AD-A276 924

Miscellaneous Paper GL-94-2
January 1994

US Army Corps
of Engineers
Waterways Experiment
Station

A Computer Program for Evaluation and Overlay Design of Roads, Streets, and Open Storage Areas Using Nondestructive Testing and Elastic Layered Method—WESROAD

by Yu T. Chou
Geotechnical Laboratory

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Prepared for Headquarters, U.S. Army Corps of Engineers

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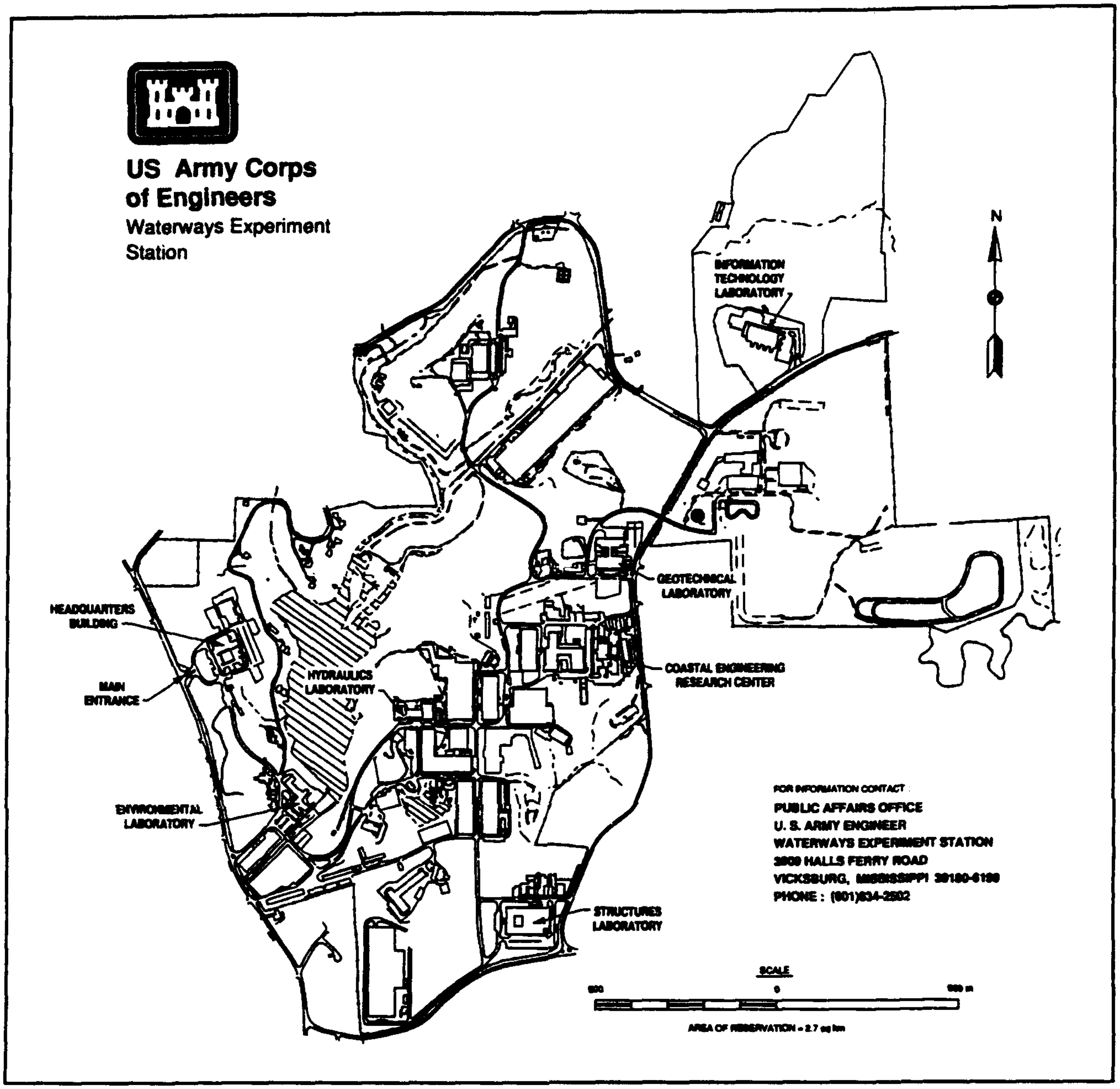
Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000



Waterways Experiment Station Cataloging-in-Publication Data

Chou, Yu T.
A computer program for evaluation and overlay design of roads, streets, and open storage areas, using nondestructive testing and elastic layered method—WESROAD / by Yu T. Chou ; prepared for U.S. Army Corps of Engineers.
31 p. : ill. ; 28 cm. — (Miscellaneous paper ; GL-94-2)
Includes bibliographical references.
1. Pavements — Overlays — Data processing. 2. WESROAD (Computer program) 3. Roads — Design and construction — Data processing. I. United States. Army. Corps of Engineers. II. U.S. Army Engineer Waterways Experiment Station. III. Title. IV. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; GL-94-2.
TA7 W34m no.GL-94-2

Contents

Preface

The work reported herein was developed under the Headquarters, U.S. Army Corps of Engineers PCASE program. Mr. Greg Hughes, U.S. Army Corps of Engineers, was the Technical Monitor.

The study was conducted from June 1989 to February 1992 at the U.S. Army Engineer Waterways Experiment Station (WES), Geotechnical Laboratory (GL), by Dr. Yu T. Chou, Pavement Systems Division (PSD). The work was performed under the general supervision of Dr. W. F. Marcuson III, Director, GL, and Dr. George Hammit II, Chief, PSD, and Dr. Al Bush, Chief, Criteria Development and Applications Branch. This report was written by Dr. Chou.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
kips (force)	4.448222	kilonewtons
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

Background

An engineering technical manual entitled "Evaluation of Roads, Streets, and Open Storage Areas Using Nondestructive Testing" has been prepared.[1] A user-friendly computer program, WESROAD, was prepared for the evaluation of the load-carrying capacity and overlay thickness requirements of existing military roads and streets.

