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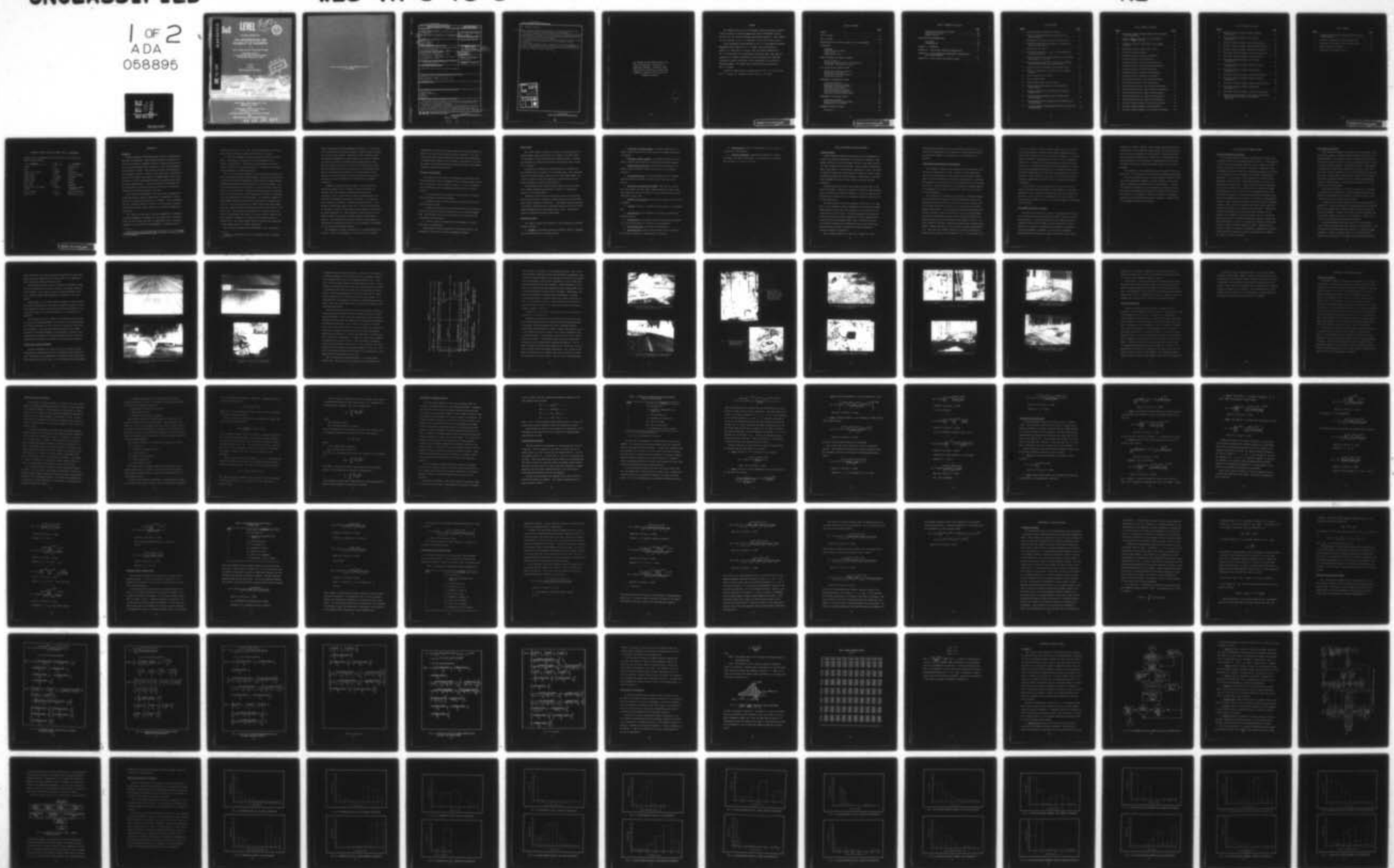

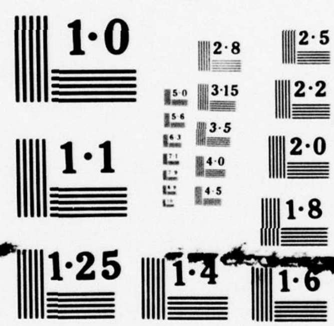

NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

TECHNICAL REPORT S-78-8

THE DETERIORATION AND RELIABILITY OF PAVEMENTS

by

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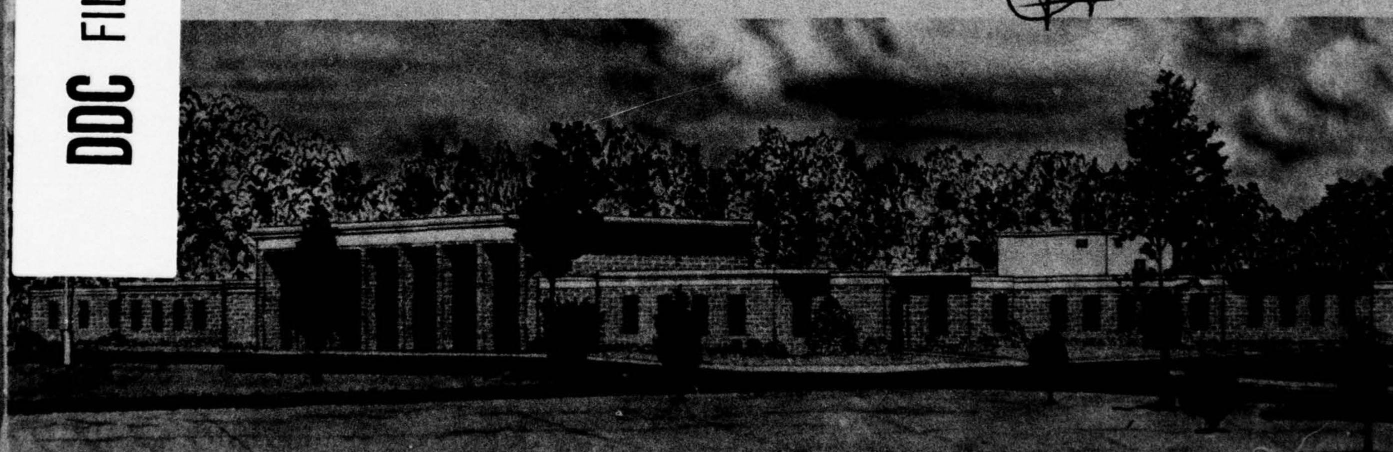

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This study utilizes the results of full-scale field and prototype laboratory testing to develop methodology for the prediction of deterioration and assessment of the reliability of pavements.

Deterministic equations are developed to predict deterioration in terms of rutting. The extensive data utilized were accumulated over four decades of research and represent a wide variety of pavement types and wheel loads. Ongoing field data collection programs are supplying additional data (Continued)

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20. ABSTRACT (Continued)

that will provide for deterioration analysis in terms of other modes, using analysis methods shown to be satisfactory in this investigation.

Reliability assessment models are developed using the deterministic deterioration equations as a basis. These models provide for a method of determining the probability that a pavement will give support and desired service for a period of time or number of vehicle operations.

The deterioration analysis and reliability assessment procedures are useful for maintenance and repair prediction as well as prediction of future serviceability.

The combined procedure provides a framework for life-cycle management of pavements. This ability to predict deterioration and assess pavement reliability will represent the first such major addition to current procedures now in use that provide for initial design only.

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PREFACE

The research that led to the developments reported herein was conducted under the auspices of Military Engineering Project 4A762719AT40, Task A2, Work Unit 011, Q6, entitled "Pavement Deterioration Analysis." This research was also sponsored by the U. S. Department of Agriculture Forest Service.

This investigation was accomplished at the U. S. Army Engineer Waterways Experiment Station (WES) by Dr. V. C. Barber, with the assistance of Messrs. E. C. Odom and R. W. Patrick, under the general supervision of Mr. J. P. Sale, Chief of the Geotechnical Laboratory, WES. This report is essentially Dr. Barber's dissertation, which was submitted to Texas A&M University in partial fulfillment of the requirements for the Doctor of Philosophy degree. The authors were provided editorial assistance by Mrs. L. M. Beall.

Directors of WES during the investigation were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
square inches	6.4516	square centimetres
pounds (mass)	0.45359237	kilograms
pounds (force)	4.448222	newtons
kips (force)	4448.222	newtons
tons (mass)	907.185	kilograms
pounds (force) per square inch	0.6894757	newtons per square centimetre
feet per second	0.3048	metres per second
miles per hour	1.609344	kilometres per hour

INTRODUCTION

Background

Pavement design has traditionally been set apart from maintenance and repair considerations. Early design procedures, by omission, provided for the design of pavements that were to perform some service up to a point where sudden failure occurred as a result of some predetermined quantity of traffic. This "failure" was some finite definition of the pavement condition. However, it has always been intuitively obvious that the pavement deterioration, or damage, began to occur upon initiation of traffic and gradually accrued to some point where conditions were unsatisfactory. It was also obvious to the designer that this unsatisfactory condition varied from one facility to another depending upon the needs and desires of the user.

More recently, and especially in the past decade, designers have sought methodology to quantify deterioration of pavements in various modes and to properly define failure of a pavement. These achievements have been considered essential in order to not only design a pavement but obtain the highest possible benefit from a pavement throughout its entire life.

This concept has been termed "life-cycle management" of pavements. Life-cycle management of pavements is a new concept, but it is clearly based upon the classical definition of engineering itself. Life-cycle management can be described as the management of a pavement from its

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The citations on the following pages follow the style of the Journal of the Geotechnical Engineering Division, Proceedings of American Society of Civil Engineers.

inception until the end of its life. The term then should include planning, design, maintenance, repair, and some control of usage.

In life-cycle management, essentially every tradeoff must be optimized. Particularly, a design must be at some minimum cost with respect to deterioration. Additionally, the design must be aimed directly at the level of reliability desired as a procedure for minimizing design redundancy or design insufficiency.

The U. S. Army Corps of Engineers (CE) has been typical in their history of developing pavement design procedures. During the early 1940's the CE adopted the California Bearing Ratio (CBR) tests for defining material strength and developed the CE design method for flexible pavements (1,2).[1] This semiemphirical method was selected in a time of military need partly for its ease of application. Similarly, a theoretical analysis characterized by an elastic plate on a liquid subgrade was selected for development of the CE design method for rigid pavements. The foundation strength for rigid pavement design was characterized by the modulus of subgrade reaction (16). The CE design methods for rigid, flexible, and other pavement types have undergone several modifications through the years and are still in use today. These methods are deterministic in that they provide for design of new pavements with respect to a specific failure cirterion, but not for analysis of gradual deterioration in the respective modes, or "system drift." This implies sudden failure of pavements upon application of some computed quantity of traffic applications.

Major research programs have been undertaken in the past decade to

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[1]Numerals in paraentheses refer to corresponding items in Appendix I.--References.

improve CE pavement design and management capabilities. In the early 1970's the WES initiated research programs to improve design procedures for the CE and other agencies. Theoretical design procedures using basic material parameters have been developed as a result of research sponsored by the CE and the Federal Aviation Administration (FAA). These procedures apply chiefly to rigid (25) and flexible (4) airport and road pavements as well as some variations of these pavement types. However, these improved procedures are still deterministic in that they utilize a specific failure criterion, assume one-time failure at some point, and do not address rate of deterioration or pavement reliability.

A program of study to fulfill the needs of the CE and FS was approved and funded in 1974 to develop life-cycle procedures for pavements based upon pavement deterioration and statistical reliability (3,10). This research is aimed at quantification of deterioration of pavements and assessing reliability. This program of study, currently in progress, is partially sponsored by the U. S. Department of Agriculture Forest Service (FS). The FS is participating in the study as a result of their need to assess damage to roads caused by logging operations (3). Data available or being collected are expected to provide for analysis of damage caused by various types of vehicles. This capability will provide the basis for development of a differential cost analysis procedure to aid in assessment of maintenance costs to private sector timber industry.

The Department of Defense, through the CE, is participating in the effort as a result of determination of the need not only to predict deterioration of roads in a military scenario but to assess pavement reliability in military tactical and logistical operations. This capability, along with current reliability concepts that are being applied to military vehicle operation, will provide for reliability of the overall systems that include ground and air vehicles as well as the mediums (pavements) upon which they operate.

