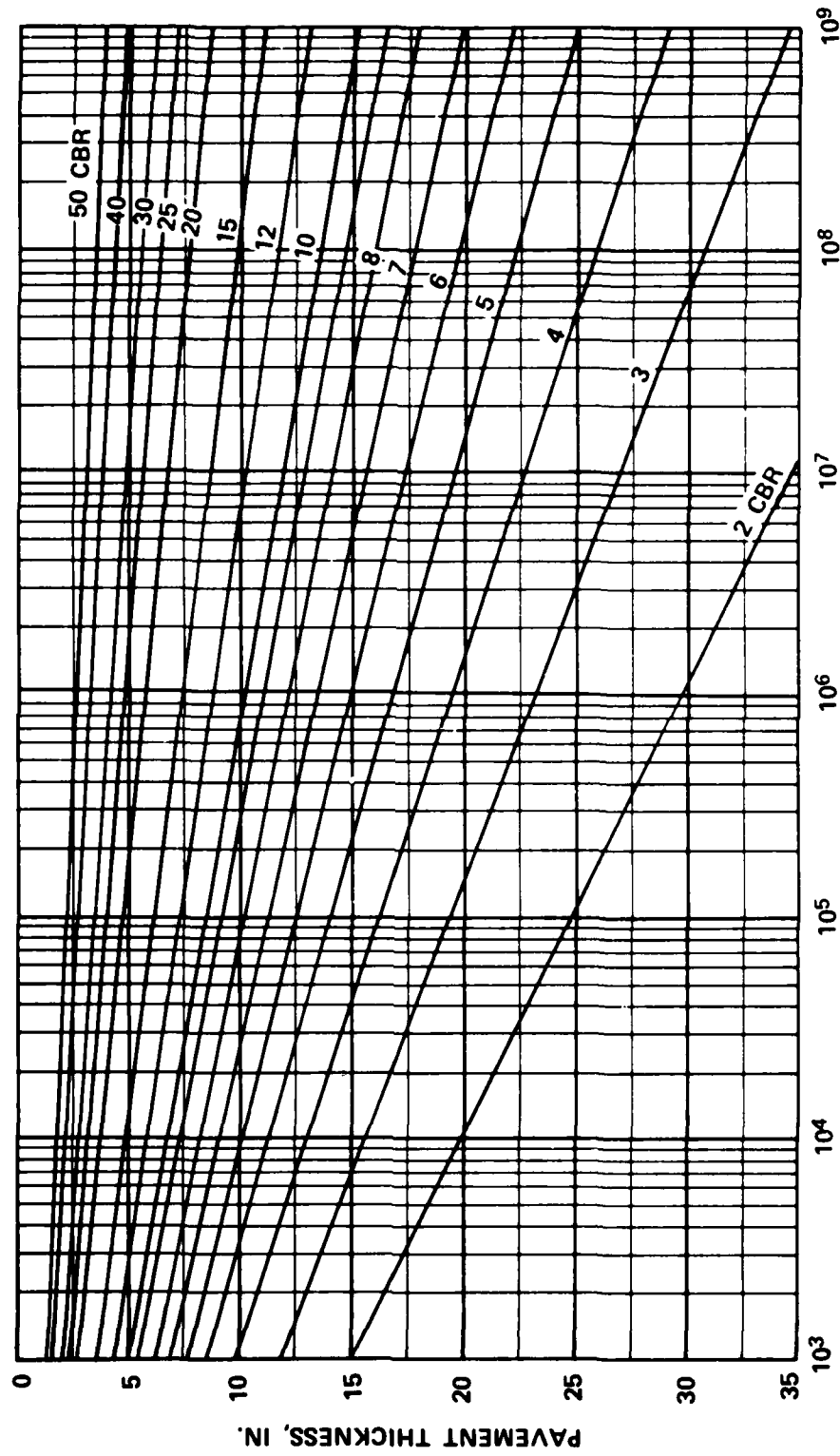


Figure 32. Flexible pavement design curves

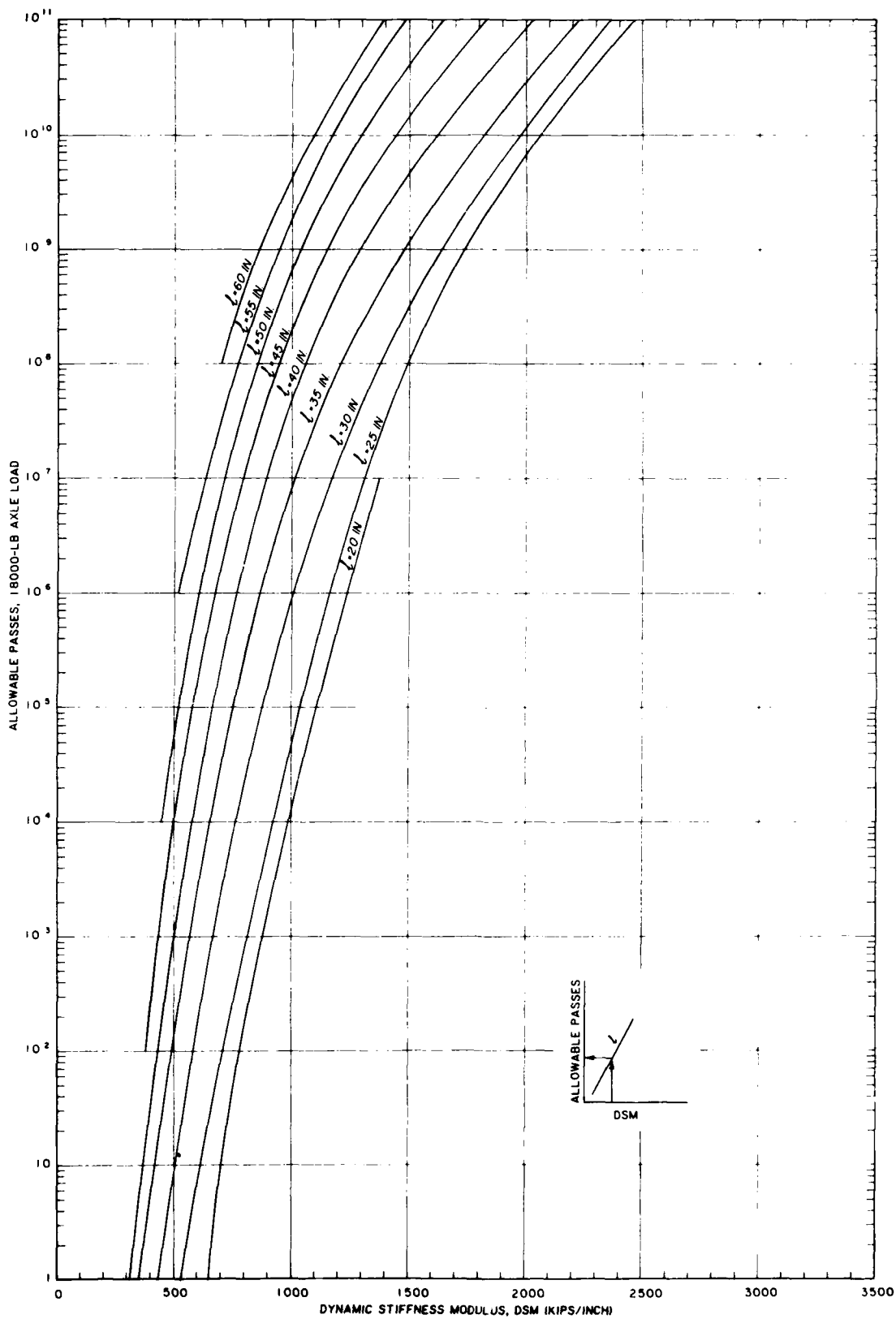


Figure 33. Rigid pavement NDT evaluation chart

- (2) Proceed vertically to the average ℓ value determined for the pavement section.
 - (3) Read the number of allowable SAL passes from the left margin.
- b. Convert the number of allowable passes to ADTN by dividing the allowable passes by 7,300.
 - c. Compare the allowable DTN (ADTN) with the current DTN (CDTN). Is the ADTN greater than the CDTN?

Yes - The pavement is structurally adequate.

No - The pavement is not structurally adequate.

Caution must be used in interpreting the evaluation results. The evaluation is based on conditions existing at the time the NDT was performed and does not take into account strength changes resulting from frost or freeze/thaw effects or from extreme dry or wet periods.

79. Overlay design procedure. The overlay thickness required to support the design traffic can be determined from the following steps:

- a. Determine the required pavement thickness, h_d , using the existing pavement thickness, h ; the number of ASALP (from step a of the evaluation procedure); and the estimated future traffic level. Determine the required pavement thickness from the rigid pavement design chart (Figure 34) as follows:
 - (1) Enter with the pavement thickness, h , and go left to the allowable pass level (ASAL).
 - (2) Move vertically from this point to the estimated future pass level.
 - (3) Read the required pavement thickness, h_d , to the nearest 1/10 in.
- b. Check the flexural strength.
 - (1) Calculate the modulus of subgrade reaction, k .

$$k = 341005.97 \frac{h^3}{(\ell \times 0.7)^4} \quad (14)$$

The 0.7 factor included in Equation 14 results from correlations between ℓ from deflection measurements and ℓ computed from pavement properties using Equation 9. These correlations were initially performed by Bush (1979) and confirmed in this study.

- (2) Enter the design chart (Figure 34) with the pavement thickness, h , and move left to the allowable pass level.
- (3) Move vertically to the k value determined above, then left to determine the flexural strength, R .

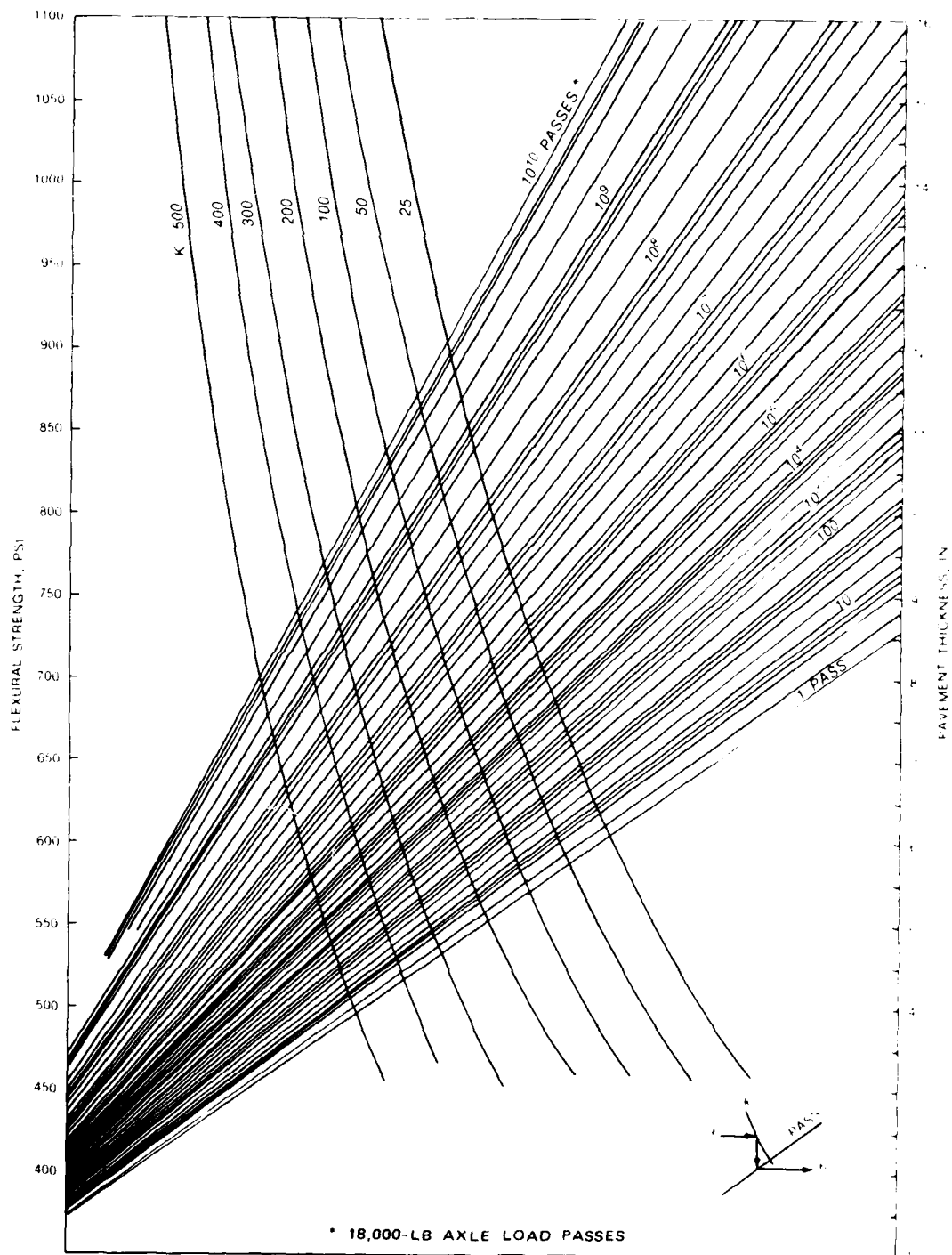


Figure 34. Rigid pavement design chart

If the flexural strength is outside a 400- to 900-psi range a flexural strength within this range (usually 650 or 700) should be used to redetermine h_d . The new value of h_d is found by entering the design chart with the assumed flexural strength and moving right to the correct k , then vertically to the estimated future traffic level, then right to determine h_d .

- c. Determine the amount of flexible overlay required to the nearest 1/2 in.*

$$t = 2.5(Fh_d - C_b h) \quad (15)$$

where

t = flexible pavement overlay thickness, in.

F = factor from Figure 35 determined for a rigid pavement design index (determined from Table 9 using expected future traffic) and k . This factor projects cracking that may be expected in existing PCC pavement.

h_d = required thickness, in.

C_b = condition factor for base pavement

$C_b = 1.00$ when rigid base pavement slabs contain only nominal initial cracking

$C_b = 0.75$ when the rigid base pavement slabs contain multiple cracks and numerous corner breaks

h = existing PCC pavement thickness

- d. Determine amount of partially bonded rigid overlay required.*

$$h_o = 1.4 \sqrt{(h_d)^{1.4} - C_r (h)^{1.4}} \quad (16)$$

where

h_o = overlay thickness required, in.

h_d = required pavement thickness, in.

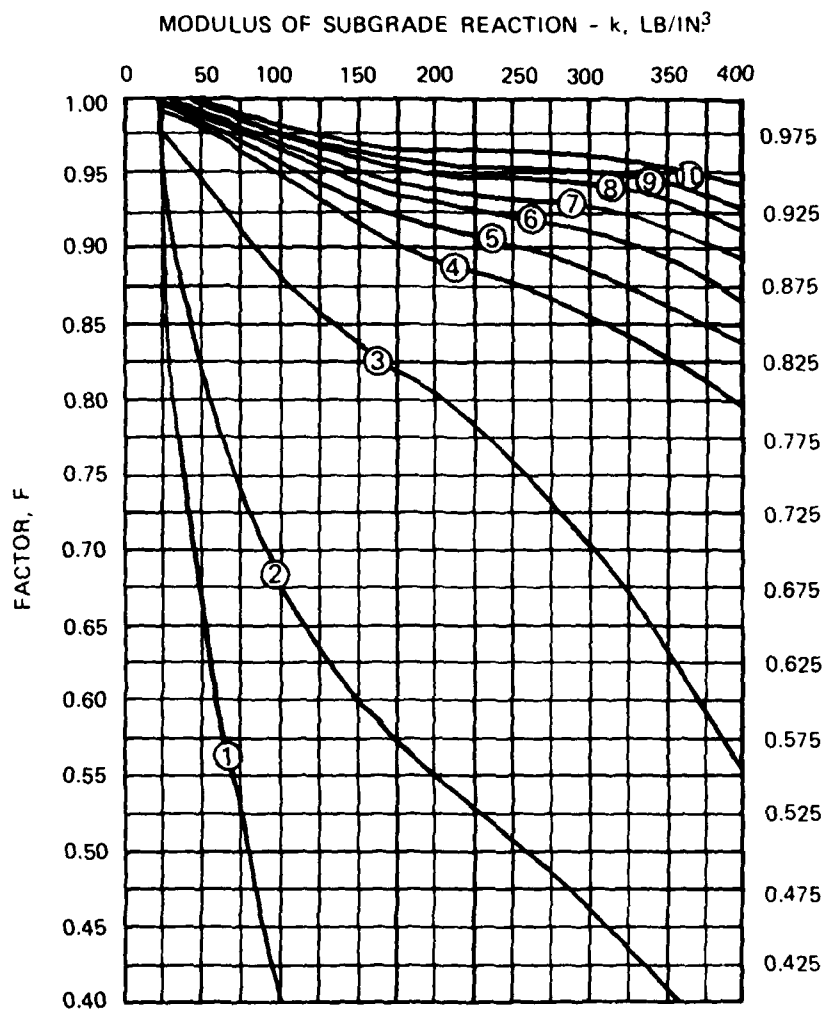
C_r = condition factor for existing pavement

$C_r = 1.00$ when the slabs are in good condition, with little or no structural cracking

$C_r = 0.75$ when the slabs show initial cracking due to loading, but little or no multiple cracking

$C_r = 0.50$ when a larger number of slabs show multiple cracking, but the majority of slabs are intact or contain only single cracks

* Reference: TM 5-822-6/AFM 88-7, Chapter 1, page 40, paragraph 13.8.2.



NOTES:

- (1) DETERMINE F FACTOR FROM ABOVE CHART USING MEASURED k . USE CURVE NUMBERED SAME AS RIGID PAVEMENT INDEX, i.e. FOR RPI OF 3, USE CURVE ③
- (2) MINIMUM F VALUE = 0.40. FOR $k > 400$ USE F FOR $k = 400$
- (3) SOURCE: TM 5-822-6/AFM 88-7, Chapt 1

Figure 35. Determination of rigid pavement cracking factor F

$C_r = 0.35$ when the majority of slabs show multiple cracking

h = existing PCC thickness

- e. Determine the amount of rigid overlay with a leveling or bond breaking course required.*

$$h_o = \sqrt{(h_d)^2 - C_r(h^2)} \quad (17)$$

Note: TM 5-822-6 (Department of the Army 1977) requires that the minimum rigid overlay pavement thickness be 6 in., while the minimum all-bituminous overlay be 4 in.

80. A complete example of the rigid pavement evaluation and overlay design procedure is presented in Appendix B.

Presentation of Data

81. Upon completion of the evaluation, a report should be prepared.

The report should include:

- a. Map showing the pavements tested.
- b. Information on the pavement structure.
- c. Traffic information.
- d. A brief description of the surface condition for each section.
- e. DSM plots for each branch.
- f. Tables showing the results of the evaluation.
- g. Conclusions and recommendations.

* Reference: TM 5-822-6/AFM 88-7, Chapter 1, page 36, paragraph 13.4.2.

PART V: DISCUSSION

Limitations

82. Certain limitations or restrictions are inherent in the nondestructive test and evaluation procedures described in this report. These are: the testing must be performed with the Road Rater Model 2008 vibrator; the test to measure the DSM must be made at a frequency of 20 Hz with an 18-in.-diam contact load plate; the thickness of the pavement layers above the subgrade and the type of material comprising each layer must be known; the evaluation is based on conditions existing at the time of the evaluation, and the load-carrying capability may be considerably different than if the pavement were under the effect of frost or freezing conditions, spring thaw, or extremely wet or dry conditions; no evaluation procedure is available for composite pavements; and thick pavements (generally greater than 12 in.) can result in a large amount of scatter in the load-deflection data.

Advantages

83. The advantages of this method of pavement evaluation are the rapid, nondestructive capabilities that provide minimal interference with vehicle operations. Since the NODET testing requires only a small amount of time (about 2 min per test), a much more thorough investigation of pavement strength variability can be made than is practical using destructive testing.