Purpose and Scope

The purpose of this report is to provide users with necessary information for running the WESROAD computer program. The report contains the programming logic, computer system requirements, user instructions, and the input and output for example problems. The overlay design includes both concrete and flexible overlays.

[1] Headquarters, Department of the Army. "Evaluation of roads, streets, and open storage areas using nondestructive testing," TM 5-826-8/AFM 32-8009, Vol 2, Washington, DC.

2 Program Logic and System Requirements

Program Logic

WESROAD is a modification of WESPAVE, an evaluation program for airfield pavements that uses nondestructive testing (NDT) and the elastic layered method developed at the U.S. Army Engineer Waterways Experiment Station (WES). The program has two separate parts, which are presented below.

INPAVE is a user-friendly computer program creating input files for running WESROAD. The necessary information includes pavement layer thicknesses and moduli (backcalculated from NDT tests), interface slip conditions, pavement surface conditions, joint conditions in concrete pavements, and traffic data. Traffic data include the type and frequency of design vehicles traveling on the pavements. When running WESROAD, the WESLEA computer program is used to compute stresses and strains in the pavement.

The design vehicles are divided into axle groups for computation of pavement stresses, strains, and damage. A passenger car has two axles, which are both single axle, single wheels. A medium weight truck usually has two axle loads: the front is single axle, single wheels, and the rear is either tandem axle, dual wheels, or single axle, dual wheels. An 18-wheeler has three axles: the front is single axle, single wheels, and the middle and back axles are tandem axle, dual wheels. For track vehicles, such as military tanks, each track load is converted into eight circular loads and is considered as one axle load. Table 1 shows 19 axle loads based on the wheel configuration and weight category, which covers a wide range of loads for designing military roads and streets. The background of the group classification is presented in Technical Report No. 3-582.[1]

[1] U.S. Army Engineer Waterways Experiment Station. (1961). "Revised method of thickness design for flexible highway pavements at military installations," Technical Report No. 3-582, Vicksburg, MS.

Table 1
Design Load Axles

Configuration	Load Range, kips
Passenger cars, trucks, buses, etc.	
Pneumatic tires	
1. Single axle, single wheels	0-5
2. Single axle, single wheels	5-10
3. Single axle, dual wheels	0-10
4. Single axle, dual wheels	10-20
5. Single axle, dual wheels	20-30
6. Tandem axle, single wheels	0-10
7 Tandem axle, single wheels	10-15
8. Tandem axle, dual wheels	10-15
9. Tandem axle, dual wheels	15-20
10. Tandem axle, dual wheels	20-50
Forklift truck	
Pneumatic tires	
11.Single axle, dual wheels	10-35
Solid rubber tires	
12.Single axle, single wheels	0-5
13.Single axle, single wheels	5-10
14.Single axle, single wheels	10-20
Tracked vehicles	
15.solid rubber grousers	0-20
16.solid rubber grousers	20-35
17.solid rubber grousers	35-50
18.solid rubber grousers	50-70
19.solid rubber grousers	70-120

Note: A table of factors for converting non-SI units of measurement to SI is presented on page v.

For example, if a road is to be designed for the following traffic:

10,000 passes of passenger cars, 9 kips for each axle
5,000 passes of truck, 9-kip front axle and 32-kip rear axle
1,000 passes of 60-ton M1 tank

The design axle loads, according to Table 1, will be:

25,000 passes of No. 2 axle load (2 × 10,000 + 5,000)
5,000 passes of No. 10 axle load (5,000)
1,000 passes of No. 19 axle load (1,000)
(Note: Axle numbers refer to the axles in Table 1.)

WESROAD is also a user-friendly computer program which first evaluates the load-carrying capacity of the existing pavement. If the pavement is capable of carrying the design traffic, the program will terminate; otherwise, the overlay de:gn will proceed. The design includes both asphalt and concrete overlavs For concrete overlays, thicknesses of partial-bond and no-bond desigms are given.

Concept of evaluation

The stresses, strains, and deflections in the pavement structure under the axle loads are computed by computer program WESLEA based on the Burmister layered elastic solution. The allowable passes on the pavement under each axle load are computed according to the failure criteiia. The pavement damage under each axle load is then computed and summed. If the total damage exceeds 1.0, the pavement requires an overlay. Damage is defined as the ratio of the design passes to the allowable passes.

Principle of overlay design

Overlay design is based on a single axle load of the selected axle loads which induce the most severe damage to the pavement. An equivalent pass determined from the relationship shown below is calculated and a required new concrete thickness is determined. The overlay thickness is determined from overlay equations based on the required new concrete thickness.

$$\text{Total damage} = \frac{\text{Equivalent pass}}{\text{Allowable pass of the critical axle}} \tag{1}$$

It should be noted that WESPAVE adopts the allowable load concept in airfield pavement evaluation. The allowable load approach is feasible because WESPAVE evaluates a pavement for one aircraft loading. For road evaluation using WESROAD, various vehicles of different axle loadings and of different frequency are involved. The damage approach is therefore used to account for the mixed effects of the axle loadings.

System Requirements

The computer program was compiled using the Microsoft FORTRAN 5.0 compiler and was designed to operate on an IBM or compatible machine under the DOS 3.0 operating system or a later system. Although not required, an IBM AT class computer or better with a math co-processor and 640 KB of main memory is recommended.

3 User's Instructions

Input data, INPAVE

INPAVE can be activated by typing INPAVE at the DOS prompt and following the instructions shown on the screen. An input file name is required. A file name with the extension .INP is suggested for easy retrieval. Special attention should be paid in selecting interface slip conditions and joint conditions explained in the following paragraphs.

