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16. Abstract:

Various capabilities of several versions of the VESYS flexible pavement model have been combined into a single computer program called VESYS IV-B. The resulting computer program was also edited and modularized to make it more convenient to use and to modify in the future. VESYS IV-B now models an n-layer flexible pavement structure using resilient moduli, creep compliance, or a combination of these for specifying layer stiffnesses, which may be varied seasonally. Both single and tandem axles are considered. Both fatigue and permanent deformation material properties may be varied seasonally, and permanent deformation properties and layer moduli may be varied with magnitude of loads as well. Seasonal variations in the fatigue constants $K_1$ and $K_2$ may be generated internally on the basis of seasonal pavement surface temperatures or stiffnesses. This state of the art model predicts fatigue cracking, rutting, and serviceability loss.

These revisions and improvements are described in the report, and a combined keyword dictionary and input guide is included.

See also: Pavement Damage Functions for Cost Allocation, Volumes 1 and 2, and Executive Summary.

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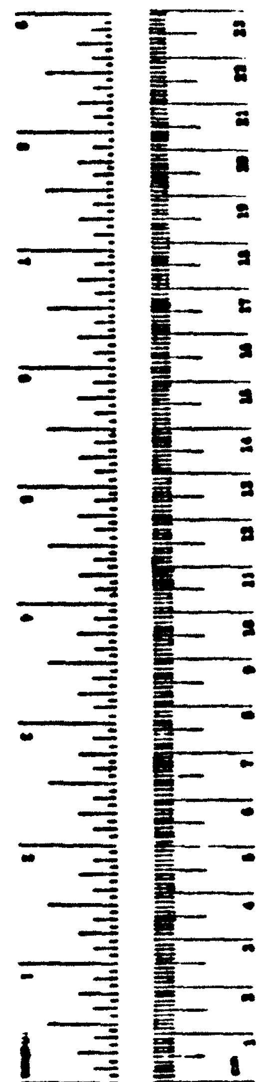
# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

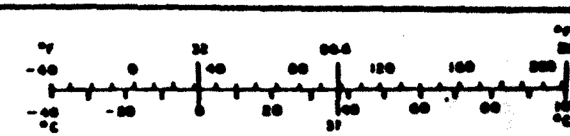
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



## PREFACE

This work was accomplished by Dr. Peter Jordahl with Brent Rauhut Engineering Inc. of Austin, Texas, in coordination with Dr. J. Brent Rauhut.

This project was originally conceived by Mr. William J. Kenis, FHWA Contract Manager, Office of Research and Development. Many useful ideas were contributed by Mr. Kenis and Mr. James Sherwood with the FHWA Office of Research and Development. Support for this research effort was provided by the Federal Highway Administration, Contract No. DTFH61-80-C-00175.

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# CHAPTER 1

## INTRODUCTION

The primary goal of this work effort was the incorporation of improvements made by BRE to the VESYS flexible pavement model into the current FHWA version called VESYS IV. VESYS IV had resulted from improvements and new capabilities added by several groups and designated individually as VESYS-A, VESYS-G, VESYS III, VESYS III-A, and ultimately VESYS IV. VESYS III-A was in some ways more advanced than VESYS IV, so it was used as the base for further improvements (resulting in VESYS III-B) by BRE to enhance development of damage functions for use in cost allocations.

A secondary goal was to make organizational improvements in the resulting computer program called VESYS IV-B. The organizational improvements implemented far exceed those identified in the contract document.

Examination of listings of VESYS-IV as provided to BRE by the FHWA, and comparison with the version of VESYS III (called VESYS III-B) currently in use at BRE, disclosed that the following two features were present in VESYS IV and not in III-B:

1. Permanent deformation calculations at each layer interface, permitting determination of the contribution of each layer to the total permanent deformation.

2. Three submodels for differing treatment of asphaltic layer modulus or creep compliance.

The following features were present as user options in VESYS III-B and not in IV:

1. Channelization of traffic (permitting the definition of rut depth as used in actual measurements).

2. Restart capability (initialization of damage to non-zero, read-in values).

3. Composite pavement analysis (treating tensile stress in the lower Portland Cement Concrete layer).

4. Tandem axle analysis

5. Unequal-length seasons

6. Input of modulus and permanent deformation parameters by load group.

7. Internal calculation of fatigue constants $K_1$ and $K_2$ from seasonal temperature or from seasonal moduli.

In addition, but of lesser importance, are

8. Print of damages by <u>season</u> for the first two years (damage index and permanent deformation).

9. Inclusion of a new relationship developed by BRE between damage index and areal cracking, based on earlier studies of AASHO Road Test data.

It was felt that the additional features of VESYS III-B, while individually not of the magnitude of the two listed for VESYS IV, were sufficiently numerous and pervasive that the improvements should use III-B as a base. In addition, since the common block structure had undergone numerous additions and revisions during the several past program modifications and since many of the block names no longer had direct relevance to their contents, it was decided that the entire common block structure would be redone. An added consideration in this decision was the problem encountered in attempting to use the program in double precision mode with the D.O.T. Amdahl computer on this project. Numerous dummy variables had to be inserted in the existing blocks to permit double precision operation.

## CHAPTER 2

## IMPROVEMENTS TO VESYS

The work to improve and reorganize VESYS was divided into several areas, as follows:

A. Common block restructuring

B. NLAYER subsection

C. MAIN program - new input

D. Subroutine PRIME (static solutions and permanent deformation parameter calculations)

E. Subroutine RANDOM and associated routines.

Each area will be discussed. A detailed description of features added by BRE to form VESYS III-B before its use to generate a "damage function factorial" appears as chapter 7 of Reference 1.

### COMMON BLOCK RESTRUCTURING.

As mentioned above, the many modifications to the program over the past 10 years had left the common blocks in a very confused state. Some block names were leftovers from the original VESYS II-M, but their contents had little to do with the names. Others had been added to transport newly added variables between specific routines.

An attempt was made to collect logically-related variables into groups, and assign meaningful names to these groups. The new common blocks are listed below. Most of the block names are more-or-less obvious to someone who has used the program, but we will indicate the use of each block below:

| | |
|---|---|
| /CLIMAT/ | climatic or environment related variables |
| /CTRL/ | variables dealing with the type of model, type of run, degree of optional print, and several available for future use |
| /CREEP/ | variables related to input creep compliance and related quantities |
| /DELTA/ | the variables $\delta$ used in representing creep compliance and response as functions of loading time (Dirichlet series) |
| /DFORML/ | permanent deformation variables $\alpha$ and $\mu$ for the layers |
| /DFORMS/ | permanent deformation variables $\alpha$ and $\mu$ for the system, and variables related to solutions for system permanent deformation <u>by layer</u>. |
| /DICT/ | Dictionary of input keywords, default values, and upper and lower bounds on those inputs which have single values and not arrays associated with them |
| /FATIG/ | Variables relating to fatigue constants and their variability. |
| /INIVAL/ | Initial values for damage index, variance of damage index, and permanent deformation for cases where a simulation continues from a previous run. These could be used, for example, with modified layer moduli to simulate moisture damage to a base |

layer. Also, initial values and variance of PSI, and minimum tolerable PSI.

/LAYER/ Variables containing information on individual layers.

/LOAD/ Variables related to size and type of loads applied, and relative (not absolute) distribution of number of loads of those types.

/LOCN/ Locations at which outputs or computations are specifically desired.

/LOTCR/ Variables related to low-temperature cracking.

/PCC/ Variables related to computations of fatigue for composite pavements (asphalt over PCC).

/RESP/ Variables containing calculated responses to the various load types and seasons.

/RFSVCR/ (Roughness, serviceability, cracking) Input variables related to the computation of distresses from the responses.

/TOLR/ Contains an input variable setting the percent area (under the (assumed) normal distribution of PSI) for which PSI < PSIMIN constitutes failure.

/TRAFIC/ Variables relating to the numbers of loads applied to the system as functions of time, and to the presence and amount of channelization in the simulation.

Several blocks used only to transfer information among subroutines in the repeated load portion of the program were left unchanged. Common blocks /ONE/ through /NINE/, and /BLOCK/, which are used internally by the NLAYER subroutines, were slightly reorganized; they are part of the NLAYER "package" which we shall treat as a "black box" in most of this documentation. One should note that the limitation to seven layers present in the current version of VESYS is primarily imposed by the dimensions (80,7,7) on four variables in block /SEVEN/ which impose severe memory requirements if enlarged.

## THE NLAYER SUBSECTION.

The NLAYER subsection accepts layer moduli and their coefficients of variation, layer thicknesses, and Poissons ratios; and returns stresses, strains, and deflections and their standard deviations. This portion of VESYS is the heart of the program, and special care was taken to ensure that changes in the common blocks did not cause any changes in operation. A separate driver program was written for this subsection only, and output was compared between runs made before and after the changes. No difference was noted. Minor changes were made in the NLAYER subroutine itself relating to printed output from that routine. It was decided that normally all printed output should be from outside the NLAYER subsection. However, if desired, one can "turn on" extensive output of all calculated stresses, strains and deflections from within NLAYER itself.

## MAIN PROGRAM

The internal input guide, previously contained within the main program, was removed to a separate subroutine (GUIDE) with no executable code, to reduce unnecessary printing when future changes are made to the main program. Nearly all common blocks not relating directly to the layer solutions are declared here. In addition to new keywords related to new functions (TANDEM, et al.; CREEP) several keywords were added to make possible easy external access to any optional code added by later users, e.g., special print routines for specific information not normally printed or not normally calculated. Details of these keywords, as well as others which have been added or changed, appear in the internal input guide, a copy of which is appended to this report.