Objectives of This Study

The objective of this study is to investigate the hypothesis that effective pavement life-cycle management can be achieved through utilization of deterioration and reliability concepts. In order to accomplish this investigation, several intermediate objectives are set forth as follows:

1. Utilize the surface rutting mode of deterioration to develop a pilot deterioration prediction procedure.

2. Further develop the rutting prediction procedure into a reliability assessment system.

3. Combine the deterioration and reliability models into a deterioration and reliability analysis procedure for use in life-cycle management. This procedure will be a pilot procedure that incorporates the rutting mode of deterioration.

4. Provide a basis for expanding these developments to include other modes of deterioration.

Accomplishment of these objectives will establish a basis for the development of an effective life-cycle management procedure.

Scope of Work

The initial efforts consisted of a search for existing data to determine whether enough rutting data were available to provide a basis for development of the deterioration and reliability models. The data were analyzed and, being found tentatively satisfactory, were utilized for this purpose.

Literature was reviewed, and studies were made to determine the most suitable method of analysis of the available data. After selecting a method for data analysis, a major portion of the research effort consisted of analysis of data and comparison of existing data with that being accumulated in ongoing field evaluations.

As deterioration and reliability models came forth from tha analysis, computer programs were developed to provide for computerized operation of the various models.

Ultimately, deterioration and reliability models for the rutting mode were developed for unsurfaced, gravel-surfaced, and two- and three-layer flexible pavements, respectively. These models were then combined to provide for deterioration and reliability analysis as well as for differential damage analysis where mixed traffic occurs. This system is termed the Differential Analysis System (DAS).

Definition of Terms

For clarity, certain terms pertinent to this document are listed and defined as follows:

1. Pavement.--A horizontal structure intended to protect a subgrade from the loading effects of wheeled vehicles.

2. Three-layer flexible pavement.--A pavement comprised of an asphalt concrete surface course, base course, and subbase course above the subgrade.

3. Two-layer flexible pavement.--A pavement consisting of an asphaltic concrete surface course and a base course above the subgrade.

4. Gravel-surfaced facility.--Any facility intended for use of wheeled vehicles and where a gravel course serves as the pavement structure.

5. Unsurfaced facility.--A facility intended for use of wheeled vehicles and where no pavement structure exists above the in situ material.

6. Equivalent single-wheel load (ESWL).--That load on a single wheel that produces the same effect (usually measured in terms of vertical deflection) beneath the wheels as a group of wheels with the same single-wheel contact area.

7. Operation or repetition.--One pass of one vehicle over a section of pavement.

8. Coverage.--One pass of a wheel over every point in a trafficable area.

9. Serviceability.--The capability of a facility to perform the intended functions.

10. Deterioration.--Any departure from the as-constructed condition of a facility that results in a reduction in serviceability.

11. Deterioration mode.--The nature of deterioration.

12. Structural mode.--A mode of deterioration that is in terms of the structural properties or capabilities of a facility.

13. Functional mode--A mode of deterioration that is in terms of a reduction in serviceability.

14. Life-cycle management.--Quantative optimization of design, maintenance, and repair, with respect to serviceability of a facility from conception to the end of its life.

DESIGN PROCEDURES AND PREVIOUS RESEARCH

Design Procedures

Several design procedures currently exist for the determination of thickness and strength requirements for protection of subgrades. Some designs currently in use are the Texas, CBR (CE), Group Index, California, FAA, and Asphalt Institute methods. These designs are empirically based, theory based, or in some cases a combination of both. The advent of computers brought about more extensive utilization of elastic theory in developing theoretical design procedures. Among these are the Shell, Chevron, Asphalt Institute, and the recently developed CE design procedures.

These procedures have served the respective agencies well in the functions intended. However, as a general rule they have been applicable only to preconstruction design of pavements. Some of the agencies have modified their procedures for use in pavement condition surveys and for overlay design tools.

The past decade has seen record pavement construction of all types. Many of these pavements either are approaching or have already exceeded their respective design lives and, therefore, lie in some state of deterioration and need of repair. The design procedures previously mentioned have usually been found inadequate as tools for quantification of deterioration and subsequent repair needs. Therefore an era has arrived where maintenance and rehabilitation are at the forefront and where quantitative analysis procedures are either nonexistent or lacking in adequacy or validation.

The CE design procedures for rigid (16), flexible (13), and gravel-surfaced pavements, as well as unsurfaced facilities (12), fall into such a category and serve as examples of design procedures that do not provide for analysis of deterioration or the reliability of a pavement.

Deterioration and Reliability Investigations

The concepts of statistics and probability are certainly not new to the field of engineering as a whole. However, the most significant inroads to the utilization of these concepts have been made in recent years. The First International Conference on Applications of Statistics and Probability to Structural and Soils Engineering was held in Hong Kong in 1971 (22). Material presented at that conference represents significant beginnings in the overall application of these tools in the field of civil engineering.

The utilization of probability and statistics to address deterioration and reliability of pavement life-cycle management is newer still. Significant contribution was made in 1974 by Lu, Lytton, and Moore (20) for the Texas Transportation Institute in cooperation with the Federal Highway Administration. They utilized data collected from pavement test sections in Texas to predict serviceability loss in flexible pavements. The concept of probabilistic design used was formulated by Darter and Hudson and applied to flexible pavement design systems in 1973 (9). Lu, Lytton, and Moore developed a two-step constrained select regression procedure to examine the effect of each variable on pavement serviceability loss. They also used stochastic reliability concepts to evaluate expected value and variance of serviceability loss. In 1975, Hudson et al.

(15,17), in a contract study for the WES, wherein the state of the art in predicting pavement reliability was reviewed, recommended that research should continue in the area of pavement reliability. The current status of reliability assessment was also given in 1975 by Barker and Brabston (4). Although the new design procedure for flexible airport pavements (4) is innovative and provides greater capabilities in design, they state that pavement deterioration is a continuous function but is treated as discontinuous by criteria that label pavements as "failed" or "unfailed." They further state that this is not the case but that unfortunately methodology still does not exist to predict deterioration realistically.

The net result of these investigations is that not only is stochastic reliability and deterioration a viable approach to life-cycle management in view of material variability and other uncertainties, but the state of the art exists for the application of these concepts to various design procedures, such as the CE design procedure as illustrated in this document.

The Pavement Deterioration Program

The need to more effectively construct new pavements and the necessity to maintain many existing pavements has been a concern of various Federal agencies. A pavement deterioration and reliability analysis program was instituted at the WES in 1974 and sponsored by various agencies for the purpose of developing methodology for the effective life-cycle management of pavements. As the initial achievement, methodology has been developed to analyze deterioration and to assess reliability in terms of rutting. These concepts have been developed to be applicable to the original CE design procedure for flexible pavements and to utilize the parameters of that procedure. Rutting was chosen as the initial mode of deterioration in which to test the hypothesis that such achievements could be made due to availability of data and since rutting has historically constituted failure criteria for CE flexible pavements.

This document, in the succeeding parts, will describe the test program as well as the deterioration and reliability assessment methodology.

The overall research and data collection program is aimed at deterioration and reliability assessment for rigid, flexible, and all other types of pavements and includes all modes of deterioration. However, this research is intended to set the technological framework for overall analysis by providing the procedures for dealing with all types of deterioration on all pavements. When these procedures are eventually applied to all deterioration modes and all pavements, a complete life-cycle management system can be developed.

DATA COLLECTION AND CURRENT STUDIES

Earlier Tests and Data Collection

The CE design method has required revalidation and revision since its adoption due to the ever-changing nature of traffic. Airfield design criteria have seen the greatest change due to the increase in aircraft weights, wheel loads, tire pressures, and number of operations. Road and highway design criteria have also changed considerably over the years due to changes in vehicle characteristics and modes and quantities of operations. To stay abreast of these changes and to provide the most applicable criteria possible, it has been necessary for the CE to conduct numerous prototype tests. These prototype tests have classically proved the best approach until recently when such studies have become cost prohibitive. The net result of such an extended series of tests has been the accumulation of myriad prototype pavement performance data. The data are necessarily in terms usable in the early CE design methods, namely rut depths, thickness of layers, strengths of layers and subgrades in terms of CBR, and vehicle characteristics, which include number and configuration of wheels, tire pressures, and wheel loads. Although the data were accumulated under closely controlled conditions, the researchers were attempting to determine end-point failure. The design method was structured to determine thicknesses required to prevent subgrade deformation as a result of loading, and the failure criterion was largely in terms of maximum allowable rut depths. Therefore, in the process of repetitive loading and intermittent, frequent data collection, large quantities of data were collected that characterize a change in rut depth as a function of traffic.

Deterioration Data Search

A data search and analysis was conducted in the early stages of the deterioration program to determine whether suitable data existed. The study consisted of a two man-year effort to review all existing data at the WES and to screen the data for overall applicability prior to initiating the development research. The results were that a large quantity of high-quality rutting data was available that applied to two- and three-layer flexible pavements as well as gravel-surfaced and unsurfaced facilities. The data were initially termed suitable if the variables were within appropriate ranges and were all included and deliberately recorded. Further analysis of distribution and range of data is presented later in this document.

The literature reviewed and utilized as data sources is tabulated for reference uses in Appendix II. The 90 references, which are not referred to individually, are considered to comprise results of essentially all key tests at the WES in recent years.

A tabulation of the data ultimately used in this study is given in Appendix III. These data represent the final data selected for development of deterioration and reliability models and are by no means the total data available. Criteria for rejection of certain data were generally based on range and reaction of test pavements. Rejection criteria will be discussed along with model development.

A prototype pavement test section typical of those upon which traffic tests were conducted and data collected is shown in Fig. 1. Such test areas are constructed under rigid controls to a specified design requirement. Traffic is normally applied in a specified pattern to simulate actual distribution. Specially designed trafficking vehicles having load wheels that exactly represent the desired tire sizes, pressures, loads, and configurations, as shown in Fig. 2, are employed to place the desired traffic upon the test area.

Various materials tests, surveys, and surface measurement are made prior to, during, and after traffic to monitor all physical conditions and all changes. Fig. 3 gives a typical rut depth measurement, while Fig. 4 shows a strength (CBR) measurement in progress on one of the layers.

Although Figs. 1-4 illustrate typical prototype test sections built and tested to generate much of the data, a significant quantity of data was accumulated on actual roads and airfields that were subjected to design traffic either on an accelerated basis or in the normal mode of operation.

The availability of such a quantity of deterioration data in terms of rutting on CE-designed pavements is the reason for selecting rutting and CE design parameters for use in this basic research on deterioration and reliability. As data are made available under the test program described in succeeding paragraphs, the developments reflected in this document will be expanded to other deterioration modes and to other design procedures according to the needs of other governmental agencies.