Possible Uses

84. There are several possible alternatives for implementing the NODET evaluation procedures described herein. The first alternative would be to use the NODET evaluation on a project basis to evaluate an existing pavement and make rehabilitation recommendations. The advantages of this alternative are that the NODET could be used to recommend the amount of overlay required without extensive destructive testing and any extremely weak areas where complete reconstruction would be required could be pinpointed and corrected prior to application of the overlay. The major disadvantage of this alternative is the time and expense involved in transporting the equipment to perform only a

small amount of testing. A second alternative would be to use the NODET evaluation to determine test pit locations. This would be especially useful in failure investigations, evaluating thick pavements (generally greater than 12 in.), or evaluating composite pavements. The advantage of using the NODET in this manner is that the relative strengths of the pavement can be determined prior to excavating the test pits. The third alternative for implementing the NODET evaluation would be to test and evaluate pavements on a "whole-sale" basis, that is, testing and evaluating the entire pavement system of an installation. This has the advantage of providing an evaluation of all the pavements so that the evaluations of different streets can be compared and maintenance priorities established. Disadvantages include the time and expense of a large-scale testing program as well as the manpower required to handle such a large amount of data.

Future Improvements and Modifications

85. There are several improvements and modifications to the present NODET equipment and evaluation procedures that, if adopted, would decrease the time required to collect and reduce the NODET data and improve the efficiency of the evaluation. One of these improvements would be the addition of an automatic data acquisition system to the instrumentation control panel. This system, presently available, would automatically collect, record, and reduce the load-deflection data, thus reducing the time required for the data collection and data reduction phases of the evaluation. Another improvement to the data collection procedure would be a statistical means for determining if sufficient data had been obtained within a given pavement section prior to leaving that section. This could be in the form of a nomograph or could be included in the automatic data acquisition system.

86. A major improvement in the evaluation of roads and streets would be the completion and implementation of the elastic layer evaluation procedure. The elastic layer evaluation procedure would enable the user to evaluate all types of pavement systems including flexible, rigid, and composite (asphalt over concrete) pavements using one basic procedure, as well as make the evaluation procedure easily adaptable to new loads and vehicles, different NDT devices, and new pavement materials.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

87. This report presents procedures for the nondestructive evaluation and overlay design of military roads and streets. The procedures are basically correlations of nondestructive vibratory test results to conventional pavement evaluation criteria. From this study it is concluded that:

- a. The flexible and rigid pavement evaluation procedures presented in this report are applicable to the evaluation of military roads and streets using the NODET nondestructive testing equipment.
- b. Results of the temperature effects study confirm that for AC pavements greater than 3 in. thick the WES DSM correction factors presently in use are applicable to the NODET and should be used to correct DSM values obtained with the NODET to a common mean pavement temperature of 70° F.
- c. AC pavements less than 3 in. thick should not be corrected for temperature effects.
- d. Although data were collected on composite pavements, a definite relationship correlating the NODET DSM to conventional evaluation procedures for these pavements was not established.

Recommendations

88. Based on the results of this study, it is recommended that:

- a. The NODET evaluation procedures for flexible and rigid highway pavements be adopted for use in evaluating military roads and streets.
- b. In the initial stages of implementation, additional test pit or core hole testing be conducted on flexible and rigid pavements and the data used to further develop and define the basic correlations.
- c. Consideration be given to installing an automatic data acquisition system to the existing NODET instrumentation control panel.
- d. A statistical means be developed to determine if sufficient load-deflection data have been obtained within a given pavement section.
- e. The elastic layer method of evaluation be completed and implemented.

REFERENCES

- American Society for Testing and Materials. 1980. "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," Designation: C 496-71, 1980 Book of ASTM Standards, Philadelphia, Pa.
- Bush, A. J. III. 1979 (Jun). "Comparison of Dynamic Surface Deflection Measurements on Rigid Pavements with the Model of an Infinite Plate on an Elastic Foundation," Masters Thesis, Mississippi State University, State College, Miss.
- Department of Defense. 1964 (Dec). "Military Standard Test Method for Pavement, Subgrade, Subbase, and Base-Course Materials," MIL-STD-621A, Washington, D. C.
- Green, J. L. and Hall, J. W., Jr. 1975 (Sep). "Nondestructive Vibratory Testing of Airport Pavements, Experimental Test Results, and Development of Evaluation Methodology and Procedure," Report No. FAA-RD-73-205-1, Vol I, Federal Aviation Administration, Washington, D. C.
- Hall, J. W., Jr., and Elsea, D. R. 1974 (Feb). "Small Aperture Testing for Airfield Pavement Evaluation," Miscellaneous Paper S-74-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Hammitt, G. M. II. 1971 (Dec). "Concrete Strength Relationships," Research Paper, Texas A&M University, College Station, Tex.
- Headquarters, Department of the Army. 1977 (Apr). "Engineering and Design; Rigid Pavements for Roads, Streets, Walks, and Open Storage Areas," Technical Manual 5-822-6, Washington, D. C.
- _____. 1980 (May). "Engineering and Design, Flexible Pavement for Roads, Streets, Walks, and Open Storage Areas," Technical Manual 5-822-5, Washington, D. C.
- _____. 1982 (Nov). "Pavement Maintenance Management," Technical Manual 5-623, Washington, D. C.
- Headquarters, Military Traffic Management Command. 1976 (Apr). "Transportation and Travel, Traffic Engineering Study Reference," MTMC Pamphlet No. 55-8, Washington, D. C.
- Ohio River Division Laboratories, U. S. Army Engineer Division, Ohio River. 1961 (Jul). "Development of Rigid Pavement Thickness Requirements for Military Roads and Streets," Technical Report No. 4-18, Cincinnati, Ohio.
- The Asphalt Institute. 1969 (Nov). "Asphaltic Overlays and Pavement Rehabilitation," Manual Series No. 17, College Park, Md.
- U. S. Army Engineer Waterways Experiment Station, CE. 1951 (Jun). "Collection of Letter Reports on Flexible Pavement Design Curves," Miscellaneous Paper No. 4-61, Vicksburg, Miss.
- _____. 1961 (Aug). "Revised Method of Thickness Design for Flexible Highway Pavements at Military Installations," Technical Report No. 3-582, Vicksburg, Miss.
- Westergaard, H. M. 1926. "Stresses in Concrete Pavements Computed by Theoretical Analyses," Public Roads, Vol 7, No. 2.

Table 1

Data Collection Locations

Facility	Location	Letter Designation	Test Dates	Number of Test Sites		
				Flexible	Rigid	Composite
Fort Eustis	Newport News, Virginia	E	25-30 Apr 1980	17	3	3
Fort Polk	Leesville, Louisiana	P	14-19 Apr 1981	0	12	9
Waterways Experiment Station	Vicksburg, Mississippi	W	Feb 1980-June 1981	8	6	0
Korean Airfields	Republic of Korea	K	10 May-31 July 1982	11	9	0
Total				36	30	12

Table 2

Data obtained from blockage tests

CBR percent	Thickness in	Layer 4 Material	BK percent	Thickness in	Layer 5 Material	CBR percent	Nondestructive Data						Temperature Data			Measurement from test	Temperature corrected from test
							1 in. 100 lbs	2 in. 400 lbs	3 in. 600 lbs	4 in. 800 lbs	5 in. 1000 lbs	Surface %	Day Mean °F	Night Mean °F	Temperature correction Factor		
23	S/G	Heavy clay	8				7.04	14.7	12.4	6.1	2.6	88.4	62.6	136.5	1.00	473	473
		Depth = 25 in.	8.5				5.05	12.1	6.6	4.1	1.9						
44							6.77	19.6	11.5	5.7	1.4	86	62.6	134.6	1.00	469	469
							5.06	11.7	6.7	4.8	1.5						
8							6.96	19.8	10.8	4.1	1.4	86	62.6	134.6	1.00	469	469
							5.20	12.2	6.7	2.6	1.1						
30	2.2	Sandy silt	15	S/G	Silty clay	--	6.87	18.1	13.4	8.3	3.9	88.2	62.6	133.8	1.00	464	465
							4.99	11.7	6.0	3.6	1.8						
--	16.2	Sandy clay	11	S/G	Heavy clay	5	6.87	18.1	13.4	8.3	3.9	88.2	62.6	133.8	1.00	464	465
							4.99	11.7	6.0	3.6	1.8						
							7.04	11.5	8.4	5.4	2.1	87	62.6	132.9	1.00	541	536
							4.98	7.6	5.5	3.3	1.2						
							6.87	13.1	8.7	4.9	2.5	86.5	62.6	132.9	1.00	466	466
							4.95	8.7	5.3	3.4	1.8						
5							6.87	13.1	8.5	4.9	2.1	86	62.6	132.9	1.00	466	466
							4.95	8.7	5.3	3.4	1.8						
12							6.87	8.7	5.3	3.4	1.8	86.2	62.6	132.8	1.00	500	504
							5.05	6.1	3.7	2.3	1.2						
24	S/G	Heavy clay	14				7.12	12.1	8.6	5.9	3.4	88.2	62.6	132.8	1.00	467	467
45	S/G	Heavy clay	21				5.03	8.3	4.2	3.3	1.4						
							6.86	12.4	7.8	3.4	1.5	84.6	62.6	132.7	1.00	466	467
							5.06	8.3	5.5	2.6	1.1						
--	S/G	Heavy clay	8				6.86	12.4	7.6	3.4	1.5	84.9	62.6	132.5	1.00	466	467
							5.06	8.3	5.5	2.6	1.1						
--	9.5	Sand	30	S/G	Heavy clay	4	6.93	14.0	7.2	3.6	1.8	88.8	62.6	131.8	1.00	465	465
							5.05	8.7	4.3	2.4	1.3						
--	4.0	Sandy clay	27	S/G	Heavy clay	15	6.84	20.2	12.8	7.2	3.7	86.5	62.6	131.5	1.00	447	451
							4.94	11.5	8.8	4.9	2.7						
--							6.79	11.5	7.6	4.2	1.9	84.6	62.6	131.5	1.00	465	465
							4.96	7.7	5.7	3.1	1.4						
10	S/G	Heavy clay	15				7.04	12.0	18.0	7.8	2.7	89.8	62.6	131.0	1.00	474	475
23							5.06	20.6	11.7	5.5	1.8						
8							6.82	8.1	5.3	2.9	1.4	85.0	62.6	128.5	1.00	525	526
							5.11	5.8	4.0	2.2	1.1						
24							6.89	12.6	6.8	2.8	1.8	82.7	57.9	128.6	1.00	467	474
							5.03	8.6	4.6	2.0	1.3						
							6.97	12.9	8.8	4.4	2.4	86.5	57.9	128.4	1.00	492	492
							5.00	8.9	5.8	3.0	1.7						
							7.03	8.1	4.6	2.6	1.7	87.5	57.9	128.4	1.00	562	562
							5.05	5.5	3.2	1.9	1.3						
24							6.99	10.2	6.3	3.2	2.2	87.5	57.9	128.4	1.00	594	594
							5.03	6.9	4.3	2.2	1.7						
							7.04	12.8	6.8	3.4	2.3	87.5	57.9	128.4	1.00	438	438
							5.92	8.1	4.3	2.3	1.5						
							7.00	9.7	5.5	3.1	1.8	108.7	83.0	128.7	1.28	635	823
							5.03	6.6	3.7	2.2	1.3						
							6.99	11.7	6.5	3.2	1.9	107.3	83.0	128.3	1.23	513	641
							5.04	7.9	4.3	2.3	1.3						
6							7.00	5.0	2.7	2.1	1.4	108.6	83.0	128.6	1.28	1106	1447
							5.01	3.2	2.0	1.5	1.1						
3.7							7.01	8.3	6.1	4.6	3.4	85.0	65.0	150.0	1.00	825	875
							5.03	5.9	4.4	3.3	2.5						
							6.98	19.8	11.6	5.5	2.7	85.0	65.0	150.0	1.00	290	290
							4.98	12.9	7.4	3.6	1.8						
							7.02	11.9	7.0	4.2	2.5	71.5	70.5	142.0	1.00	469	469
							5.05	7.7	4.3	2.6	1.6						
							6.99	12.7	8.5	5.4	3.0	71.5	70.5	142.3	1.00	433	442
							5.00	8.1	5.5	3.5	2.0						
							6.99	3.4	2.0	1.9	1.3	115.3	64.6	179.9	1.28	2167	2687
							5.04	2.5	1.5	1.3	0.9						
	S/G	Silty gravelly sand	29				7.02	3.6	2.0	1.2	0.8	90.0	64.4	154.4	1.08	2030	2192
		Depth = 34 in.	22				4.99	2.4	1.4	0.8	0.6						
	S/G	Sand (fine)	27				6.99	9.8	5.1	3.4	2.1	90.0	67.8	157.6	1.08	594	642
							5.03	6.5	3.6	2.4	1.5						
							6.99	7.7	5.9	4.3	2.8	88.0	70.5	158.5	1.10	843	927
							5.05	5.4	4.1	3.0	2.0						
							7.03	12.8	9.1	6.4	4.0	90.0	70.5	160.5	1.11	523	581
							4.99	8.9	6.4	4.5	2.8						
							7.02	17.9	9.3	5.8	3.6	--	--	--	1.00	313	313
							5.08	11.7	6.3	4.0	2.4						
	S/G	Lean clay	--				7.11	15.6	10.6	6.8	3.7	108.0	73.8	181.8	1.14	339	386
							5.04	9.5	6.2	4.3	2.6						

Table 3

Data obtained from Rigid Pavement Test Sites

Site Number	PCB Thickness Correlated		Layer 1		Layer 2		Layer 3		Nondestructive Data				Deflection Ratio		Relative Stiffness
	Thickness in.	Strength psi	Thickness in.	Material	CBR percent	Thickness in.	Material	CBR percent	Load P_0 kips	Δ_0 mils	Δ_{18} mils	Δ_{30} mils	Δ_{48} kips/in.	Δ_{18} in.	
E5	7.0	911	S/G	Silty sand	9	190			6.91	8.5	6.4	5.5	4.0	0.625	40.0
E11	8.5	765	S/G	Sandy clay	5	115			5.01	6.5	4.5	3.8	2.8	0.696	47.9
E16	8.0	660	S/G	Sandy clay	6	130			6.80	6.6	5.6	5.0	3.9	0.612	38.6
P1	7.25	970	S/G	Sandy clay	10	200			4.99	4.7	4.3	3.6	2.8	0.60	37.5
P2	6.5	1035	S/G	Sandy clay	9	190			7.07	6.2	4.9	4.1	3.0	0.588	36.6
P3	7.5	975	S/G	Sandy clay	5	115			5.12	4.5	3.6	2.9	2.1	0.714	50.7
P4	8.0	775	15.0	Heavy clay	5	165	S/G	Lean clay	6	6.97	6.7	5.5	4.7	0.709	49.8
P5	8.0	830	S/G	Lean clay	8	170			5.06	4.9	4.0	3.4	2.9	0.704	49.0
P7	7.3	875	S/G	Lean clay	58	300			6.99	8.8	5.4	4.6	3.8	0.648	42.3
P9	7.2	970	S/G	Lean clay	10	200			5.24	6.4	3.9	3.3	2.8	0.691	47.1
P10	7.5	940	S/G	Silty sand	6	75			6.97	7.5	5.4	4.3	3.5	0.740	53.8
P11	7.25	970	S/G	Lean clay	16	270			5.08	5.3	3.9	3.2	2.6	0.667	54.6
P13	7.5	860	S/G	Lean clay	8	170			6.87	9.4	5.5	4.5	3.8	0.655	43.0
P15	8.0	755	0.25	Asphalt slabjacking	--	--	S/G	Silty sand	39	5.02	6.5	4.0	3.3	0.639	41.3
P21	7.2	780	S/G	Heavy clay	4	130			5.21	7.7	5.8	5.0	4.3	0.633	40.7
W9	5.75	645	6.0	Clay gravel	75	350	S/G	Lean clay	31	6.95	5.3	3.6	2.9	0.475	39.2
W10	5.5	730	7.0	Clay gravel	75	450	S/G	Lean clay	55	5.08	3.8	2.6	2.0	0.484	29.9
W11	6.0	800	10.0	Clay gravel	76	350	S/G	Lean clay	38	6.97	6.2	4.9	3.9	0.515	31.5
W12	6.25	860	11.0	Clay gravel	81	400	S/G	Lean clay	44	4.99	4.4	3.5	2.8	0.588	36.6
W13	5.6	875	2.0	Clay gravel	--	200	S/G	Silty clay	10	7.02	10.3	6.1	4.8	0.471	29.1
W14	7.5	770	S/G	Silty clay	6	130			4.96	7.2	4.2	3.1	2.0	0.600	37.5
K11	12.5	724	Fill	Sandy gravel	--	460			7.00	6.0	3.1	2.3	1.5	0.64	41.3
K12	15.2	763	Fill	Sandy gravel	--	340			7.02	5.5	3.3	2.6	1.7	0.73	52.2
K13	11.0	565	12.0	Sandy gravel	--	220	11.0	Sandy gravel	--	4.97	3.9	2.3	1.8	0.72	50.7
							S/G	Clayey sand	--	7.00	6.7	5.1	4.0		
										5.00	4.9	3.5	2.7		
										7.00	6.8	5.0	4.3		
										5.00	4.7	3.5	3.0		
										6.98	3.4	1.1	0.9		
										5.01	2.4	0.8	0.6		
										6.94	2.8	1.1	1.0		
										5.06	2.0	0.8	0.7		
										7.04	4.8	3.2	2.8		
										5.07	3.4	2.3	2.0		

(Continued)

* Test sites where both a CBR and k are given indicate locations where CBR measurements were taken and converted to k values. Locations where only k values are given indicate the results of plate-bearing testing.

Table 3 (Concluded)

Site Number	PCC Thickness		Correlated		Layer 1		Layer 2		Layer 3		Nondestructive Data						Deflection		Radius of Relative Stiffness in.
	Thickness in.	Flexural Strength psi	Thickness in.	CBR Percent	k psi	Thickness in.	Material	CBR Percent	Thickness in.	Material	Load kips	Δ_0 in.	Δ_{18} in.	Δ_{30} in.	Δ_{48} in.	DSH kips/in.	Δ_{18} in.		
R14	15.0	575	25.0	--	292	S/G	Sandy gravel	--	--	--	6.97	4.7	4.6	4.5	4.2	1393	0.91	107	
R15	13.0	541	16.0	--	340	S/G	Sandy gravel	--	--	--	7.00	2.8	1.4	1.2	0.9	2463	0.64	41.8	
R16	12.5	615	25.5	--	370	S/G	Gravelly sand	--	--	--	7.16	2.8	1.2	1.1	0.9	2488	0.75	55.3	
R17	15.25	570	6.0	--	320	21.75	Gravelly sand	--	S/G	Silty sand	7.08	3.1	1.2	0.9	0.7	2000	0.58	35.9	
R18	13.5	516	23.5	--	450	S/G	Gravelly sand	--	--	--	5.08	2.1	0.9	0.8	0.7	1593	0.69	47.0	
R19	11.25	614	S/G	--	330	S/G	Sand	--	--	--	7.10	4.2	1.3	1.2	0.9	1593	0.69	47.0	
											4.87	2.8	0.9	0.8	0.7	1683	0.55	33.6	
											5.04	3.0	1.6	1.4	1.1				

Site Number	AC Pavement Thickness in.	PCC Pavement		Thickness in.	Layer 1		CBR percent	Layer 2	
		Thickness in.	Correlated Flexural Strength psi		Material			Thickness in.	Material
E4	5.0	6.0	770	Subgrade	Sandy clay		5		
E19	3.75	11.25	640	11.0	Lean clay		7	Subgrade	Heavy clay
E20	7.5	8.5	750	Subgrade	Heavy clay		3		
E21	4.75	8.0	750	3.25	Sand gravel		37	10.0	Crushed stone
P6	6.25	7.25	860	Subgrade	Sandy clay		47		
P8	1.25	7.7	915	Subgrade	Sandy clay		6		
P12	5.0	7.7	940	Subgrade	Sandy clay		4		
P14	4.0	7.0	940	1.5	Asphalt Slabjacking		--	Subgrade	Silty sand
P16	5.5	7.4	950	Subgrade	Silty sand		39		
P17	6.5	7.0	925	0.5	Asphalt		--	Subgrade	Heavy clay
P18	6.5	7.0	925	0.5	Asphalt		--	Subgrade	Heavy clay
P19	6.75	7.5	915	1.25	Asphalt		--	Subgrade	Heavy clay
P20	6.25	7.1	910	Subgrade	Heavy clay		1.0		

* If thickness <3.0 in., correction factor = 1.0.