Several of the features added in the development work at BRE are appropriately discussed here. The program user has the option of providing either one or two asphalt concrete layers, with separate temperatures for each; hence, in a Submodel 2 or 3 run, one may have the same input creep compliance curve for both parts of an artificially split asphalt layer, and account for temperature stratification; or one may model two types of asphalt, perhaps an original pavement and a later overlay, with different creep curves or moduli. Except for the asphaltic layers, for which moduli are expected for Submodel 1, and creep compliance for Submodel 2 and 3, either moduli varying by season or creep compliance and associated seasonal multipliers (if desired) can be input for any layer for any Submodel. This is particularly useful in Submodels 2 and 3 where the prime focus of attention is the behavior of the asphaltic concrete, and the creep compliance and seasonal multipliers for lower-lying layers are sometimes obtained by inverting the corresponding moduli; here these moduli may be entered directly.

Another added feature is the ability to input <u>moduli</u> (not creep compliance) for any layer as functions of the load class. This permits consideration of stress sensitivity in the base and subgrade layers, which may have a considerable effect in altering the behavior of the layered system under different loads. As well, permanent deformation parameters $\alpha$ and $\mu$ for the individual layers may be input by load class, looking forward to the time when adequate laboratory information on the variation of these parameters with stress state becomes available.

The input of a non-zero value associated with the keyword FLEXSTR changes the fatigue analysis from one considering strain to one considering the quantity (stress/flexural strength). Thus it is possible to consider composite pavements (asphalt over Portland Cement) where the critical point for fatigue is at the bottom of the Portland Cement layer, but where one wishes also to analyze the permanent deformation in the asphalt. $\alpha$ and $\mu$ for the PCC layer may be set to 1.0 and 0., respectively, for all seasons, indicating that no permanent deformation is expected in the PCC layer itself.

Channelization of traffic, if desired, is provided through the means of keywords CENTCHAN and SIDECHAN. The value "a" associated with CENTCHAN is the fraction of wheel loads expected to affect the center "pathway" or channel, defined approximately by the width of a dual tire. The value "b" associated with SIDECHAN is the fraction of wheel loads whose primary effect is on the strip of pavement on one side of the central channel and of width equal to that of the central channel. This value defaults to b = (1 - a)/2, considering that all traffic essentially falls in a path three "channels" wide. This is an attempt to simulate better the measurement of rut depth as the maximum depression under a four-foot straight-edge, the ends of which lie on pavement which itself experiences some traffic.

Consistent with the input of coefficients of variation for layer moduli or creep compliances, and with coefficient of variation of fatigue constants, it was decided to input coefficient of variation of tire pressure and load duration rather than the actual variances. These are now associated with keywords CVAMP and CVDUR, rather than the previous VCAMP and VCDUR.

## SUBROUTINE PRIME

Subroutine PRIME was completely rewritten. Several portions were removed and placed in separate routines. PRIME now acts as a calling and organizing routine, controlling loops over season, radius, and load duration. PRIME and associated subroutines handle completely the variations in procedure among the submodels. The routines called by PRIME, and their function, are listed below:

CURVE — Fits Dirichlet series to creep compliance data (no change) as well as to computed responses for submodel 3.

GTMOD2 — For Submodel 2, evaluates the Dirichlet series at the input value of load duration to obtain corresponding creep compliance and hence modulus. If a layer is asphaltic concrete, the duration is shifted for the input seasonal temperature; if it is not, the creep compliance obtained is multiplied by the appropriate seasonal multiplier. The result from this routine is seasonal moduli for all layers for which creep and not moduli were input.

GTMOD3 — For Submodel 3, evaluates creep compliances, and hence layer moduli, for those layers having creep compliance input, at each of the values of load duration used for this submodel. Again the asphaltic layer results are corrected for seasonal temperatures and the non-asphaltic layer results are corrected by input seasonal multipliers.

PRELAY (MODE = 1) Transfer into common blocks associated with the NLAYER package information which does not vary with season or load (e.g., layer thickness, locations at which output is desired, etc.). (MODE = 2) Transfer, as above, information which depends on load but not season (e.g., load radius, tandem spacing). (MODE = 3) Transfer, as above, information which depends on season, or season and load (e.g, layer moduli).

NLAYER The main subroutine of the package that actually performs the layer solutions. Takes layer thicknesses, moduli, and Poissons ratios, as well as load pressure and radius, and generate stresses, strains and deflections at specified points.

STORE Take results from NLAYER solutions and stores those specifically needed for further analysis by load duration and radial position.

UNLOAD Performs the abbreviated layer solutions for deflections as a function of layer moduli, the latter being varied to simulate the effect of removal of a load after passage of varying numbers of loads. A function of the deflections is then regressed against numbers of loads to obtain parameters of the permanent deformation behavior of the entire system.

SUMPRT Prints a compact summary of the layer and permanent deformation solutions.

One goal of this rewrite of PRIME was to reduce the points of contact between VESYS itself and the specific n-layered elastic layer solution subprograms. This makes possible the future replacement of NLAYER by another solution procedure or subprogram, should this ever prove desirable, with a minimum of problems. At present, the only routines outside the NLAYER package which contain NLAYER common blocks are PRELAY, STORE, and ABLAYR (a routine called by UNLOAD to interface with NLAYER for the abbreviated solutions mentioned earlier).

From the discussion above, it is apparent that the revised PRIME and associated subprograms form a modular and highly structured set of routines in which overlapping functions are kept to a minimum. Future revisions of VESYS will greatly benefit from this modular approach.

SUBROUTINE RANDOM AND ASSOCIATED ROUTINES

As before, subroutine RANDOM acts mainly as a calling routine for the other subprograms in the repeated load analysis. It also, at the beginning of the analysis, calculates the time (in seconds) from the beginning of the analysis period to the end of each season in the period. This makes possible convenient determination of total axles in a given season by determining the traffic level at the middle of each season and multiplying by the elapsed time during a season. The special attention given here is required by the new capability of non-equal season lengths.

The PRIME (and NLAYER) group of subroutines produce (for each season and load group (load radius):

1. Surface deflection at the center (r=o) of a load at a pressure of (QQ) PSI (QQ normally = 1.0)

2. If tandem axles are present in this load group (FTAN >0) surface deflection at r=x/2 and r=x, where

x=TANSPACE, the front-to-back spacing of the axles in a tandem axle.

3. Radial strain at the bottom of the asphalt concrete (or stress divided by flexural strength if a PCC pavement is being analyzed) at r=o, again at 1 PSI load pressure.

4. If tandem axles are present in this load group, the tangential strains calculated at r=x/2 and r=x, x as in (2).

Actually, what is provided is Dirichlet series representations of the above as functions of load durations; however, in submodels 1 and 2 these series consist only of the first term, in a series of the form:

$$f(t) = \sum_{i=1}^{N} g_i \, e^{-\delta_i t}$$

where the $g_i$ are constants fitted to the results of layer solutions and where $\delta_1$ is always zero; hence $f(t) = g_1$. In submodel 3, the full series is used, representing the variation in response found for the range of load duration (t) for which asphalt creep compliance was obtained and layer solutions run.

RANDOM separates the calculation of distress into two parts: fatigue cracking, and permanent deformation and resulting slope variance and loss of serviceability. For each part, the procedure is similar, and is as follows:

1. Call GRESP (generalized response to evaluate the Dirichlet series mentioned above, for each season, load radius, and position. For Submodel 3, the input

load duration and a haversine load pulse shape are mathematically modeled to obtain a peak response from the full series. For Submodels 1 and 2 essentially a rectangular load pulse is assumed, and the input value of load duration (in the case of Submodel 2) was accounted for in evaluating the seasonal moduli from input creep compliance.

2. Loop over season and load group, and

   a. determine if any tandems are present,

   b. if so, call TANDEM to combine responses appropriately,

   c. determine if any of the responses are negative; if so, flag as an error and halt. (Subroutine NEGCHK)

3. Call CRACKS (fatigue) or ROUGH (permanent deformation) to obtain the appropriate distress at the end of each season.

After damage index and its variance, and corresponding area cracked have been obtained from CRACKS, and permanent deformation and its variance have been obtained from ROUGH, subroutine SERVC computes Present Serviceability Index (PSI) and its variance, and subroutine MARG obtains the marginal probabilities on PSI, at each time input under the keyword "TRANDOM". (Marginal probabilities express the probability of finding a section of pavement with PSI in a specified range, given a predicted mean and variance of PSI, or, put another way, express the fraction of pavement area expected to fall within each of the specified ranges of PSI.)

The operation of Subroutines CRACKS and ROUGH is the same as before, with the following exceptions:

1. In each routine, a loop has been added to obtain the seasonal values of distress in each of the three channels, if channelization is desired.

2. In ROUGH, one may obtain the permanent deformation (in the central channel) at the top of any or all layers.

3. In CRACKS, fatigue constants $K_1$ and $K_2$ are obtained as functions of seasonal temperatures or seasonal moduli from external routine FATCON, rather than being calculated within the subroutine.

4. CRACKS now prints the inverse of the expected value of $(1/N_f)$, which was used in the calculations of damage index, where $N_f$ is the number of load repetitions to failure in fatigue, instead of the expected value of $N_f$, which was never used and had only indirect relation to what was used. ($N_f$ is a non-linear function of strain $\varepsilon$ and fatigue constants $K_1$ and $K_2$; the expected value takes into consideration the variance of all three of these variables.) CRACKS also prints the coefficient of variation of the above expected value, not the variance.