Current Data Collection Programs

The CE-FS agreement (10) called for the pilot studies to develop methodology as reported herein and for a large-scale field testing program. The purpose of the program was to accumulate actual deterioration data pertinent to FS and CE roads for use in validation of this procedure

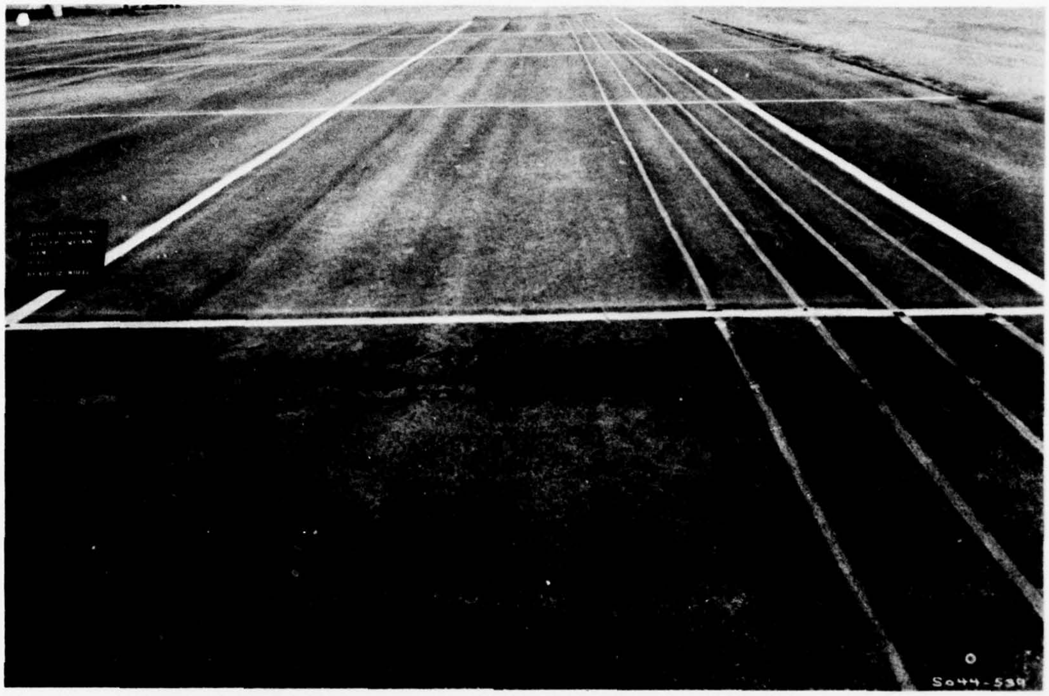

FIG. 1.--PROTOTYPE FLEXIBLE PAVEMENT TEST SECTION

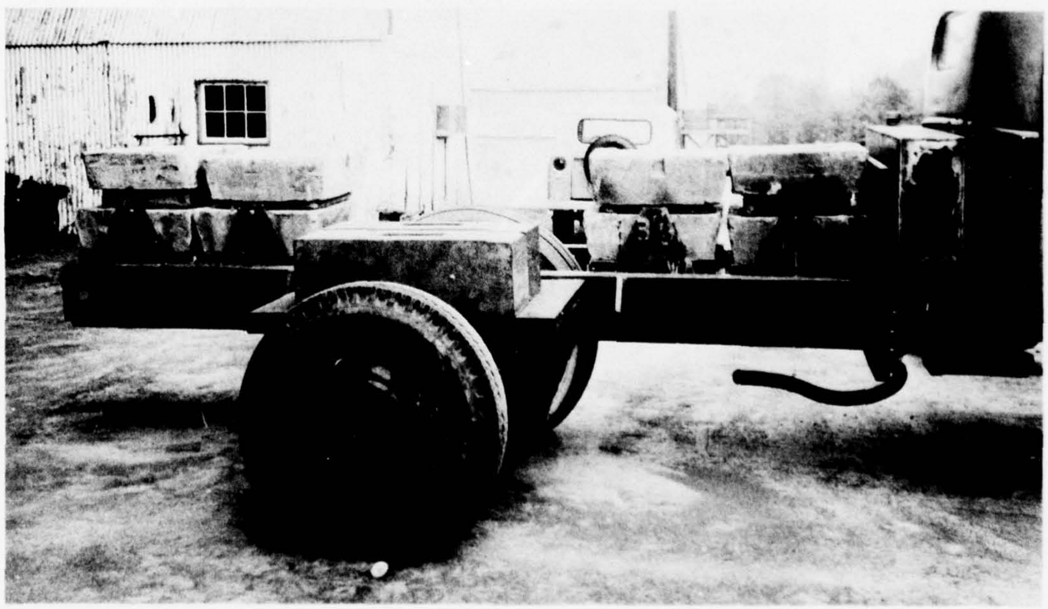

FIG. 2.--LOAD CART WITH REPRESENTATIVE LOAD WHEEL USED IN TRAFFIC TESTING

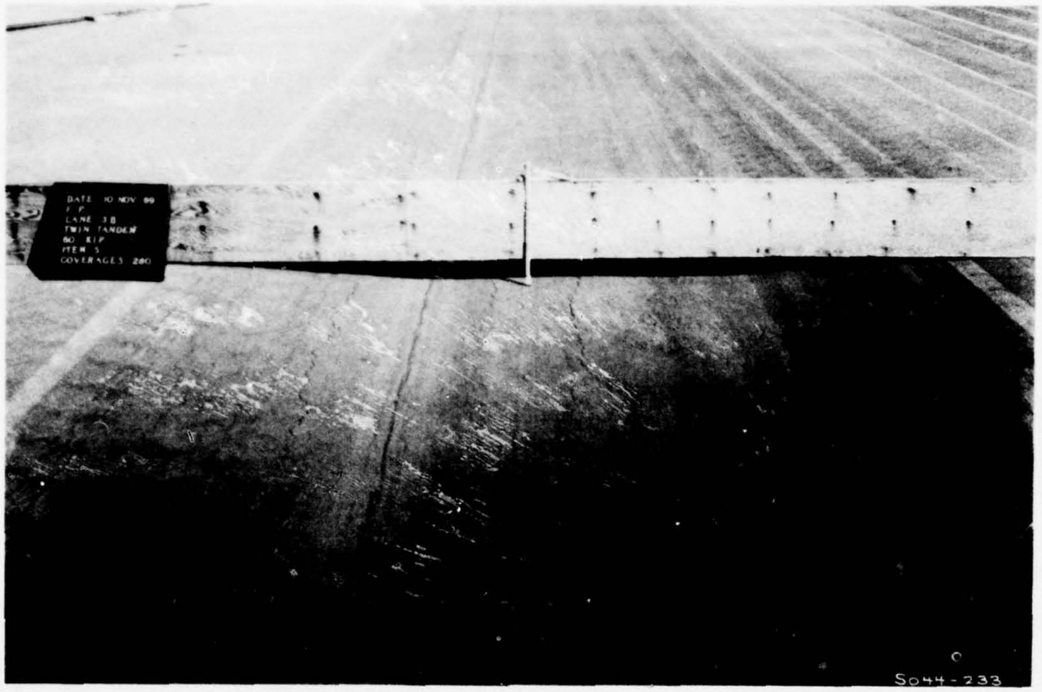

FIG. 3.--MEASUREMENT OF RUT DEPTHS ON PROTOTYPE TEST SECTION

FIG. 4.--CALIFORNIA BEARING RATIO MEASUREMENT IN PROGRESS ON A LAYER OF A TEST SECTION

for employment by the respective agencies. The modes of deterioration considered paramount for this study were rutting, roughness, slipperiness, cracking, and surface loss on aggregate-surfaced roads. These field tests have been in progress for approximately two years. Initial liaison was established in most cases by FS personnel who also assisted in establishing test sites at several locations throughout the United States. Currently, approximately 40 test sites exist that are respectively being monitored for deterioration in the various modes. It is anticipated that the program will continue for approximately four more years. During the latter stages, data collected will be applied to the system developed herein.

Test sites have been selected at the various regional locations in areas having suitable design and traffic features to provide a deterioration environment. Test sections are established at these test sites whereon surface conditions and pavement layer strengths and thicknesses are monitored periodically. Fig. 5 gives a layout used at most test sites. The layout shows locations of test pits as well as locations for profiling for roughness and cross-section and rut depth measurements. These tests are conducted in a conventional manner and in sufficient detail to depict any deterioration. In addition to these tests, roughness is monitored using a Mays ride meter. Skid resistance is measured in terms of energy required to produce slip or loss of traction. The slip-energy device and recorder were especially designed for this test. The data collected from this test are also expected to be applicable to slip-energy studies being conducted by the FS (9).

Fig. 6 illustrates rut depth measurement on a one-lane gravel-surfaced road. The device used is a standard 10-ft straightedge, and

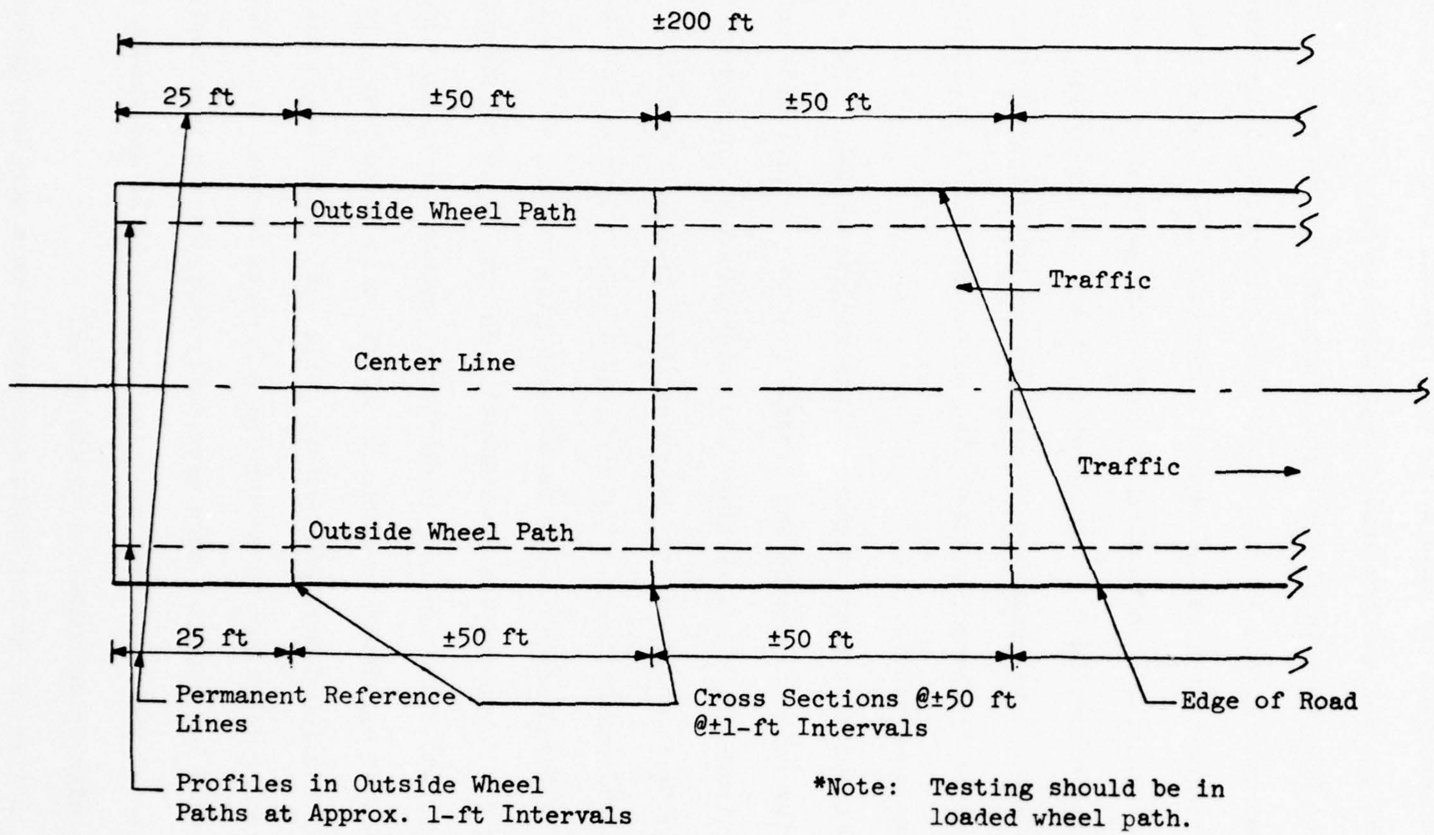

FIG. 5.--TYPICAL TEST SITE LAYOUT

the rut depth is considered to be the maximum deviation. Fig. 7 shows survey personnel conducting profile and cross-section measurements, both of which are normally taken at 1-ft intervals to provide for the maximum practical definition of the surface configuration. Fig. 8 shows small aperture testing (SAT) of layer strengths. The SAT procedure (11) provides a 6-in.-diam access hole through which layer strengths CBR values as well as thicknesses in inches can be determined. Additionally, samples can be retained for moisture content determination. Moisture content determination is frequently made using nuclear testing devices (26) as is illustrated in Fig. 9. Such procedures, when used in conjunction with SAT, provide for more rapid and economical monitoring of changes in pavement conditions.

In addition to these tests, climatological data are collected for the area on a continuous basis.