(1)

Table 4
Data Obtained from Composite Pavement Test Sites

Thickness in.	Layer 2		Thickness in.	Layer 3		Thickness in.	Layer 4		Loc ki
	Material	CBR percent		Material	CBR percent		Material	CBR percent	
Subgrade	Heavy clay	8							6.0 5.0
10.0	Crushed stone	--	5.0	Silty clay	42	Subgrade	Lean clay	11	6.0 4.0 6.0 5.0 6.0 5.0 6.0 5.0 7.0 5.0 7.0 5.0 6.0 5.0 6.0 5.0 7.0 5.0
Subgrade	Silty sand	70+							
Subgrade	Heavy clay	9							
Subgrade	Heavy clay	5							
Subgrade	Heavy clay	1.0							

2

ID	CBR percent	Nondestructive Data					Temperature Data			Temperature Correction Factor*	Measured DSM kips/in.	Corrected DSM kips/in.
		Load kips	Δ_0 mils	Δ_{18} mils	Δ_{30} mils	Δ_{48} mils	Surface °F	5-Day Mean °F	Surface + 5-Day Mean °F			
11	6.87	8.7	5.8	4.2	2.1		95.0	61.7	156.7	1.07	659	605
	5.09	6.0	4.0	2.9	1.5							
	6.86	4.5	4.2	3.0	2.4		86.7	63.7	150.4	1.05	1300	1235
	5.04	3.1	2.9	2.2	1.7							
	7.08	7.4	4.7	3.5	2.2		66.0	62.4	128.4	0.97	800	776
	5.08	4.9	3.3	2.5	1.6							
	6.86	3.8	3.1	2.7	2.0		73.0	62.4	135.4	1.01	1709	1686
	4.98	2.7	2.2	1.9	1.5							
	6.98	3.0	1.8	1.2	0.9		98.2	73.1	171.3	1.16	1790	2076
	5.19	2.0	1.2	0.9	0.6							
	6.95	5.8	5.1	4.2	3.5		89.5	73.1	162.6	1.00	1088	1088
	5.21	4.2	3.7	3.0	2.5							
	6.99	4.1	2.9	2.5	2.1		103.0	73.1	176.1	1.17	1477	1728
	5.07	2.8	2.0	1.7	1.5							
	7.04	5.0	3.7	2.9	2.3		92.4	73.1	165.5	1.11	1273	1413
	5.13	3.5	2.6	2.0	1.6							
	7.00	3.3	2.4	1.9	1.5		95.1	73.1	168.2	1.14	1960	2204
	5.04	2.3	1.7	1.3	1.0							
	7.13	5.5	4.3	3.6	2.9		97.5	73.1	170.6	1.16	1176	1336
	5.13	3.8	3.0	2.5	2.0							
	6.89	5.7	4.5	3.8	3.1		91.5	73.1	176.1	1.19	1156	1326
	5.04	4.1	3.3	2.8	2.3							
	6.98	7.7	6.3	5.4	4.6		114.0	73.1	187.1	1.26	800	988
	5.14	5.4	4.4	3.9	3.3							
	7.04	5.0	4.2	3.5	3.0		87.0	73.1	166.9	1.14	1329	1505
	5.18	3.6	3.1	2.6	2.2							

(B)

Table 5

DSM-MPT Data from WES Temperature Study

Dates	Site W-1		Site W-2		Site W-3		Site W-4		Site W-5	
	MPT °F	DSM kips/in.	MPT °F	DSM kips/in.	MPT °F	DSM kips/in.	MPT °F	DSM kips/in.	MPT °F	DSM kips/in.
13 Aug 80	111.2	328	115.4	316	115.1	648	116.2	433	116.7	382
8 Sep 80	104.0	386	115.2	438	111.2	659	112.7	505	113.4	412
23 Sep 80	102.7	343	111.3	462	101.5	641	102.6	462	104.9	472
3 Oct 80	81.5	410	87.4	468	85.7	690	86.6	588	87.4	529
23 Oct 80	83.7	392	94.0	455	90.9	712	91.6	623	89.4	532
6 Nov 80	73.5	465	76.9	493	79.6	754	80.3	594	80.5	238
5 Dec 80	66.8	450	72.1	428	71.1	619	72.6	495	71.4	383
22 Jan 81	45.1	394	45.1	404	49.9	579	49.6	497	50.3	400
6 Feb 81	51.0	411	53.1	414	51.8	573	53.2	489	52.3	420
17 Mar 81	75.5	335	82.3	431	79.6	551	80.5	442	81.0	351
8 Apr 81	80.9	311	82.2	386	82.2	503	84.8	391	86.1	450
4 May 81	89.9	307	94.2	474	91.1	623	92.9	543	95.2	491

Table 6
Calculated DSM Temperature Correction Factors

<u>Mean Pavement Temperature, °F</u>	<u>"Best Fit" DSM kips/in.</u>	<u>DSM Temperature Correction Factor</u>
<u>Site W-1</u>		
140	231.4	1.79
135	244.5	1.70
130	257.6	1.61
125	270.7	1.53
120	283.8	1.46
115	296.9	1.40
110	309.97	1.34
105	323.1	1.28
100	336.2	1.23
95	349.2	1.19
90	362.4	1.14
85	375.4	1.10
80	388.5	1.07
75	401.6	1.03
70	414.7	1.00
65	427.8	0.97
60	440.9	0.94
55	454.0	0.91
50	467.1	0.89
45	480.2	0.86
40	493.3	0.84
<u>Site W-3</u>		
140	485.0	1.41
135	499.3	1.37
130	513.5	1.33
125	527.8	1.30
120	542.0	1.26
115	556.3	1.23
110	570.5	1.20
105	584.8	1.17
100	599.0	1.14
95	613.3	1.12
90	627.5	1.09
85	641.8	1.07
80	656.0	1.04
75	670.3	1.02
70	684.5	1.00
65	698.8	0.98
60	713.0	0.96
55	727.3	0.94
50	741.5	0.92
45	755.8	0.91
40	770.0	0.89

Table 7
Equivalency Factors to Convert Pavements
to Equivalent Subbase*

<u>Material</u>	<u>Equivalency Factor</u>
AC	2.30
Crushed stone (100 CBR)	2.00
Stabilized gravel	2.00
Stabilized sand	1.50
Unbound granular material	1.00
Subbase	1.00

* Reference: TM 5-822-5, para 7-5.

Table 8
Relationship Between Flexible Pavement Design
Index and Equivalent Passes of the Standard
Axle Loading

<u>Design Index</u>	<u>Equivalent 18,000-lb</u> <u>Axle Load Passes</u>
1	3,100
2	13,500
3	59,000
4	260,000
5	1,150,000
6	5,000,000
7	22,500,000
8	100,000,000
9	440,000,000
10	2,000,000,000

Adapted from U. S. Army Engineer Waterways Experiment
Experiment Station Technical Report 3-582, Aug 1961.

Table 9
Relationship Between Rigid Pavement Design Index
and Equivalent Passes of the Standard Axle
Loading

Rigid Pavement Design Index	Equivalent 18,000-lb Axle Load Passes	Range of Equivalent Passes	
		Minimum	Maximum
1	26.4	1	119
2	475.2	119	1,584
3	8,580	1,584	34,320
4	125,400	34,320	343,200
5	924,000	343,200	2,112,000
6	4,752,000	2,112,000	9,240,000
7	19,536,000	9,240,000	36,960,000
8	66,000,000	36,960,000	105,600,000
9	184,800,000	105,600,000	290,400,000
10	501,600,000	290,400,000	792,000,000

(From: Table 6, Ohio River Division Laboratories, Technical Report No. 4-18, July 1961.)

Table 10
Vehicle Groups

Group Number	Vehicles
1	Passenger cars and panel and pickup trucks
2	Two-axle trucks and buses Forklift trucks, <5,000 lb Track vehicles, <20,000 lb
3	3-, 4-, and 5-axle trucks Forklift trucks, 5,000-10,000 lb Track vehicles, 20,000-40,000 lb
4	Forklift trucks, 10,000-15,000 lb Track vehicles, 40,000-60,000 lb
5	Forklift trucks, 15,000-20,000 lb Track vehicles, 60,000-90,000 lb
6	Forklift trucks, 20,000-35,000 lb Track vehicles, 90,000-120,000 lb

Table 11
Equivalent Operations Factors for Vehicle Groups by Axle Load or Gross Weight

Axle Load kips	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		
	Passenger Cars and Panel and Pickup Trucks	2-Axle Trucks	Fork- lifts <5 kips	Tracked Vehicle <20 kips	3-, 4- 5-Axle Trucks	Forklifts 5-10 kips	Tracked Vehicle 20-40 kips	Forklifts 10-15 kips	Tracked Vehicle 40-60 kips	Forklifts 15-10 kips	Tracked Vehicle 60-90 kips	Forklifts 20-35 kips	Tracked Vehicle 90-120 kips
		0		Δ			Δ		Δ		Δ		Δ
1	.00017		.00019	.00069	.00023								
2	.00048		.0005	.0014	.00049								
4	.0022		.0022	.0052	.0017								
6	.010	.013		.0115	.0046	.0084							
8	.029	.032		.026	.0098	.0218							
10	.066	.068		.048	.019	.057		.057					
12		.15		.104	.083			.143					
14		.28		.182	.055			.30		.30			
16		.56		.30	.14			.53		.54			
18		1.00		.71	.21					1.07			
20		1.76			.36		.28			1.79		1.73	
25		6.90			1.00		.71					5.70	
30		22.20			2.30		1.66					18.00	
36					6.40		6.38					61.5	
40					11.0		11.30		11.30			129.0	
50					43.0				41.00				
60											52.6		
70											134.5		
80											427.0		
90											1030.0		1030.0
100													2375.0
120													9500.0

Adapted from Table 8, WES TR 3-582, Aug 1961.

Table 12
Equivalent Operations Factors for Vehicle Groups

<u>Group</u>	<u>Vehicle</u>	<u>Equivalent Operations Factor</u>	
1	Passenger cars and panel and pickup trucks	0.025	
2	Two-axle trucks and buses Forklift trucks, 5 kips Track vehicles, 20 kips	3.5	
3	3-, 4-, and 5-axle trucks Forklift trucks, 5-10 kips Track vehicles, 20-40 kips	8.2	
4	Forklift trucks, 10-15 kips Track vehicles, 40-60 kips	0.36 29.0	29.0*
5	Forklift trucks, 15-20 kips Track vehicles, 60-90 kips	1.3 480.0	480.0*
6	Forklift trucks, 20-35 kips Track vehicles, 90-120 kips	52.0 5,700.0	5,700.0*

* If no breakdown between forklift trucks and track vehicles is available use the equivalent operations factor for the track vehicle.

APPENDIX A

EXAMPLE EVALUATION AND OVERLAY DESIGN, FLEXIBLE PAVEMENTS

Required Information and Test Data

1. A nondestructive pavement evaluation and overlay design are to be made on a section of roadway for the following conditions:

Pavement structure

<u>Layer</u>	<u>Material</u>	<u>Thickness, in.</u>
Surface	Asphaltic concrete	3.0
Base	Crushed stone	6.0
Subbase	Clay gravel	6.0
Subgrade	Lean clay	--

Traffic data (Daily traffic obtained from traffic count)

<u>Group</u>	<u>Vehicle Type</u>	<u>Average Daily Traffic/Lane</u>
1	Passenger car and panel and pickup trucks	100
2	2-axle trucks and buses	10
	Forklift trucks, <5 kips	0
	Track vehicles, <20 kips	0
3	3-, 4-, and 5-axle trucks (40-kip gross weight)	35
	Forklift trucks, 5-10 kips	0
	Track vehicles, 20-40 kips (25-kip gross weight)	1
4	Forklift trucks, 10-15 kips (15-kip gross weight)	1
	Track vehicles, 40-60 kips	0

Convert current traffic to standard axle load passes

2. The current average daily traffic is converted to equivalent standard axle load passes using the equivalent operation factors in Tables 11 and 12, main text.

<u>Group</u>	<u>Vehicle Type</u>	<u>Vehicles/Day</u>	<u>Equivalent Operations Factor</u>	<u>Standard Axle Load Passes</u>
1	Passenger cars and panel and pickup trucks	100	0.025*	2.5
2	2-axle trucks	10	3.5*	35
3	3-, 4-, and 5-axle trucks (40-kip gross weight)	35	11.0*	385
	Forklift trucks, <5 kips	0		
	Track vehicles, <20 kips	0		
4	Forklift trucks, 10-15 kips (15-kip gross weight)	1	0.43**	0.4
	Track vehicles, 40-60 kips	0		
Total equivalent standard axle load passes				423

Current daily traffic number = CDTN = 423.

* Equivalent operations factor from Table 12.

** Equivalent operations factor from Table 11.

Estimate of future traffic for overlay design

3. Based on a recent traffic-volume study it is estimated that 5,000,000 equivalent standard axle load passes will use this roadway in the next 20 years.

Test data

4. The NODET test data obtained on the roadway are transferred from the data tape to the NODET flexible pavement data sheet as shown in Figure A1. Notice that two lines are required for each test location on this data sheet. The 7-kip load data are normally recorded on the first line and the 5-kip data recorded on the second line.

Calculation of temperature correction factor

5. The DSM temperature correction factor is calculated as shown in Figure A2 and placed in the appropriate column of the NDT data sheet.

DSM calculation and correction for temperature effects

6. The DSM is calculated from the NODET load-deflection data and recorded in the proper column of the data sheet. Each DSM value is then multiplied by the DSM temperature correction factor to obtain the corrected

Facility: WES														
Branch: Road B														
Date: 2 MARCH 1963														
Page 1 of 4														
NDT Data Sheet: Flexible Pavements														
Section Number	Station Number	Test Number	Load kips	Deflection Δ , mils, at				AC Thickness in.	Pavement Surface Temperature of	Previous 5-Day Mean Air Temperature of	Surface + 5-Day Mean Temperature of	Dsh* kips/in	Temperature Correction Factor	Corrected DSM** kips/in.
				0 in.	18 in.	30 in.	48 in.							
1	0466	174	6.95	2.4	2.3	1.5	0.8	3.0	57.0	55.3	112.3	743	0.75	706
			5.24	5.1	2.1	1.1	0.6							
	1466	175	7.14	2.2	3.7	1.8	0.7					641		609
			5.09	6.0	2.5	1.2	0.6							
	2464	176	7.65	11.6	5.3	2.7	1.4					457		434
			5.13	7.4	3.5	1.8	1.0							
	3464	177	7.14	2.6	3.9	1.6	0.7					666		652
			5.15	6.7	2.6	1.1	0.5							
	4460	178	7.17	2.4	1.9	1.0	0.5					582		559
			5.17	5.0	1.3	0.7	0.4							
	5463	224	7.04	5.4	2.1	1.3	0.6					574		564
			5.01	4.9	1.5	0.8	0.4							
	6465	179	7.02	16.0	6.0	1.2	0.6					622		591
			5.03	6.8	4.1	0.8	0.5							
	7462	223	7.14	2.2	4.6	1.3	0.6					645		613
			5.01	5.7	3.1	0.8	0.4							
	8463	180	7.00	2.1	5.2	1.1	0.5					714		667
			5.10	6.4	4.5	0.7	0.4							
	9462	222	6.46	7.4	2.3	1.2	0.6					733		628
			4.98	4.7	1.7	0.8	0.3							
	10465	181	6.74	7.7	6.0	1.8	0.7					668		635
			5.11	4.9	4.1	0.6	0.3							
	11462	221	7.32	4.5	5.0	1.3	0.5					664		621
			4.92	5.9	1.6	0.8	0.4							

* $DSM = [(F_1 - F_2)/(D_1 - D_2)] \times 1000$
 ** Corrected $DSM = DSM \times$ temperature correction factor.

Figure A1. Example NDT flexible pavement data sheet

NDT Data Sheet: Flexible Pavements														
Facility: WES		Date: 2 MAR 1983												
Branch: ROAD B		Page 2 of 4												
Section Number	Station Number	Test Number	Load kips	Deflection Δ, mils, at				AC Thickness in.	Pavement Surface Temperature of	Previous 5-Day Mean Air Temperature of	Surface + 5-Day Mean Temperature of	DSM* kips/in	Temperature Correction Factor	Corrected DSM** kips/in.
				0 in.	18 in.	30 in.	48 in.							
1	12+01	182	7.05	10.6	3.7	1.2	0.5	3.0	57.0	55.3	112.3	53.5	0.75	56.8
			5.67	6.9	4.4	0.8	0.4							
	13+00	220	7.36	7.0	3.1	1.9	1.0							
			4.96	5.4	2.1	1.2	0.6					66.7		67.4
	14+01	183	6.44	8.9	4.2	1.5	0.8							
			5.06	5.7	3.5	1.1	0.6					62.7		52.6
	14+87	219	7.37	7.5	2.1	1.3	0.7							
			5.66	4.7	1.3	0.8	0.5					85.4		91.1
	16+01	184	6.77	7.5	4.7	1.3	0.5							
			5.00	5.5	3.7	0.7	0.3					77.5		94.5
2	16+22	218	7.66	7.0	2.0	0.9	0.5							
			4.49	4.5	1.0	0.5	0.3					52.8		78.7
	18+03	185	7.03	11.2	6.8	1.5	0.6							
			4.77	7.3	4.1	1.1	0.5					52.8		50.2
	19+02	217	6.72	7.8	4.2	1.1	0.6							
			5.00	5.0	1.6	0.8	0.4					68.5		65.1
	20+00	186	6.46	10.6	6.4	1.6	0.8							
			5.02	6.8	3.7	1.2	0.6					51.6		44.0
	21+03	215	6.45	10.1	5.6	0.9	0.5							
			5.17	6.8	5.0	0.6	0.3					53.3		56.6
	22+35	187	7.07	8.4	7.7	1.4	0.6							
			5.14	5.7	6.2	1.0	0.4					71.5		67.9
	22+89	214	7.04	8.6	4.9	1.0	0.6							
			5.07	5.6	3.1	0.7	0.4					65.7		62.4

* $DSM = [(F_1 - F_2)/(D_1 - D_2)] \times 1000$

** Corrected DSM = DSM $\times$ temperature correction factor.

* DSM = $[(F_1 - F_2)/(D_1 - D_2)] \times 1000$

** Corrected DSM = DSM $\times$ temperature correction factor.

Figure A1. (Continued)

NDF Data Sheet: Flexible Pavements														
Facility: WES		Date: 2 MAR 11 1983												
Branch: Road B		Page 3 of 4												
Section Number	Station Number	Test Number	Load kips	Deflection Δ , mils. at				AC Thickness in.	Pavement Surface Temperature of	Previous 5-Day Mean Air Temperature of	Surface + 5-Day Mean Temperature of	DSM* kips/in.	Temperature Correction Factor	Corrected DSM** kips/in.
				0 in.	18 in.	30 in.	48 in.							
2	24+01	190	7.01	16.2	5.2	2.3	1.3	3.0	57.0	55.3	112.3	612	0.95	581
			5.05	7.0	4.6	1.4	0.7							
	24+26	213	7.39	7.0	1.9	1.3	0.7		57.0	55.3	112.3	831	0.95	787
			4.98	4.1	1.3	0.8	0.4							
	26+00	191	7.07	9.5	4.5	1.6	0.7		57.6	55.3	112.3	661	0.96	635
			5.02	6.4	2.2	1.2	0.5							
	27+04	212	7.01	10.4	2.6	1.6	0.8					637		612
			5.10	7.4	1.6	1.2	0.6							
	28+05	192	6.93	10.1	6.8	2.6	1.4					668		641
			5.06	7.3	4.4	1.6	0.9							
	28+15	211	7.05	9.1	4.4	1.7	0.7					660		576
			5.07	5.8	2.2	0.8	0.4							
	30+15	193	6.95	15.1	7.8	4.6	2.4					380		345
			5.09	10.2	4.5	3.2	1.7							
	30+23	210	6.99	12.2	3.5	2.2	1.1					554		532
			5.05	9.7	2.8	1.4	0.8							
	32+04	194	7.00	14.2	10.1	3.2	1.2					411		325
			5.11	9.6	4.3	2.0	0.8							
	33+08	202	7.09	10.5	7.7	1.6	0.7					547		527
			4.95	6.6	5.5	1.2	0.5							
	34+20	195	6.94	10.7	6.1	2.4	1.3					422		453
			5.10	6.8	4.6	1.8	0.9							
	35+00	208	6.97	11.3	3.2	1.7	1.0					533		512
			5.05	7.7	2.1	1.3	0.8							

* DSM = $[(F_1 - F_2)/(D_1 - D_2)] \times 1000$
 ** Corrected DSM = DSM $\times$ temperature correction factor.