5. CRACKS now permits the user to calculate area cracked either as a percent area under the normal distribution of damage index for which damage index is greater than 1.0, or from an equation which relates area cracked to mean damage index alone and not to the variance of damage index. The two parameters of

the equation (which represents an S-shaped curve) may be input by the user; the default values represent 10% area cracked at damage index equal to 1.0 and 45% area cracked at damage index equal to 1.38, values derived by Rauhut from the NCHRP 1-10B study of AASHO Road Test materials and data (Ref. 2).

Subroutine FATCON returns seasonal values of fatigue constants $K_1$, $K_2$ based on seasonal values of pavement temperature or of pavement modulus, or returns values input directly by the user. A relation between $K_1$ and $K_2$ which has been derived from many fatigue studies is used to obtain $K_2$ from $K_1(T)$ or $K_1(E)$, and can be used as well if the user wishes to input seasonal values of $K_1$ only. If it is desired to consider fatigue cracking at the bottom of the deeper of two layers of asphaltic concrete, the variable ZCRACK can be set to the depth from the surface to that point, and the temperature, (or modulus) and strain will be obtained for that layer. ZCRACK is normally input as the thickness of the top layer; the default value of 0. will yield the same results.

The relationships governing the calculation of $K_1$ and $K_2$ are as follows:

$$K_1(T) = K_1(TR) \ \exp[.001336 \ (T^2 - TR^2)]$$

$$K_1(E) = K_1(ER) \cdot (E/ER)^{-4}$$

$$K_2(K_1) = 1.75 - .252 \log_{10} (K_1)$$

Default values of ER, TR, and $K_1 \binom{ER}{TR}$ are 500000 psi, 70F, and $7.87 \times 10^{-7}$, respectively; one or all can be set from input values as well.

Subroutine LOTMPC calculates the amount of pavement area affected by low-temperature cracking using the Hajek-Haas model. This procedure was discussed and documented in an earlier FHWA report (Ref. 3).

Subroutine CRPRNT is executed when more than one load group (load radius) is present, and prints a summary of the contribution of each load group to damage index and its variance. Where tandems are modeled, the output shows the contribution from single axles and tandem axles separately.

Subroutine TANDEM returns the appropriate combined strains or deflections for simulation of single or tandem axles from the deflections and strains at the three radial distances mentioned earlier. For deflections the values d returned are ($x \doteq$ TANSPACE, r=radial distance from center of a dual tire):

singles d = defl (r=0)
tandems d = defl (r=0) + defl (r=x)

For strains, the values $\varepsilon$ returned are ($\varepsilon_r$ = radial strain; $\varepsilon_t$ = tangential strain)

| | |
|---|---|
| singles | $\varepsilon = \varepsilon_r\ (r=0)$ |
| tandems | $\varepsilon_1 = \varepsilon_r\ (r=0) + \varepsilon_t\ (r=x)$ |
| | $\varepsilon_2 = \varepsilon_1 - 2 \cdot \varepsilon_t\ (r=x/2)$ |

For tandems, $\varepsilon_1$ represents the maximum strain under the first tire or dual tire to pass over a point, and $\varepsilon_2$ represents the height of the second maximum due to passage of the second tire of a tandem axle (also equal to $\varepsilon_i$) above the minimum strain achieved between the first and second tires. Fatigue effects from the strains $\varepsilon_1$ and $\varepsilon_2$ are separately added to the damage index for each tandem axle simulated.

Subroutine LAYDEF returns, for each season throughout the analysis period, the accumulated permanent deformation at the top of the first NINT layers, where NINT is the first digit of the three digit integer input under the keyword UNLOAD. The procedure is the same as that used in ROUGH for the surface permanent deformation. Here $\alpha$ and $\mu$ values defined in the static solution for each of the required layer interfaces are used. It is assumed that the permanent deformation per load at an interface should be calculated as a fraction of the total vertical displacement at that interface; therefore at each interface the surface deflection calculated from ROUGH and GRESP is multiplied by the ratio of static vertical displacement at that interface to the static vertical displacement at the surface; the result then approximates the displacement under the simulated load at that interface.

Subroutine SERVC converts area cracked, C, mean rut depth, RD, and slope variance, SV, at any time to PSI, using the regression equation derived at the AASHO Road Test. That equation is:

$$PSI = 5.03 - 1.91 \log_{10} (1 + SV) - 1.38(RD)^2 - .01 (C+P)^{1/2}$$

where P is area patched (always = 0 in VESYS), and C and P are both measured in square yards per thousand square yards, RD is in inches, and SV is in [$10^{-6}$ radians]. VESYS simulations normally start with both rut depth and area cracked equal to zero; since slope variance is derived from variance of rut depth, and variance of rut depth from rut depth, it is then also zero. This yields a value of 5.03 for PSI at time zero, whereas it is known that in most cases the initial PSI of a newly-constructed highway is usually in the range 4.0 to 4.5. Also, it should be noted that the value 5.03 is a regression constant, as are the other constants in the above equation;

they are chosen for best fit between the selected equation form and <u>all</u> the data, not just the data for newly constructed roads.

There are several ways of avoiding this problem of non-realistic PSI predictions early in the life of a pavement. Both involve assumptions. The method used in VESYS prior to this project involved replacing the constant 5.03 in the equation with the value of initial PSI read in from the data. This in effect simply shifts the <u>entire</u> predicted curve of PSI vs time down by the difference between the two numbers (typically about 0.8 to 1.0).

The second approach, implemented as an option during this project, utilizes the fact that a newly constructed pavement is <u>not</u> perfectly smooth, even with zero rut depth. Some roughness may be due to imperfect smoothing during construction, some may be due to the effects of construction vehicles travelling on finished roadway to access unfinished roadway. The difference between the theoretical value of PSI obtained from the equation with zero slope variance, rutting, and cracking, and that considered typical of a new pavement just opened for traffic, is therefore attributed to a "construction slope variance", $SV_o$, that one might measure at that time. Mathematically,

$$PSI(t=0) = 5.03 - 1.91 \log_{10} (1+SV_o)$$

or

$$SV_o = 10^{(5.03 - PSI(t=0))/1.91}$$

While this approach may seen more reasonable than an arbitrary vertical shift, an assumption is required about the manner in which the initial slope variance $SV_o$ is to be combined with that calculated from rut depth and its variance as a result of the passage of traffic. Lacking hard data to answer this question, simple addition was assumed for use on this project, i.e.

$$SV(t) = SV_o + SV\ (\text{rut depth})$$

and SV(t) is inserted into the original AASHO regression equation, along with calculated rut depths and area cracking.

The effects of the two different approaches can be summarized as follows: the former is a vertical shift, the latter effectively is a horizontal shift. Both approaches result in a specified value of PSI at time zero; the former yields a steeper initial drop in PSI with time than the latter. As mentioned earlier, the user may select either approach as he wishes.

Subroutine MARG, PLIFE, and PROB as a group are used to compute marginal probabilities on PSI, as discussed earlier in this section. They have not been modified during the course of this contract.

Modifications for performing the "Damage Function" factorial, as well as further discussion of improvements made in VESYS III-B prior to the factorial, are presented in Chapter 7 of Reference 1.

# CHAPTER 3

## NEW OR MODIFIED KEY WORDS

In the course of this project, as has been indicated earlier, several new features have been added to the program, and old features changed. Many of these changes are reflected in changes and additions to the keywords used to identify input data. We present here a list of those keywords which either are new, or have had changes in their use. They are grouped together approximately by function.

| CONTROL | TANDEMS | INITIALIZATION |
|---|---|---|
| SUBMODEL | TANDEM | INITDI |
| UNLOAD | TANSPACE | INITVDI |
| EXTRA IN | TANMULT | INITRUT |
| EXTRAOUT | | |

| CREEP COMPLIANCE | REPEATED LOAD | DAMAGE OPTIONS |
|---|---|---|
| CREEP | SEASLENG | ACRKSW |
| REFTEMPC | CENTCHAN | ACRKCDEF |
| | SIDECHAN | ACRKEXP |
| | REFTEMP | PSISW |
| | REFMOD | |
| | CVAMP | |
| | CVDUR | |

| COMPOSITE PAVEMENT |
|---|
| FLEXSTR |
| COEFFLEX |

A thorough reading of the keyword dictionary/input guide (Appendix A) is recommended for all users, including those who have used previous versions of the program. Defaults were established to make the program operate as closely as possible to VESYS III-A if none of the keywords listed above appear in the user's data file. Those from the above list which will be used most often are: SUBMODEL, UNLOAD (to turn on the calculation and print of permanent deformation by layer); CVAMP, CVDUR (now coefficients of variation of Amplitude (tire pressure) and load duration, not variances, as were input under the keywords VCAMP, VCDUR); and SEASLENG (for unequal season lengths). CREEP and REFTEMPC will normally be used only for submodels 2 and 3; the remainder normally will be used for special purpose runs. As users become more familiar with some of the new options provided in VESYS IV-B, they may use them more often in which case consideration can be given to changing the default values associated with certain keywords; these values are all contained in the BLOCK DATA subprogram. The current defaults are also indicated in the input guide, which is appended to this report.