Monitoring to determine type and quantity of traffic that brings about deterioration has been of primary concern and interest throughout the program. Several procedures and items of equipment have been utilized with varying degrees of success. However, the greatest success to date has been by use of an inductive loop counter synchronized with a 35-mm movie camera. This combination provides for not only a traffic count but a sequence of photographic frames that depicts each vehicle crossing the loop, including those conducting maintenance. Fig. 10 shows the manner of installing the induction loop, while Figs. 11 and 12 show the hidden counter and camera, respectively. Fig. 13 gives an example of heavy traffic that frequents many roads, especially in timber sale operations in national forests. Figs. 14 and 15, show maintenance

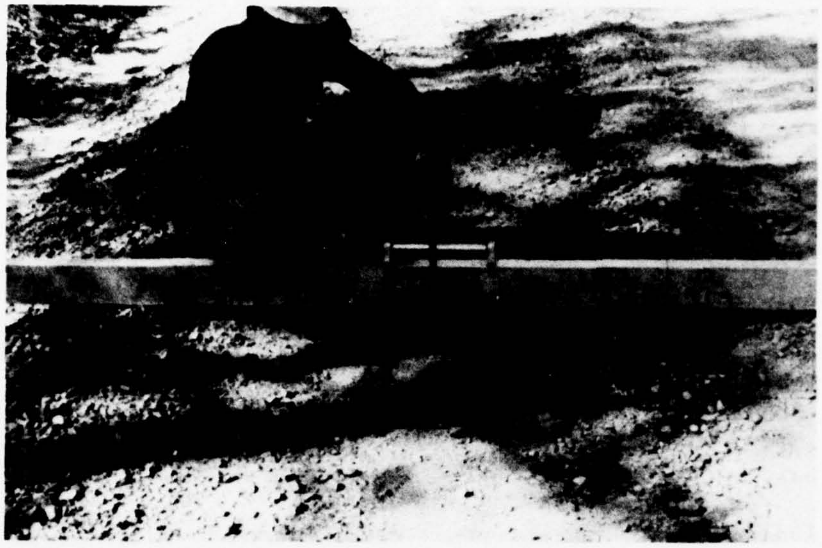

FIG. 6.--RUT DEPTH MEASUREMENT AT A SITE ON A GRAVEL-SURFACED ONE-LANE FOREST ROAD

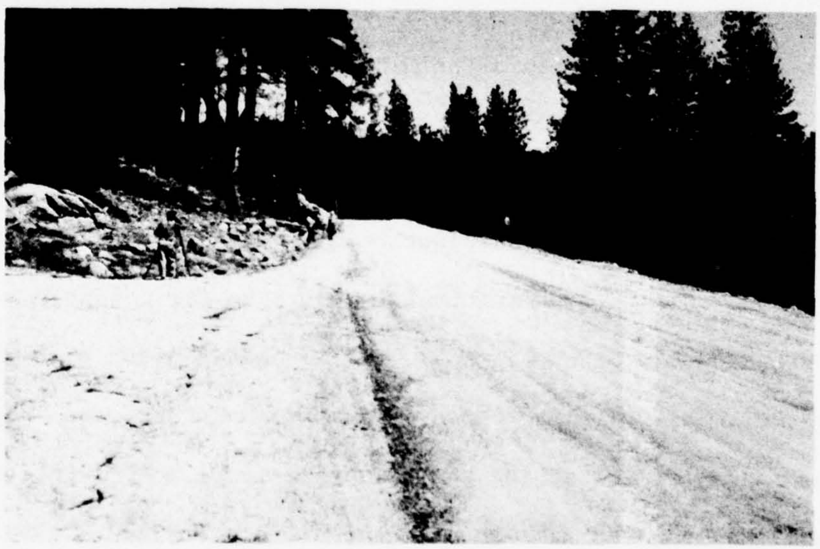

FIG. 7.--SURFACE CHARACTERIZATION WITH CROSS-SECTION AND PROFILE MEASUREMENTS AT A TEST SITE

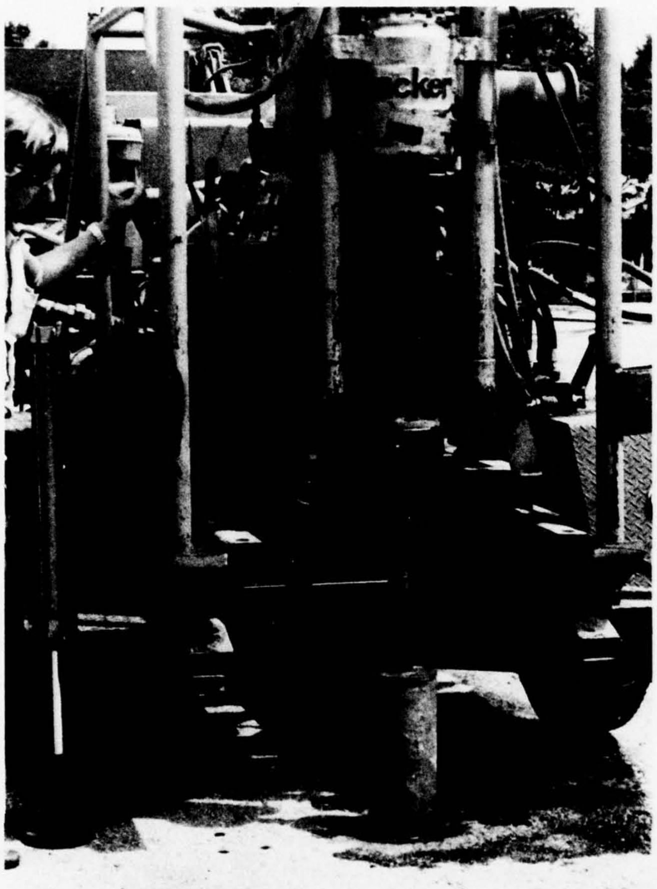

FIG. 8.--SMALL APERTURE TESTING (SAT) IN PROGRESS TO DETERMINE LAYER THICKNESS, CBR, AND MOISTURE CONTENT

FIG. 9.--MOISTURE CONTENT DETERMINATION WITH NUCLEAR DEVICE

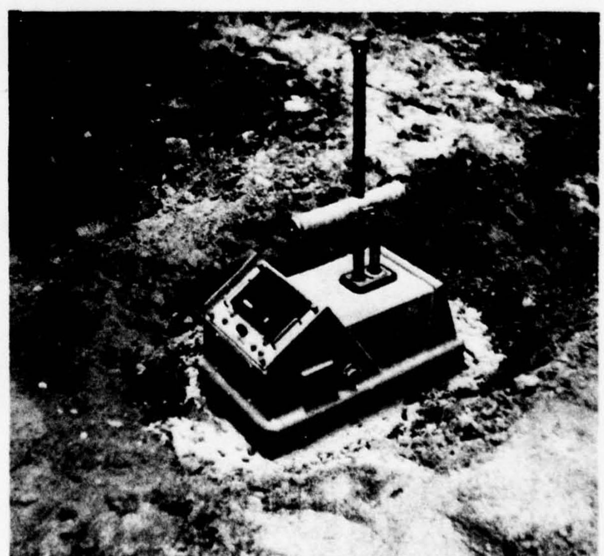

FIG. 10.--MANNER OF INSTALLATION OF INDUCTION LOOP
FOR TRAFFIC COUNTING

FIG. 11.--VIEW OF HIDDEN TRAFFIC COUNTER

VIEW A VIEW B

FIG. 12.--VIEW OF HIDDEN CAMERA

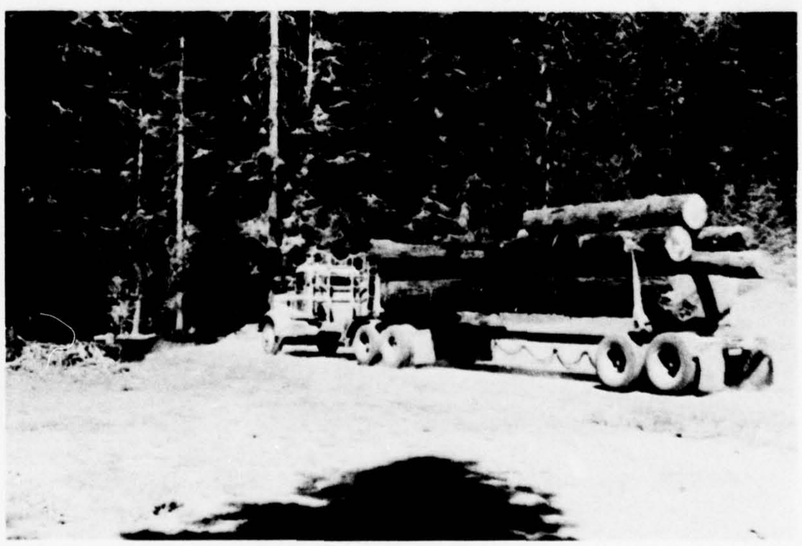

FIG. 13.--TYPICAL HEAVY TRAFFIC ON FOREST ROADS

FIG. 14.--TYPICAL MAINTENANCE OPERATION ON GRAVEL-SURFACED FOREST ROADS

FIG. 15.--WATERING IS NECESSARY TO MINIMIZE DUST PROBLEMS ON FEEDER ROADS

operations on an unsurfaced logging road. Use of the induction loop counter and camera will not only aid in counting and describing traffic but also serve as a permanent maintenance record.

Tests similar to those described above are being conducted at military posts and in private industry forests in the South in cooperation with the respective agencies in an attempt to further expand the data base. The combination of tests and traffic monitoring, when successfully pursued over a period of approximately six years, is expected to provide abundant data for deterioration and reliability system validation.

Future Data Collection

Plans have tentatively been formulated to expand the testing procedure to include aggregate surface loss tests. The surface loss mode of deterioration is critical due to the high cost of replacement of surface aggregate lost each year as a result of both traffic and maintenance operations. The initial stages of surface loss studies would consist of development of test procedures as well as preliminary determination of pertinent variables. Although aggregate loss is not held in high regard universally as a deterioration mode, it carries significant impact with the FS. It has been determined that annual cost of replacement of aggregate on gravel-surfaced roads is a major cost item for that agency. Inroads have been made into the surface loss problem by way of slip-energy and associated tire wear concepts (9). However, it is hypothesized that another valid approach is the deterioration and reliability concept set forth in this document. The cooperating agencies therefore hope to achieve results through at least one of the approaches.

The thrust of these paragraphs has been to set forth the overall philosophy of the program. Namely, in order for the overall work to be accomplished in the foreseeable future, existing data are used to explore the hypothesis that deterioration and reliability concepts can be employed to effect life-cycle management while a full-blown data collection program for validation is in progress. The succeeding portion of this document reports findings as to the development of pilot procedures for predicting the deterioration and reliability of pavements.

DEVELOPMENT OF DETERIORATION MODELS

Initial Data Analysis

The primary objective in examining the hypothesis that the rate of deterioration of a pavement structure can be quantified was the establishment of the rate of rut depth (RD) change as a function of the independent variables. In the case of this work, where up to eight independent variables were involved, it was recognized early that the method of data analysis would be critical in terms of time, cost, and overall results of the analysis. The initial analysis consisted of utilizing a conventional one-step regression for the entire set of variables involved. The procedure quickly proved to be rather time-consuming and produced rather poor correlation in cases where it was intuitively obvious that better results could be attained. With this experience in hand, other procedures were considered for analysis, including imposing forms and coefficients onto the variables and performing regressions on these "new" variables. Again, the results were not satisfactory.

The initial data analysis, although largely unsuccessful, provided at least two results that would prove valuable in future efforts. First, it was determined that some reasonable correlations did exist between the rate of rutting and the nature of traffic on given pavement structures. Second, it became possible to make the judgment that imposing what appeared to be a suitable form on the variables in some instances could effectively provide for a better overall correlation and a more direct route in attaining that correlation.

Regression Analysis Procedures

The procedure of analysis ultimately selected for use is an orderly method of developing mathematical relations from sets of data using multiple regression analysis. This procedure was developed by Lu, Lytton, and Moore (20), although the basic method has probably been employed by others, due to its direct approach to the analysis of data. The procedure was first described in reference 20, although it was first used by Lytton and Castleberry (6) in a study on damage to houses located on expansive clays.

As originally developed, the procedure used the SELECT regression program, which had been developed at Texas A&M University by researchers with the Institute of Statistics, namely R. R. Hocking, R. N. Leslie, L. R. La Motte, and D. A. Debuse. Their development of the SELECT regression method and computer program is recorded in references 8, 14, and 19. The SELECT procedure is desirable because of its several good features and was utilized in the earlier stages of development of equations shown herein. However, the final regressions performed herein were conducted using a WES library program called STAT21. The program is similar to SELECT and was confirmed to produce nearly identical results. Its availability at WES dictated its use for this study.