Figure A1. (Continued)

NDT Data Sheet: Flexible Pavements														
Facility: WES		Date: 2 March 1963												
Branch: Road 8		Page 4 of 4												
Section Number	Station Number	Test Number	Load kips	Deflection Δ , mils. at				AC Thickness in.	Pavement Surface Temperature of	Previous 5-Day Mean Air Temperature of	Surface + 5-Day Mean Temperature of	DSM* kips/in.	Temperature Correction Factor	Corrected DSM** kips/in.
				0 in.	18 in.	30 in.	48 in.							
2	36+14	196	7.00	2.4	5.5	1.9	0.9	3.0	57.6	55.3	112.7	626	0.96	669
			5.19	6.5	4.3	1.3	0.6							
	36+38	207	6.96	7.3	3.8	1.6	0.9					783		756
			5.07	4.9	2.4	1.1	0.6							
	38+15	197	6.95	9.5	4.4	2.0	1.0					606		592
			4.25	6.2	2.7	1.4	0.7							
	38+22	206	7.14	10.2	6.0	2.0	1.0					500		480
			5.19	6.3	4.1	1.2	0.7							
	40+00	199	6.93	12.1	6.5	3.4	1.8					574		551
			5.04	8.7	3.6	2.0	1.2							
	40+26	205	7.03	9.6	4.9	2.0	1.1					574		570
			5.07	6.3	3.4	1.4	0.8							
	42+05	192	6.93	10.9	5.8	2.1	1.1					454		436
			5.16	7.6	4.9	1.5	0.8							
	42+24	204	6.95	9.8	2.3	2.3	1.1					727		698
			5.56	7.2	5.8	1.5	0.7							
	44+06	200	7.09	13.8	9.4	2.7	1.3					420		470
			5.12	9.8	7.9	1.8	1.0							
	44+25	203	7.11	10.7	6.1	2.6	1.4					547		525
			5.03	6.9	5.6	1.5	1.0							
	46+01	201	7.05	14.5	4.6	3.1	1.7					377		362
			5.55	9.2	3.7	2.1	1.2							
	46+55	202	6.90	12.1	6.0	2.7	2.3					495		475
			4.97	8.2	5.5	2.5	1.5							
								4860 = END OF ROAD B						

* $DSM = [(F_1 - F_2)/(D_1 - D_2)] \times 1000$
 ** Corrected DSM = DSM $\times$ temperature correction factor.

Figure A1. (Concluded)

TEMPERATURE CORRECTION FACTOR COMPUTATION SHEET*

Facility: WES
 Branch: ROAD B
 Section: 1 STATIONS 0+00 to 20+00 AND 2 STATIONS 20+00 to 25+00
 Date: 2 MARCH 1983 Time: 0900 - 1000

1. Previous 5-day mean air temperature:	<u>55.3</u> °F
2. Pavement surface temperature:	<u>57.0</u> °F
3. Pavement surface plus previous 5-day mean air temperature:	<u>112.3</u> °F
4. Thickness of AC layer:*	<u>3.0</u> in.
5. Mid-depth of AC layer:	<u>1.5</u> in.
6. Temperature at surface of AC layer:	<u>57.0</u> °F
7. Temperature at mid-depth of AC layer:	<u>60.5</u> °F
8. Temperature at bottom of AC layer:	<u>58.5</u> °F
9. Mean pavement temperature:	<u>58.7</u> °F
10. DSM correction factor:	<u>0.95</u>

EQUATIONS: Line 3 = line 1 + line 2
 Line 5 = line 4 ÷ 2
 Line 9 = (line 6 + line 7 + line 8)/3
 Line 10: Determine from DSM correction factor chart
 (Figure 28, main text)

* Pavement thicknesses less than 3 in. are not corrected for temperature effects.

Figure A2. Example temperature correction factor calculation

DSM, which is recorded in the last column of the data sheet.

Selecting representative DSM values

7. The temperature corrected DSM values are plotted in profile form as shown in Figure A3. The mean DSM and standard deviation for Section 1 is calculated and marked on the DSM profile. The DSM values for Section 2 are variable, and this section was divided into four subsections based on the relative DSM values. The mean DSM and standard deviation for each subsection were calculated and marked on the DSM profile.

Evaluation of Existing Pavement, Section 1

Determine number of allowable standard axle load passes (ASALP)

8. The mean DSM minus one standard deviation ($\bar{x} - \sigma$) for Section 1 is 525 kips/in.

$$\text{ASALP} = \text{antilog} [0.0169 \times (\text{DSM}) - 0.2919] \quad (8, \text{ main text})$$

$$\text{ASALP} = \text{antilog} [0.0169 \times (525) - 0.2919]$$

$$\text{ASALP} = \text{antilog} [8.5806]$$

$$\text{ASALP} = 3.81 \times 10^8 \text{ passes}$$

Convert to allowable daily traffic number (ADTN)

$$\text{ADTN} = \frac{\text{ASALP}}{7,300}$$

$$\text{ADTN} = \frac{3.81 \times 10^8}{7,300}$$

$$\text{ADTN} = 52,153$$

Compare ADTN with current daily traffic number (CDTN)

Is $\text{ADTN} > \text{CDTN}$?

$$\text{ADTN} = 52,153 > \text{CDTN} = 423$$

Yes, pavement is adequate

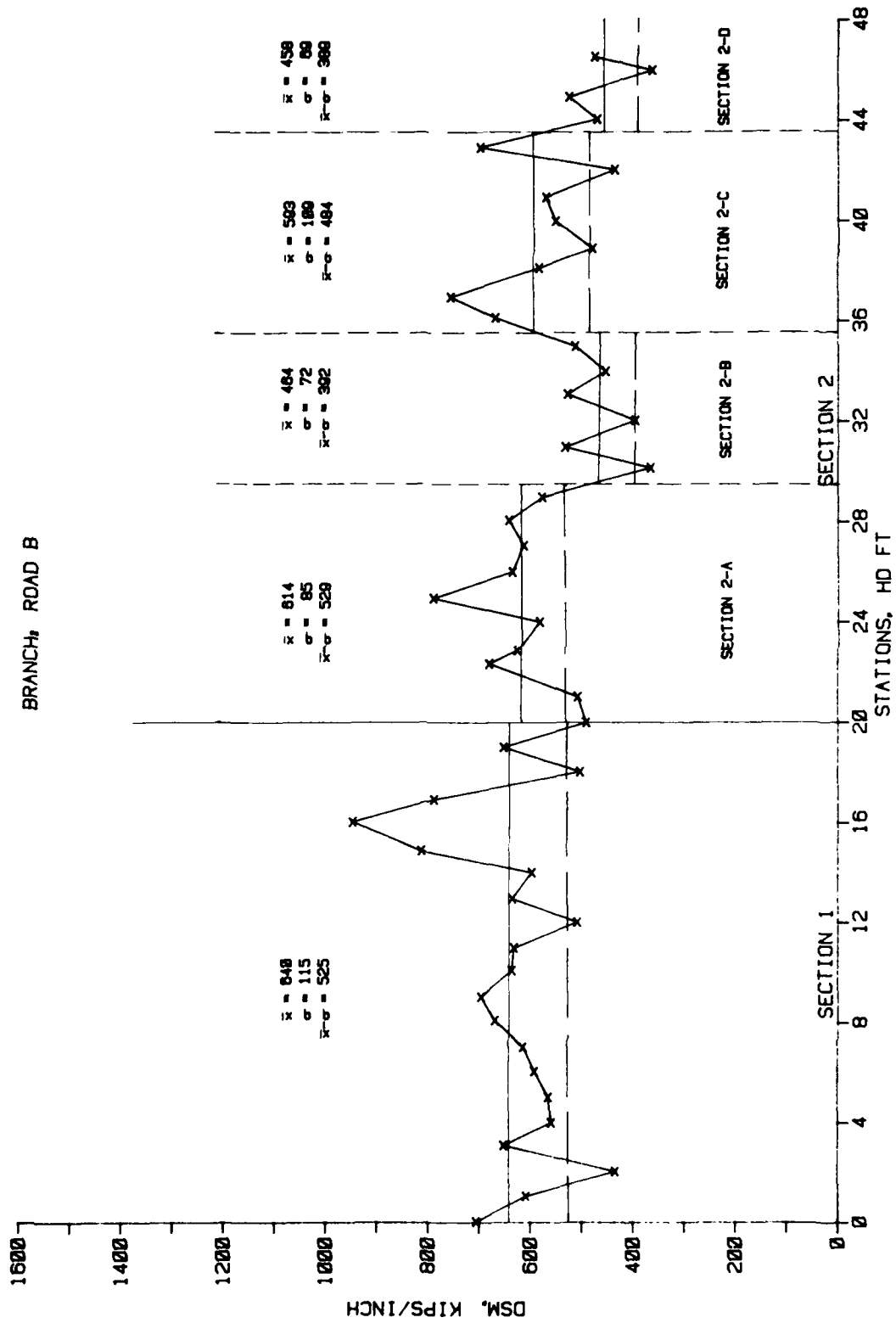


Figure A3. Example DSM profile, flexible pavement

Evaluation of Existing Pavement, Section 2B

Determine the number of allowable standard axle load passes (ASALP)

9. The mean DSM minus one standard deviation ($\bar{x} - \sigma$) for Section 2-B is 392 kips/in.

$$\text{ASALP} = \text{antilog} [0.0169 \times (\text{DSM}) - 0.2919] \quad (8, \text{ main text})$$

$$\text{ASALP} = \text{antilog} [0.0169 \times (392) - 0.2919]$$

$$\text{ASALP} = \text{antilog} [6.3329]$$

$$\text{ASALP} = 2.15 \times 10^6 \text{ passes}$$

Convert ASALP to allowable daily traffic number (ADTN)

$$\text{ADTN} = \frac{\text{ASALP}}{7,300}$$

$$\text{ADTN} = \frac{2.15 \times 10^6}{7,300}$$

$$\text{ADTN} = 295$$

Compare ADTN with current daily traffic number (CDTN)

Is $\text{ADTN} > \text{CDTN}$?

$$\text{ADTN} = 295 < \text{CDTN} = 423$$

No, pavement is not adequate

Pavement Overlay Thickness Design, Section 2B

10. Since the ADTN for Section 2B was less than the CDTN, a strengthening overlay is required.

Compute the total equivalent pavement thickness T_{EQ}

11. The existing pavement is first converted to total equivalent

subbase T_s , using the appropriate equivalency factors selected from Table 7 (main text).

<u>Material</u>	<u>Thickness in.</u>		<u>Equivalency Factor</u>		<u>Equivalent Subbase Thickness in.</u>
AC	3.0	×	2.30	=	6.90
Crushed stone	6.0	×	2.00	=	12.00
Clay gravel	6.0	×	1.00	=	6.00
				T_s =	24.90

12. The total equivalent subbase thickness (inches), $T_s = 24.90$, is then converted to the total equivalent pavement section thickness T_{EQ} .

$$T_{EQ} = T_s - 8.55 \quad (3, \text{ main text})$$

$$T_{EQ} = 24.90 - 8.55$$

$$T_{EQ} = 16.35 \text{ in.}$$

Determine the required pavement thickness T_R

13. Enter the design curves (Figure 32) with the number of allowable SAL passes ($ASALP = 2.15 \times 10^6$) and the equivalent thickness ($T_{EQ} = 16.35 \text{ in.}$) to determine the effective subgrade CBR.

$$CBR = 5.7$$

14. Reenter the design curves (Figure 32) with the estimated future traffic (5,000,000 passes) and the 5.7 CBR to determine the required thickness T_r .

$$T_r = 17.2 \text{ in.}$$

Compute the overlay thickness required

$$T_o = \frac{T_r - T_{EQ}}{2.30} \quad (13)$$

$$T_o = \frac{17.2 - 16.35}{2.30} = \frac{0.85}{2.3}$$

$$T_o = 0.37 \text{ in.}$$

Use $T_o = 1.5$ in. minimum recommended overlay

APPENDIX B

EXAMPLE EVALUATION AND OVERLAY DESIGN, RIGID PAVEMENTS

Required Information and Test Data

1. A nondestructive pavement evaluation and overlay design are to be made on a section of roadway for the following conditions:

Pavement structure

<u>Layer</u>	<u>Material</u>	<u>Thickness, in.</u>
Surface	PCC	8
Base	Clay gravel	6
Subgrade	Sand clay	--

Traffic data, (Daily traffic obtained from traffic count)

<u>Group</u>	<u>Vehicle Type</u>	<u>Average Daily Traffic/Lane</u>
1	Passenger car and panel and pickup trucks	100
2	2-axle trucks and buses	10
	Forklift trucks, <5 kips	0
	Track vehicles, <20 kips	0
3	3-, 4-, and 5-axle trucks	35
	Forklift trucks, 5-10 kips	0
	Track vehicles, 20-40 kips	1
4	Forklift trucks, 10-15 kips (15-kip gross weight)	1
	Track vehicles, 40-60 kips	0

Convert current traffic to standard axle load passes

2. The current average daily traffic is converted to equivalent standard axle load passes using the equivalent operation factors in Tables 11 and 12, main text.

Group	Vehicle Type	Vehicles/Day	Equivalent Operations Factors	Standard Axle Load Passes
1	Passenger cars and panel and pickup trucks	100	0.025*	2.5
2	2-axle trucks	10	3.5*	35
3	3-, 4-, and 5-axle trucks (40-kip gross weight)	35	11.0**	385
	Forklift trucks, <5 kips	0		
	Track vehicles, <20 kips	0		
4	Forklift trucks, 10-15 kips (15-kip gross weight)	1	0.42**	0.4
	Track vehicles, 40-60 kips	0		

Total equivalent standard axle load passes

423

Current daily traffic number = CDTN = 423

* Equivalent operations factor from Table 12.

** Equivalent operations factor from Table 11.

Estimate of future traffic for overlay design

3. Based on a recent traffic-volume study it is estimated that 5,000,000 equivalent standard axle load passes will use this roadway in the next 20 years.

Test data

4. The NODET test data obtained on the roadway are transferred from the data tape to the NODET rigid pavement data sheet as shown in Figure B1. Notice that two lines are required for each test location on this data sheet to facilitate the radius of relative stiffness calculation. The 7-kip load data are normally recorded on the first line and the 5-kip data recorded on the second line.

Calculation of radius of relative stiffness, ℓ

5. The radius of relative stiffness, ℓ , is determined from Figure 31 using the deflection ratio (Δ_{48}/Δ_{18}) calculated from the NODET load-deflection data, as described in paragraph 71, and recorded in the proper column of the NDT data sheet shown in Figure B1.

Selecting representative DSM and ℓ values

6. The DSM and ℓ values are plotted in profile form as shown in

AD-A145 039

NONDESTRUCTIVE VIBRATORY TESTING AND EVALUATION
PROCEDURE FOR MILITARY RO..(U) ARMY ENGINEER WATERWAYS
EXPERIMENT STATION VICKSBURG MS GEOTE... D M COLEMAN
JUL 84 WES/MP/GL-84-9 F/G 13/2

2/2

UNCLASSIFIED

NL

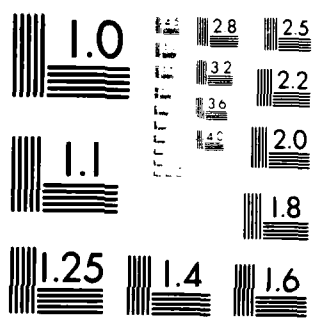
END

DATE

FILED

9 84

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NDF Data Sheet: Rigid Pavement													
Facility: <u>WES</u>				Date: <u>10 MARCH 1983</u>									
Branch: <u>MISSOURI ROAD</u>				Page: <u>1 of 2</u>									
Section Number	Station Number	Test* Number	Load kips	Deflection Δ, mils at				DSM** kips/in.	Deflection Ratio Δ 48" Δ 18"†	Radius of Relative Stiffness, in. ℓ	Remarks		
				0 in.	18 in.	30 in.	48 in.						
<u>1</u>	<u>0+12</u>	<u>25</u>	<u>6.95</u>	<u>4.8</u>	<u>2.9</u>	<u>2.6</u>	<u>1.9</u>	<u>130.7</u>	<u>0.66</u>	<u>41.0</u>			
			<u>4.99</u>	<u>3.3</u>	<u>2.1</u>	<u>1.8</u>	<u>1.3</u>						
	<u>1+12</u>	<u>26</u>	<u>6.91</u>	<u>4.7</u>	<u>2.6</u>	<u>2.4</u>	<u>2.0</u>	<u>121.2</u>	<u>0.77</u>	<u>59.0</u>			
			<u>4.97</u>	<u>3.1</u>	<u>1.9</u>	<u>1.7</u>	<u>1.4</u>						
	<u>2+12</u>	<u>27</u>	<u>6.93</u>	<u>3.9</u>	<u>2.6</u>	<u>2.4</u>	<u>2.1</u>	<u>144.3</u>	<u>0.81</u>	<u>67.0</u>			
			<u>4.91</u>	<u>2.5</u>	<u>1.9</u>	<u>1.7</u>	<u>1.5</u>						
	<u>3+12</u>	<u>28</u>	<u>6.95</u>	<u>5.0</u>	<u>3.0</u>	<u>2.6</u>	<u>1.9</u>	<u>127.3</u>	<u>0.63</u>	<u>40.5</u>			
			<u>5.04</u>	<u>3.5</u>	<u>2.1</u>	<u>1.8</u>	<u>1.3</u>						
	<u>4+12</u>	<u>29</u>	<u>6.85</u>	<u>3.5</u>	<u>2.8</u>	<u>2.5</u>	<u>2.0</u>	<u>144.6</u>	<u>0.71</u>	<u>49.5</u>			
			<u>4.97</u>	<u>2.2</u>	<u>1.9</u>	<u>1.7</u>	<u>1.4</u>						
<u>2</u>	<u>5+12</u>	<u>30</u>	<u>6.94</u>	<u>4.8</u>	<u>2.6</u>	<u>2.4</u>	<u>1.8</u>	<u>89.1</u>	<u>0.69</u>	<u>47.0</u>			
			<u>4.98</u>	<u>2.6</u>	<u>1.8</u>	<u>1.6</u>	<u>1.2</u>						
	<u>6+12</u>	<u>31</u>	<u>6.89</u>	<u>6.9</u>	<u>2.2</u>	<u>2.0</u>	<u>1.5</u>	<u>66.8</u>	<u>0.68</u>	<u>46.0</u>			
			<u>5.02</u>	<u>4.1</u>	<u>1.7</u>	<u>1.4</u>	<u>1.1</u>						
	<u>7+12</u>	<u>32</u>	<u>6.95</u>	<u>5.8</u>	<u>2.0</u>	<u>1.8</u>	<u>1.4</u>	<u>102.1</u>	<u>0.70</u>	<u>48.0</u>			
			<u>5.01</u>	<u>3.9</u>	<u>1.9</u>	<u>1.2</u>	<u>1.0</u>						
	<u>8+12</u>	<u>33</u>	<u>6.96</u>	<u>4.9</u>	<u>2.8</u>	<u>2.6</u>	<u>2.2</u>	<u>90.5</u>	<u>0.79</u>	<u>63.0</u>			
			<u>5.01</u>	<u>2.8</u>	<u>1.9</u>	<u>1.8</u>	<u>1.5</u>						

* One test requires two lines of this form.