# CHAPTER 4

## TEST COMPARISON

The material sent to BRE by the FHWA relating to the modification to VESYS included computer printouts of runs made by ARE on their initial version of VESYS IV and comparable runs on VESYS III-A. Computer runs were made with the later (BRE) version of VESYS IV and agreement was excellent. The results for Submodel 3 differed slightly, but this was expected; the older version perpetuated a logic problem which had been present in VESYS for many years. That is, it performed a time-temperature shift on the computed strains and displacements to obtain the effects of seasonal temperature changes in the asphalt, which implies that one is shifting the creep compliance curves for all layers in the system; whereas in fact only the creep curves for asphaltic concrete layer(s) should be shifted. The BRE VESYS IV-B performs the time-temperature shift directly on the creep compliance of the asphaltic concrete layer(s) before the static solutions are performed, in both Submodel 2 and Submodel 3.

# CHAPTER 5

## SUMMARY AND CONCLUSIONS

Significant revisions and improvements to combine desirable features developed in several earlier versions of the VESYS flexible pavement model have been completed and described previously. The program has also been considerably edited and modularized to simplify its use and future modification. The result is VESYS IV-B, an extremely flexible computer model with state of the art capabilities for pavement structure analysis, and for the utilization of these analytical results in its own sophisticated distress models to predict fatigue cracking, rutting, and serviceability loss.

This report describes these revisions and improvements, and includes a combined keyword dictionary and input guide for convenience in using VESYS IV-B.