Interface condition

One drawback of every elastic layered computer program is that the interface condition between total adhesion and total slip cannot be quantified. In the WESLEA program, an interface condition of 1 indicates total adhesion, 0 indicates full slip, and 2-1,000 indicates partial slip. For an interface condition from 2 to 1,000, the physical meaning cannot be identified except it is known as a partial slip case in which the higher number means greater slip. In other words, the exact value of interface condition between a Portland cement concrete slab layer and the supporting clay subgrade is not known. It is suggested that a value of 1,000 be used for this case and that total adhesion be used for flexible pavements, i.e., total adhesion between the asphalt concrete and the granular or stabilized layers and total adhesion between the granular or the stabilized layer and the subgrade. It is important to know that WESLEA is fixed for five layers and if full slip is used at the interface, the program is fixed so that the first and second interfaces have full slip and the remaining interfaces have total adhesion.

Joint condition

For concrete roads, the free edge loading condition is the most critical and should be used for design. However, the failure criteria on which the design is based were established in test tracks where good load transfer was provided, and the test data were analyzed using the elastic layered method (interior loading). The failure criteria are presented in TM 5-822-13/AFM 32-8007[1] and the development of the criteria is explained in Chou (1989).[2] To account for the more critical edge loading condition, a scheme was developed by Chou (1989)[2] to multiply the concrete stresses computed using the elastic layered method (WESLEA) by 1.33 to increase the concrete thickness.

In INPAVE, the user is asked to input the joint efficiency for the concrete pavement. The joint efficiency is the ratio of the deflection of the unloaded slab to the deflection of the loaded slab. A factor is computed based on the equation:

FACTOR = 0.7557 + 0.2058*RATIO + 0.1505*RATIO**2
for RATIO less than 0.75

FACTOR = 1.0 for RATIO greater than 0.75 (2)

The computed stresses are then divided by this factor to account for the joint condition. Note that the smallest value of FACTOR is 0.7557. In other words, when there is no load transfer across the concrete pavement joints, the computed stresses will be increased by a factor of 1.323.

Since the computed concrete stresses are increased by a factor of 1.33 to account for the more critical edge loading effect as discussed above, it can be argued whether or not joint condition should be considered in pavement evaluation. In the WESROAD program, users are requested to input a measured deflection ratio (i.e., equal or less than 1.0). If the user feels that the joint condition should not be considered, the deflection ratio can be input as 1.0. Note that a deflection ratio less than 1.0 will increase the computed stresses and make the evaluation on the safer side. If the user does not have a strong feeling on this matter, either a measured deflection ratio or a value between 0.75 and zero should be used, preferably zero.

In WESROAD, an answer of "NO" to the question "DO YOU HAVE JOINT EFFICIENCY MEASUREMENTS" will automatically set the value of FACTOR to 1.0 in Equation 2.

Pavement condition

If the pavement surface is severely cracked, the "poor" option should be answered in INPAVE. In doing so the computed stresses are multiplied by a factor of 1.33 for both flexible and rigid pavements.

---

[1] Headquarters, Department of the Army. "Pavement design for roads, streets, and open storage areas, elastic layered method," TM 5-822-13/AFM 32-8007, Vol 1, Washington, DC.

[2] Yu T. Chou. (1989). "Development of failure criteria of rigid pavement thickness requirements for military roads and streets, elastic layered method," Miscellaneous Paper GL-89-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Evaluation criteria

In WESROAD, users are asked to select the evaluation criteria of either initial failure or extended traffic. Initial failure refers to the failure condition that 50 percent of the slabs to be evaluated are cracked into two or three pieces at the end of the design pass level. Extended traffic refers to the condition that at the end of the design pass level, 50 percent of the slabs are cracked into approximately six pieces due to the design traffic.

Stress and Strain Computation, INLEA and WESLEA

Computer program INLEA creates input files for stress and strain computations in WESLEA. It should be noted that INLEA is different from INPAVE which creates input files for WESROAD for pavement evaluation and overlay design. INLEA inputs only pavement dimensions and loads, while INPAVE inputs not only these data but also pavement surface and joint conditions, traffic data, and many others. INLEA can be activated by typing in INLEA at the DOS prompt and following the instructions on the screen. An input file should first be prepared in INLEA to run WESLEA. The input file may be copied, manually modified, and renamed to expedite the input process, but care should be exercised not to alter the format of the file. Otherwise, run-time errors will be encountered in running the WESLEA program. WESLEA can be activated by typing in WESLEA at the DOS prompt and following the instructions shown on the screen. WESLEA is fixed at five layers. In other words, for a concrete slab on subgrade soil, the subgrade should be divided into four layers having any layer thicknesses but having identical material properties and full adhesion at the interfaces. However, a reasonable layer thickness should be used, such as 10 in., except the bottom layer, which is a half space. An extremely small layer thickness may cause a solution convergence problem.

Pavement Evaluation and Overlay Design, WESROAD

WESROAD can be activated by typing in WESROAD at the DOS prompt and following the instructions shown on the screen. An input file should first be prepared using INPAVE. The input file may be copied, manually modified, and renamed to expedite the input process, but care should be exercised not to alter the format of the file. Otherwise, run-time errors will be encountered in running WESROAD.

4 Example Problems

This chapter presents the results of computer problem runs which the user may use to check his own computer results to ensure the correctness of the computer runs.

INLEA and WESLEA

Pavement and load conditions are as follows:

a. Loads (Number 10 axle in Table 1):

Two dual-tandem axle loads spaced at 72 in. side by side
Axle load: 32 kips
Dual-tandem wheel dimension: 13.5 by 48 in.
Contact area radius: 4.265 in.
Selected computational points:
x = 6.75 in. y = 0. in. z = 6 in.
x = 13.5 in. y = 0. in. z = 6 in.

b. Pavement section:

Concrete slab thickness: 6 in.
E modulus of the concrete: 4,387,500 psi
Poisson's ratio of the concrete: 0.15
Slip condition under the concrete slab: Partial slip, 1,000
Subgrade modulus: 6,000 psi
Poisson's ratio of the subgrade: 0.4

The input data WESLEAR1.INP is shown in Table 2. The subgrade is divided into four layers.