** $DSM = [(F_7 - F_5)/(D_7 - D_5)] \times 1000$.

† Deflection ratio is calculated for 7.0-kip load only.

* One test requires two lines of this form.

** $DSM = [(F_7 - F_5)/(D_7 - D_5)] \times 1000$.

† Deflection ratio is calculated for 7.0-kip load only.

Figure B1. Example NDT rigid pavement data sheet

Figure B2. The mean DSM and standard deviation for each section were calculated and marked on the DSM profile. The average ℓ for each section was also calculated and noted on the plot.

Evaluation of Existing Pavement, Section 2

Determine the number of allowable standard axle load passes (ASALP)

7. The mean DSM minus one standard deviation ($\bar{x} - \sigma$) for Section 2 is 666 kips/in. The average ℓ ($\bar{\ell}$) is 40.5 in.

8. Enter the rigid pavement evaluation chart (Figure 33, main text) with the mean DSM and ℓ values.

Mean DSM = 666 kips/in.

Mean ℓ = 40.5 in.

ASALP = 1×10^6 (from Figure 33, main text)

Convert ASALP to allowable daily traffic number (ADTN)

$$\text{ADTN} = \frac{\text{ASALP}}{7,300}$$

$$\text{ADTN} = \frac{1 \times 10^6}{7,300}$$

$$\text{ADTN} = 137$$

Compare ADTN with current daily traffic number (CDTN)

Is $\text{ADTN} > \text{CDTN}$?

$$\text{ADTN} = 137 < \text{CDTN} = 423$$

No, pavement is not adequate

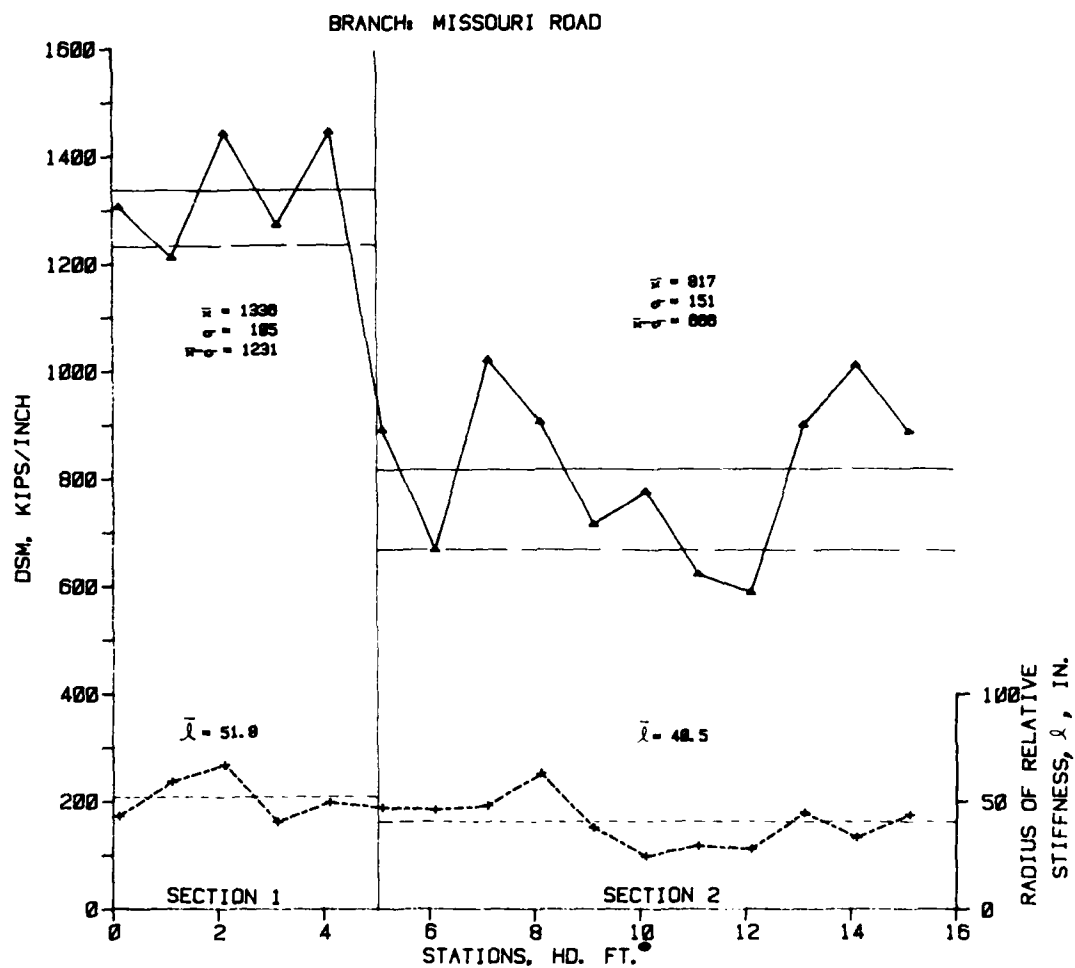


Figure B2. Example DSM profile, rigid pavement

Pavement Overlay Thickness Design, Section 2

9. Since the ADTN for Section 2 is less than the CDTN, a strengthening overlay is required. The overlay design may be for an AC overlay or a PCC overlay.

Determine the required pavement thickness, h_d

10. Enter the rigid pavement design chart (Figure 34, main text) with the existing thickness of 8 in. and the number of allowable passes, 1.0×10^6 . Move vertically to the estimated future pass level, 5×10^6 passes, and determine the required thickness, h_d .

$$h_d = 8.6 \text{ in.}$$

Check the flexural strength

11. Compute the modulus of subgrade reaction, k , for the 8-in. pavement thickness and the 40.5-in. radius of relative stiffness.

$$k = 341005.97 \frac{(h)^3}{(\ell \times 0.7)^4} \quad (14, \text{ main text})$$

$$k = 341005.97 \frac{(8)^3}{(40.5 \times 0.7)^4}$$

$$k = 270 \text{ pci}$$

12. Use the rigid pavement design chart to check the flexural strength. Enter with the existing thickness, 8 in., move to the allowable pass level, 1.0×10^6 , then move vertically to the k determined above (270), then left to the flexural strength.

$$R = 512 \text{ psi}$$

13. The flexural strength is within the expected ranges.

Compute thickness of flexible overlay

14. The required AC overlay (t_o) is computed as follows:

$$t_o = 2.5 (Fh_d - C_b h) \quad (15, \text{main text})$$

$$t_o = 2.5 [(0.92)(8.6) - (0.90)(8.0)]$$

$$t_o = 2.5 [7.91 - 7.2]$$

$$t_o = 2.5 (0.71)$$

$$t_o = 1.8 \text{ in.}$$

Use 4.0 in. in accordance with TM 5-822-6, paragraph 13.8.3 (Headquarters, Department of the Army 1977).

where $F = 0.92$ from Figure 35 and $C_b = 0.90$.

Compute thickness of rigid overlay

15. The thickness of PCC overlay to be placed directly on the existing rigid pavement is computed in the following manner:

$$h_o = 1.4 \sqrt{(h_d)^{1.4} - C_r (h)^{1.4}}$$

$$h_o = 1.4 \sqrt{(8.6)^{1.4} - (0.75)(8)^{1.4}}$$

$$h_o = 3.8 \text{ in.}$$

Use 6.0 in. in accordance with TM 5-822-6, paragraph 13.4.2 (Headquarters, Department of the Army 1977).

where $C_r = 0.75$

Compute thickness of rigid overlay with a leveling or bond-breaking course

$$h_o = \sqrt{h_d^2 - C_r h^2}$$

$$h_o = \sqrt{(8.6)^2 - (0.75)(8)^2}$$

$$h_o = 5.1 \text{ in.}$$

Use 6.0 in accordance with TM 5-822-6, paragraph 13.4.2 (Headquarters, Department of the Army 1977).

APPENDIX C

INSTRUCTION MANUAL FOR THE NODET

by

Darrell E. Elsea, Patrick S. McCaffrey, Jr.

Pavement Systems Division

Geotechnical Laboratory

U. S. Army Engineer Waterways Experiment Station

Vicksburg, Mississippi

Background

1. Facility Engineers (FE's) are responsible for the maintenance, repair, and rehabilitation of roads, streets, and airfields on Army installations. The ability to predict maintenance requirements and to evaluate load-carrying capabilities of these pavements would improve the FE's efficiency through proper allocation of available fundings.

2. To determine the load-carrying capability of these pavements, the U. S. Army Facilities Engineering Support Agency has obtained a Model 2008 Road-Rator. The Road-Rator is an electrohydraulic (electronically controlled hydraulic force generator) nondestructive test device, generally referred to as the NODET. The NODET applies a vibratory sinusoidal force to the pavement surface and measures the resulting response. The force is measured with three load cells mounted on an 18-in.-diam plate that contacts the pavement surface. Deflections are monitored with velocity sensors that measure velocity of the pavement surface. These velocities are integrated electronically to produce deflections.

3. The NODET is contained in a tandem-axle trailer which is towed by a crew-cab pickup truck. A gasoline engine supports the hydraulic and electrical systems. The force-generating system consists of a 4000-lb reaction mass, three load cells, a hydraulic actuator, and air springs for equal load distribution. Figure C1 is a schematic diagram of the force-generating system. A digital control box is connected to the trailer with cables.

4. The NODET is designed to obtain load-deflection measurements of any pavement surface accessible to it and the tow vehicle. After initial setup, successive measurements can be made by the operator(s) without leaving the tow vehicle.

Purpose and Scope

5. This instruction manual describes the operation, calibration, and maintenance procedures for the NODET. It applies only to the operation of the NODET device and does not contain methods for analyzing the data collected. This manual is intended to supplement the owner's manuals for component parts of the NODET.

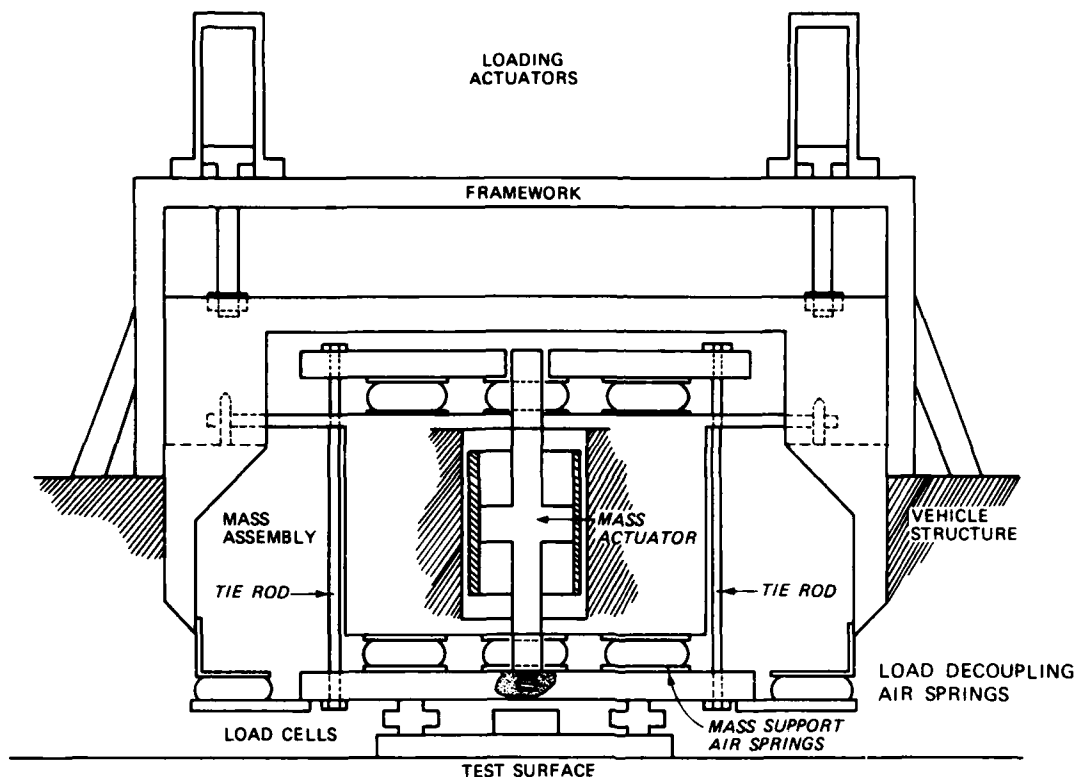


Figure C1. Schematic of the force-generating system

Digital Instrumentation System

6. The NODET digital instrumentation system console contains all the instrumentation controls and readouts necessary for operation. The console includes 16 pushbutton switches arranged in a four by four matrix. Each switch is labeled with an identification of its function. The switch faces are illuminated when active. A layout of the control console is shown in Figure C2, and a description of each control switch is listed below.

SAFE

7. When depressed, this switch renders all operating functions inactive and will automatically raise the force generator to its fully elevated position. When depressed, the switch flashes green. When the switch is not depressed and the force generator is in the fully elevated position, the switch is lighted constantly green and a safety beeper within the console will sound to indicate the SAFE switch is not engaged. When the force generator is not fully elevated, this switch lamp is off, the UNSAFE switch glows red, and

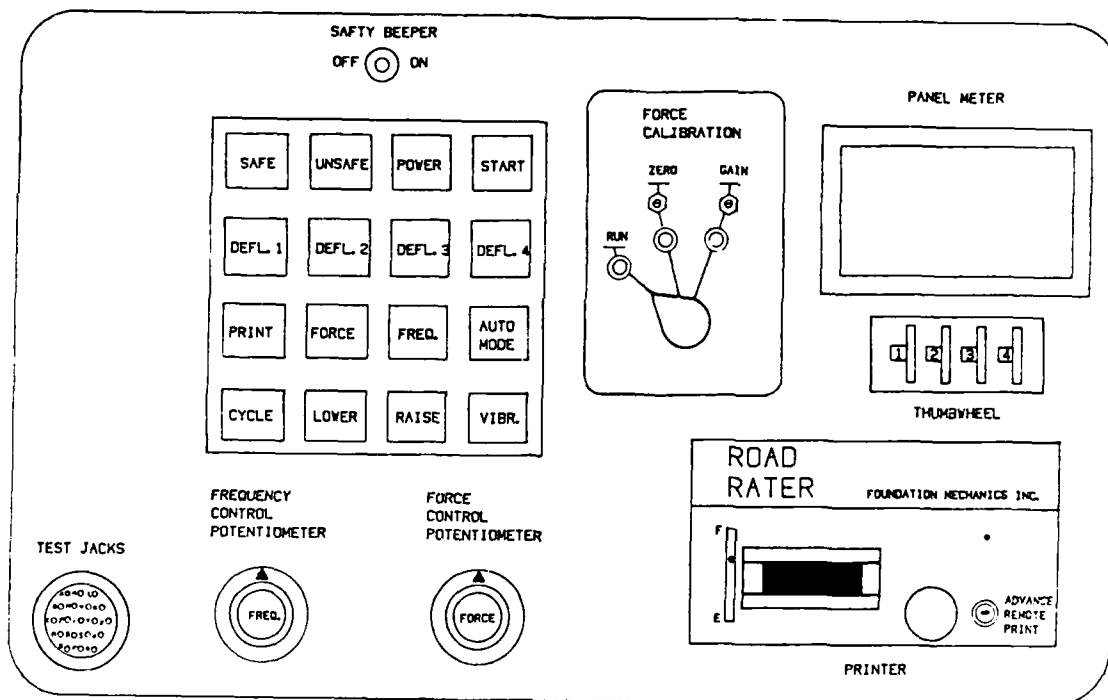


Figure C2. Layout of instrumentation control console

the beeper frequency increases. The SAFE switch should be depressed when moving the tow vehicle. Just above the switch matrix, there is an on-off switch to make the beeper operational.

UNSAFE

8. This switch glows red any time the force generator is not fully elevated. Depressing this switch will stop the automatic cycle at any point and clear all system functions. When the UNSAFE switch is illuminated, the tow vehicle should never be moved.

POWER

9. This switch, when depressed, glows white indicating the system is active. When released, the system is off.

START

10. When depressed, this switch activates the engine starter.

DEFL. 1 through DEFL. 4

11. These switches, when depressed individually, glow white, indicating that the panel meter display is the peak-to-peak deflection, in mils, of the pavement surface at the location of the appropriate numbered velocity sensor.

PRINT

12. When depressed, this switch causes the system to scan and print the following seven functions: (a) identification number, (b) frequency, (c) force, (d) deflection 1, (e) deflection 2, (f) deflection 3, and (g) deflection 4.

FORCE

13. When depressed, this switch glows white indicating the peak-to-peak dynamic force, in kips, is displayed on the panel meter.

FREQ.

14. When depressed, this switch glows white indicating that the frequency of dynamic loading, in Hertz, is displayed on the panel meter.

AUTO MODE

15. When depressed, this switch is staged for automatic operation, and a cycle may then be initiated by depressing the CYCLE switch.

CYCLE

16. When in the automatic mode, depressing the CYCLE switch starts the cycle sequence which (a) lowers the force generator, (b) activates the vibrator to the preset levels of force and frequency, (c) scans and prints, and (d) elevates the force generator to the safe (travel) position.

LOWER

17. This switch, when depressed and held, lowers the force generator.

RAISE

18. This switch, when depressed and held, raises the force generator.

VIBR.

19. This switch, when depressed, activates the hydraulic vibrator to preset levels of force and frequency. It must be noted that before the VIBR. switch is depressed the FORCE CALIBRATION switch, located in the center of the console, must be in the RUN position.

Frequency knob (frequency control potentiometer)

20. When the FREQ. switch is active, the frequency of the dynamic loading is displayed on the panel meter. The force generator does not need to be lowered nor vibrating to change frequency levels. Clockwise rotation of the control increases frequency. The minimum frequency of the NODET is 5 Hz, and the maximum frequency is 50 Hz.

Force knob (force control potentiometer)

21. This control is used to adjust the dynamic force. When the FORCE switch is activated and the force generator is down and vibrating, the level of peak-to-peak dynamic force input to the pavement surface is displayed on the panel meter. Clockwise rotation of this control increases force. The peak-to-peak (P-P) force output of the NODET ranges from 0 to 8,000 lb.

Digital printer

22. The printer provides a permanent record of the test data. The printout format includes function identification, by channel number, as shown below.

<u>Function</u>	<u>Channel No.</u>	<u>Data</u>	<u>Units</u>
I. D. number	1	0036	--
Force	2	3.93	kips P-P
Frequency	3	15.0	Hertz
Deflection	4	19.3	mils P-P
Deflection	5	18.1	mils P-P
Deflection	6	14.7	mils P-P
Deflection	7	9.8	mils P-P

Printer ADVANCE-REMOTE-PRINT switch

23. The printer controls are operated by a toggle switch located on the face of the printer. The switch is spring-centered in REMOTE position. When in this position, the printer is controlled electronically from within the console. When the switch is held in the ADVANCE position, the recording paper advances to provide space for handwritten notes. When the switch is pushed into the PRINT position, the single function displayed on the panel meter will be printed.

Thumb-wheel switch

24. The four-digit thumb-wheel switch is set by the operator to provide an identification number on the data printout. The setting will be printed on channel 1 of the printout on activation of the PRINT switch.

Digital panel meter

25. The panel meter provides a visual display of any of the test data, except I. D. number, by depressing the switch identified with the parameter of interest.

Force calibration

26. The force calibration portion of the console was added by the Instrumentation Services Division of WES to aid in the calibration of the NODET. The force calibration will be discussed in detail later in this manual.

Master switch

27. The electrical power is routed through a master switch which must be turned ON to enable the engine ignition and starter operation. This switch is located inside the NODET trailer, in the front left corner near the engine hour meter. The master switch should be turned off whenever the operator leaves the NODET (with the engine off) for any long period of time. Failure to turn off the master switch may result in a dead battery.

Test jacks

28. A monitor junction containing 19 test jacks is located on the lower left on the control console. After removal of the dust cover, the following parameters of interest can be monitored with the aid of a digital multimeter.