# APPENDIX A

# VESYS IV INPUT GUIDE

```
C********** CONTROL COMMANDS
C
C  *TYPE     * - THIS SPECIFIES WHICH TYPE OF SYSTEM ANALYSIS IS TO BE
C     PERFORMED ON THE DATA.  THE INTERNAL VARIABLE ASSOCIATED WITH
C     THIS COMMAND IS MTYPE.  THE VALUE APPEARING AFTER THE COMMAND
C     CODE INDICATES THE TYPE OF ANALYSIS BY THE FOLLOWING
C        1 - STATIC LOAD ANALYSIS AND REPEATED LOAD ANALYSIS
C        2 - STATIC LOAD ANALYSIS ONLY
C        3 - REPEATED LOAD ANALYSIS ONLY
C     TYPE 2 RUNS HAVE FULL OUTPUT FROM THE NLAYER SUBROUTINE.  TYPE 1
C     RUNS PRINT CONDENSED SUMMARIES OF THE LAYER OUTPUT.
C     (DEFAULT = 1)
C
C  *SUBMODEL* - THIS SPECIFIES HOW THE ASPHALTIC LAYER MODULI (AND THE
C     RESPONSES) ARE TO BE OBTAINED.  THE INTERNAL ASSOCIATED VARIABLE
C     IS -MODEL-, DEFAULT = 1.  THE SUBMODELS AVAILABLE ARE:
C        1 - MODULI INPUT FOR EACH SEASON, ALREADY ADJUSTED FOR SEASON-
C            AL TEMPERATURES AND FOR A SPECIFIC LOAD DURATION.
C
C        2 - CREEP COMPLIANCES ARE INPUT FOR THE ASPHALTIC CONCRETE FOR
C            A WIDE RANGE OF LOAD DURATIONS, AT A STANDARD REFERENCE
C            TEMPERATURE.  THESE ARE CONVERTED TO SEASONAL MODULI USING
C            THE INPUT SEASONAL TEMPERATURES, THE INPUT LOAD DURATION,
C            AND THE TIME-TEMPERATURE SHIFT FACTOR.  FROM THIS POINT,
C            THE SOLUTION IS IDENTICAL TO THAT OF SUBMODEL 1.
C
C        3 - CREEP COMPLIANCES ARE INPUT AS IN SOLUTION 2.  MODULI ARE
C            OBTAINED, FOR EACH SEASON, AT A NUMBER OF LOAD DURATIONS.
C            FOR EACH DURATION, A STATIC SOLUTION IS OBTAINED, AND THE
C            RESULTS (HORIZONTAL STRAIN, VERTICAL DISPLACEMENT) ARE FIT-
C            TED TO A DIRICHLET SERIES WITH LOAD DURATION AS INDEPENDENT
C            VARIABLE.  THESE SERIES, MODIFIED FOR A SPECIFIC LOAD WAVE-
C            FORM, ARE THEN EVALUATED IN THE REPEATED LOAD SOLUTION TO
C            OBTAIN PEAK RESPONSES.
C
C     NOTE 1:  EITHER ONE OR TWO LAYERS MAY BE ASPHALTIC CONCRETE AND
C     THUS BE AFFECTED BY THE TIME-TEMPERATURE SHIFT.  ONE MAY READ
C     SEPARATE TEMPERATURES FOR THE TWO LAYERS.
C
C     NOTE 2:  FOR SUBMODEL 2 OR 3, EITHER CREEP COMPLIANCES OR SEASONAL
C     MODULI MAY BE INPUT FOR ANY LAYER BELOW THOSE WHICH ARE AFFECTED
C     BY THE TIME-TEMPERATURE SHIFT.
C
C  *TITLE    * - THIS SPECIFIES THAT THE NEXT CARD CONTAINS A HEADING
C     WHICH IS TO BE PRINTED ON THE OUTPUT FOR EACH RUN UNTIL REPLACED
C     BY A NEW TITLE.  THE INTERNAL ASSOCIATED ARRAY IS ITITLE(20), AND
C     THE 80 CHARACTERS ARE STORED IN A4 FORMAT.  (DEFAULT IS 80 BLANKS)
C
C  *INDEX    * - THIS SPECIFIES THAT THE PRESENT DATASET IS TO BE
C     REFERENCED BY THE VALUE APPEARING AFTER INDEX ON THE DATA CARD.
C     THE INTERNAL VARIABLE ASSOCIATED WITH THIS COMMAND IS INDEX.
C     (DEFAULT = 1.  STEPPED BY 1 INTERNALLY FOR EACH RUN IN A "JOB" IF
```

```
C      A NEW VALUE IS NOT READ.)
C
C   *UNLOAD  * - CONTROLS THE -UNLOAD- PORTION OF THE PROGRAM.  INTERNAL
C      ASSOCIATED VARIABLE LY12 (=VAL+0.09)=100*NINT + 10*L1 + L2, WHERE:
C         NINT = NUMBER OF INTERFACES (COUNTING FROM THE AIR-ASPHALT IN-
C                TERFACE) AT WHICH PERMANENT DEFORMATION IS TO BE OBTAIN-
C                ED.  IF 1 OR 0, ONLY THE PERMANENT DEFORMATION AT THE
C                TOP OF THE SYSTEM IS TO BE CONSIDERED.
C           L1 = 1 + THE POWER OF 10 REPRESENTING THE SMALLEST NUMBER OF
C                LOADS IN THE -UNLOAD- MODIFICATION OF LAYER MODULI BY
C                LAYER PERMANENT DEFORMATION PARAMETERS ALPHA/GNU
C           L2 = 1 + THE POWER OF 10 REPRESENTING THE LARGEST NUMBER OF
C                LOADS USED AS ABOVE.  THE NUMBER OF LOADS IS STEPPED BY
C                FACTORS OF 10 FROM 10**(L1-1) TO 10**(L2-1).
C      IF LY12=0 THEN NO UNLOAD LAYER SOLUTIONS ARE PERFORMED, AND NO
C      PERMANENT DEFORMATIONS (AND HENCE NO SLOPE VARIANCE AND PSI) CAN
C      BE COMPUTED.  THIS CAPABILITY MAY BE USED FOR STUDIES INVOLVING
C      FATIGUE ONLY.  (DEFAULT = 36).
C
C   *SAVETAPE* - THIS SPECIFIES THAT AFTER ALL THE STATIC SOLUTIONS ARE
C      DONE, THE RESULTS ARE TO BE WRITTEN TO FILE TAPE1, ALONG WITH THE
C      RUN TITLE, THE LAYER THICKNESSES, AND THE TEMPERATURES AND
C      RADII USED.  THIS FILE MAY THEN BE SAVED ON DISK PERMANENT FILE
C      OR ON MAGNETIC TAPE, AND USED FOR SUBSEQUENT TYPE 3 RUNS.
C      INTERNAL ASSOCIATED VARIABLE - IFSAVE.  DEFAULT - OFF, OR 0.
C
C   *READTAPE* - THIS SPECIFIES THAT DATA FOR STATIC SOLUTIONS FROM A
C      PREVIOUS COMPUTER RUN ARE TO BE READ FROM FILE TAPE1.  THE LAYER
C      THICKNESSES AND NUMBER OF DELTAS, TEMPERATURES, AND RADII ARE
C      CHECKED FOR CONSISTENCY WITH THOSE READ FROM CARDS.  THIS KEYWORD
C      IS EFFECTIVE ONLY FOR A TYPE 3 RUN.  INTERNAL ASSOCIATED VARIABLE
C      -IFREAD-.  DEFAULT OFF, OR 0.
C
C   *NOTAPE  * - THIS RETURNS CONTROL VARIABLES IFREAD, IFSAVE TO THEIR
C      DEFAULT CONDITIONS (OFF).  WOULD BE USED IN THE CASE OF MULTIPLE
C      TYPE 3 RUNS ON ONE SET OF STATIC SOLUTIONS.
C
C   *DEBUG   * - AT PRESENT, THIS KEYWORD TURNS ON THE FULL OUTPUT FROM
C      THE -NLAYER- SUBROUTINE REGARDLESS OF THE RUN TYPE.  CAN BE USED
C      IN OTHER ROUTINES FOR CONTROLLING ADDITIONAL DEBUG OUTPUT ADDED
C      BY A USER IF DESIRED.  REQUIRES COMMON BLOCK /CTRL/.  ASSOCIATED
C      INTERNAL VARIABLE -NODBUG-. (DEFAULT=.TRUE., THAT IS, NO DEBUG
C      PRINT.)
C
C   *DETAIL  * - PRESENTLY CONTROLS PRINT OF DETAILS OF THE UNLOAD SOLN.
C      (RECOMMENDED).  MAY BE USED IN ANY ROUTINE TO CONTROL OPTIONAL
C      DETAILED OUTPUT, BY PLACING PRINT STATEMENTS PRECEDED BY -IF (DE-
C      TAIL)- ALONG WITH COMMON BLOCK /CTRL/.  (DEFAULT=.FALSE.)
C
C   *EXTRA IN* - THIS INDICATES THAT THE PROGRAM IS TO CALL IMMEDIATELY
C      A USER-SUPPLIED SUBROUTINE -INP(KEY)- TO READ DATA WHICH DOES NOT
C      CORRESPOND TO ONE OF THE STANDARD KEYWORDS.  THE DATA MUST BE
C      PLACED IN EITHER A NEW SPECIAL-PURPOSE COMMON BLOCK OR ONE OF THE
```

```
C     EXISTING BLOCKS.  KEY (=VAL + 0.09) SPECIFIES WHAT INPUT IS EXPEC-
C     TED.  THIS KEYWORD CAN BE USED SEVERAL TIMES WITH DIFFERENT VALUES
C     OF -KEY-, DEPENDING ON THE SUBROUTINE -INP-.
C
C  *EXTRAOUT* - THIS INDICATES THAT THE PROGRAM IS TO CALL IMMEDIATELY
C     A USER-SUPPLIED SUBROUTINE -OUTP(KEY)-.  MIGHT BE USED TO INPUT
C     A SWITCH FOR TURNING PRINT ON AND OFF IN USER-SUPPLIED SUBROUTINES
C     -OUT1- AND -OUT2-.  (-OUT1- AND -OUT2- ARE ALWAYS CALLED, BUT THE
C     ROUTINES SUPPLIED WITH VESYS SIMPLY PERFORM AN IMMEDIATE RETURN,
C     AS DO THE ROUTINES -INP- AND -OUTP-.
C
C  *ENDOFRUN* - THIS SPECIFIES THAT THE ABOVE DATASET IS COMPLETE AND
C     COMPUTATION MAY BEGIN.  ANY NUMBER OF RUNS CAN BE MADE
C     CONSEQUETIVELY BY SEPARATING THE DATASETS BY THE ENDOFRUN
C     COMMAND.  NOTE  THIS CARD MUST APPEAR.  THERE IS NO DEFAULT.
C
C  *ENDOFJOB* - THIS SPECIFIES THAT ALL THE DATASETS TO BE RUN AT
C     THIS TIME HAVE BEEN RUN.  IT SHOULD BE THE LAST CARD IN THE
C     DATA DECK.  DEFAULT MEANS THAT THE COMPUTER SYSTEM YOU ARE ON
C     WILL TERMINATE YOUR JOB BY READING THE STANDARD ENDOFFILE CARD.
C
C
C**********  PRIMARY RESPONSE COMMANDS
C
C  *NLAYER  * - NUMBER OF LAYERS (TOTAL, INCLUDING SUBGRADE).
C     INTERNAL VARIABLE IS NS.  THIS KEYWORD -MUST- PRECEDE ALL OF THE
C     FOLLOWING KEYWORDS:  LAYER, VARCOEF, THICK, POISSON, GNU, ALPHA.
C
C  *LAYER   * - ARRAY OF MODULI BY SEASON (NTEMP VALUES) ON FOLLOWING
C     CARDS (6E12.4 FORMAT) FOR THE LAYER WHOSE NUMBER (=VAL + 0.09)
C     FOLLOWS ON THE DIRECTIVE CARD.  INTERNAL ASSOCIATED VARIABLE IS
C     ELAYER (25,8).  NO DEFAULT.  IF THE NUMBER HAS TWO DIGITS,
C     THE SECOND DIGIT IS THE LAYER NUMBER AND THE FIRST DIGIT IS THE
C     INDEX ON THE LOAD (ACTUALLY, ON THE LOAD RADIUS) FOR WHICH THE
C     MODULI ARE BEING READ.  THIS PERMITS THE INCLUSION OF ESTIMATED
C     STRESS SENSITIVITY EFFECTS.  IF THE FIRST DIGIT IS BLANK OR ZERO,
C     THE MODULI READ WILL APPLY FOR ALL LOAD RADII FOR THAT LAYER.
C
C  *VARCOEF * - ARRAY OF COEFFICIENTS OF VARIATION FOR THE LAYER MODULI
C     OR CREEP COMPLIANCES.  -NLAYER- VALUES ARE READ IN 6E12.4 FORMAT
C     FROM THE FOLLOWING CARDS.  INTERNAL ASSOCIATED VARIABLE -EVAR(8)-.
C     DEFAULTS = 0.
C
C  *THICK    * - ARRAY OF LAYER THICKNESSES.  INTERNAL ASSOCIATED
C     VARIABLE IS HH(8).
C
C  *POISSON  * - ARRAY OF POISSON'S RATIO OF ALL LAYERS.