The procedure utilized is termed a two-step constrained regression procedure. The first step of this method is essentially a selection regression procedure using a multiplicative model to obtain the approximate exponents of the independent variables. The second step determines the coefficients of linear combinations of the products. The final model is selected based upon four factors:

1. As simple an expression as can reasonably describe what is actually taking place in terms of the dependent variable and reflecting the effect of the independent variables.

2. High multiple correlation of the model.

3. Small prediction error.

4. Satisfaction of physical constraints.

The procedure used in this study represents an alteration of the original procedure utilized in program SELECT. The departure was possible due to the fact that normally there were several measured values of rut depth that increased according to the number of load repetitions for each series of data. Since the data were composed of rut depth-load histories, the regression itself was broken into several stages as described in the following paragraphs.

The variables involved in the equations are tabulated as follows:

RD ≡ rut depth, in.

P ≡ equivalent single-wheel load, lb

t_p ≡ tire pressure, psi

R ≡ number of load repetitions

t_i ≡ layer thickness, in.

C_i ≡ layer strength in CBR

The total number of variables changes from one pavement type to another depending upon the number of layers that make up the payment. The procedure described below is in general terms and applicable to all of the pavement types.

The first step in equation development is determining the rut depth as a function of the traffic variables, which are equivalent single-wheel load, tire pressure, and number of repetitions. The equations thus derived will take the form:

$$RD = f_1(P, t_p, R) + SE_1$$

where SE_1 is the regression error due to lack of fit and to variables that have not yet been included.

The next step was a regression upon a "normalized" rut depth, NRD, given by the following equation:

$$NRD = \frac{RD}{f_1(P, t_p, R)} = f_2(C_i t_i) + SE_2$$

This is termed "normalized" because any effects of loading are accounted for in the new dependent variable. The remaining variables (pavement structure) were used to show how their properties influenced rut depth. The new regression error, SE_2 , is affected by three factors, which are lack of fit of the new equation, stochastic variation of the variables and climatic variations, and other factors not explained in the variables.

The third step consisted of multiplying f_1 by f_2 and running the regression a third time to correct the nonlinearities that were introduced in the first two steps. The form of this third equation becomes

$$RD = f_3 + SE_3 = a(f_1 f_2)^b + SE_3$$

This step is the final regression step and generally results in a higher correlation coefficient, r , and lower error, SE_3 , than all the previous models.

The last step is to determine the size of the error, SE_3, which is accomplished by getting the sum of square errors, σ_t^2, between the observed and mean rut depths. This step is expressed as

$$\sigma_t^2 = \sum_{i=1}^{n} \frac{(RD_i - \overline{RD}_i)^2}{n - 1}$$

where

$\overline{RD}$ = the mean rut depth

RD = the observed value of rut depth

This sum of square errors is composed of the sum of the variances due to the regression equation used and the lack of fit of the equation

$$\sigma_t^2 = \sigma_r^2 + \sigma_{\ell of}^2$$

where

σ_r^2 = variance due to regression

$\sigma_{\ell of}^2$ = variance due to lack of fit

The error SE_3 is measured by the lack-of-fit variance and is determined by

$$\sigma_{\ell of}^2 = \sum_{i=1}^{n} \frac{(RD_i - \hat{RD}_i)^2}{n - 1}$$

where $\hat{RD}_i$ is the value of the rut depth predicted by the regression equation. The variance due to regression is determined by

$$\sigma_r^2 = \sum_{i=1}^{n} \frac{(\hat{RD}_i - \overline{RD})^2}{n - 1}$$

or the regression variance may be approximated by a method based upon the Taylor's series expansion of the predictive function.

Development of Regression Models

The data shown in Appendix II were used to develop models for rutting in the manner described in the preceding paragraphs. Experience and familiarity in the area of CE pavement design procedures provided some insight into the probable behavior of the variables; therefore, some transformations were attempted in the case of many of the variables. The thickness equations currently in use by the CE (13) were studied to determine the most likely form that some of the variables might assume. Although the procedure essentially provides for determining thickness required to protect subgrades, rutting was normally the limiting criterion. Therefore, the design equations can be considered as having the ability to predict one certain value of a rut depth. If an inversion of variables is envisioned, one can see that even in those equations, rutting could be considered "dependent" and thickness could be a controlled variable. If this were the case, repetitions could be varied to determine thickness required to produce the limiting rut depth. Thus, certain forms were imposed upon the variables in an attempt to intuitively achieve better representation of the data in the regression analysis.

First among these considerations was the indication from sample data that the rut depth increased in some cases with the square root of tire pressure and in others with the common logarithm of tire pressure. Therefore, these two forms were attempted and can be seen in the equations.

Additionally, thickness of some layers seemed to have various types of correlation with rut depth. Some examples of the forms for thickness and tire pressure that were intuitively developed and employed in the final equation are as follows:

$$RD = \ldots\ldots\ f(t_p)^{1/2}\ \ldots\ldots\ldots$$

$$RD = \ldots\ldots\ f[\log(t_p)]\ \ldots\ldots$$

$$RD = \ldots\ldots\ f[1 + \log(t_1)]\ \ldots$$

$$RD = \ldots\ldots\ f(at_1 + bt_2)\ \ldots\ldots$$

where a and b were constants usually having values of 1.00 and 1.25, respectively, which are weighted coefficients intuitively selected.

The following four parts of this document give a description of the development of the models for the four categories of pavements where applicable data existed.

Unsurfaced Facility Model

The data available for development of rutting models fell into two categories. The first category is one where the surface CBR (C_1) is usually equal to or lower in value than the subgrade CBR (C_2). The second category is when C_1 is greater than C_2 and will be discussed subsequently. These data typify many facilities where in situ materials are used and the facility is constructed merely by grading a smooth surface. The CBR in the upper portion is usually lower due to moisture or organic materials, while the lower (subgrade) portion is more stable due to lesser moisture fluctuation and other disturbances.

The data in this category were inspected, and a total of 142 data points were retained for analysis. The variables influencing the rut depth are shown in Table 1.

TABLE 1.--VARIABLES FOR UNSURFACED AND GRAVEL-SURFACED FACILITY RUTTING MODELS

Index	Variable
1	RD = rut depth, in.
2	P = equivalent single-wheel load (ESWL), lb
3	t_p = tire pressure, psi
4	t = thickness of top layer, in.
5	*C_1 = CBR of top layer
6	*C_2 = CBR of bottom layer
7	R = repetitions of load or passes

* $C_1 < C_2$ for unsurfaced facilities.

$C_1 > C_2$ for gravel-surfaced facilities.

The data used in development of the unsurfaced model are given in Appendix III. Numerous iterations were performed using the regression analysis techniques previously described. As models were developed, they were rejected on one or more of the four criteria previously discussed. The usual basis for rejection was low correlation of the data. However, several models were rejected due to improper behavior of variables or simply to unseemly appearance of the model when compared with forms found in the earlier pavement thickness design equations.

Of the 142 unsurfaced data points where the surface CBR was lower than the subgrade CBR, 8 points that had rut depths 9 in. or higher were eliminated since it was considered unreasonable to predict such high values. For the 134 remaining points, the equation considered best was

$$RD = \frac{0.00609 \left(\frac{P}{C_2}\right)^{0.4336} t_p^{1.0461} (\log t)^{1.0670} R^{0.5226}}{C_1^{2.0267}}$$

where the standard error of estimate (SE) and the coefficient of correlation (r) equal 0.530 and 0.9137, respectively. This model shows an increase in RD with an increase in P, t_p, t, and R and a decrease in RD with an increase in C_1 and C_2. It should be noted that in the case of the gravel-surfaced facility model where the top layer was stronger, the RD shows a decrease with higher thicknesses, but in the data points where the top layer is weaker, the RD shows an increase with higher thicknesses. For this equation, the exponent of C_2 is low compared with the exponent of C_1. However, this equation was considered the best by comparison. Using the residuals of this equation, 20 "bad" data points were deleted leaving 114 points.

Using the remaining 114 data points, the equation considered best was derived using the step regression as follows:

1. Step 1.--Solve for RD as function of four variables:

$$RD = 0.0025 \frac{P^{0.4976} t_p^{0.8628} R^{0.5070}}{C_1^{1.9976}}$$

where $SE = 0.408$ and $r = 0.9373$

2. Step 2.--Divide RD by the expression on the right, and solve for the other two variables:

$$\frac{RD}{\dfrac{P^{0.4976} t_p^{0.8628} R^{0.5070}}{C^{1.9976}}} = 0.108 \frac{(\log t)^{0.4337}}{C_2^{1.2138}}$$

3. Step 3.--Multiply expression on right by denominator on left:

$$RD = 0.110 \left[\frac{P^{0.4976}\ t_p^{0.8628}\ R^{0.5070}\ (\log t)^{0.4337}}{C_1^{1.9976}\ C_2^{1.2138}} \right]^{0.9898}$$

where SE = 0.399 and r = 0.9403

4. Step 4.--Multiply exponent of each variable by 0.9898, and the final equation becomes

$$RD = 0.110\ \frac{P^{0.4925}\ t_p^{0.8548}\ R^{0.5018}\ (\log t)^{0.4293}}{C_1^{1.9773}\ C_2^{1.2015}}$$

where SE = 0.399 and r = 0.9403

With this step the outside radical can be eliminated.

This is the model finally selected as a result of regression analysis. Other equations and partial step equations that were tried and eliminated, along with the reasons for eliminating them, were as follows:

$$RD = 17.773\ \frac{P^{0.4712}\ t_p^{1.0005}\ t^{0.1349}\ R^{0.4610}}{C_1^{1.9899}\ C_2^{2.9654}}$$

where SE = 0.401 and r = 0.9394

exponent of t too low; exponent of C_2 too high

. . . .

$$RD = 0.0214 \left(\frac{P}{C_2}\right)^{0.5042} \frac{t_p^{0.8895} R^{0.4889}}{t^{0.1941} C_1^{2.011}}$$

where SE = 0.406 and r = 0.9380

t_1 not in numerator

. . . .

$$RD = 0.00254 \left(\frac{P}{C_2}\right)^{0.1038} \left(\frac{t_p}{C_1}\right)^{1.6943} \frac{R^{0.5545}}{t^{0.0765}}$$

where SE = 0.557 and r = 0.8797

t_1 not in numerator; exponent of $\frac{P}{C_2}$ too low

. . . .

$$RD = 9{,}383{,}500 \left(\frac{t_p}{C_1}\right)^{1.7452} \frac{P^{0.1490} t^{0.9184} R^{0.4417}}{C_2^{8.029}}$$

where SE = 0.492 and r = 0.9076

coefficient too high; exponent of C_2 too high;

exponent of P too low

. . . .

$$RD = 0.00296 \frac{P^{0.5053} t_p^{0.8692} R^{0.4966}}{C_1^{2.0110} (\log t)^{0.6198}}$$

where SE = 0.409 and r = 0.9371

log t not in numerator

. . . .

$$RD = 26.302 \frac{P^{0.4700} t_p^{1.0025} (\log t)^{0.4220} R^{04613}}{C^{1.9888} C_2^{2.9964}}$$

where SE = 0.401 and r = 0.9395

exponent of C_2 too high

. . . .

Gravel-Surfaced Facility Model

The gravel-surfaced facility data include a total of 299 data points. The data typify a facility where a gravel or similar surface generally referred to as "gravel" is placed upon the existing subgrade to provide for protection of that subgrade. Therefore, these data are characterized by gravel-surfacing CBR values (C_1) higher than the CBR values of the subgrade (C_2). The variables shown in Table 1 are applicable to this model also. However, it should be noted that C_1 represents a surfacing of some type of gravel with a finite thickness t .

Numerous regressions were performed on the original 299 data points, and the final equation was derived in steps as follows:

1. Step 1.--Rut depth was determined as a function of three variables:

$$RD = 0.0123 \left(\frac{P}{C_1}\right)^{0.5439} R^{0.1647}$$

where SE = 0.611 and r = 0.6809

2. Step 2.--These three variables were transposed, and regression was performed on the remaining three variables:

$$\frac{RD}{\left(\frac{P}{C}\right)^{0.5439} R^{0.1647}} = 0.0103 \frac{t_p^{0.5343}}{t^{0.6914} C_2^{0.3340}}$$

where SE = 0.527 and r = 0.4982

3. Step 3.--All variables were then moved to the right side, and a third regression was performed to adjust the exponents and the slope intercept:

$$RD = 0.366 \left[\left(\frac{P_K}{C_1}\right)^{0.5439} \frac{t_p^{0.5343} R^{0.1647}}{t^{0.6914} C_2^{0.3340}} \right]^{1.1410}$$

where SE = 0.520 and r = 0.7820

In this particular version, the variable P is expressed in kips (P_K).