<u>Test Jack</u>	<u>Identifi- cation</u>	<u>Description</u>
A	V1	Raw signal from velocity sensor No. 1
B	V2	Raw signal from velocity sensor No. 2
C	V3	Raw signal from velocity sensor No. 3
D	V4	Raw signal from velocity sensor No. 4
E	F (input)	Raw signal from load cells
F	F (DC)	Force signal to panel meter
G	OSC (HI)	Frequency signal from control box to the mass actuator
H	f (DC)	DC frequency signal to panel meter
J	D1 (+)	
K	+5 VDC	Power supply output
L	GND	Ground
M	D1 (-)	
P	-15 VDC	Power supply output
T	+15 VDC	Power supply output
V	GND	Ground

Operational Preparation

29. All steps necessary to prepare the NODET for operation are described below. Before beginning operation the trailer must be attached to a properly prepared tow vehicle by hitch, safety chains, breakaway brakes, and electrical connections for trailer and brake lights.

Control console hookup

30. Remove the console cover and place the console on its stand in the floor of the tow vehicle. Attach the three control cables to their connectors on the back of the console. Remove the control cable receptacle covers from the rear of the tow vehicle and the front of the NODET and store them. (These covers must be in place at all times when the truck-trailer interconnect cables are not connected to prevent moisture from entering the NODET electrical system.) Attach the truck-trailer interconnect cables to the connectors near the truck bumper and the left front of the trailer, taking care to run the cable through the cable clamps on the trailer tongue.

Velocity sensor hookup

31. The four velocity sensors are marked to indicate their relative position on the NODET, with No. 1 being at the center of the force generator contact plate. Screw sensor No. 1 into the top of the contact plate. The remaining three velocity sensors are suspended from the sensor positioning device under the rear center of the trailer, at distances of 18, 30, and 48 in. from the center of the plate. Route the velocity sensor cables through the force generator opening in the bottom of the trailer in such a manner that they will not be damaged during the operation. A junction box is located in the rear of the trailer just forward of the left side of the fuel tank. Remove the dust covers from the connectors marked 1, 2, 3, and 4. Connect the velocity sensor cables to their respective connector.

Engine preparation

32. Normal engine checks should be made prior to starting the NODET engine. The fuel filler opening and fuel gage are both located on the tank at the rear of the trailer. The engine is located in the front of the trailer with the oil dipstick located on the right side of the engine. The hydraulic fluid reservoir is located in the right front of the trailer. Engine fuel and oil grades and hydraulic fluid specifications are given in the maintenance portion of this manual.

Starting the engine

33. Depress the POWER switch on the control console to its ON position. Move both the master switch and ignition switch on the engine control panel to the ON position. A choke control on the engine control panel can be used if necessary. Start the engine by depressing either the START switch on the control console or the starter button on the engine control panel. The choke control, if used, should be pushed into its run position as soon as possible. Allow the engine to run for 20 to 25 min to allow warmup of the hydraulic fluid and electronics before calibrating force.

Air springs

34. The NODET has eight air springs. Six of these are used to center the mass and transfer the dynamic force to the test surface. Figure C1 shows the position of the air springs. Three are located above and three below the mass. The upper air springs are manifolded together, as are the lower, to equalize the pressure and to provide only two valves for pressurization. Pressurize the lower set of air springs first, with the force generator in the raised position with all pressure off the upper air springs. The lower air springs are pressurized to 90 psi. After the lower air springs have been pressurized, lower the force generator to the ground. With the force generator in the down position, pressurize the upper air springs to 60 psi. Two automotive-type air valves for pressurizing the upper and lower air springs are located on the rear side of the force generator, along with an indicator for determining the mass position. After the lower and upper air springs have been pressurized to 90 and 60 psi, respectively, the reaction mass of the force generator should be in the center position. Recommended pressure should be maintained at all times for the NODET to work properly.

35. The two remaining air springs are located outboard of the force generator on the bottom left and right. These two air springs allow some of the trailer static weight to be transferred to the force generator and minimize vibrator feedback to the trailer. Each of these two air springs has its own air valve, located to the left and right of the force generator, and should be inflated at 40 to 50 psi (45 psi). Figure C3 shows the location of the air valves for pressurizing the air springs.

36. A 12-volt DC-powered air compressor is mounted in the rear of the trailer. It is switch-controlled directly off the engine battery. It

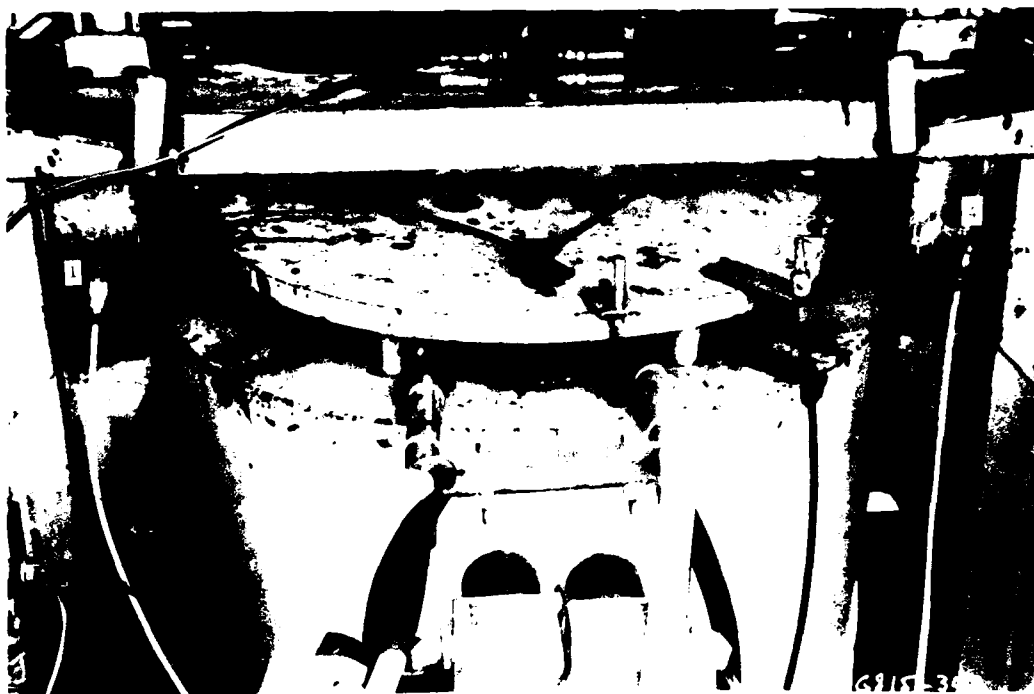


Figure C3. Location of air spring pressurization valves:
 (1) left outboard, (2) upper mass, (3) lower mass,
 (4) right outboard

should not be used unless the engine is running and should be turned off when pressurization of the air springs is complete.

Force Calibration

37. The force calibration of the NODET is very important for accurate pavement load and displacement measurements. The NODET was calibrated at WES by using three BLH load cells sandwiched between two 18-in.-diam steel plates. The NODET was then placed over this sandwich construction and run at frequency ranges of 5 to 50 Hz at 3,000 lb peak to peak. From these data, the value for force calibration is established.

Field force calibration procedures

38. The force calibration on the console has a three-position switch, which is labeled RUN, ZERO, and GAIN. To calibrate the force, the force generator must be in the SAFE position, and the engine should have been running 20 to 25 min. After the warmup period is complete, the following

steps must be taken for proper calibration:

- a. Depress the FORCE switch on the control console to display force calibration values on the panel meter.
- b. With the FORCE CAL. switch in the RUN position, the panel meter displays a value of 0.00 to 0.03. This value is the dynamic force output in the SAFE position.
- c. Set the FORCE CAL. switch to the ZERO position. The value on the panel meter should be the same as in Step b above. If there is a difference, a new ZERO value must be set. To do this, turn the ZERO trimpot one way or the other with a small screwdriver. Bring the panel meter reading toward 0.00; this is a nulling zero. The best calibration accuracy is with the trimpot turned as far clockwise as possible and still obtain a value of 0.00.
- d. Set the FORCE CAL. switch to the GAIN position. To set the force amplified gain, adjust the GAIN trimpot until the panel meter reads the laboratory calibration value of 9.70. This value is printed on the console above the panel meter. This value should be checked at WES annually.
- e. Set the FORCE CAL. switch to the RUN position.

After these steps have been completed, the force system is calibrated. These values should be checked several times a day, usually at midmorning, noon, and midafternoon.

Velocity Sensor Calibration

39. The velocity sensors were calibrated at WES by using a calibrated shake table. Each sensor was vibrated at known deflections, and the NODET electronics were adjusted to that deflection. The calibration of the velocity sensors should be checked at WES at regular intervals of 6 months or 600 operating hours, whichever comes first.

40. No field calibration procedure exists for the velocity sensors. One method of quickly checking the velocity sensors in the field is to place the sensors side by side on the contact plate. Then actuate the vibrator and monitor the deflection values. All velocity sensors should produce approximately the same deflections.

41. The velocity sensors are delicate instruments and should be detached and stored when the NODET is being transported.

Maintenance

Engine

42. The NODET is equipped with a Kohler Model K532, two-cylinder air-cooled engine. For details of the service schedule, the operator should consult the manufacturer's owner's manual. The operator should keep a log noting the date that maintenance or any other type of work is performed on the NODET. Original copies of the owner's manuals should be on file at the operators office, and copies of these manuals should be kept in the tow vehicle, assuming that the same tow vehicle will be used at all times.

Alternator

43. The NODET is equipped with an Onan alternator. For general information and the parts list, see the owner's manual.

Hydraulic fluid

44. The hydraulic fluid used in the NODET must meet the specification, Mil H5606. This is an aircraft hydraulic fluid with a red petroleum base. NO OTHER TYPE OF HYDRAULIC FLUID SHOULD BE USED. Damage will result if hydraulic fluid is substituted. Most airports or airfields have Mil H5606 hydraulic fluid.

45. The hydraulic system is equipped with a disposable filter and a pressure indicator located in the left front corner above the battery. The pressure indicator reads 0 psi when the filter is clean. As the pressure reaches 10 psi or after 100 hours of operation, the filter should be changed. The filter is the UCC brand, part No. UC-MS-1518-4-10.

Step-by-Step Setup Checklist

46. A step-by-step setup checklist is provided below for the convenience of the operator. Paragraph numbers indicate where detailed information may be found.

- a. Connect the trailer to the tow vehicle and attach the safety chains, breakaway brakes, and electrical connections for the trailer and brake lights (paragraph 30).
- b. Attach the three control cables to their connectors in the back of the control console (paragraph 30).
- c. Attach the truck-trailer interconnect cables to the connectors on the truck bumper and the left front of the trailer (paragraph 30).

- d. Attach the four velocity transducers in their proper positions to the transducer positioning device under the rear center of the trailer. Connect the velocity transducer cables to the proper connector on the junction box located in the left rear of the trailer (paragraph 31).
- e. Make normal engine checks including fuel, engine oil, and hydraulic fluid (paragraph 32).
- f. Turn on NODET POWER switch and engine master switch (paragraph 33).
- g. Start the engine and run for 25 min to allow warmup of the hydraulic fluid and electronics (paragraph 33).
- h. Remove locking pins.
- i. Pressurize outboard air springs to 45 psi (paragraphs 34-36).
- j. Release pressure from upper air springs (left valve) and pressurize lower air springs (right valve) to 90 psi (paragraphs 34-36).
- k. Lower force generator and pressurize upper air springs to 60 psi (paragraphs 34-36).
- l. Perform force calibration with force generator fully elevated and in SAFE position (paragraphs 37-38).

Instructions for Using the Bidirectional Distance-Measuring Instrument

47. The NODET tow vehicle is equipped with a Nu-Metrics distance-measuring instrument (DMI) to accurately determine test locations. The DMI display and operating switches are located below the dash just to the right of the driver.

48. The DMI installed in the NODET tow vehicle is a precision electronic instrument designed for computing and displaying measurement data from mobile vehicles. To measure the distance traveled, sensing targets (which are attached to the tow vehicles front wheel rim) move past a sensing head creating electrical pulses. These pulses are conveyed to the DMI via an electrical cable where they are processed and displayed.

Functional controls

49. The DMI has four pushbutton switches, two toggle switches, and a series of four thumb-wheel switches. The functional control switches are:

ON/OFF - Input power switch. This switch turns the unit on and off.

HOLD - Holds all displayed data and stops the count.

- RESET - Returns the display to zero.
- BI-DIR - The bidirectional switch in the out position allows the unit to count additively. When the switch is depressed the unit counts subtractively.
- DATA - The data toggle switch is used for entering data via the thumb-wheel switches.
- SENSOR ON/OFF - This toggle switch located on the lower dash to the left of the driver is used to activate the sensing head.
- THUMB-WHEEL SWITCHES - The thumb-wheel switches located on the DMI unit are used for calibrating the DMI and for entering data.

Operation

50. General. The electronic distance-measuring instrument installed in the NODET tow vehicle is easy to operate. When using the DMI the distance, in feet, along the street can be measured starting from zero at some reference point, or a preestablished station number can be input into the system.

51. The steps involved in using the DMI are:

- a. Check to make sure the correct calibration program number is set in the thumb wheels (see Calibration).
- b. Turn on the unit and sensing head switches.
- c. With the tow vehicle stationary, press the reset switch to clear the display.
- d. Depress the HOLD switch to keep the display at zero.
- e. Upon reaching the point where measurement is to begin, stop the front bumper, driver's door, center of the NODET wheels, or other convenient reference over the beginning point.
- f. Release the HOLD switch and move forward. The display should now be counting additively.
- g. When the end of the section to be measured is reached, depress the HOLD switch to stop the count.

52. Using bidirectional switch. The bidirectional switch permits distances to be subtracted from the displayed measurement. To activate the bidirectional feature press the BI-DIR switch. The display should now count subtractively as the vehicle moves forward. Remember to release the BI-DIR switch when you are ready to count additively again.

53. Using data entry. The data entry toggle switch along with the bidirectional switch allows arbitrary distances, such as a manually measured distance, to be added or subtracted from the display. The data entry function

is also used when measurements begin from some position other than zero. For example, to measure a road in stations, the starting station number is entered into the display; measurements are then made either forward or reverse to locate the next station number or to locate and display a point between stations. The procedure for adding a desired number in the display is:

- a. Stop the vehicle.
- b. Depress the HOLD switch.
- c. Dial the desired number into the thumb-wheel switches.
- d. Throw the toggle switch to the DATA position and then return to normal position. The sum of the initial display and the number entered in the thumb-wheel switches will now appear in the display.
- e. Reenter the calibration program number into the thumb-wheel switches.
- f. Release the HOLD switch.
- g. Resume normal measurement.

To subtract a desired number, press the BI-DIR switch after Step b above. Be sure to release the BI-DIR switch upon completing Step d.

Calibration

54. The DMI must be calibrated to ensure correct operation and accurate measurements. The tire pressure in the tow vehicle should be checked and, if necessary, adjusted to the optimum pressure recommended by the tire manufacturer. For accurate distance measurements, it is important that the tire pressure be maintained within ± 2 lb of the tire pressure used to calibrate the DMI.

55. The first step in calibrating the DMI is to accurately measure a road course using a steel tape. For accurate calibration, the course distance should be a minimum of 1000 ft. It is recommended that permanent reference marks be established at the beginning and end of the course, to provide a permanent calibration course.

56. The actual DMI calibration is performed as follows:

- a. Drive the vehicle to the starting marker.
- b. Depress the DMI power switch to ON and throw the sensing head toggle switch ON.
- c. Set the thumb-wheel switch to 1000, with all the switches OUT except the power switch.
- d. Depress the RESET button to zero the display.

- e. Drive the tow vehicle accurately along the measured course and stop exactly at the stop marker. Make positive starts and stops, DO NOT creep. Note the reading on the DMI, this is your calibration number. Drive the measured course several times. The calibration number should be the same each time. Remember to reset the display prior to driving the course.
- f. Using the 1000-ft calibration table (Table C1), find your calibration number and dial the corresponding Program Number into the thumb-wheel switches. The DMI is now calibrated and the Program Number should be posted on the vehicle dash for future reference. Greater accuracy can be achieved by measuring and driving a calibration course of more than 1000 ft, such as a course of 3000 ft. The calibration number is divided by 3 to enter the calibration chart.
- g. The DMI is now ready to measure distance in feet. Drive the calibration course a number of times. Be sure to start and stop positively without creeping. The DMI should display the actual footage of the course. If your count is 1 ft more or less than 1000 ft, reset the program number 1 digit higher for obtaining more footage, or 1 digit lower for less footage.

Example: Assume the program number is 0836 and over 1000 ft, you record 999 ft. Advance the program number 1 digit to 0837.

Speed is important in making measurements. Always try to measure within ± 5 mph of the speed used in calibration.

57. The DMI can output units other than linear feet. To change the output to miles, meters, or square yards make the following modifications to the program numbers.

Miles and Ten-Thousandths of a Mile:

To measure in miles and ten-thousandths of a mile, divide the program number obtained for feet by 0.528. Dial the result into the thumb-wheel switches.

$$\frac{\text{Program No. (ft)}}{0.528} = \text{Prog. No. (miles and ten-thousandths of a mile)}$$

Meters:

To measure in meters multiply the program number obtained for feet by 0.3048. Enter the result into the thumb-wheel switches.

$$\text{Program No. (ft)} \times 0.3048 = \text{Prog. No. (meters)}$$

Square Yards:

Divide the width of the road by 9 and multiply times the program number obtained for feet.

$$\frac{\text{Road width (ft)}}{9} \times \text{Prog. No. (ft)} = \text{Prog. No. (sq yd)}$$

General Program Number:

$$\frac{\text{Desired reading} \times 1000}{\text{Actual DMI display}} = \text{Program Number (PRM)}$$

Installation and Troubleshooting

58. This section is intended only to be an introduction to the DMI and to give the user guidance in using the DMI that is installed in the NODET tow vehicle. Complete installation instructions, along with a troubleshooting guide, are contained in "Instruction Manual - Nu-Metrics Distance Measuring Instruments" by Nu-Metrics, Connellsville, PA.