When WESLEA is run, output is stored in the file WESLEAR1.OUT as shown in Table 3.

Table 2
Input Data File of WESLEA, WESLEAR1.INP

```
      NO. OF PROBLEMS
      ***************
            1
                                             TITLE
************************************************************************
Input file for WESLEA, rigid slab under one 32-k dual tandem axle load
 E, PSI     NU   THICK., IN  SLIP
********* ****  **********  *****
 4387500.   .15      6.0    1000.
    6000.   .40     10.0       1.
    6000.   .40     10.0       1.
    6000.   .40     10.0       1.
    6000.   .40
NO. OF LOADED AREAS
*******************
            8
LOAD, LBS  RAD.,IN  X, IN   Y, IN
********* ******* ******* *******
    4000.   4.265     .00     .00
    4000.   4.265   13.50     .00
    4000.   4.265     .00   48.00
    4000.   4.265   13.50   48.00
    4000.   4.265   72.00     .00
    4000.   4.265   85.50     .00
    4000.   4.265   72.00   48.00
    4000.   4.265   85.50   48.00
NO. OF EVALUATION POSITIONS
***************************
            2
 LAYER X, IN   Y, IN   Z, IN
 ***** ******* ******* *******
    1   13.50     .00    6.00
    1    6.75     .00    6.00
```

Table 3
Output File of WESLEA, WESLEAR1.OUT

```
                 ****************WESLEA DRA-07.90.18****************
                       P R O B L E M   N U M B E R =  1
                 **********EXECUTED: 12- 2-1991 @ 15:19*************


  Input file for WESLEA, rigid slab under one 32-k twin tandem axle load

                            STRUCTURE INFORMATION
                            *********************

                                                  INTERFACE
      MODULUS      POISSON      THICKNESS          1=NO SLIP
        PSI         RATIO          IN           >1=PARTIAL SLIP
     *********     *******     *********        ***************

     4387500.        .15          6.00
                                                      1000.
        6000.        .40         10.00
                                                         1.
        6000.        .40         10.00
                                                         1.
        6000.        .40         10.00
                                                         1.
        6000.        .40

  INTEGRATION STEP :  .004


                              LOAD INFORMATION
                              ****************

     LOAD     RADIUS      LOAD        CO-ORDINATES, IN
      NO.       IN         LB           X          Y
     ****     ******    ********    *********  *********

       1       4.27      4000.          .00        .00
       2       4.27      4000.        13.50        .00
       3       4.27      4000.          .00      48.00
       4       4.27      4000.        13.50      48.00
       5       4.27      4000.        72.00        .00
       6       4.27      4000.        85.50        .00
       7       4.27      4000.        72.00      48.00
       8       4.27      4000.        85.50      48.00



  ***********************************************************************
  ***********************************************************************

                               POSITION:  1
                   CO-ORDINATES, IN
     LAYER       X          Y          Z
     *****  *********  *********  *********
       1      13.50        .00       6.00
```

(Continued)

Table 3 (Concluded)

```
                               X            Y             Z
                          **********   **********   **********
NORMAL STRESS, PSI          -188.2       -226.8           2.2
SHEAR STRESS, PSI              -.1           .0           6.1
NORMAL STRAIN, IN/IN    -.3522E-04   -.4533E-04     .1469E-04
DISPLACEMENT, MILS            .189         .497       -33.872

************************************************************************
************************************************************************

                              POSITION:  2
                    CO-ORDINATES, IN
     LAYER       X          Y          Z
     ***** ********* ********* *********
       1       6.75        .00       6.00

                               X            Y             Z
                          **********   **********   **********
NORMAL STRESS, PSI          -156.6       -220.2           2.2
SHEAR STRESS, PSI              -.1          -.1          10.8
NORMAL STRAIN, IN/IN    -.2823E-04   -.4491E-04     .1338E-04
DISPLACEMENT, MILS            .407         .482       -33.160

************************************************************************
```

INPAVE and WESROAD

Rigid pavement evaluation and overlay design

The existing pavement has the following characteristics and design traffic:

a. Pavement characteristics:

Concrete thickness: 6 in.
E modulus of the concrete backcalculated from NDT testing:
4,387,500 psi
Flexural strength of the concrete: 675 psi
Pavement surface condition: Poor with cracks
Subgrade modulus backcalculated from NDT testing: 6,000 psi
Frost code of the subgrade: zero
Interface condition under the concrete slab: Partial slip value of 1,000
Joint deflection ratio: 0.9
Pavement condition CB = 0.75
Pavement condition CR = 0.50
Evaluation criteria: Initial crack
Complete output: Yes
Compute overlays: Yes

b. Traffic:

100,000 operations of No. 1 axle, 1.5 kips
200,000 operations of No. 2 axle, 9.0 kips
700,000 operations of No. 10 axle, 32.0 kips
(Note: Axle numbers refer to Table 1.)

After INPAVE is run, the input file EXAMPR1.INP is created as shown in Table 4. Axle coverages on the table are converted from input operations based on the operation per coverage values shown in Table 7 of WES Technical Report 3-582.

Table 4
Input File of WESROAD for Rigid Pavement, EXAMPR1.INP

```
      NO. OF PROBLEMS
      ***************
            1
                                    TITLE
**********************************************************************
Example Problem, Rigid Base Pavement, Three axle loads.
   PAVEMENT TYPE        PAVEMENT      CONDITION    COMPUTE OVERLAYS
R=RIG/F=FLEX/C=COMP                  G=GOOD/P=POOR    Y=YES,N=NO
******************* ************   ************* ****************
       'r'              'S'             'P'             'Y'
NO. OF LAYERS  LAYER FOR SURFACE CRITERIA  LAYER FOR SUBGRADE CRITERIA
*************  **************************  ***************************
     2                   1                              2
TYPE  FROST CODE   E, PSI    THICK, IN   NU   SLIP
****  **********  *********  *********  ****  *****
  2       0       4387500.      6.0      .15  1000.
  6       0          6000.               .40    0.
          ************RIGID & COMPOSITE PAVEMENTS ONLY*************
COMPLETE  *   PCC      JOINT     I=INIT FAILURE  * OVERLAYS ONLY *
 OUTPUT   * FLEX STR DEFL RATIO  E=EXT TRAFFIC   *   CB     CR   *
********  * ******** **********  **************  *  ****   ****  *
  'Y'         675.      .90           'I'           .75    .50
NO. OF AXLES CONSIDERED
***********************
          3
  AXLE      AXLE          AXLE            AXLE
  CODE    LOAD, KIPS   OPERATIONS       COVERAGES
  ****    **********   **********       *********
   1         1.5      .100000E+06      .104275E+05
   2         9.0      .200000E+06      .320000E+05
  10        32.0      .500000E+06      .242718E+06
```