4. Step 2a.--The term "log t" was substituted for the term "t", and Step 2 was repeated:

$$\frac{RD}{\left(\frac{P}{C}\right)^{0.5439} R^{0.1647}} = 0.00169 \frac{t_p^{0.5777}}{(\log t)^{1.6676} C_2^{0.3569}}$$

where SE = 0.526 and r = 0.5035

5. Step 3a. Step 3 was repeated:

$$RD = 0.00062 \left[\left(\frac{P}{C_1}\right)^{0.5439} \frac{t_p^{0.5777} R^{0.1647}}{(\log t)^{1.6676} C_2^{0.3569}} \right]^{1.1456}$$

where SE = 0.518 and r = 0.7842

Note: A higher r value was attained for Steps 2a and 3a than for Steps 2 and 3; therefore, the imposed term "log t" was allowed to remain.

6. Step 4.--The variable P in pounds was changed to P_K in kips to make the coefficient (0.00062) higher:

$$RD = 0.0459 \left[\left(\frac{P_K}{C_1} \right)^{0.5439} \frac{t_p^{0.5777} R^{0.1647}}{(\log t)^{1.6676} C_2^{0.3569}} \right]^{1.1457}$$

where SE = 0.517 and r = 0.7842

7. Step 5.--The exponents of variables were multiplied by 1.1457:

$$RD = 0.0459 \left[\left(\frac{P_K}{C_1} \right)^{0.6231} \frac{t_p^{0.6619} R^{0.1887}}{(\log t)^{1.9106} C_2^{0.4089}} \right]$$

where SE = 0.517 and r = 0.7842

Using the residuals of the equation from Step 5, 45 points that were considered undesirable were deleted resulting in 254 data points. The criteria in choosing the equation from Step 5 as the best of the equations derived were first that this equation showed an increase in RD with an increase in P , t_p , and R and a decrease in RD with an increase in C_1 , C_2 , and t as should be expected. In addition, the exponents of the variables seemed reasonable with the possible exception of the exponent for repetitions R , which seemed to be low. However, this equation was considered the best overall.

After the 45 points were deleted, a new set of equations was derived from the remaining 254 data points. The equation considered the best of these was

$$RD = 0.1741 \frac{P_K^{0.4707} \left(\frac{t_p^2}{C_2}\right)^{0.2848} R^{0.2476}}{(\log t)^{2.0020} \; C_1^{0.9335}}$$

where SE = 0.294 and r = 0.9177

or by moving C_2 to the denominator

$$RD = 0.1741 \frac{P_K^{0.4707} \; t_p^{0.5695} \; R^{0.2476}}{(\log t)^{2.0020} \; C_1^{0.9335} \; C_2^{0.2848}}$$

Other equations that were considered and eliminated were as follows:

$$RD = 0.0723 \frac{P_K^{0.5401} \; t_p^{0.6666} \; R^{0.2533}}{C_1^{0.9383} \; (\log t)^{2.0467} \; C_2^{0.1448}}$$

where SE = 0.292 and r = 0.9187

exponent of C_2 too low

. . . .

$$RD = 0.124 \frac{P_K^{0.3933} \; t_p^{0.4964} \; R^{0.1829}}{C_1^{0.8898} \; t^{0.6889} \; C_2^{0.2728}}$$

where SE = 0.310 and r = 0.9087

derived by steps; exponent of P and R too low

. . . .

$$RD = 1.075 \frac{P_K^{0.2328} \, t_p^{0.3088} \, R^{0.2221}}{C_1^{0.8699} \, (t \times C_2)^{0.5303}}$$

where SE = 0.325 and r = 0.8984

exponent of P too low

. . . .

$$RD = 0.0348 \frac{P_K^{0.3987} \left(\frac{t_p}{C_2}\right)^{0.4190} R^{0.2377}}{C_1^{0.9293} \, (\log t)^{1.8823}}$$

where SE = 0.302 and r = 0.9125

exponents of P and t_p/C_2 too low

. . . .

$$RD = 0.156 \left(\frac{P_K}{C_1}\right)^{0.6942} \left(\frac{t_p}{C_2}\right)^{0.3724} \frac{R^{0.2082}}{(\log t)^{1.8838}}$$

where SE = 0.334 and r = 0.8921

exponent of R too low; r lower than others

. . . .

$$RD = 0.00676 \frac{P_K^{0.4706} \left(\frac{t_p^2}{C_2}\right)^{0.2848} R^{0.2476}}{C_1^{0.9335} \, (\log t)^{2.0019}}$$

where SE = 0.294 and r = 0.9176

by changing P to P_K final equation derived

. . . .

$$RD = 1.510 \frac{P^{0.4483} \left(\frac{t_p^{\,2}}{C_2}\right)^{0.2616} R^{0.2548}}{C_1^{0.9450}\ t^{0.8125}}$$

where SE = 0.297 and r = 0.9159

poor results with substitution of "t" instead of "log t"

. . . .

$$RD = 0.0186 \frac{P^{0.5170}\ t_p^{0.6191}\ R^{0.2607}}{C_1^{0.9502}\ t^{0.8311}\ C_2^{0.1216}}$$

where SE = 0.295 and r = 0.9170

exponent of C_2 too low.

Two-Layer Flexible Pavement Model

The data search resulted in the selection of 630 data points for flexible pavements. The data are tabulated in Appendix III. Two hundred and ninety-three of the data points were applicable to three-layer flexible pavements.

The remaining 337 points represented a two-layer flexible pavement, or one not having a subbase directly above the subgrade. The variables considered in development of the two-layer flexible pavement model are shown in Table 2. Regression analysis was performed on the 337 data points in steps as previously described. Several forms were imposed upon some of the variables, but certain of the data appeared to be unreasonable in terms of conventional pavement design. The residual

TABLE 2.--VARIABLES FOR TWO-LAYER FLEXIBLE PAVEMENT MODEL

Index	Variable
1	RD = rut depth, in.
2	P = equivalent single-wheel load (ESWL), lb
3	t_p = tire pressure, psi
4	t_1 = AC thickness, in.
5	t_2 = thickness of base, in.
6	C_1 = CBR on top of base
7	C_2 = CBR on top of subgrade
8	R = repetitions of load or passes

error values between these preliminary equations and the actual data were used to eliminate some of these points. A total of 60 points were eliminated in this manner, and after one additional iteration, one more data point that had been overlooked was removed. The final model was therefore based upon 276 data points. Some of the equations developed and rejected, along with reasons for rejecting them are shown as follows:

$$RD = 0.000831 \frac{P^{1.400} R^{0.319}}{t_p^{0.614} t_1^{0.306} t_2^{0.577} C_1^{1.206} C_2^{0.176}}$$

where SE = 0.403 and r = 0.8834

t_p in denominator, indicating that rut depth decreases as t_p increases, which is erroneous.

. . . .

$$RD = 0.00250 \frac{P^{1.269} R^{0.319}}{t_1^{0.230} t_2^{0.755} C_1^{1.756} C_2^{0.060}}$$

where SE = 0.421 and r = 0.8720

omitted t_p ; exponent of C_2 was low.

. . . .

$$RD = 0.00341 \frac{P^{1.285} R^{0.321}}{(t_1 + t_2)^{1.027} C_1^{1.700} C_2^{0.077}}$$

where SE = 0.416 and r = 0.8752

same as above

. . . .

$$RD = 0.00430 \frac{P^{1.276} R^{0.320}}{(1.25t_1 + t_2)^{1.033} C_1^{1.703} C_2^{0.072}}$$

where SE = 0.415 and r = 0.8755

higher r than with $(t_1 + t_2)$ but exponent of C_2

still low

. . . .

These examples, along with several others, represent the efforts made to develop the correlation. The significant factor in this development, however, was combining the thicknesses of the surface and base course layers. The final selected model uses the combined form of the thickness and indicates a common log relationship. Additionally, the sensitivity of the subgrade CBR was increased to a more acceptable level.

The final form of the two-layer flexible pavement model is given as follows:

$$RD = 1.9431 \left[\frac{P_K^{1.3127} \ t_p^{0.0499} \ R^{0.3240}}{[\log (1.25t_1 + t_2)]^{3.4204} \ C_1^{1.6877} \ C_2^{0.1156}} \right]$$

where SE = 0.411 and r = 0.8779.

This version represents the best combination of variable coefficients and apparent behavior.

Three-Layer Flexible Pavement Model

The variables pertinent to the three-layer flexible pavement model are shown in Table 3. The three-layer model includes nine independent variables, whereas the two-layer model only included seven

TABLE 3.--VARIABLES FOR THREE-LAYER FLEXIBLE PAVEMENT MODEL

Index	Variable
1	RD = rut depth, in.
2	P = equivalent single-wheel load (ESWL), lb
3	t_p = tire pressure, psi
4	t_1 = thickness of AC, in.
5	t_2 = thickness of base, in.
6	C_1 = CBR on top of base
7	t_3 = thickness of subbase, in.
8	C_2 = CBR on top of subbase
9	C_3 = CBR on top of subgrade
10	R = repetitions of load or passes

independent variables. The two additional variables are subbase thickness (t_3) and subbase CBR (C_2), respectively.

Included in the three-layer flexible pavement data was one test item, which was a multiple-layered system (more than three layers). For the data analysis, the values used for the base, subbase, and subgrade CBR variables of the 62 data points from the multiple-layered item were usually an average CBR of two layers. Similarly, the thickness variables were usually the sum of the thicknesses of the two layers. Since these values may not have accurately represented the actual pavement structure of the test item, the 62 data points were removed to see if the correlation coefficient would improve. A better correlation was obtained, and these 62 points were eliminated from further analysis.

As in the case of the previous equations, numerous computer runs were tried using the remaining 231 points to obtain an equation considered the best fit. Some of the equations generated and rejected, along with reasons for rejection, are as follows:

$$RD = 0.000021 \frac{P^{1.158} \, t_p^{0.256} \, R^{0.376} \, t_1^{0.503}}{t_2^{0.536} \, C_1^{0.394} \, t_2^{0.527} \, C_2^{0.541} \, C_3^{0.289}}$$

where SE = 0.528 and r = 0.8217

t_1 in the numerator indicating improper relation to RD

. . . .

$$RD = 0.0000017 \frac{P^{1.625}\ t_p^{0.114}\ R^{0.367}}{t_2^{0.531}\ C_1^{0.682}\ t_3^{0.590}\ C_2^{0.595}\ C_3^{0.203}}$$

where SE = 0.552 and r = 0.8037

omitted t_1 in attempt to improve correlation

. . . .

$$RD = 0.000011 \frac{\left(\frac{P}{1 + \log t_1}\right)^{1.506} \left(\frac{\log t_p}{C_1}\right)^{0.291} R^{0.330}}{t_2^{0.410}\ t_3^{0.523}\ C_2^{0.617}\ C_3^{0.164}}$$

where SE = 0.635 and r = 0.7281

exponent of C_1 too low; r lower.

. . . .

$$RD = 0.000005 \frac{\left(\frac{P}{1 + \log t_1}\right)^{1.516} \left(\frac{\sqrt{t_p}}{t_2}\right)^{0.276} R^{0.330}}{C_1^{0.631}\ t_3^{0.492}\ C_2^{0.589}\ C_3^{0.211}}$$

where SE = 0.638 and r = 0.7258

r still low

. . . .

The final equation selected was one of three equations considered almost equally good. To obtain a higher coefficient, the ESWL (P) was changed from pounds to kips (P_K) in each of the following three equations:

$$RD = 0.2218 \frac{P_K^{1.657}\ t_p^{0.074}\ R^{0.364}}{(t_1 + t_2)^{0.411}\ C_1^{0.844}\ t_3^{0.546}\ C_2^{0.563}\ C_3^{0.267}}$$

where SE = 0.564 and r = 0.7937

. . . .

$$RD = 0.2184 \frac{P_K^{1.638}\ t_p^{0.085}\ R^{0.363}}{(1.25t_1 + t_2)^{0.335}\ C_1^{0.864}\ t_3^{0.534}\ C_2^{0.554}\ C_3^{0.302}}$$

where SE = 0.566 and r = 0.7920

. . . .

$$RD = 0.2065 \frac{P_K^{1.614}\ t_p^{0.094}\ R^{0.363}}{(1.25t_1 + t_2)^{0.257}\ C_1^{0.877}\ t_3^{0.523}\ C_2^{0.545}\ C_3^{0.337}}$$

where SE = 0.568 and r = 0.7907

. . . .