C     INTERNAL VARIABLE IS VX(8).
C
C  *LOADING  * - INTENSITY OF THE APPLIED LOADING IN PSI.
C     INTERNAL VARIABLE IS QQ. (DEFAULT = 1.0)
C
C  *NRADIUS * - THIS SPECIFIES THE NUMBER OF RADIUS VALUES FOR WHICH
```

```
C     STATIC SOLUTIONS ARE DESIRED.  INTERNAL ASSOCIATED VARIABLE NRAD.
C     (DEFAULT=1, MAXIMUM=12)  IF NRADIUS .GT. 1, THIS COMMAND MUST
C     PRECEDE ALL OF THE FOLLOWING:  AMPLITUD, LOADDIST, RADIUS.
C
C  *RADIUS  * - RADIUS OF APPLIED LOADING, IN INCHES.  INTERNAL
C     ASSOCIATED ARRAY IS RADIUS(12).  THE VALUE USED IN A CURRENT
C     STATIC SOLUTION IS IN THE VARIABLE AAA.  IF NRADIUS = 1, THE VALUE
C     IS READ FROM THE NUMERIC FIELD ASSOCIATED WITH THE COMMAND.  IF
C     NRADIUS .GT. 1, VALUES ARE READ IN (6E12.4) FORMAT FROM FOLLOWING
C     CARD(S).  DEFAULT = 6.4 (ONE VALUE ONLY).
C
C  *NRPOINTS  * - NUMBER OF RADIAL POINTS OF INTEREST.
C     INTERNAL VARIABLE IS NUMRS. THIS COMMAND MUST APPEAR
C     BEFORE THE NEXT COMMAND.
C
C  *RPOINTS  * - ARRAY OF RADIAL POINTS OF INTEREST. INTERNAL
C     VARIABLE IS RR(20)
C
C  *NZPOINTS  * - NUMBER OF Z POINTS OF INTEREST.
C     INTERNAL VARIABLE IS NUMZS. THIS COMMAND MUST APPEAR
C     BEFORE THE NEXT COMMAND.
C
C  *ZPOINTS  * - ARRAY OF Z POINTS OF INTEREST. INTERNAL
C     VARIABLE IS ZZ(20)
C
C  *ZCRACK  * - DEPTH AT WHICH STRAIN FOR DETERMINATION OF
C     CRACKING INDEX IS TAKEN. INTERNAL VARIABLE IS ZCRACK.
C     DEFAULT IS TO DEPTH OF FIRST LAYER.
C
C  *GNU     * - VECTOR OF THE FRACTIONAL DIFFERENCES IN THE CREEP
C     COMPLIANCE FUNCTIONS OF THE VARIOUS LAYERS IN LOADING AND
C     UNLOADING.  ONE VECTOR OF VALUES FOR DIFFERENT SEASONS MUST BE
C     INPUT FOR EACH LAYER.  LAYR (=VAL+0.09) TELLS WHICH LAYER.
C     INTERNAL ASSOCIATED VARIABLE IS GGU(25,3).  LAYR MAY BE EITHER
C     ONE OR TWO DIGITS, ALLOWING THE GNU VALUES TO BE INPUT BY LOAD
C     RADIUS AS WELL AS BY LAYER NUMBER AND TEMPERATURE.  SEE THE
C     -LAYER - DIRECTIVE FOR DETAILS.  NO DEFAULT.
C
C   *ALPHA   * - VECTOR OF THE EXPONENTS IN THE RELATIONSHIPS OF CREEP
C     COMPLIANCE FUNCTIONS DURING LOADING AND UNLOADING AS A FUNCTION
C     OF THE NUMBER OF LOADS APPLIED.
C     ONE VECTOR OF VALUES FOR DIFFERENT SEASONS MUST BE INPUT FOR
C     EACH LAYER.  LAYR (=VAL+0.09) TELLS WHICH LAYER.  INTERNAL
C     ASSOCIATED VARIABLE IS GGU(25,3).  LAYR MAY BE EITHER
C     ONE OR TWO DIGITS, ALLOWING THE GNU VALUES TO BE INPUT BY LOAD
C     RADIUS AS WELL AS BY LAYER NUMBER AND TEMPERATURE.  SEE THE
C     -LAYER - DIRECTIVE FOR DETAILS.
C
C  *FLEXSTR * - FLEXURAL STRENGTH OF THE PCC LAYER IN COMPOSITE PAVE-
C     MENT OR OF A CONCRETE STABILIZED BASE.  INPUT OF A NON-ZERO VALUE
C     FOR THIS QUANTITY SWITCHES THE FATIGUE CALCULATION TO ONE BASED
C     ON STRESS, NOT STRAIN.  INPUT OF A ZERO VALUE RETURNS THE PROGRAM
C     TO FATIGUE BASED ON STRAIN.  INTERNAL ASSOCIATED VALUE IS FLXSTR.
```

```
C     DEFAULT = 0.
C
C  *COEFFLEX* - COEFFICIENT OF VARIATION OF CONCRETE FLEXURAL STRENGTH.
C     USED ONLY WHEN FLEXSTR IS INPUT .GT. 0.  INTERNAL ASSOCIATED
C     VARIABLE CVFLEX (DEFAULT = 0.10).
C
C  *NTSTATIC* - NUMBER OF LOAD DURATIONS (TSTATIC VALUES).  INTERNAL
C     ASSOCIATED VARIABLE -NTYME-.  DEFAULT = 0.  MUST BE READ BEFORE
C     THE FOLLOWING KEYWORDS:  TSTATIC, CREEP.
C
C  *TSTATIC * - ARRAY OF LOAD DURATIONS FOR WHICH CREEP COMPLIANCES WILL
C     BE INPUT.  INTERNAL ASSOCIATED VARIABLE -TYME(20)-.  NO DEFAULT.
C
C  *CREEP   * - ARRAY OF CREEP COMPLIANCES FOR LAYER L (=VAL + 0.09).
C     INTERNAL ASSOCIATED VARIABLE -CREEP(20,8)-.  NO DEFAULT.
C
C  *REFTEMPC* - TEMPERATURE (DEG F) TO WHICH THE CREEP COMPLIANCES COR-
C     RESPOND.  INTERNAL ASSOCIATED VARIABLE -TREFC-.  NO DEFAULT.
C
C  *SEASMULT* - MULTIPLIERS ON LAYER CREEP COMPLIANCES TO ALLOW FOR SEA-
C     SONAL CHANGES OTHER THAN ASPHALT TEMPERATURE, E.G., MOISTURE CHAN-
C     GES IN BASE AND SUB-BASE DUE TO SPRING THAW.  INTERNAL ASSOCIATED
C     VARIABLE SMLT(25,8).  DEFAULT=1. FOR ALL LAYERS AND SEASONS.
C     *NOTE* THIS IS A MULTIPLIER ON COMPLIANCE, NOT ON MODULUS.
C            WOULD BE USED ONLY FOR SUBMODEL 2 OR 3.
C
C  *BETA    * - TIME-TEMPERATURE SHIFT FACTOR, USED (FOR ASPHALT ONLY)
C     TO CONVERT CREEP AT TEMPERATURE T1 TO CREEP AT T2 BY CONVERTING
C     TEMPERATURE DIFFERENCE AT CONSTANT LOAD DURATION TO LOAD DURATION
C     DIFFERENCE AT CONSTANT TEMPERATURE.  INTERNAL ASSOCIATED VARIABLE
C     -BETA-.  DEFAULT = 0.
C
C  *DELTAS  * - ARRAY OF CONSTANTS USED IN DIRICHLET SERIES.  IT IS SUG-
C     GESTED THAT THE DEFAULT VALUES BE USED.  INTERNAL ASSOCIATED VAR-
C     IABLE -DELTA(15)-.  DEFAULT = (100.,30.,8.,1.,.1,.03,0.) IF NDEL
C     NOT READ.  NOT USED IN SUBMODEL 1.
C
C  *NDELTAS * - NUMBER OF DELTAS.  INTERNAL ASSOCIATED VARIABLE -NDEL-.
C     DEFAULT = 7.
C
C**********  COMBINED STATIC AND REPEATED LOAD COMMANDS
C
C  *NTEMPS  * - NUMBER OF  INTERVALS INTO WHICH THE TEMPERATURE YEAR
C     IS DIVIDED, CALLED SEASONS.  INTERNAL ASSOCIATED VARIABLE IS
C     NTEMP.  THIS COMMAND -MUST- APPEAR BEFORE ANY OF THE FOLLOWING
C     COMMANDS:
C         TEMPS, SEASMULT, STRNCOEF AND STRNEXP (IF SEASONAL VALUES
C         ARE INPUT), GNU AND ALPHA, LAYER, AND TRAFMULT.
C
C  *TEMPS   * - VECTOR OF SEASONAL PAVEMENT TEMPERATURES, IN DEGREES F.
C     L (=VAL + 0.09) TELLS FOR WHICH  ASPHALTIC LAYER (OF UP TO 2).
C     INTERNAL ASSOCIATED VECTOR IS TEMP(25,2).  THERE ARE NO DEFAULT
C     VALUES.  IF VAL = 0 OR LEFT BLANK, FIRST LAYER IS ASSUMED.
```

```
C
C  *TANDEM  * - FRACTION OF DAILY AXLES FOR EACH LOAD RADIUS THAT ARE
C     TANDEM AXLES.  INTERNAL ASSOCIATED VARIABLE IS FTAN(12).  IF
C     NRADIUS .EQ. 1, THE VALUE IS READ FROM THE NUMERIC FIELD ASSOCIA-
C     TED WITH THE COMMAND.  IF NRADIUS .GT. 1, VALUES ARE READ IN
C     6E12.4 FORMAT FROM FOLLOWING CARDS.  DEFAULT=0. (ALL)
C       THIS COMMAND INSTRUCTS THE SYSTEM TO
C        (1) SET UP RADIAL POINTS AT .5 AND 1 TIMES THE TANDEM SPACING.
C        (2) EVALUATE THE TOTAL STRAIN PERPENDICULAR TO THE DIRECTION OF
C            TRAVEL AT ONE LOAD AND HALF-WAY BETWEEN THE LOADS.
C        (3) SAVE  (A)  THE RADIAL STRAIN FROM ONE LOAD, UNDER THE LOAD.
C                  (B)  THE TANGENTIAL STRAIN FROM A SEOND LOAD AT A
C                       DISTANCE OF ONE TANDEM AXLE SPACING.
C                  (C)  THE TANGENTIAL STRAIN FROM A LOAD AT A DISTANCE
C                       OF ONE HALF THE TANDEM SPACING.
C            WITH THEIR ERRORS.
C        (4) COMBINE (A-C) IN THE RANDOM PORTION OF THE SYSTEM TO SIMU-
C            LATE THE STRAIN FROM THE FIRST LOAD, AND THE "DELTA STRAIN"
C            (HEIGHT OF SECOND PEAK ABOVE THE MIDPOINT STRAIN).  ADD
C            FATIGUE CONTRIBUTIONS FROM BOTH STRAIN LEVELS.
C        (5) EVALUATE THE MAXIMUM SURFACE DEFLECTION (UNDER ONE LOAD)
C            CAUSED BY TWO LOADS AT THE GIVEN SPACING, AND USE THIS
C            WITH AN INPUT (OR DEFAULT) MULTIPLIER (SEE TANMULT) ON THE
C            NUMBER OF TANDEM AXLES TO ACCOUNT FOR THE EFFECTS OF TAN-
C            DEMS ON SURFACE PERMANENT DEFORMATION (HENCE RUTTING AND
C            ROUGHNESS).
C
C  *TANSPACE* - SPACING BETWEEN FRONT AND REAR AXLES OF A TANDEM CONFIG-
C        URATION.  INTERNAL ASSOCIATED VARIABLE IS SPTAN(12).  IF NRAD-
C        IUS .EQ. 1 THE VALUE IS READ FROM THE NUMERIC FIELD ASSCIATED
C        WITH THE COMMAND.  IF NRADIUS .GT. 1, NRADIUS VALUES ARE READ
C        (6E12.4 FORMAT) FROM FOLLOWING CARDS.  DEFAULT IS 50.0 FOR ALL
C        VALUES.
C
C  *TANMULT * - MULTIPLIER FOR TANDEM AXLE APPLICATIONS FOR USE -ONLY-
C        IN RUTTNG AND ROUGHNESS CALCULATIONS. (CRACKING CALCULATIONS
C        ARE HANDLED IN A DIFFERENT MANNER - SEE -TANDEM-.)  THIS NUMBER
C        MULTIPLIES THE NUMBER OF TANDEM AXLES CALCULATED FOR A PARTI-
C        CULAR LOAD GROUP TO OBTAIN AN EQUIVALENT NUMBER OF SINGLE LOAD
C        APPLICATIONS.  INTERNAL ASSOCIATED VARIABLE IS -RMTAN-.  ONE
C        VALUE FOR ALL LOAD GROUPS.  DEFAULT IS 1.4
C
C**********  REPEATED LOAD COMMANDS
C
C  *NTRANDOM* - NUMBER OF TIMES USED IN REPEATED LOAD ANALYSIS.
C     INTERNAL ASSOCIATED VARIABLE IS NTIME.  NOTE   THE NTRANDOM
C     COMMAND MUST APPEAR BEFORE THE TRANDOM COMMAND. (DEFAULT = 1.)
C
C  *TUNITS  * - THIS SPECIFIES WHICH UNITS OF TIME WERE USED IN THE
C     TRANDOM COMMAND.  THE VALUE APPEARING AFTER THE COMMAND CODING
C     INDICATES THE TIME UNITS BY THE FOLLOWING
C        1 - SECONDS
C        2 - MINUTES
```