After WESROAD is run, the complete output is stored in EXAMPR1.OUT as shown in Table 5. The complete output is explained as follows:

Table 5
Output File of WESROAD for Rigid Pavement, EXAMPR1.OUT

```
******************************************************************************
********************"WESPAVE" VERSION DRA-09.89.12*****************************
*********************EXECUTED: 11-19-1991 @ 13:44******************************

                          PROBLEM NUMBER   1

    Example Problem, rigid base pavement, three axle loads



                        PAVEMENT INPUT PARAMETERS
                        *************************

LAYER                               FROST       MODULUS, PSI      THICK.  POIS  SLIP
 NO      MATERIAL TYPE               CODE      NDT       FROST      IN.   RAT.  VALUE
***** *****************           ******* ********* ********* ******** **** *****

  1           PCC                     0    4387500.  4387500.     6.00  .15 1000.
  2        SUBGRADE                   0       6000.     6000.    10.00  .40    1.
  3        SUBGRADE                   0       6000.     6000.    10.00  .40    1.
  4        SUBGRADE                   0       6000.     6000.    10.00  .40
  5        SUBGRADE                   0       6000.     6000. SEMI-INF  .40

                         PAVEMENT EVALUATION SUMMARY
                        (ALLOWABLE LOAD NOT APPLICABLE)
                                                              REQ'D OVERLAY,
                                                                   IN.
                              DESIGN        ALLOW-  ALLOWABLE **************
                        ****************    ABLE COVERAGES OF         PCC
      DESIGN            LOAD   COVERAGE     LOAD   DESIGN         PATRIAL   NO
      AXLE ID           KIPS      LEVEL     KIPS     AXLE     AC   BOND   BOND
******************** ****** ********     ****** ********* **** ****   ****

        10              32.0   .244876E+07                  13.4    7.6    8.4


******************************************************************************
******************************************************************************
******************************************************************************
```

(Sheet 1 of 5)

Table 5 (Continued)

```
                         BLIST FOR PROBLEM NUMBER   1

************************************************************************

                          01:VEHICLE-PNEUM SA-SW   0-5

**************STRESSES FROM WES-5***************

                                              ADJUSTED
                                           TENSILE STRESS
              ******LOCATION******          AT BOTTOM OF
 EVALUATION                      DEPTH,      PCC LAYER,
 POSITION   X,IN.   Y,IN.   IN.            PSI
**********  *****   *****  ******       **************

    1          .0      .0    6.00         .550253E+02

         STRESSES HAVE BEEN MULTIPLIED BY  1.773


                     RIGID PAVEMENT EVALUATION

    LAYER 1 THICKNESS=  6.00        OVERLAY THICKNESS=   .00
    ALLOWABLE STRESS=  284.84    COMPUTED STRESS=   55.03
    STRESS RATIO=  5.18
    NO. OF COVERAGES=        104275.0          STREET PAVEMENT AREA
    DESIGN AXLE LOAD(KIPS)=  2.         ALLOWABLE LOAD=NOT APPLICABLE
    MODULUS OF SUBGRADE REACTION, k (PCI) =   69.3
    EFFECTIVE  k (PCI) =   69.3      PCC FLEXURAL STR (PSI)=  675.0
    DEFL. RATIO=     .90     LOAD REDUCTION FACTOR =  1.000
    IMPACT FACTOR=   1.00     EVALUATION FOR:  INITIAL FAILURE
    CONDITION= POOR     CONDITION FACTOR=    .75


************************************************************************

                          02:VEHICLE-PNEUM SA-SW  5-10

**************STRESSES FROM WES-5***************

                                              ADJUSTED
                                           TENSILE STRESS
              ******LOCATION******          AT BOTTOM OF
 EVALUATION                      DEPTH,      PCC LAYER,
 POSITION   X,IN.   Y,IN.   IN.            PSI
**********  *****   *****  ******       **************

    1          .0      .0    6.00         .324207E+03

         STRESSES HAVE BEEN MULTIPLIED BY  1.773
```

(Sheet 2 of 5)