Table C1
Calibration Table for DMI Programming (Computed for Calibration of
Fixed Course Distance of 1000 ft)

<u>Calibration</u>	<u>Program</u>	<u>Calibration</u>	<u>Program</u>	<u>Calibration</u>	<u>Program</u>
750	1.333	793	1.261	836	1.196
751	1.332	794	1.260	837	1.195
752	1.330	795	1.258	838	1.193
753	1.328	796	1.256	839	1.192
754	1.326	797	1.255	840	1.191
755	1.325	798	1.253	841	1.189
756	1.323	799	1.252	842	1.188
757	1.321	800	1.250	843	1.186
758	1.319	801	1.249	844	1.185
759	1.318	802	1.247	845	1.184
760	1.316	803	1.245	846	1.182
761	1.314	804	1.244	847	1.181
762	1.312	805	1.242	848	1.179
763	1.311	806	1.241	849	1.178
764	1.309	807	1.239	850	1.177
765	1.307	808	1.238	851	1.175
766	1.306	809	1.236	852	1.174
767	1.304	810	1.235	853	1.172
768	1.302	811	1.233	854	1.171
769	1.300	812	1.232	855	1.170
770	1.299	813	1.230	856	1.168
771	1.297	814	1.229	857	1.167
772	1.295	815	1.227	858	1.166
773	1.294	816	1.226	859	1.164
774	1.292	817	1.224	860	1.163
775	1.290	818	1.223	861	1.162
776	1.289	819	1.221	862	1.160
777	1.287	820	1.220	863	1.159
778	1.285	821	1.218	864	1.158
779	1.284	822	1.217	865	1.156
780	1.282	823	1.215	866	1.155
781	1.281	824	1.214	867	1.154
782	1.279	825	1.212	868	1.152
783	1.277	826	1.211	869	1.151
784	1.276	827	1.209	870	1.150
785	1.274	828	1.208	871	1.148
786	1.272	829	1.206	872	1.147
787	1.271	830	1.205	873	1.146
788	1.269	831	1.203	874	1.144
789	1.268	832	1.202	875	1.143
790	1.266	833	1.201	876	1.142
791	1.264	834	1.199	877	1.140
792	1.263	835	1.198	878	1.139

(Continued)

(Sheet 1 of 6)

Table C1 (Continued)

<u>Calibration</u>	<u>Program</u>	<u>Calibration</u>	<u>Program</u>	<u>Calibration</u>	<u>Program</u>
879	1.138	925	1.081	971	1.030
880	1.136	926	1.080	972	1.029
881	1.135	927	1.079	973	1.028
882	1.134	928	1.078	974	1.027
883	1.133	929	1.077	975	1.026
884	1.131	930	1.075	976	1.025
885	1.130	931	1.074	977	1.024
886	1.129	932	1.073	978	1.023
887	1.127	933	1.072	979	1.022
888	1.126	934	1.071	980	1.021
889	1.125	935	1.070	981	1.019
890	1.124	936	1.068	982	1.018
891	1.122	937	1.067	983	1.017
892	1.121	938	1.066	984	1.016
893	1.120	939	1.065	985	1.015
894	1.119	940	1.064	986	1.014
895	1.117	941	1.063	987	1.013
896	1.116	942	1.062	988	1.012
897	1.115	943	1.061	989	1.011
898	1.114	944	1.059	990	1.010
899	1.112	945	1.058	991	1.009
900	1.111	946	1.057	992	1.008
901	1.110	947	1.056	993	1.007
902	1.109	948	1.055	994	1.006
903	1.108	949	1.054	995	1.005
904	1.106	950	1.053	996	1.004
905	1.105	951	1.052	997	1.003
906	1.104	952	1.051	998	1.002
907	1.103	953	1.049	999	1.001
908	1.101	954	1.048	1000	1.000
909	1.100	955	1.047	1001	0.999
910	1.099	956	1.046	1002	0.998
911	1.098	957	1.045	1003	0.997
912	1.097	958	1.044	1004	0.996
913	1.095	959	1.043	1005	0.995
914	1.094	960	1.042	1006	0.994
915	1.093	961	1.041	1007	0.993
916	1.092	962	1.040	1008	0.992
917	1.091	963	1.039	1009	0.991
818	1.089	964	1.037	1010	0.990
819	1.088	965	1.036	1011	0.989
920	1.087	966	1.035	1012	0.988
921	1.086	967	1.034	1013	0.987
922	1.085	968	1.033	1014	0.986
923	1.084	969	1.032	1015	0.985
924	1.082	970	1.031	1016	0.984

(Continued)

(Sheet 2 of 6)

Table C1 (Continued)

Calibration	Program	Calibration	Program	Calibration	Program
1017	0.983	1063	0.941	1109	0.902
1018	0.982	1064	0.940	1110	0.901
1019	0.981	1065	0.939	1111	0.900
1020	0.980	1066	0.938	1112	0.899
1021	0.980	1067	0.937	1113	0.899
1022	0.979	1068	0.936	1114	0.898
1023	0.978	1069	0.936	1115	0.897
1024	0.977	1070	0.935	1116	0.896
1025	0.976	1071	0.934	1117	0.895
1026	0.975	1072	0.933	1118	0.895
1027	0.974	1073	0.932	1119	0.894
1028	0.973	1074	0.931	1120	0.893
1029	0.972	1075	0.930	1121	0.892
1030	0.971	1076	0.929	1122	0.891
1031	0.970	1077	0.929	1123	0.891
1032	0.969	1078	0.928	1124	0.890
1033	0.968	1079	0.927	1125	0.889
1034	0.967	1080	0.926	1126	0.888
1035	0.966	1081	0.925	1127	0.887
1036	0.965	1082	0.924	1128	0.887
1037	0.964	1083	0.923	1129	0.886
1038	0.963	1084	0.923	1130	0.885
1039	0.963	1085	0.922	1131	0.884
1040	0.962	1086	0.921	1132	0.883
1041	0.961	1087	0.920	1133	0.883
1042	0.960	1088	0.919	1134	0.882
1043	0.959	1089	0.918	1135	0.881
1044	0.958	1090	0.918	1136	0.880
1045	0.957	1091	0.917	1137	0.880
1046	0.956	1092	0.916	1138	0.879
1047	0.955	1093	0.915	1139	0.878
1048	0.954	1094	0.914	1140	0.877
1049	0.953	1095	0.913	1141	0.877
1050	0.952	1096	0.913	1142	0.876
1051	0.952	1097	0.912	1143	0.875
1052	0.951	1098	0.911	1144	0.874
1053	0.950	1099	0.910	1145	0.873
1054	0.949	1100	0.909	1146	0.873
1055	0.948	1101	0.908	1147	0.872
1056	0.947	1102	0.908	1148	0.871
1057	0.946	1103	0.907	1149	0.870
1058	0.945	1104	0.906	1150	0.870
1059	0.944	1105	0.905	1151	0.869
1060	0.943	1106	0.904	1152	0.868
1061	0.943	1107	0.903	1153	0.867
1062	0.942	1108	0.903	1154	0.867

(Continued)

(Sheet 3 of 6)

Table C1 (Continued)

Calibration	Program	Calibration	Program	Calibration	Program
1155	Ø.866	1201	Ø.833	1247	Ø.802
1156	Ø.865	1202	Ø.832	1248	Ø.801
1157	Ø.864	1203	Ø.831	1249	Ø.801
1158	Ø.864	1204	Ø.831	1250	Ø.800
1159	Ø.863	1205	Ø.830	1251	Ø.799
1160	Ø.862	1206	Ø.829	1252	Ø.799
1161	Ø.861	1207	Ø.829	1253	Ø.798
1162	Ø.861	1208	Ø.828	1254	Ø.798
1163	Ø.860	1209	Ø.827	1255	Ø.797
1164	Ø.859	1210	Ø.827	1256	Ø.796
1165	Ø.858	1211	Ø.826	1257	Ø.796
1166	Ø.858	1212	Ø.825	1258	Ø.795
1167	Ø.857	1213	Ø.825	1259	Ø.794
1168	Ø.856	1214	Ø.824	1260	Ø.794
1169	Ø.856	1215	Ø.823	1261	Ø.793
1170	Ø.855	1216	Ø.822	1262	Ø.792
1171	Ø.854	1217	Ø.822	1263	Ø.792
1172	Ø.853	1218	Ø.821	1264	Ø.791
1173	Ø.853	1219	Ø.820	1265	Ø.791
1174	Ø.852	1220	Ø.820	1266	Ø.790
1175	Ø.851	1221	Ø.819	1267	Ø.789
1176	Ø.850	1222	Ø.818	1268	Ø.789
1177	Ø.850	1223	Ø.818	1269	Ø.788
1178	Ø.849	1224	Ø.817	1270	Ø.788
1179	Ø.848	1225	Ø.816	1271	Ø.787
1180	Ø.848	1226	Ø.816	1272	Ø.786
1181	Ø.847	1227	Ø.815	1273	Ø.786
1182	Ø.846	1228	Ø.814	1274	Ø.785
1183	Ø.845	1229	Ø.814	1275	Ø.784
1184	Ø.845	1230	Ø.813	1276	Ø.784
1185	Ø.844	1231	Ø.812	1277	Ø.783
1186	Ø.843	1232	Ø.812	1278	Ø.783
1187	Ø.843	1233	Ø.811	1279	Ø.782
1188	Ø.842	1234	Ø.810	1280	Ø.781
1189	Ø.841	1235	Ø.810	1281	Ø.781
1190	Ø.840	1236	Ø.809	1282	Ø.780
1191	Ø.840	1237	Ø.809	1283	Ø.780
1192	Ø.839	1238	Ø.808	1284	Ø.779
1193	Ø.838	1239	Ø.807	1285	Ø.778
1194	Ø.838	1240	Ø.807	1286	Ø.778
1195	Ø.837	1241	Ø.806	1287	Ø.777
1196	Ø.836	1242	Ø.805	1288	Ø.776
1197	Ø.836	1243	Ø.805	1289	Ø.776
1198	Ø.835	1244	Ø.804	1290	Ø.775
1199	Ø.834	1245	Ø.803	1291	Ø.775
1200	Ø.833	1246	Ø.803	1292	Ø.774

(Continued)

(Sheet 4 of 6)

Table C1 (Continued)

Calibration	Program	Calibration	Program	Calibration	Program
1293	Ø.773	1339	Ø.747	1385	Ø.722
1294	Ø.773	1340	Ø.746	1386	Ø.722
1295	Ø.772	1341	Ø.746	1387	Ø.721
1296	Ø.772	1342	Ø.745	1388	Ø.721
1297	Ø.771	1343	Ø.745	1389	Ø.720
1298	Ø.771	1344	Ø.744	1390	Ø.720
1299	Ø.770	1345	Ø.744	1391	Ø.719
1300	Ø.769	1345	Ø.743	1392	Ø.718
1301	Ø.769	1347	Ø.742	1393	Ø.718
1302	Ø.768	1348	Ø.742	1394	Ø.717
1303	Ø.768	1349	Ø.741	1395	Ø.717
1304	Ø.767	1350	Ø.741	1396	Ø.716
1305	Ø.766	1351	Ø.740	1397	Ø.716
1306	Ø.766	1352	Ø.740	1398	Ø.715
1307	Ø.765	1353	Ø.739	1399	Ø.715
1308	Ø.765	1354	Ø.739	1400	Ø.714
1309	Ø.764	1355	Ø.738	1401	Ø.714
1310	Ø.763	1356	Ø.738	1402	Ø.713
1311	Ø.763	1357	Ø.737	1403	Ø.713
1312	Ø.762	1358	Ø.736	1404	Ø.712
1313	Ø.762	1359	Ø.736	1405	Ø.712
1314	Ø.761	1360	Ø.735	1406	Ø.711
1315	Ø.761	1361	Ø.735	1407	Ø.711
1316	Ø.760	1362	Ø.734	1408	Ø.710
1317	Ø.759	1363	Ø.734	1409	Ø.710
1318	Ø.759	1364	Ø.733	1410	Ø.709
1319	Ø.758	1365	Ø.733	1411	Ø.709
1320	Ø.758	1366	Ø.732	1412	Ø.708
1321	Ø.757	1367	Ø.732	1413	Ø.708
1322	Ø.757	1368	Ø.731	1414	Ø.707
1323	Ø.756	1369	Ø.731	1415	Ø.707
1324	Ø.755	1370	Ø.730	1416	Ø.706
1325	Ø.755	1371	Ø.729	1417	Ø.706
1326	Ø.754	1372	Ø.729	1418	Ø.705
1327	Ø.754	1373	Ø.728	1419	Ø.705
1328	Ø.753	1374	Ø.728	1420	Ø.704
1329	Ø.753	1375	Ø.727	1421	Ø.704
1330	Ø.752	1376	Ø.727	1422	Ø.703
1331	Ø.751	1377	Ø.726	1423	Ø.703
1332	Ø.751	1378	Ø.726	1424	Ø.702
1333	Ø.752	1379	Ø.725	1425	Ø.702
1334	Ø.753	1380	Ø.725	1426	Ø.701
1335	Ø.749	1381	Ø.724	1427	Ø.701
1336	Ø.749	1382	Ø.724	1428	Ø.700
1337	Ø.748	1383	Ø.723	1429	Ø.700
1338	Ø.747	1384	Ø.723	1430	Ø.699

(Continued)

(Sheet 5 of 6)

Table C1 (Concluded)

Calibration	Program	Calibration	Program	Calibration	Program
1431	Ø.699	1477	Ø.677	1523	Ø.657
1432	Ø.698	1478	Ø.677	1524	Ø.656
1433	Ø.698	1479	Ø.676	1525	Ø.656
1434	Ø.697	1480	Ø.676	1526	Ø.655
1435	Ø.697	1481	Ø.675	1527	Ø.655
1436	Ø.696	1482	Ø.675	1528	Ø.655
1437	Ø.696	1483	Ø.674	1529	Ø.654
1438	Ø.696	1484	Ø.674	1530	Ø.654
1439	Ø.695	1485	Ø.674	1531	Ø.653
1440	Ø.695	1486	Ø.673	1532	Ø.653
1441	Ø.694	1487	Ø.673	1533	Ø.652
1442	Ø.694	1488	Ø.672	1534	Ø.652
1443	Ø.693	1489	Ø.672	1535	Ø.652
1444	Ø.693	1490	Ø.671	1536	Ø.651
1445	Ø.692	1491	Ø.671	1537	Ø.651
1446	Ø.692	1492	Ø.670	1538	Ø.650
1447	Ø.691	1493	Ø.670	1539	Ø.650
1448	Ø.691	1494	Ø.669	1540	Ø.649
1449	Ø.690	1495	Ø.669	1541	Ø.649
1450	Ø.690	1496	Ø.669	1542	Ø.649
1451	Ø.689	1497	Ø.668	1543	Ø.648
1452	Ø.689	1498	Ø.668	1544	Ø.648
1453	Ø.688	1499	Ø.667	1545	Ø.647
1454	Ø.688	1500	Ø.667	1546	Ø.647
1455	Ø.687	1501	Ø.666	1547	Ø.647
1456	Ø.687	1502	Ø.666	1548	Ø.646
1457	Ø.686	1503	Ø.665	1549	Ø.646
1458	Ø.686	1504	Ø.665		
1459	Ø.686	1505	Ø.665		
1460	Ø.685	1506	Ø.664		
1461	Ø.685	1507	Ø.664		
1462	Ø.684	1508	Ø.663		
1463	Ø.684	1509	Ø.663		
1464	Ø.683	1510	Ø.662		
1465	Ø.683	1511	Ø.662		
1466	Ø.682	1512	Ø.661		
1467	Ø.682	1513	Ø.661		
1468	Ø.681	1514	Ø.661		
1469	Ø.681	1515	Ø.662		
1470	Ø.682	1516	Ø.660		
1471	Ø.680	1517	Ø.659		
1472	Ø.679	1518	Ø.659		
1473	Ø.679	1519	Ø.658		
1474	Ø.679	1520	Ø.658		
1475	Ø.678	1521	Ø.658		
1476	Ø.678	1522	Ø.657		

APPENDIX D
SOIL AND PAVEMENT DATA USED IN DEVELOPMENT OF
EVALUATION METHODOLOGIES

Table D1
Flexible Pavements

Site Number	Location	Base	Location	Depth in.	Material Classification	Atterberg Limits		In-Place Water Content		In-Place CBR percent		In-Place Dry Density pcf
						LL	PL	percent	percent	percent	percent	
E1A	Ft. Eustis		Washington Street 958 ft north of Madison	0.0-5.5	AC			--		66		
				5.5-10.0	Crushed stone			--		49		
				10.0-13.0	Sandy gravel					23		
				13.0-17.0	Sandy clay			14.2		8		
				17.0	Heavy clay			17.1		3.3		
E3	Ft. Eustis		Washington Street 1052 ft north of Madison	27.0	Heavy clay			18.3				
				0.0-3.75	AC							
				3.75-5.0	Sandy gravel			8.6		68		
				5.0-7.0	Sandy clay			--		--		
				8.0	Lean clay			11.6		44		
E3A	Ft. Eustis		Harrison Street 2303 ft north of Madison	13.0	Lean clay			16.2		10		
				0.0-3.75	AC					--		
				3.75-5.0	Sandy gravel			--		--		
				5.0-16.0	Lean clay			13.8		36		
				20.0	Silty clay			21.2		8		
E6	Ft. Eustis		Wilson Avenue 560 ft from Mulberry	26.5	Silty clay			21.5		10		
				31.0	Silty clay			20.4		9		
				0.0-6.0	AC					--		
				6.0-7.25	Surface treatment			--		--		
				7.25-9.75	Crushed stone			--		--		
E6A	Ft. Eustis		Wilson Avenue	9.75-11.75	Sandy gravel			10.3		30		
				11.75-14.0	Sandy silt			14.7		15		
				14.0+	Silty clay			--		--		
				0.0-6.0	AC					--		
				6.0-7.25	Surface treatment			--		--		
E7	Ft. Eustis		Goodman Road	7.25-9.5	Crushed stone			--		--		
				9.5-12.5	Sandy gravel			--		--		
				12.5-28.7	Sandy clay			19.9		11		
				28.7	Heavy clay			19.2		3		
				0.0-8.0	AC					--		
				8.0-20.0	Silty clay			19.2		11		
				20.0	Silty sand			17.0		51		

(Continued)

Table D1 (Continued)

Site Number	Location		Depth in.	Material Classification	Atterberg Limits		In-Place Water Content		In-Place CBR		In-Place Dry Density pcf
	Base	Location			LL	PL	Percent	Percent	percent	percent	
E8	Ft. Eustis	Bullard Street 259 ft from McClain	0.0-4.0 4.0-9.0 9.0	AC Crushed stone Silty clay			3.1 14.3		80 23		
E8A	Ft. Eustis	Wilson Avenue 560 ft from Mulberry	0.0-4.0 4.0-9.0 9.0-13.5 13.5	AC Crushed stone Silty clay Lean clay			-- 13.6 16.2		80 19 5		
E9	Ft. Eustis	Jefferson Street 416 ft from Madison	0.0-8.0 8.0-13.0 13.0-17.0 17.0	AC Crushed stone River run Silty sand			-- 8.7 19.5		95 35 12		
E10	Ft. Eustis	Jefferson Street 88 ft north of North Washington	0.0-10.0 10.0-12.0 12.0-14.5 14.5-17.5 17.5+ 22.0	AC River run Silty sand River run Heavy clay Heavy clay			9.9 -- 10.5 -- 26.7		74 -- 24 -- 14		
E12	Ft. Eustis	Monroe Street 200 ft south of Dorsey	0.0-4.0 4.0-5.5 5.5-8.0 8.0-11.0 11.0	AC Surface treatment Crushed stone Sandy gravel Heavy clay			-- -- --		-- 45 21		
E12A	Ft. Eustis	Monroe Street 195 ft south of Dorsey	0.0-4.0 4.0-5.5 5.5-9.5 9.5-13.0 13.0 21.0 26.5 29	AC Surface treatment Crushed stone Sandy gravel Heavy clay Heavy clay Heavy clay Heavy clay			-- -- 23.2 28.9 25.3 25.9		-- -- 8 10 9 7		
E13A	Ft. Eustis	PX parking lot 5 ft west of Hub No. 13	0.0-2.0 2.0-9.5 9.5-12.0	AC Crushed stone Sandy gravel			-- --		91 24		

(Continued)

(Sheet 2 of 6)

Table D1 (Continued)

Site Number	Base	Location	Location	Depth in.	Material Classification	Atterberg Limits		In-Place Water Content		In-Place CBR		In-Place Dry Density	
						LL	PL	percent	percent	percent	percent	pcf	pcf
E13A (Cont)				12.0-16.0	Sandy clay			--		--			
				16.0-25.5	Sand			--		30			
				25.5	Heavy clay			25.8		4			
E14A	Ft. Eustis	28th Street 1351 ft north of Jefferson		0.0-3.0	AC								
				3.0-5.0	Surface treatment								
				5.0-8.5	Sand			--		66			
				8.5-15.0	Silty sand			--		--			
				15.0-19.0	Sandy clay			23.3		27			
				19	Heavy clay			17.0		15			
				29	Heavy clay			19.6		6			
E15	Ft. Eustis	Sternburg 499 ft east of 25th Street		0.0-6.0	AC								
				6.0-8.0	Clay gravel			9.8		25			
				8.0-11.0	Sand			10.7		13			
				11.0	Silty clay			--		--			
E17	Ft. Eustis	13th Street south of Patton		0.0-3.0	AC								
				3.0-4.75	Oil treated base			--		--			
				4.75-10.55	River run			4.8		42			
				10.55-13.0	Organic			22.4		10			
				13.0	Heavy Clay			17.9		15			
				21.0	Heavy clay			17.5		2			
E18	Ft. Eustis	11th Street 200 ft from Jackson		0.0-4.5	AC								
				4.5-10.5	Crushed stone			--		100+			
				10.5-19.0	River run			--		--			
				19.0	Lean clay			14.0		23			
				27.5	Lean clay			21.0		9			
W1	WFS	Columbia Road 235 ft north of Chesapeake Road		0.0-4.75	AC								
				4.75-5.5	Clay gravel			--		--			
				5.5-13.0	Lean clay			16.3		40			
				14.25	Lean clay			18.6		8			
W2	WFS	Columbia Road 185 ft north from Mississippi Road		0.0-2.0	AC								
				2.0-7.0	Lime stabilized clay gravel			--		100+			
				7.0-9.0	Clay gravel			--		--			
				9.0	Lean clay			21.3		24			