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C          3 - HOURS
C          4 - DAYS
C          5 - MONTHS
C          6 - YEARS
C      INTERNAL ASSOCIATED VARIABLE IS LTIME.  (DEFAULT = 6, YEARS.)
C
C   *TRANDOM * - VECTOR OF TIMES, IN THE ABOVE UNITS, IN REPEATED LOAD
C      ANALYSIS.  INTERNAL ASSOCIATED VECTOR IS TIME(25).
C      THERE ARE NO DEFAULT VALUES.
C
C   *SEASLENG* - VECTOR OF NTEMP SEASON LENGTHS, EXPRESSED IN MONTHS.
C      PERMITS USE OF UNEQUAL SEASON LENGTHS, E.G. FOR SPRING THAW.
C      IF ALL VALUES ARE ZERO, EQUAL LENGTHS OF (12/NTEMP) MONTHS WILL BE
C      USED.  EFFECT OF ONE SEASON CAN BE REMOVED BY SETTING ITS LENGTH
C      TO ZERO.  SUM OF LENGTHS SHOULD NORMALLY = 12.
C      INTERNAL ASSOCIATED VARIABLE IS SLNG (DEFAULT = 0.)
C
C   *LAMBDA  * - VECTOR OF TRAFFIC RATES, IN AXLES/DAY.  INTERNAL ASSO-
C      DIATED VARIABLE ADT(25).  NO DEFAULTS.  ADT(I) APPLIES FROM TRAN-
C      DOM(I-1) TO TRANDOM(I), OR FROM T=0 TO TRANDOM(1) FOR I = 1.
C
C   *CENTCHAN* - FRACTION OF TOTAL LOADS WHICH FALL IN THE CENTRAL CHAN-
C      NEL OF THE LATERAL TRAFFIC DISTRIBUTION.  INTERNAL ASSOCIATED
C      VARIABLE -CCFRAC-.  DEFAULT = 1.0 (NO CHANNELIZATION)
C
C   *SIDECHAN* - FRACTION OF TOTAL LOADS WHICH FALL IN ONE OF THE TWO
C      "CHANNELS" AROUND THE CENTRAL CHANNEL.  EACH OF THESE TWO, AND THE
C      CENTRAL CHANNEL, ARE ASSUMED TO BE OF EQUAL WIDTH.  INTERNAL ASSO-
C      VARIABLE -SCFRAC-.  DEFAULT = (1.-CCFRAC)/2.
C
C   *LOADDIST* - VECTOR OF FRACTIONAL DISTRIBUTION OF AXLE LOADINGS BY
C      WEIGHT CATEGORY AS SPECIFIED BY AMPLITUD AND RADIUS.  NORMALLY
C      THE VALUES SHOULD SUM TO 1.0, CORRESPONDING TO THE CURRENT VALUE
C      OF LAMBDA OR OF LAMBDA*TRAFMULT.  INTERNAL ASSOCIATED VARIABLE
C      TRDIST.  DEFAULT TRDIST(1)=1.0, REMAINING VALUES ALL 0.  NEED ONLY
C      BE INPUT IF NRADIUS .GT. 1, IN WHICH CASE NRADIUS VALUES ARE READ
C      FROM FOLLOWING CARD(S) IN (6E12.4) FORMAT.
C
C   *TRAFMULT* - VECTOR OF SEASONAL TRAFFIC MULTIPLIERS, TO ALLOW FOR
C      VARIATIONS IN TOTAL (AXLES PER DAY) BY SEASON.  IF PRESENT, NTEMPS
C      VALUES ARE READ FROM FOLLOWING CARD(S) IN (6E12.4) FORMAT.
C      INTERNAL ASSOCIATED VARIABLE TRMULT.  DEFAULT ALL VALUES=1.0
C
C   *AMPLITUD* - VECTOR OF MEAN INTENSITIES OF REPEATED LOADINGS, IN PSI.
C      INTERNAL ASSOCIATED ARRAY IS AMPL.  THE VALUE USED IN CONNECTION
C      WITH A SPECIFIC STATIC SOLUTION IS IN THE VARIABLE AMP.  INPUT
C      CONVENTION IS THE SAME AS FOR RADIUS.  DEFAULT:  AMPL(1)=80.,
C      ALL REMAINING VALUES 0.
C
C   *CVAMP   * - COEFFICIENT OF VARIATION OF -AMPLITUD-.  INTERNAL ASSOC-
C      IATED VARIABLE -CVAMP-.  DEFAULT = 0.
C
C   *DURATION* - MEAN DURATION, IN SECONDS, OF REPEATED LOADINGS.
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C      INTERNAL ASSOCIATED VARIABLE IS DUR.  (DEFAULT = 0.05)
C      THIS HAS RELEVANCE ONLY FOR SUBMODELS 2 AND 3.
C
C  *CVDUR    * - COEFFICIENT OF VARIATION OF DURATION OF REPEATED LOAD-
C      INGS.  INTERNAL ASSOCIATED VARIABLE IS CVDUR. (DEFAULT = 0.0)
C      THIS HAS RELEVANCE ONLY FOR SUBMODEL 3.
C
C  *STRNEXP * - THE EXPONENT IN THE MINER*S LAW FORMULATION FOR DAMAGE.
C      THIS VARIABLE CAN BE INPUT AS A SINGLE VALUE (INTERNAL NAME
C      ASAVE), OR AS AN ARRAY (INTERNAL NAME K2(25)).  IF A SINGLE
C      VALUE IS GIVEN, IT IS ASSUMED TO HOLD AT -REFTEMP- DEGREES F.
C      VALUES FOR OTHER TEMPERATURES ARE COMPUTED BY THE PROGRAM ACCOR-
C      DING TO A PREDEFINED RELATION.  IF AN ARRAY IS INPUT, IT REPRE-
C      SENTS THE VALUES TO BE USED AT THE CORRESPONDING TEMPERATURES IN
C      THE -TEMPS- ARRAY.  EXACTLY NTEMPS ELEMENTS ARE REQUIRED.
C
C  *STRNCOEF* - THE COEFFICIENT IN THE MINER*S LAW FORMULATION.
C      THIS VARIABLE CAN BE INPUT AS A SINGLE VALUE (INTERNAL NAME
C      CSAVE), OR AS AN ARRAY (INTERNAL NAME K1(25)).  IF A SINGLE
C      VALUE IS SUPPLIED, IT IS ASSUMED TO HOLD AT -REFTEMP- DEGREES F.
C      VALUES FOR OTHER TEMPERATURES ARE COMPUTED USING A PREDEFINED
C      RELATION.  IF AN ARRAY IS INPUT, IT REPRESENTS THE VALUES TO
C      BE USED AT THE CORRESPONDING TEMPERATURES IN THE TEMPS ARRAY.
C      EXACTLY NTEMPS ELEMENTS ARE REQUIRED.
C
C  *REFTEMP * - THE ASPHALT CONCRETE TEMPERATURE FOR WHICH (SINGLE)
C      VALUES OF STRNCOEF AND STRNEXP ARE INPUT.  IMPLIES THAT SEASONAL
C      VALUES OF THE ABOVE ARE TO BE OBTAINED ON THE BASIS OF SEASONAL
C      TEMPERATURES.
C
C  *REFMOD  * - THE ASPHALT CONCRETE MODULUS FOR WHICH (SINGLE) VALUES
C      OF STRNCOEF AND STRNEXP ARE INPUT.  IMPLIES THAT SEASONAL VALUES
C      OF THE ABOVE ARE TO OBTAINED ON THE BASIS OF THE RATIO OF SEASONAL
C      MODULUS TO REFMOD, RATHER THAN ON THE BASIS OF SEASONAL TEMPERA-
C      TURE.  CANNOT BE USED IN A SUBMODEL 3 ANALYSIS BECAUSE THERE ARE
C      NO EXPLICIT SEASONAL MODULI.
C
C  *COEFK1  * - COEFFICIENT OF VARIATION OF STRNCOEF.THE COEFFICIENT IN
C      THE MINER*S LAW FORMULATION.  INTERNAL ASSOCIATED VARIABLE IS CK1.
C      (DEFAULT = 0.0)
C
C  *COEFK2  * - COEFFICIENT OF VARIATION OF STRNEXP, THE EXPONENT IN
C      THE MINER*S LAW FORMULATION.  INTERNAL ASSOCIATED VARIABLE IS
C      CK2.  (DEFAULT = 0.0)
C
C  *K1K2CORL* - COERRELATION COEFFICIENT FOR STRNCOEF AND STRNEXP.
C      INTERNAL ASSOCITED VARIABLE IS CK12.  (DEFAULT = 0.0)
C
C  *ACRKSW  * - CONTROLS HOW AREA CRACKING IS COMPUTED.  INTERNAL ASSO-
C      CIATED VARIABLE IFAREA (=VAL + 0.09).  (DEFAULT=0).
C         IF = 0 OR 1 THEN AREA CRACKED IS EQUAL TO THE PERCENT OF AREA
C              BEYOND DAMAGE INDEX = 1 UNDER NORMAL CURVE CENTERED ON
C              CURRENT DAMAGE INDEX HAVING STANDARD DEVIATION = STD. DEV.
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C              OF DAMAGE INDEX.
C         IF = 2 THEN PERCENT AREA CRACKED IS CALCULATED FROM AN S-SHAPED
C              CURVE FITTED THRU TWO POINTS OBTAINED FROM NCHRP 1-10B
C              STUDY OF AASHO ROAD TEST, IN CONJUNCTION WITH FATIGUE RE-
C              LATION OBTAINED FROM SAME STUDY.  WITH THIS RELATION, D.I.
C              OF 1 CORRESPONDS TO 10 PER CENT AREA CRACKING, NOT 50 PER
C              CENT, AS IT DOES WITH FIRST METHOD.  THIS METHOD SHOULD BE
C              USED WITH CAUTION, AS IT IS BASED ON LIMITED DATA, AND BE-
C              CAUSE THERE IS NO VARIATION WITH VARIANCE OF DAMAGE INDEX,