Table 5 (Continued)

```
                    RIGID PAVEMENT EVALUATION

    LAYER 1 THICKNESS=  6.00         OVERLAY THICKNESS=    .00
    ALLOWABLE STRESS=  265.48    COMPUTED STRESS=  324.21
    STRESS RATIO=    .82
    NO. OF COVERAGES=          320000.0          STREET PAVEMENT AREA
    DESIGN AXLE LOAD(KIPS)=  9.           ALLOWABLE LOAD=NOT APPLICABLE
    MODULUS OF SUBGRADE REACTION, k (PCI) =    69.3
    EFFECTIVE  k (PCI) =    69.3      PCC FLEXURAL STR (PSI)=  675.0
    DEFL. RATIO=      .90      LOAD REDUCTION FACTOR =  1.000
    IMPACT FACTOR=   1.00      EVALUATION FOR:  INITIAL FAILURE
    CONDITION= POOR      CONDITION FACTOR=     .75


************************************************************************

                         10:VEHICLE-PNEUM TA-DW 20-50


**************STRESSES FROM WES-5***************

                                                ADJUSTED
                                             TENSILE STRESS
              ******LOCATION******            AT BOTTOM OF
 EVALUATION                     DEPTH,          PCC LAYER,
 POSITION     X,IN.   Y,IN.     IN.               PSI
**********    *****   *****    ******      **************

    1           6.8      .0     6.00          .391407E+03
    2           6.8    24.0     6.00          .226994E+03
    3          13.5      .0     6.00          .405058E+03

        STRESSES HAVE BEEN MULTIPLIED BY  1.773


                    RIGID PAVEMENT EVALUATION

    LAYER 1 THICKNESS=  6.00         OVERLAY THICKNESS=    .00
    ALLOWABLE STRESS=  236.44    COMPUTED STRESS=  405.06
    STRESS RATIO=    .58
    NO. OF COVERAGES=         2427180.0          STREET PAVEMENT AREA
    DESIGN AXLE LOAD(KIPS)= 32.           ALLOWABLE LOAD=NOT APPLICABLE
    MODULUS OF SUBGRADE REACTION, k (PCI) =    69.3
    EFFECTIVE  k (PCI) =    69.3      PCC FLEXURAL STR (PSI)=  675.0
    DEFL. RATIO=      .90      LOAD REDUCTION FACTOR =  1.000
    IMPACT FACTOR=   1.00      EVALUATION FOR:  INITIAL FAILURE
    CONDITION= POOR      CONDITION FACTOR=     .75


************************************************************************

                         10:VEHICLE-PNEUM TA-DW 20-50
```

(Sheet 3 of 5)

Table 5 (Continued)

```
***************STRESSES FROM WES-5***************

                                              ADJUSTED
                                           TENSILE STRESS
                  ******LOCATION******      AT BOTTOM OF
 EVALUATION                       DEPTH,      PCC LAYER,
 POSITION      X,IN.   Y,IN.      IN.           PSI
***********   *****   *****    ******    ***************

     1           6.8      .0    10.28      .212674E+03
     2           6.8    24.0    10.28      .149693E+03
     3          13.5      .0    10.28      .213897E+03

          STRESSES HAVE BEEN MULTIPLIED BY  1.773


                     RIGID PAVEMENT EVALUATION

    LAYER 1 THICKNESS= 10.28          OVERLAY THICKNESS=  4.28
    ALLOWABLE STRESS=  236.33    COMPUTED STRESS=  213.90
    STRESS RATIO=  1.10
    NO. OF COVERAGES= 2448760.2              STREET PAVEMENT AREA
    DESIGN AXLE LOAD(KIPS)=        32.         ALLOWABLE LOAD=NOT APPLICABLE
    MODULUS OF SUBGRADE REACTION, k (PCI)=   69.3
    EFFECTIVE k (PCI)=   69.3       PCC FLEXURAL STR (PSI)=  675.0
    F-FACTOR FOR AC OVERLAY=  .95    CB=  .75    CR=  .50
    DEFL. RATIO=      .90    LOAD REDUCTION FACTOR =  1.000
    IMPACT FACTOR=   1.00    EVALUATION FOR:  INITIAL FAILURE
    CONDITION= POOR      CONDITION FACTOR=     .75

    ESTIMATED NEW THICKNESS=       9.61



*************************************************************************

                          10:VEHICLE-PNEUM TA-DW 20-50


***************STRESSES FROM WES-5***************

                                              ADJUSTED
                                           TENSILE STRESS
                  ******LOCATION******      AT BOTTOM OF
 EVALUATION                       DEPTH,      PCC LAYER,
 POSITION      X,IN.   Y,IN.      IN.           PSI
***********   *****   *****    ******    ***************

     1           6.8      .0     9.61      .229757E+03
     2           6.8    24.0     9.61      .158448E+03
     3          13.5      .0     9.61      .231785E+03

          STRESSES HAVE BEEN MULTIPLIED BY  1.773


                     RIGID PAVEMENT EVALUATION
```

(Sheet 4 of 5)

Table 5 (Concluded)

```
LAYER 1 THICKNESS=  9.61        OVERLAY THICKNESS=  3.61
ALLOWABLE STRESS=  236.33    COMPUTED STRESS=  231.78
STRESS RATIO=  1.02
NO. OF COVERAGES= 2448760.2            STREET PAVEMENT AREA
DESIGN AXLE LOAD(KIPS)=        32.       ALLOWABLE LOAD=NOT APPLICABLE
MODULUS OF SUBGRADE REACTION, k (PCI)=   69.3
EFFECTIVE k (PCI)=   69.3     PCC FLEXURAL STR (PSI)=  675.0
F-FACTOR FOR AC OVERLAY=  .95   CB=  .75   CR=  .50
DEFL. RATIO=    .90     LOAD REDUCTION FACTOR =  1.000
IMPACT FACTOR=    1.00     EVALUATION FOR:  INITIAL FAILURE
CONDITION= POOR     CONDITION FACTOR=    .75

ESTIMATED NEW THICKNESS=      9.45


          THICKNESS OF LAYER 1 =         9.45
```

(Sheet 5 of 5)

a. Page 1 of Table 5 shows the pavement information. Since the computed damage was greater than 1, overlay design was started. The axle load chosen for the overlay design was the 32-kip No. 10 axle with an equivalent coverage of 2,448,760. The design overlay thicknesses are:

Asphalt concrete = 13.4 in.
Concrete, partial-bond = 7.6 in.
Concrete, no-bond = 8.4 in.

b. Page 2 of Table 5 shows the computed stresses in the 6-in.-thick concrete slab under the three axle loads. The stresses were multiplied by a factor of 1.773 (1.33 × 1.33) accounting for the edge load effect and poor pavement surface condition. Stresses were not adjusted for joint condition as the input deflection ratio was 0.9.

c. The remaining part of the table shows results for the selected axle load at different stages of the overlay design iterations. In the first iteration, the thickness of the trial concrete was 10.28 in., resulting in a stress ratio of 1.10. The stress ratio is the ratio of the allowable stress to the computed stress. The concrete thickness was reduced to 9.61 in. with a stress ratio of 1.02. A new concrete thickness of 9.45 in. was thus selected for a stress ratio of 1.0. Overlay thicknesses were computed from overlay equations based on the new concrete thickness of 9.45 in. New concrete thickness is defined as the required concrete thickness on the same subgrade.

d. Bonded concrete overlay is not allowed for existing concrete slabs which are in poor condition. The required bonded concrete overlay thickness will be the difference {~} between the new concrete thickness and the existing concrete if the latter is in good condition.