In the first of the three equations above, it can be noted that for two different pavement structures, as long as the sum of t_1 and t_2 are equal it does not matter what the individual thicknesses of t_1 and t_2 are; thus, no benefit is to be gained by using asphaltic concrete in lieu of base course material. This was considered erroneous. However, in the other two equations, if the sum of t_1 and t_2 are equal, the pavement with the larger asphalt thickness would decrease the rut depth. Since the second equation has a higher correlation than the third, it was selected as the best equation. Using the residuals of the second equation, 25 points that were considered erroneous were deleted, resulting in 206 data points.

The selection of the best equation using the remaining 206 points was again narrowed to one of three equations. The first equation was the same form as that selected earlier.

$$RD = 0.1846 \frac{P_K^{1.709} \; t_p^{0.050} \; R^{0.346}}{(1.25t_1 + t_2)^{0.403} \; C_1^{0.761} \; t_3^{0.582} \; C_2^{0.571} \; C_3^{0.269}}$$

where SE = 0.445 and r = 0.8414

Substituting the common log of the thicknesses for the thickness variables resulted in the other two equations considered best.

$$RD = \frac{0.0680 P_K^{1.730} \; t_p^{0.045} \; R^{0.346}}{[\log (1.25t_1 + t_2)]^{1.223} \; C_1^{0.759} \; t_3^{0.589} \; C_2^{0.578} \; C_3^{0.243}}$$

where SE = 0.443 and r = 0.8425

. . . .

$$RD = \frac{0.0312 P_K^{1.525} \; t_p^{0.090} \; R^{0.345}}{[\log (1.25t_1 + t_2)]^{0.885} \; C_1^{0.762} \; (\log t_3)^{1.167} \; C_2^{0.551} \; C_3^{0.309}}$$

where SE = 0.444 and r = 0.8418

All three of the above-mentioned equations showed an increase in rut depth proportional to an increase in P , t_p , and R and a decrease in rut depth proportional to an increase in the other six variables. The final selection of the best of these three models was delayed until the analysis of the other group of flexible pavement data was performed. The latter of these three models was then selected based upon the behavior of the thickness variables as well as its similarity to the two-layer flexible pavement model. Carrying the exponents to four decimal places and rearranging, the final equation becomes

$$RD = 0.03117 \left\{ P_K^{1.5255} \, t_p^{0.0897} \, R^{0.3450} \Big/ [\log(1.25t_1 + t_2)]^{0.8847} \right.$$

$$\left. \times (\log t_3)^{1.1674} \, C_1^{0.7616} \, C_2^{0.5505} \, C_3^{0.3089} \right\}$$

where SE = 0.444 and r = 0.8418

DEVELOPMENT OF RELIABILITY MODELS

Development Procedure

The deterioration models for rut depth analyses of the four respective pavement types as developed previously are necessarily deterministic models. They represent not necessarily the best fit of all the data, but instead a "good fit" as indicated by the error and correlation values. Therefore, the models predict rutting in a sense that the predictive error could be either positive or negative depending upon the specific set of data being used. To further expand the applicability and utility of the models, statistical reliability concepts are invoked to account for the variability of all input data and predict rutting in terms of expected rut depth and variance from that expected rut depth. This concept provides for models for each pavement type that utilizes a total description of the input variables in terms of means and variances of a set of values for one variable. This further accounts for the variability of pavement properties in a statistical manner instead of accepting only averages of values of measured parameters, such as thickness and CBR. The statistical determination of the rut depth in terms of expected value and variance provides not only for better analysis of rut depth in terms of an expected rut depth and a probable deviation from that value but also for an accounting for material variability in a statistical manner. The primary benefit of using total input data and determining the expected values and variances of a probability density function of rut depth is the ability to evaluate the reliability of the pavement. The reliability of a facility can be determined in terms of the probability that a given rut depth will occur under given circumstances. It follows then that such a system can be an excellent evaluation tool as well as a design tool. The great advantage as a design procedure is the capability to adjust reliability or conservatism to a desired value and to select design parameters to suit those conditions. To address these concepts of reliability and the accounting for material variability, it was necessary to develop stochastic models for the definition of a probability density function of the rut depth.

Probabilistic pavement design concepts have been applied to pavement studies since the 1960's. References 5, 7, 18, 21, 23, and 24 give illustrations of these studies wherein the concept of pavement reliability has been adopted. The reliability of a pavement is a statistical measure of the probability that a pavement will perform in a given manner during its life. Lu, Lytton, and Moore (20) showed the use of the above-mentioned expected value and variance equations as applied to forecasting serviceability loss in pavements. These principles were adopted and utilized to develop expected value and variance equations for predicting change in rut depth. The methods for the determination of expected value and variance of rut depth by a Taylor's series expansion (20) are shown in the following paragraphs.

If rut depth (RD) is considered a continuous, random variable with some probability density function $f(RD)$, the expected value of $H(RD)$ is defined as

$$E[H(RD)] = \int_{-\infty}^{\infty} H(RD)\, f(RD)\, dRD$$

The expected value of RD is the mean or average of RD , which is termed μ_{RD} , or it can be written as $\mu_{RD} = E(RD)$. The variance of RD as a variable is denoted by σ_{RD}^2 and is defined to be

$$\sigma_{RD}^2 = E[(RD - \mu_{RD})^2]$$

Its positive square root is the standard deviation of RD . Thus,

$$\sigma_{RD} = \sqrt{\sigma_{RD}^2}$$

The operation of taking expected values and variances of random variables is found in various textbooks and is illustrated by Lu, Lytton, and Moore (20). Occasionally, taking the expected value of a complicated function can be a difficult process as in the case of the rut depth models previously shown. In order to overcome these difficulties, the expected value was approximated by taking a Taylor's series expansion and truncating all but the first three terms as follows:

$$f(RD) = f(RD - \Delta RD) + f'(RD - \Delta RD)\Delta RD + 1/2\ F''(RD - \Delta RD)\Delta RD^2 + \ldots$$

If ΔRD becomes $RD - \mu_{RD}$, then the final generalized form can be expressed as follows:

$$E[f(RD)] = f(\mu_{RD}) + 1/2\ f''(\mu_{RD})\sigma_{RD}^2$$

Taking the variance of the rut depth models was also a painstaking operation, further complicated by the forms imposed upon some of the variables. The Taylor's series expansion was again applied. As was previously stated, the variance was

$$\sigma^2_{RD} = [(RD - \mu_{RD})^2]$$

The variance of the rut depth models is denoted V(RD) and is expressed as

$$V(RD) = [f'(\mu_{RD})]^2\sigma^2_{RD} - \frac{1}{4}[f''(\mu_{RD})]^2 \sigma^4_{RD} + \sigma^2_{\ell of}$$

where $\sigma^2_{\ell of}$ is the variance of lack of fit.

The deterministic rut depth analysis models have already been derived in this document. The principles shown above were invoked to develop the expected value and variance models from the original model. The nature of the equations that provided for numerous mathematical operations precludes showing details of development in this document. However, these mathematical operations are considered fundamental and are not shown. The final forms of the equations are listed in the following figures.

Expected Value and Variance Models

Figs. 16-19 show the expected value and variance models for the four respective categories. The rut depth models previously discussed are also shown. This version of the rut depth model differs from the original model in that each independent variable actually represents a mean value, and the equation is therefore redesignated "Q."

$$RD = 0.1101 \frac{P^{0.4925}\, t_p^{0.8540}\, (\log t)^{0.4293}\, R^{0.5018}}{C_1^{1.9773}\, C_2^{1.2015}}$$

(= Q in the following equations)

$$E[RD] = Q + \frac{1}{2} Q \left\{ \frac{(0.4293)(0.4343)}{\mu_t^2 \log \mu_t} \left[\frac{(-0.5707)(0.4343)}{\log \mu_t} - 1 \right] \sigma_t^2 \right.$$

$$+ \frac{(0.4925)(0.5075)}{\mu_P^2} \sigma_P^2 + \frac{0.8540(-0.1450)}{\mu_{t_P}^2} \sigma_{t_P}^2$$

$$+ \frac{(0.5018)(-0.4982)}{\mu_R^2} \sigma_R^2 + \frac{(-1.9773)(-2.9773)}{\mu_{C_1}^2} \sigma_{C_1}^2$$

$$\left. + \frac{(-1.2015)(-2.2015)}{\mu_{C_2}^2} \sigma_{C_2}^2 \right\}$$

$$V[RD] = Q^2 \left[\left(\frac{0.4925}{\mu_P} \right)^2 \sigma_P^2 + \left(\frac{0.8540}{\mu_{t_P}} \right)^2 \sigma_{t_P}^2 + \left(\frac{0.4343}{\mu_t \log \mu_t} \right)^2 \sigma_t^2 \left(\frac{0.5018}{\mu_R} \right)^2 \sigma_R^2 \right.$$

$$\left. + \left(\frac{-1.9773}{\mu_{C_1}} \right) \sigma_{C_1}^2 + \left(\frac{-1.2015}{\mu_{C_2}} \right)^2 \right] \sigma_{C_2}^2$$

$$- \frac{1}{4} Q^2 \left\{ \left[\frac{(0.4293)(0.4343)}{\mu_t^2 \log \mu_t} \left(\frac{(-0.5757)(0.4343)}{\log \mu_t} - 1 \right) \sigma_t^2 \right]^2 \right.$$

$$+ \left[\frac{(0.4925)(-0.5075)}{\mu_P^2} \sigma_P^2 \right]^2 + \left[\frac{(0.8540)(-0.1460)}{\mu_{t_P}^2} \sigma_{t_P}^2 \right]^2$$

$$+ \left[\frac{(0.5018)(-0.4982)}{\mu_R^2} \sigma_R^2 \right]^2 + \left[\frac{(-1.9773)(-2.9773)}{\mu_{C_1}^2} \sigma_{C_1}^2 \right]^2$$

$$\left. + \left[\frac{(-1.2015)(-2.2015)}{\mu_{C_2}^2} \sigma_{C_2}^2 \right]^2 \right\}$$

FIG. 16.--UNSURFACED FACILITY EXPECTED VALUE, VARIANCE, AND RUTTING MODELS

$$RD = \frac{0.1741\ P_K^{0.4707}\ t_P^{0.5695}\ R^{0.2476}}{(\log t)^{2.002}\ C_1^{0.9335}\ C_2^{0.2848}}$$

(= Q in the following equations)

$$E[RD] = Q\left\{1 + \frac{1}{2}\left[\frac{0.8695}{\mu_t^2 \log \mu_t}\left(\frac{1.3038}{\log \mu_t} + 1\right)\sigma_t^2 - \frac{0.2491\sigma_{P_K}^2}{\mu_{P_K}^2} - \frac{0.2452\sigma_{t_P}^2}{\mu_{t_P}^2} - \frac{0.1863\sigma_R^2}{\mu_R^2} + \frac{1.8049\sigma_{C_1}^2}{\mu_{C_1}^2} + \frac{0.3659\sigma_{C_2}^2}{\mu_{C_2}^2}\right]\right\}$$

$$V[RD] = Q^2\left[\left(\frac{0.4707\sigma_{P_K}}{\mu_{P_K}}\right)^2 + \left(\frac{0.5695\sigma_{t_P}}{\mu_{t_P}}\right)^2 + \left(\frac{0.2476\sigma_R}{\mu_R}\right)^2 + \left(\frac{-0.8695\sigma_t}{\mu_t \log \mu_t}\right)^2 + \left(\frac{-0.9335\sigma_{C_1}}{\mu_{C_1}}\right)^2\left(\frac{-0.2848\sigma_{C_2}}{\mu_{C_2}}\right)^2\right]$$

$$- \frac{1}{4} Q^2\left\{\left[\frac{0.8695}{\mu_t \log \mu_t}\left(\frac{1.3038}{\log \mu_t} + 1\right)\sigma_t^2\right]^2 + \left[\frac{-0.2491}{\mu_P^2}\sigma_P^2\right]^2 + \left[\frac{-0.2452}{\mu_{t_P}^2}\sigma_{t_P}^2\right]^2 + \left[\frac{-0.1863}{\mu_R^2}\sigma_R^2\right]^2 + \left[\frac{1.8049}{\mu_{C_1}^2}\sigma_{C_1}^2\right]^2 + \left[\frac{0.3659}{\mu_{C_2}^2}\sigma_{C_2}^2\right]^2\right\}$$