(Continued)

(Sheet 3 of 6)

Table D1 (Continued)

Site Number	Location		Depth in.	Material Classification	Atterberg Limits		In-Place Water Content		In-Place CBR		In-Place Dry Density pcf
	Base	Location			LL	PL	percent	percent	percent	percent	
W3	WES	Missouri Road 390 ft east of Soils Lab parking lot	0.0-3.0 3.0-18.5 18.5	AC Sandy gravel Lean clay			4.8 22.1		54 14		
W4	WES	Missouri Road 480 ft east of Soils Lab parking lot	0.0-2.5 2.5-10.0 10.0-14.0 14.0	AC Sandy gravel Lean clay Lean clay			5.1 -- 16.5		78 -- 24		
W5	WES	Missouri Road 580 ft east of Soils Lab parking lot	0.0-2.0 2.0-8.75 8.75 15.25	AC Sandy gravel Lean clay Lean clay			6.6 15.6 18.3		55 42 16		
W6	WES	West end of asphalt strip	0.0-7.5 7.5-13.5 13.5 25.0	AC Crushed stone Lean clay Lean clay			-- -- --		100+ 15 6		
W7	WES	Asphalt strip in front of PB-19	0.0-4.0 4.0-12.0 12.0 25.0	AC Crushed stone Lean clay Lean clay			-- -- --		100+ 18 23		
W8	WES	Northwest corner of new Soils Lab parking lot	0.0-7.0 7.0-11.0 11.0-35.0 35.0	AC Crushed stone Clay gravel Lean clay			-- -- --		100+ 45 6		
K1	Seoul Airbase, Korea	Test pit 1	0.0-3.5 3.5-7.5	AC Sandy gravel (GW-GM)	NP	NP	3		126		134.9
K2	Seoul Airbase, Korea	Test pit 3	7.5-30.0	Sandy gravel (GP)	NP	NP	2		45		128.3
			30.0+	Clayey sand (SC)	33	18	20		4		101.9
			0.0-2.2 2.2-6.2	AC Sandy gravel (GP-GM)	NP	NP	6		15		136.3
			6.2-12.0 12.0-18.0	Silty gravel (GM) Gravelly sand (SW-SM)	NP	NP	9 9		20 20		128.9 125.2
			18.0+	Silty sand (SM)	NP	NP	8		7		124.7

(Continued)

(Sheet 4 of 6)

Table D1 (Continued)

Site Number	Location		Depth in.	Material Classification	Atterberg Limits		In-Place Water Content		In-Place Dry Density	
	Base	Location			LL	PL	percent	percent	pcf	pcf
K3	Kumi Landing Strip, Korea	Test pit 1	0.0-2.75	AC	NP	NP	3	57	141.3	
			2.75-8.0	Sandy gravel (GP)	NP	NP	3	58	141.3	
			8.0-15.0	Sandy gravel (GP)	NP	NP	6	29	116.8	
			15.0-21.0	Gravelly sand (SW-SM)	NP	NP	17	11	--	
			21.0+	Gravelly sand (SW-SM)	NP	NP				
K4	Kumi Landing Strip, Korea	Test pit 2	0.0-7.5	AC	NP	NP	5	36	131.0	
			7.5-13.0	Sandy gravel (GW-GM)	NP	NP	5	50	130.7	
			13.0-24.0	Sandy gravel (GW-GM)	NP	NP	5	12	123.9	
			24.0-26.0	Silty sand (SM)	NP	NP	18	10	110.1	
			26.0+	Silty sand (SM)	NP	NP				
K5	Eonyang Landing Strip, Korea	Test pit 1	0.0-15.0	AC	NP	NP	3	40	139.1	
			15.0-19.5	Silty sand (GP-GM)	NP	NP	6	100+	147.4	
			19.5-26.0	Silty sandy gravel (GP)	NP	NP	3	33	135.9	
			26.0+	Silty sand (GP)	NP	NP				
K6	Eonyang Landing Strip, Korea	Test pit 2	0.0-9.5	AC	NP	NP	7	35	134.7	
			9.5-16.0	Silty sand (SP-SM)	NP	NP	4	68	137.1	
			16.0-20.0	AC	NP	NP	5	29	127.3	
			20.0-26.0	Silty sand (GP-GM)	NP	NP	6	20	136.1	
			26.0-34.0	Silty gravelly sand (GP)	NP	NP	16			
K7	Pusan Airbase, Korea	Test pit 2	34.0-46.0	Silty gravelly sand (GP)	NP	NP				
			46.0	Clayey sand (SC)	31	20				
			0.0-3.5	AC	NP	NP	12	79	119.9	
			3.5-11.5	Bituminous black base	NP	NP	19	22	106.1	
			11.5-16.0	Silty sandy gravel (GC)	NP	NP	18	18	100.3	
			16.0-23.0	Sandy clay (SP-SM)	NP	NP				
			23.0	Sand (SP)	NP	NP	30			

(Continued)

(Sheet 5 of 6)

Table D1 (Concluded)

Site Number	Location		Depth in.	Material Classification	Atterberg Limits		In-Place Water Content		In-Place CBR		In-Place Dry Density	
	Base	Location			LL	PL	percent	percent	percent	percent	pcf	pcf
K8	Cheong-Eup Landing Strip, Korea	Test pit 1	0.0-7.0	AC	NP	NP	5	94			138.9	
			7.0-15.0	Gravelly sand (SP-SM)	NP	NP	6	55			124.9	
			15.0-21.0	Gravelly sand (SP-SM)	NP	NP	6	30			118.3	
			21.0-25.0	Gravelly sand (SP-SM)	NP	NP	12	20			117.6	
			25.0	Silty sand (SM)	NP	NP	6	90			125.4	
K9	Cheong-Eup Landing Strip, Korea	Test pit 2	0.0-6.0	AC	NP	NP	5	18			113.7	
			6.0-13.0	Gravelly sand (SP-SM)	NP	NP	13	14			--	
			13.0-18.0	Gravelly sand (SP-SM)	NP	NP	9	--			117.6	
			18.0-21.0	Lean clay (CL)	38	19						
			21.0	Silty sand (SM)	NP	NP						
K10	Chinhae Airbase, Korea	Test pit 1	0.0-2.25	AC	NP	NP	5	85			139.5	
			2.25-11.0	Sandy gravel (GP)	NP	NP	11	47			121.3	
			11.0-15.0	Silty sand (SM)	NP	NP	12	56			125.0	
			15.0-21.0	Silty sand (SM)	NP	NP	14	30			115.3	
			21.0-70.0	Silty sand (SM)	NP	NP	--	--			--	
K20	Yanggu Airbase, Korea	Test pit 1	0.0-3.0	AC	NP	NP	5.0	59			128.5	
			3.0-11.0	Sandy gravel (GW)	NP	NP	9.0	50			131.6	
			11.0-18.0	Gravelly sand (SP)	NP	NP	10.0	17			125.6	
			18.0-28.0	Gravelly sand (SP)	NP	NP	15.0	10			110.7	
			28.0-39.0	Gravelly clay (GC)	25	17						
			39+	Silty clay (CL-ML)	25	20	16.0					

Table D2
Rigid Pavements

Site Number	Base	Location	Depth in.	Material Classification*	Atterberg Limits LL PL	In-Place Water Content percent	In-Place CBR percent**	In-Place Modulus of Soil Reaction k pci**	In-Place Dry Density pcf	PCC Cores		
										Splitting Tensile Strength psi	Unit Weight pcf	Correlated Flexural Strength psi
E5	Ft. Eustis	Patch Road 728 ft west of railroad	0.0-7.0 7.0+	PCC Silty sand		17.6	9			700.4		911
E11	Ft. Eustis	Walker Street 943 ft south of Jefferson	0.0-8.5 8.5+	PCC Sandy clay		16.4	5			532.1		743
E16	Ft. Eustis	Madison Avenue at Bldg. 2732	0.0-8.0 8.0+	PCC Sandy clay		15.6	6			447.3		658
P1	Ft. Polk	23rd Street 68 ft west of Georgia Avenue	0.0-7.2 7.2-13.0 13.0-20.0 20.0-25.0 25.0+	PCC Lean clay Lean clay Lean clay Lean clay		13.2 18.5 18.1 19.3	7 9 16 10			757		968
P2	Ft. Polk	Vermont Street 75 ft west of Georgia Avenue	0.0-6.2 6.2-14.0 14.0-20.0 20.0+	PCC Lean clay Lean clay Lean clay		16.5 20.5 20.2	9 11 7			823		1033
P3	Ft. Polk	16th Street 90 ft west of Georgia Avenue	0.0-7.6 7.6-13.0 13.0-18.0 18.0-25.0 25.0-37.0 37.0+	PCC Sandy clay Sandy clay Sandy clay Lean clay Lean clay		13.6 15.3 14.6 14.2 17.1	5 3 7 3 7			763		974
P4	Ft. Polk	Alabama Avenue 530 ft south of Vermont Street	0.0-7.8 7.8-16.0 16.0-23.0 23.0+	PCC Heavy clay Heavy clay Lean clay		18.9 15.5 15.7	2 7 6			565		775
P5	Ft. Polk	6th Street 75 ft west of Georgia Avenue	0.0-7.9 7.9-20.0 20.0-33.0 33.0+	PCC Lean clay Lean clay Lean clay		9.8 10.3 16.0	6 8 10			622		832
P7	Ft. Polk	Alabama Avenue 400 ft north of 4th St.	0.0-7.3 7.3-15.0 15.0-21.0 21.0+	PCC Lean clay Lean clay Lean clay		9.6 6.0 6.5	44 70 59			664		874
P9	Ft. Polk	Mississippi Avenue 400 ft south of 4th St.	0.0-7.2 7.2-18.0 18.0-29.0 29.0+	PCC Lean clay Lean clay Lean clay		14.3 11.8 13.4	10 5 10			761		972
P10	Ft. Polk	Mississippi Avenue 290 ft west of Alabama Avenue	0.0-7.5 7.5-18.0 18.0-24.0 24.0+	PCC Silty sand Silty sand Silty sand		11.4 7.1 6.3	6 14 40			727		937

(Continued)

* Where no Unified Soil Classification symbol is given, classification is based on visual field classification.
 ** If only modulus of soil reaction k values are given, the modulus of soil reaction k was determined from plate-bearing test. If only CBR values are given, the modulus of soil reaction k was determined from the k -value graph using Plate 3 (Hall and Elwood 1934).

Table D2 (Continued)

Site Number	Base	Location	Depth in ft	Material Classification	Atterberg Limits LL PL	In-Place Water Content Percent	In-Place CBR Percent	In-Place Modulus of Soil Reaction k pci	In-Place Dry Density pcf	PCC Cores		
										Unit Weight pcf	Splitting Tensile Strength psi	Correlated Flexural Strength psi
P11	Ft. Polk	Mississippi Avenue 500 ft north of Hwy 10	0.0-7.25 7.25-16.0 16.0-24.0 24.0+	PCC Sandy clay Sandy clay Sandy clay		13.6 12.1 18.1	16 10 3				757	967
P13	Ft. Polk	Alabama Avenue 25 ft south of 23rd St.	0.0-7.5 7.5-16.0 16.0+	PCC Sandy clay Sandy clay		19.6 18.6	8 13				651	862
P15	Ft. Polk	New Jersey Avenue 30 ft west of railroad	0.0-8.0 8.0-8.25 8.25-15.0 15.0-25.0 25.0+	PCC AC slabjacking Silty sand Silty sand Silty sand		15.2 16.3 9.4	70 29 19				543	753
P21	Ft. Polk	13th Street 100 ft east of "J" Avenue	0.0-7.2 7.2-19.0 19.0-26.0 26.0-36.0 36.0+	PCC Heavy clay Heavy clay Heavy clay Heavy clay		22.6 22.8 16.8 17.4	1.2 1.0 9 --				572	782
W9	WES	Missouri Road	0.0-5.75 5.75-13.0 13.0-18.0 18.0+	PCC Clay gravel Silty clay Silty clay		6.2 17.3 18.6	75 25 16				433.2	644
W10	WES	Yukon Street	0.0-5.5 5.5-13.0 13.0-21.0 21.0+	PCC Clay gravel Lean clay Lean clay		5.3 16.1 16.7	75 46 44				517.7	728
W11	WES	Yukon Street	0.0-6.0 6.0-14.0 14.0-16.0 16.0-24.0 24.0-30.0 30.0+	PCC Clay gravel Clay gravel Lean clay Lean clay Lean clay		-- -- -- -- --	76 19 33 36 28				588.6	799
W12	WES	Yukon Street	0.0-6.25 6.25-17.0 17.0-23.0 23.0+	PCC Clay gravel Lean clay Lean clay		5.6 16.1 17.3	81 27 24				647.5	858
W13	WES	Adjacent Bldg 3393	0.0-5.6 5.6-7.5 7.5-13.5 13.5+	PCC Sandy clay gravel Silty clay Silty clay		-- 17.9 21.4	-- 16 5				664.2	875
W14	WES	Adjacent Bldg. 6010	0.0-7.5 7.5-14.5 14.5+	PCC Silty clay Silty clay		23.5 23.7	6 5				558.2	769
K11	Seoul Airbase, Korea	Test pit 2	0.0-12.5 12.5-18.2 18.2-32.0 32.0+	PCC Sandy gravel (GP-GM) Sandy gravel (GP-GM) Sandy gravel (GP-GM)	NP NP NP NP NP NP NP NP	6.0 7.0 4.0	-- -- --	460	134.6	150.5	511.5	724

(Continued)

(Sheet 2 of 3)

Table D2 (Concluded)

Site Number	Base	Location	Location	Depth in.	Material Classification	Atterberg Limits		In-Place Water Content percent	In-Place CBR percent	In-Place Modulus of Soil Reaction k pci	In-Place Dry Density pcf	Unit Weight pcf	PCC Cores		
						LL	PL						Splitting Tensile Strength psi	Correlated Flexural Strength psi	
K12	Seoul Airbase, Korea	Test pit 4		0.0-15.2 15.2+	PCC Gravelly sand (SW)	NP	NP	5.0	--	340	120.1	149.2	552.5	761	
K13	Pohang Airbase, Korea	Test pit 1		0.0-13.0 13.0-25.0 25.0-38.0	PCC Sandy gravel (GP) Sandy gravel (GW-GH)	NP	NP	7.0 6.0	--	220	132.6	150.7	354.5	565	
K14	Pohang Airbase, Korea	Test pit 2		38.0+	Sandy clay (SC)	NP	NP	16.0							
				0.0-15.0 15.0-40.0 40.0+	PCC Sandy gravel (GP) Sandy clay (SC)	NP	NP	4.0 18.0	--	292	132.8	--	364.5	575	
K15	Pohang Airbase, Korea	Test pit 3		0.0-13.0 13.0+	PCC Silty sand (SH)	NP	NP	6.0	--	340	132.4	150.0	330.5	541	
K16	Chong-Ju Airbase, Korea	Test pit 1		0.0-12.5 12.5-38.0	PCC Gravelly sand (SP-SH)	NP	NP	5.0	--	370	133.8	--	404.5	615	
				38.0+	Silty sand (SH)	NP	NP	9.0							
K17	Chong-Ju Airbase, Korea	Test pit 2		0.0-15.25 15.25-21.0	PCC Gravelly sand (SP-SH)	NP	NP	7.0	--	320	131.2	--	359.5	570	
				21.0-43.0 43.0+	Sandy gravel (GP) Silty sand (SH)	NP	NP	5.0 9.0							
K18	Kangnung Airbase, Korea	Test pit 2		0.0-13.5 13.5-17.0 17.0-43.0	PCC Gravelly sand (SP) Gravelly sand (SW-SH)	NP	NP	5.0 6.0	--	450	126.8	--	305.5	516	
				43.0+	Gravelly sand (SP)	NP	NP	12.0							
K19	Kangnung Airbase, Korea	Test pit 3		0.0-11.25 11.25+	PCC Gravelly sand (SP)	NP	NP	4.0	--	310	125.1	--	403.5	614	

Table D3
Composite Pavements

Site Number	Location	Base	Depth in.	Material Classification	Atterberg Limits LL PL	In-Place Water Content percent	In-Place CBR percent	In-Place Modulus of Soil Reaction k per ft	In-Place Dry Density per ft	Unit Weight per ft	PCC Cores Splitting Tensile Strength per sq in	Correlated Flexural Strength per sq in
E6	Ft. Eustis	Kerr Road 833 ft west of railroad	0.0-5.0 5.0-11.0 11.0 15.0	AC PCC Sandy clay Sandy clay		16.0 14.5	5 16			--	560.6	770
E19	Ft. Eustis	Jackson Street 100 ft north of Butler Street	0.0-3.75 3.75-15.0 15.0-16.0 16.0-24.0 24.0-27.0 27.0*	AC PCC Sand Lean clay Lean clay Heavy clay		-- -- 16.2 21.0	-- 7 14 8			--	429.1	640
E20	Ft. Eustis	Lee Blvd. 1563 ft west of Gaffery Place	0.0-7.5 7.5-16.0 16.0*	AC PCC Heavy clay						--	542.5	754
E21	Ft. Eustis	Taylor Avenue 300 ft west of 24th St.	0.0-4.75 4.75-12.75 12.75-16.0 16.0-26.0 26.0-31.0 31.0*	AC PCC Sandy gravel Crushed stone Silty clay Heavy clay		20.9	2.6			--	543.4	754
P6	Ft. Polk	Georgia Avenue 100 ft north of 4th Street	0.0-6.25 6.25-13.5 13.5-25.0 25.0-31.0 31.0*	AC PCC Sandy clay Sandy clay Sandy clay		-- -- 22.5 15.0	17 -- 42 11			--	647.0	858
P8	Ft. Polk	4th Avenue 174 ft west of Alabama	0.0-1.25 1.25-8.9 8.9*	AC PCC Sandy clay		14.2	6			--	703.5	913
P12	Ft. Polk	Georgia Avenue	0.0-5.0 5.0-12.7 12.7-20.0 20.0*	AC PCC Silty clay Silty clay		16.0 15.5	4.2 6			--	728.5	949
P14	Ft. Polk	Louisiana Avenue	0.0-4.0 4.0-11.0 11.0-12.5	AC PCC Asphalt		--	--			--	727.0	938
P16	Ft. Polk	Georgia Avenue 390 ft south of 5th St	12.5-20.0 20.0*	Slabjacking Silty sand Silty sand		5.6 5.6	70 50			--	740.5	951
P17	Ft. Polk	Entrance Road 4150 ft east of Chaffee Road	0.0-5.5 5.5-12.9 12.9*	AC PCC Silty sand		7.6	19			--	714.5	925
			0.0-6.4 6.4-13.4 13.4-16.0 16.0-28.0 28.0-33.0 33.0*	AC PCC AC Heavy clay Heavy clay Heavy clay		14.6 13.6 24.6	9 7 3.3			--		

(Continued)

Table D3 (Concluded)

Site Number	Base	Location	Location	Depth in ft.	Material Classification	Atterberg Limits		In-Place Water Content Percent	In-Place CBR percent	In-Place Modulus of Soil Reaction k pci	In-Place Dry Density pcf	PCC Cores		Unit Weight pcf	Splitting Tensile Strength psi	Correlated Flexural Strength psi
						LL	PI									
P18	Ft. Polk	9th Street 135 ft east of "A" Avenue		0.0-6.5	AC											
				6.5-13.5	PCC											
				13.5-14.0	AC											
				14.0+	Heavy clay			--	5					--	714.5	925
P19	Ft. Polk	9th Street 200 ft east of "D" Avenue		0.0-6.75	AC											
				6.75-14.25	PCC											
				14.25-15.5	AC											
				15.5-28.0	Heavy clay			32.5	1.2					--	703.4	914
P20	Ft. Polk	9th Street 235 ft west of "K" Avenue		0.0-6.25	AC											
				6.25-13.35	PCC											
				13.35-20.0	Heavy clay			29.0	1.0							
				20.0+	Heavy clay			32.9	1.0						697.0	907

DATE
LME