Flexible pavement evaluation and overlay design

The existing pavement has the following characteristics and design traffic.

a. *Existing pavement:*

Asphalt concrete thickness: 4 in.
E modulus of the asphalt concrete: 200,000 psi
Poisson's ratio of the asphalt concrete: 0.35
Interface condition under the asphalt: Total adhesion value of 1.0
Granular base layer thickness: 8 in.
E modulus of the granular layer: 40,000 psi
Poisson's ratio of the granular layer: 0.35
Interface condition under the granular layer: Total adhesion of 1.0
Emodulus of the subgrade: 10,000 psi
Poisson's ratio of the subgrade: 0.4
Complete output: Yes
Surface condition: Poor
Overlay design: Yes

b. *Traffic:*

20,000,000 operations of No. 4 axle load, 18 kips

After INPAVE is run, the input file EXAMPF1.INP is created as shown in Table 6. After WESROAD is run, the output is stored in EXAMPF1.OUT as shown in Table 7. Table 7 shows that the required asphalt concrete overlay thickness is 7.0 in.

Table 6
Input File of WESROAD for Flexible Pavement, EXAMPF1.INP

```
        NO. OF PROBLEMS
        ****************
              1
                                   TITLE
***************************************************************************
ROAD EVALUATION AND OVERLAY DESIGN, FLEXIBLE PAVEMENT
   PAVEMENT TYPE        PAVEMENT       CONDITION     COMPUTE OVERLAYS
R=RIG/F=FLEX/C=COMP                   G=GOOD/P=POOR      Y=YES,N=NO
********************  *************  **************  *****************
        'F'                'R'              'P'              'Y'
NO. OF LAYERS  LAYER FOR SURFACE CRITERIA  LAYER FOR SUBGRADE CRITERIA
*************  ****************************  *****************************
     3                    1                               3
TYPE  FROST CODE   E, PSI    THICK, IN   NU   SLIP
****  **********  *********  *********  ****  *****
 1        0       200000.       4.0     .35    1.
 5        0        40000.       8.0     .35    1.
 6        0        10000.               .40    0.
          ************RIGID & COMPOSITE PAVEMENTS ONLY*************
COMPLETE  *   PCC        JOINT      I=INIT FAILURE  * OVERLAYS ONLY *
 OUTPUT   * FLEX STR  DEFL RATIO   E=EXT TRAFFIC   *   CB      CR   *
********  * ********  **********   **************  *  ****    ****  *
  'Y'        -----       ----           ---           ----    ----
NO. OF AXLES CONSIDERED
************************
          1
  AXLE        AXLE          AXLE           AXLE
  CODE     LOAD, KIPS    OPERATIONS      COVERAGES
********  ***********    *********      ***********
   4         18.0       .200000E+08     .757576E+07
```

Table 7
Output File for WESROAD for Flexible Pavement, EXAMPF1.OUT

```
*************************************************************************
*********************"WESPAVE" VERSION DRA-09.89.12**********************
**********************EXECUTED: 11-19-1991 @ 14: 8***********************

                         PROBLEM NUMBER    1

    ROAD EVALUATION AND OVERLAY DESIGN, FLEXIBLE PAVEMENT



                      PAVEMENT INPUT PARAMETERS
                      *************************

 LAYER                          FROST      MODULUS, PSI      THICK.  POIS  SLIP
  NO       MATERIAL TYPE         CODE     NDT       FROST      IN.    RAT. VALUE
****** *****************  ******* ********* ********* ******** **** ****

  1            AC                 0     200000.   200000.     4.00  .35    1.
  2     BASE OR SUBBASE           0      40000.    40000.     8.00  .35    1.
  3         SUBGRADE              0      10000.    10000.    10.00  .40    1.
  4         SUBGRADE              0      10000.    10000.    10.00  .40
  5         SUBGRADE              0      10000.    10000. SEMI-INF  .40


                      PAVEMENT EVALUATION SUMMARY
                    (ALLOWABLE LOAD NOT APPLICABLE)
                         DESIGN        ALLOW-  ALLOWABLE
                    ****************    ABLE COVERAGES OF      REQ'D
       DESIGN        LOAD,  COVERAGE   LOAD     DESIGN        OVERLAY,
      AXLE ID        KIPS    LEVEL     KIPS      AXLE            IN.
******************** ****** ********  ****** *********     ********

         4           18.0     7575760.                          7.0

*************************************************************************
*************************************************************************
*************************************************************************
```

(Sheet 1 of 4)

Table 7 (Continued)

BLIST FOR PROBLEM NUMBER 1

****

04:VEHICLE-PNEUM SA-DW 10-20

***************************STRAINS FROM WES-5**************************

EVALUATION POSITION	X,IN.	Y,IN.	ADJUSTED VERTICAL STRAIN AT TOP OF SUBGRADE, IN/IN	DEPTH, IN.	ADJUSTED RADIAL STRAIN AT BOTTOM OF AC LAYER, IN/IN	DEPTH, IN.
**********	*****	*****	***************	******	*************	******
1	6.8	.0	.9885038E-03	12.00	.3238798E-03	4.00
2	13.5	.0	.9432652E-03	12.00	.4011891E-03	4.00