C              AND HENCE THERE IS AN INHERENT ASSUMPTION OF QUALITY CON-
C              TROL COMPARABLE TO THAT AT THE ROAD TEST.
C
C   *ACRKCOEF* - CONSTANT A IN THE RELATIONSHIP
C              PCT. AREA CRKD = 100.*(1.-(1-EXP(-A/DI))**B)
C      WHERE DI IS DAMAGE INDEX.  INTERNAL ASSOCIATED VARIABLE CRKA
C      (DEFAULT=6.29, FROM STUDY ABOVE).  SEE COMMENTARY UNDER ACRKSW.
C
C   *ACRKEXP - CONSTANT B IN THE RELATION QUOTED FOR ACRKCOEF.  INTERNAL
C      ASSOCIATED VARIABLE CRKB (DEFAULT=56.7).  SEE COMMENTARY UNDER
C      ACRKSW.
C
C   *CORLCOEF* - AUTOCORRELATION FUNCTION COEFFICIENT FOR THE PAVEMENT
C      SYSTEM.  INTERNAL ASSOCIATED VARIABLE IS B.  (DEFAULT = 0.0)
C
C   *CORLEXP * - AUTOCORRELATION FUNCTION EXPONENT FOR THE PAVEMENT
C      SYSTEM.  INTERNAL ASSOCIATED VARIABLE IS C.  (DEFAULT = 10.0)
C      C IS MEASURED IN THOUSANDS OF INCHES.
C
C   *INITDI  * - INITIAL DAMAGE INDEX VALUES FOR THE CENTRAL AND SIDE
C      CHANNELS AND FOR THE HYPOTHETICAL -FULL TRAFFIC- CHANNEL, FROM A
C      PREVIOUS VESYS RUN.  ALLOWS RESTART OF SIMULATION WITH A MODIFIED
C      SYSTEM (E.G., A NEW BASE MODULUS).  3 VALUES READ FROM FOLLOWING
C      CARD IN 6E12.4 FORMAT.  INTERNAL ASSOCIATED VARIABLE -DIN(3)-.
C      (DEFAULT=0)
C
C   *INITVDI * - VARIANCES OF INITIAL DAMAGE INDEX VALUES READ UNDER
C      INITDI (SEE ABOVE COMMENTARY).  3 VALUES READ FROM FOLLOWING CARD
C      IN 6E12.4 FORMAT.  INTERNAL ASSOCIATED VARIABLE -VDIN(3)-.
C      (DEFAULT=0)
C
C   *INITRUT * - INITIAL VALUES OF PERMANENT VERTICAL DEFORMATION FOR
C      RESTARTING A SIMULATION FROM A PREVIOUS VESYS RUN.  SEE -INITDI-
C      COMMENTARY.  INTERNAL ASSOCIATED VARIABLE -DEPN(3)-.  (DEFAULT=0)
C
C   *WINTTEMP* - THE WINTER DESIGN TEMPERATURE FOR LOW TEMPERATURE
C      CRACKING (FROM THE HAJEK-HAAS MODEL), IN DEGREES CENTIGRADE (NOTE
C      UNITS). INTERNAL ASSOCIATED VARIABLE IS TDW.  (DEFAULT = 0.)
C
C   *STIFF   * - ASPHALT STIFFNESS AT THE WINTER DESIGN TEMPERATURE,
C      IN KG/SQ CM.  (NOTE METRIC UNITS)  INTERNAL ASSOCIATED VARIABLE
C      IS STF.  VALUE READ IN MUST EQUAL OR EXCEED 10., OR THE LOW TEMP.
C      CRACKING WILL BE SET = 0. (DEFAULT=0.)
C
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C  *SUBGTYPE* - A DIMENSIONLESS CODE NUMBER FOR SUBGRADE TYPE.
C     (SAND=5., LOAM=3., CLAY = 2.)  FOR LOW TEMP. CRACKING ONLY.
C     INTERNAL ASSOCIATED VARIABLE IS SBGT. (DEFAULT = 2.)
C
C  *PSISW   * - CONTROLS COMPUTATION OF PSI (PRESENT SERVICEABILITY
C     INDEX).  ASSOCIATED INTERNAL VARIABLE IS IFPSI (DEFAULT = 0)
C     IFPSI = IOPT(1) + 2*IOPT(2) + 4*IOPT(3) + 8*IOPT(4)
C     IOPT(1) = 1  PRINT ADDITIONAL COLUMN OF PSI VALUES CALCULATED
C                  USING STRAIGHTFORWARD AASHO EQUATION UNMODIFIED FOR
C                  STOCHASTICS.
C     IOPT(1) = 0  DO NOT PRINT.
C
C     IOPT(2) = 1 COMPUTE PSI ASSUMING THAT THE DIFFERENCE BETWEEN THE
C                 ASSUMED INITIAL PSI, QUALITY0, AND THE REGRESSION
C                 VALUE WITH ZERO DISTRESS (ROUGHNESS, RUT DEPTH, AND
C                 CRACKING) IS DUE TO AN INITIAL -AS CONSTRUCTED- ROUGH-
C                 NESS (SLOPE VARIANCE) WHICH IS COMPUTED AND THEN ADDED
C                 TO THAT CALCULATED FROM RUT DEPTH VARIANCE.
C     IOPT(2) = 0 COMPUTE PSI ASSUMING THAT THE REGRESSION VALUE WITH
C                 ZERO DISTRESS (5.03) MAY SIMPLY BE REPLACED BY THE
C                 ASSUMED INITIAL PSI.
C
C     IOPT(3), IOPT(4) - NOT USED AT PRESENT.
C
C  *QUALITY0* - MEAN VALUE OF THE SERVICEABILITY INDEX DISTRIBUTION
C     AT TIME = 0.  INTERNAL ASSOCIATED VARIABLE IS EM0.
C     (DEFAULT = 5.0)
C
C  *STDEV0  * - STANDARD DEVIATION OF THE SERVICEABILITY INDEX
C     DISTRIBUTION AT TIME = 0.  INTERNAL ASSOCIATED VARIABLE IS
C     SIG0.  (DEFAULT = 0.0)
C
C  *PSIFAIL * - SPECIFIES THE LEVEL OF UNACCEPTABLE SERVICEABILITY,
C     OR THE UPPER BOUND OF THE FAILURE STATE.  INTERNAL ASSOCIATED
C     VARIABLE IS PSIMIN. (DEFAULT = 2.5)
C
C  *TOLERNCE* - MINIMUM RELIABILITY EXPRESSED AS A PERCENT.  RE-
C     LIABILITY IS THE PROBABILITY THAT THE PAVEMENT HAS NOT FAILED
C     AT OR BEFORE SOME SPECIFIED TIME.  INTERNAL ASSOCIATED VARI-
C     ABLE IS TLR.  (DEFAULT IS 50.0)
C
C*************************************************************************
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C***********************************************************************
C
C     HINTS ON COMMANDS USAGE
C
C     1)  IN THE COMMANDS STATED ABOVE, THE ALPHAMERIC PHRASE APPEARING
C         IN BETWEEN THE ASTERISKS IS THE COMMAND CODING.  IT MUST BE
C         WRITTEN, EXACTLY AS GIVEN ABOVE, IN CARD COLUMNS 1-8 ON THE
C         DATA DECK.  MISSPELLED OR UNRECOGNIZED CODES ARE EXHIBITED
C         WITH ERROR MESSAGES BY THE PROGRAM.
C
C     2)  THE VALUE ASSOCIATED WITH THE COMMAND CODE MUST APPEAR IN
C         FLOATING POINT FORMAT IN CARD COLUMNS 11-20, ON THE SAME
C         CARD AS THE COMMAND CODE.  BOTH INTEGER AND REAL NUMBERS
C         ARE WRITTEN WITH A DECIMAL POINT.  THAT IS, INSTEAD OF THE
C         INTEGER 9, TYPE 9.0
C
C     3)  VALUES ASSOCIATED WITH VECTOR COMMANDS BEGIN ON THE CARD
C         IMMEDIATELY FOLLOWING THE COMMAND CARD.  THEY ARE WRITTEN
C         IN 6E12.4 FORMAT FOR AS MANY CARDS AS IT TAKES TO COMPLETE
C         THE VECTOR.  THE MAXIMUM DIMENSION OF THE VECTORS IN THE
C         ABOVE COMMANDS IS IN PARENTHESES AFTER THE NAME OF THE
C         INTERNAL ASSOCIATED VECTOR.
C
C     4)  THE COMMAND CODES MUST BE LEFT JUSTIFIED, THAT IS, THE FIRST
C         CHARACTER OF THE CODE MUST BEGIN IN CARD COLUMN 1.  THE
C         BLANKS BETWEEN THE ASTERISKS IN SOME OF THE COMMAND CODES
C         MUST ALSO BE WRITTEN.  THAT IS, NOTHING OTHER THAN THE
C         EXACT COMMAND CODE, BLANKS AND ALL, CAN APPEAR IN CARD
C         COLUMNS 1-8 WITHOUT GIVEN AN ERROR MESSAGE.
C
C**********   EXAMPLES OF COMMANDS
C
C     1)        RADIUS     9.1
C     2)        INDEX      2.0
C     3)        NRPOINTS   1.0
C     4)        RPOINTS
C                 0.5000E+00
C
C***********************************************************************
C***********************************************************************
C
C
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## REFERENCES


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