STRAINS HAVE BEEN MULTIPLIED BY 1.333

FLEXIBLE PAVEMENT EVALUATION

LAYER 1 THICKNESS= 4.00 OVERLAY THICKNESS= .00
ALLOWABLE ASPHALT STRAIN= .216E-03 COMPUTED STRAIN= .401E-03
ASPHALT STRAIN RATIO= .54
ALLOWABLE SUBGRADE STRAIN= .420E-03 COMPUTED STRAIN= .989E-03
SUBGRADE STRAIN RATIO= .43
NO. OF COVERAGES= 7575760.0 ROAD PAVEMENT AREA
DESIGN AXLE LOAD(KIPS)= 18. ALLOWABLE LOAD=NOT APPLICABLE
CALCULATED SUBGRADE CBR= 6.7 IMPACT FACTOR= 1.00
CONDITION= POOR CONDITION FACTOR= .75

MINIMUM RATIO= .43

****

04:VEHICLE-PNEUM SA-DW 10-20

***************************STRAINS FROM WES-5**************************

EVALUATION POSITION	X,IN.	Y,IN.	ADJUSTED VERTICAL STRAIN AT TOP OF SUBGRADE, IN/IN	DEPTH, IN.	ADJUSTED RADIAL STRAIN AT BOTTOM OF AC LAYER, IN/IN	DEPTH, IN.
**********	*****	*****	***************	******	*************	******
1	6.8	.0	.4963186E-03	17.41	.2092720E-03	9.41

(Sheet 2 of 4)

Table 7 (Continued)

```
     2         13.5      .0      .4614246E-03  17.41    .2044041E-03   9.41

          STRAINS HAVE BEEN MULTIPLIED BY  1.333


                         FLEXIBLE PAVEMENT EVALUATION

    LAYER 1 THICKNESS=  9.41         OVERLAY THICKNESS=  5.41
    ALLOWABLE ASPHALT STRAIN=  .216E-03    COMPUTED STRAIN=  .209E-03
    ASPHALT STRAIN RATIO=      1.03
    ALLOWABLE SUBGRADE STRAIN=  .420E-03    COMPUTED STRAIN=  .496E-03
    SUBGRADE STRAIN RATIO=   .85
    NO. OF COVERAGES= 7575760.0            ROAD   PAVEMENT AREA
    DESIGN AXLE LOAD(KIPS)=      18.      ALLOWABLE LOAD=NOT APPLICABLE
    CALCULATED SUBGRADE CBR=   6.7     IMPACT FACTOR=    1.00
    CONDITION= POOR      CONDITION FACTOR=    .75

    MINIMUM RATIO=    .85

    ESTIMATED THICKNESS TO MEET ASPHALT CRITERIA=  9.14
    ESTIMATED THICKNESS TO MEET SUBGRADE CRITERIA= 10.72

    MAXIMUM ESTIMATED THICKNESS= 10.72



***********************************************************************

                          04:VEHICLE-PNEUM SA-DW 10-20


***************************STRAINS FROM WES-5**************************

                              ADJUSTED                 ADJUSTED
                           VERTICAL STRAIN           RADIAL STRAIN
                             AT TOP OF               AT BOTTOM OF
EVALUATION                   SUBGRADE,      DEPTH,     AC LAYER,      DEPTH
 POSITION   X,IN.   Y,IN.      IN/IN          IN.        IN/IN         IN.
**********  *****   *****  ***************  ******  *************   *****

    1        6.8      .0    .4318432E-03   18.72    .1836207E-03   10.72
    2       13.5      .0    .4031153E-03   18.72    .1767300E-03   10.72

          STRAINS HAVE BEEN MULTIPLIED BY  1.333


                         FLEXIBLE PAVEMENT EVALUATION

    LAYER 1 THICKNESS= 10.72         OVERLAY THICKNESS=  6.72
    ALLOWABLE ASPHALT STRAIN=  .216E-03    COMPUTED STRAIN=  .184E-03
    ASPHALT STRAIN RATIO=      1.18
    ALLOWABLE SUBGRADE STRAIN=  .420E-03    COMPUTED STRAIN=  .432E-03
    SUBGRADE STRAIN RATIO=   .97
    NO. OF COVERAGES= 7575760.0            ROAD   PAVEMENT AREA
    DESIGN AXLE LOAD(KIPS)=      18.      ALLOWABLE LOAD=NOT APPLICABLE
    CALCULATED SUBGRADE CBR=   6.7     IMPACT FACTOR=    1.00
```

(Sheet 3 of 4)

Table 7 (Concluded)

```
CONDITION= POOR     CONDITION FACTOR=    .75

MINIMUM RATIO=   .97

ESTIMATED THICKNESS TO MEET ASPHALT CRITERIA=  9.09
ESTIMATED THICKNESS TO MEET SUBGRADE CRITERIA= 10.98

MAXIMUM ESTIMATED THICKNESS= 10.98


          THICKNESS OF LAYER 1 =        10.98
```

(Sheet 4 of 4)

5 Recommendations

Computer program WESROAD should be used for the evaluation and overlay design of roads, streets, and open storage areas that have been evaluated using the NDT method. Computer program WESLEA is used for computing pavement stresses and strains. Although the programs are user-friendly, this report will be beneficial for users when questions arise. To ensure the correctness of the computer run, first-time users should run the programs using the input data provided in the example problem and check the computer results with those provided in Tables 2-7.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
January 1994

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
A Computer Program for Evaluation and Overlay Design of Roads, Streets, and Open Storage Areas Using Nondestructive Testing and Elastic Layered Method - WESROAD

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Miscellaneous Paper
GL-94-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A user-friendly computer program, WESROAD, is presented for the evaluation and overlay design of roads, streets, and open storage areas using the elastic layered method. The program is designed to operate on an IBM or compatible machine under the DOS 3.0 operating system or a later system. This report provides users with necessary information for running WESROAD, including the programming logic, computer system requirements, user instructions, and the input and output of an example problem. The pavements to be evaluated include flexible, concrete, and composite (asphalt over concrete) pavements. The overlay design includes flexible and concrete overlays.

14. SUBJECT TERMS
Pavements--Overlays--Data processing
WESROAD (Computer program)
Roads--Design and construction--Data processing

15. NUMBER OF PAGES
30

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std Z39-18
298-102