FIG. 17.--GRAVEL-SURFACED FACILITY EXPECTED VALUE, VARIANCE, AND RUTTING MODELS

$$RD = 1.9431 \frac{P_K^{1.3127} t_P^{0.0499} R^{0.3240}}{[\log(1.25t_1 + t_2)]^{3.4204} C_1^{1.6877} C_2^{0.1156}}$$

(= Q in the following equations)

$$E[RD] = Q + \frac{1}{2} Q \left\{ \frac{(1.3127)(0.3127)}{\mu_{P_K}^2} \sigma_{P_K}^2 + \frac{(0.0499)(-0.9501)}{\mu_{t_P}^2} \sigma_{t_P}^2 \right.$$

$$+ \frac{(0.3240)(-0.6760)}{\mu_R^2} \sigma_R^2$$

$$+ \frac{(1.25)^2(0.4343)(3.4204)}{\left(1.25\mu_{t_1} + \mu_{t_2}\right)^2 \log\left(1.25\mu_{t_1} + \mu_{t_2}\right)} \left[\frac{1 + (4.4204)(0.4343)}{\log\left(1.25\mu_{t_1} + \mu_{t_2}\right)}\right] \sigma_{t_1}^2$$

$$+ \frac{(1)^2(0.4343)(3.4204)}{\left(1.25\mu_{t_1} + \mu_{t_2}\right)^2 \log\left(1.25\mu_{t_1} + \mu_{t_2}\right)} \left[\frac{1 + (4.4204)(0.4343)}{\log\left(1.25\mu_{t_1} + \mu_{t_2}\right)}\right] \sigma_{t_2}^2$$

$$\left. + \frac{(-1.6877)(-2.6877)}{\mu_{C_1}^2} \sigma_{C_1}^2 + \frac{(-0.1156)(-1.1156)}{\mu_{C_2}^2} \right\} \sigma_{C_2}^2$$

$$V[RD] = Q^2 \left\{ \left(\frac{1.3127}{\mu_{P_K}}\right)^2 \sigma_{P_K}^2 + \left(\frac{0.0499}{\mu_{t_P}}\right)^2 \sigma_{t_P}^2 + \left(\frac{0.3240}{\mu_R}\right)^2 \sigma_R^2 \right.$$

$$+ \left[\frac{(-3.4204)(1.25)(0.4343)}{\left(1.25\mu_{t_1} + \mu_{t_2}\right) \log\left(1.25\mu_{t_1} + \mu_{t_2}\right)}\right]^2 \sigma_{t_1}^2$$

$$+ \left[\frac{(-3.4204)(1)(0.4343)}{\left(1.25\mu_{t_1} + \mu_{t_2}\right) \log\left(1.25\mu_{t_1} + \mu_{t_2}\right)}\right]^2 \sigma_{t_2}^2$$

FIG. 18.--TWO-LAYER FLEXIBLE PAVEMENT EXPECTED VALUE, VARIANCE, AND RUTTING MODELS

$$+ \left(\frac{-1.6877}{\mu_{C_1}}\right)^2 \sigma_{C_1}^2 + \left(\frac{-0.1156}{\mu_{C_2}}\right)^2 \sigma_{C_2}^2 \Bigg\}$$

$$- \frac{1}{4} Q^2 \left\{ \left[\frac{(1.3127)(0.3127)}{\mu_P^2} \sigma_P^2\right]^2 \right.$$

$$+ \left[\frac{(0.0499)(-0.9501)}{\mu_{t_P}^2} \sigma_{t_P}^2\right]^2 + \left[\frac{(0.3240)(-0.6760)}{\mu_R^2} \sigma_R^2\right]^2$$

$$+ \left[\frac{1.25^2(0.4343)(3.4204)}{\left(1.25\mu_{t_1} + \mu_{t_2}\right)^2 \log\left(1.25\mu_{t_1} + \mu_{t_2}\right)} \left(1 + \frac{(4.4204)(0.4343)}{\left(\log 1.25\mu_{t_1} + \mu_{t_2}\right)}\right) \sigma_{t_1}^2\right]^2$$

$$+ \left[\frac{(1)^2(0.4343)(3.4204)}{\left(1.25\mu_{t_1} + \mu_{t_2}\right)^2 \log\left(1.25\mu_{t_1} + \mu_{t_2}\right)} \left(1 + \frac{(4.4204)(0.4343)}{\log\left(1.25\mu_{t_1} + \mu_{t_2}\right)}\right) \sigma_{t_2}^2\right]^2$$

$$+ \left[\frac{(-1.6877)(-2.6877)}{\mu_{C_1}^2} \sigma_{C_1}^2\right]^2 + \left.\left[\frac{(-0.1156)(-1.1156)}{\mu_{C_2}^2} \sigma_{C_2}^2\right]^2 \right\}$$

FIG. 18.--continued

$$RD = 0.03117 \left\{ P_K^{1.5255} t_P^{0.0897} R^{0.3450} \Big/ [\log(1.25t_1 + t_2)]^{0.8847} \right.$$

$$\left. \times (\log t_3)^{1.1674}\ C_1^{0.7616}\ C_2^{0.5505}\ C_3^{0.3089} \right\}$$

(= Q in the following equations)

$$E[RD] = Q + \frac{1}{2} Q \left\{ \frac{(1.5255)(0.5255)}{\mu_{P_K}^2} \sigma_{P_K}^2 + \frac{(0.0897)(-0.9103)}{\mu_{t_P}^2} \sigma_{t_P}^2 \right.$$

$$+ \frac{(0.3450)(-0.6550)}{\mu_R^2} \sigma_R^2$$

$$+ \frac{(1.25)^2(0.4343)(0.8847)}{\left(1.25\mu_{t_1} + \mu_{t_2}\right)^2 \log\left(1.25\mu_{t_1} + \mu_{t_2}\right)} \left[1 + \frac{(1.8847)(0.4343)}{\log\left(1.25\mu_{t_1} + \mu_{t_2}\right)} \right] \sigma_{t_1}^2$$

$$+ \frac{(1)^2(0.4343)(0.8847)}{\left(1.25\mu_{t_1} + \mu_{t_2}\right) \log\left(1.25\mu_{t_1} + \mu_{t_2}\right)} \left[\frac{(1)^2(0.4343)(1.8847)}{\log\left(1.25\mu_{t_1} + \mu_{t_2}\right)} \right] \sigma_{t_2}^2$$

$$+ \left[\frac{(0.4343)(1.1674)}{\mu_{t_3}^2 \log \mu_{t_3}} \right] \left[1 + \frac{(2.1674)(0.4343)}{\log \mu_{t_3}} \right] \sigma_{t_3}^2$$

$$+ \frac{(-0.7616)(-1.7616)}{\mu_{C_1}^2} \sigma_{C_1}^2 + \frac{(-0.5505)(-1.5505)}{\mu_{C_2}^2} \sigma_{C_2}^2$$

$$\left. + \frac{(-0.3089)(-1.3089)}{\mu_{C_3}^2} \sigma_{C_3}^2 \right\}$$

FIG. 19.--THREE-LAYER FLEXIBLE PAVEMENT EXPECTED VALUE, VARIANCE, AND RUTTING MODELS

$$V[RD] = Q^2\Bigg\{\left(\frac{1.5255}{\mu_{P_K}}\right)^2 \sigma^2_{P_K} + \left(\frac{0.0897}{\mu_{t_P}}\right)^2 \sigma^2_{t_P} + \left(\frac{0.3450}{\mu_R}\right)^2 \sigma^2_R$$

$$+ \left[\frac{(-0.8847)(1.25)(0.4343)}{\log\left(1.25\mu_{t_1} + \mu_{t_2}\right)\left(1.25\mu_{t_1} + \mu_{t_2}\right)}\right]^2 \sigma^2_{t_1}$$

$$+ \left[\frac{(-0.8847)(1)(0.4343)}{\log\left(1.25\mu_{t_1} + \mu_{t_2}\right)\left(1.25\mu_{t_1} + \mu_{t_2}\right)}\right]^2 \sigma^2_{t_2} + \left[\frac{(-1.1674)(0.4343)}{\left(\log \mu_{t_3}\right)\left(\mu_{t_3}\right)}\right]^2 \sigma^2_{t_3}$$

$$+ \left(\frac{-0.7616}{\mu_{C_1}}\right)^2 \sigma^2_{C_1} + \left(\frac{-0.5505}{\mu_{C_2}}\right)^2 \sigma^2_{C_2} + \left(\frac{-0.3089}{\mu_{C_3}}\right)^2 \sigma^2_{C_3}\Bigg\}$$

$$- \frac{1}{4} Q^2\Bigg\{\left[\frac{(1.5255)(0.5255)}{\mu^2_P} \sigma^2_P\right]^2 + \left[\frac{(0.0897)(-0.9103)}{\mu^2_{t_P}} \sigma^2_{t_P}\right]^2$$

$$+ \left[\frac{(0.3450)(-0.6550)}{\mu^2_R} \sigma^2_R\right]^2$$

$$+ \left[\frac{(1.25)^2(0.4343)(0.8847)}{\left(1.25\mu_{t_1} + \mu_{t_2}\right)^2 \log\left(1.25\mu_{t_1} + \mu_{t_2}\right)}\left(1 + \frac{(1.8847)(0.4343)}{\log\left(1.25\mu_{t_1} + \mu_{t_2}\right)}\right) \sigma^2_{t_1}\right]^2$$

$$+ \left[\frac{(1)^2(0.4343)(0.8847)}{\left(1.25\mu_{t_1} + \mu_{t_2}\right)^2 \log\left(1.25\mu_{t_1} + \mu_{t_2}\right)}\left(1 + \frac{(1.8847)(0.4343)}{\log\left(1.25\mu_{t_1} + \mu_{t_2}\right)}\right) \sigma^2_{t_2}\right]^2$$

$$+ \left[\frac{(0.4343)(1.1674)}{\mu^2_{t_3} \log \mu t_3}\left(1 + \frac{(2.1674)(0.4343)}{\log \mu_{t_3}}\right) \sigma^2_{t_3}\right]^2$$

$$+ \left[\frac{(-0.7616)(-1.7676)}{\mu^2_{C_1}} \sigma^2_{C_2}\right]^2 + \left[\frac{(-0.5505)(-1.5505)}{\mu^2_{C_2}} \sigma^2_{C_2}\right]^2$$

$$+ \left[\frac{(-0.3089)(-1.3089)}{\mu^2_{C_3}} \sigma^2_{C_3}\right]^2\Bigg\}$$

FIG. 19.--continued

Actually "Q" exists as a factored term from the expected value and variance models, developed in the process of evaluating the first and second partial derivatives of the original model.

As can be seen, the models are combined equations representing the first three terms of a Taylor's series expansion. Many of the terms have been allowed to remain in unfactored form to display the actual nature of the models to the reader. Any attempt to solve the models by hand should be preceded by as many simplifications of the models as possible. However, hand solution of the models is necessarily time-consuming and leaves room for many possible errors. The models have been programmed for computer solution as part of the analysis model, as shown in Appendix IV.

Determination of Reliability

It should be noted that each variable in the two models is used in terms of its respective mean and variance and that in turn an expected value and variance of rut depth is determined. As has been previously stated, reliability as defined and used in this study is the probability that the rut depth will not exceed some predetermined value subject to conditions that are expressed by the independent variables.

The nature of the data including the range and distribution will be discussed in succeeding parts of this document, along with an explanation for assumption of normal distribution on the dependent variable. If normality is assumed, the reliability statistic P used to determine the reliability R that the rut depth will not exceed some maximum value RD_A can be expressed by

$$P = \frac{RD_A - E(RD)}{\sqrt{V(RD)}}$$

where

E(RD) = the expected value of the rut depth as determined from the appropriate model

V(RD) = the variance of the rut depth as similarly determined

Figure 20 illustrates a standard normal distribution curve and the parameters utilized to compute the reliability statistic P . Table 4 is a table of areas under the standard normal distribution, or its entries are the values of reliability R .

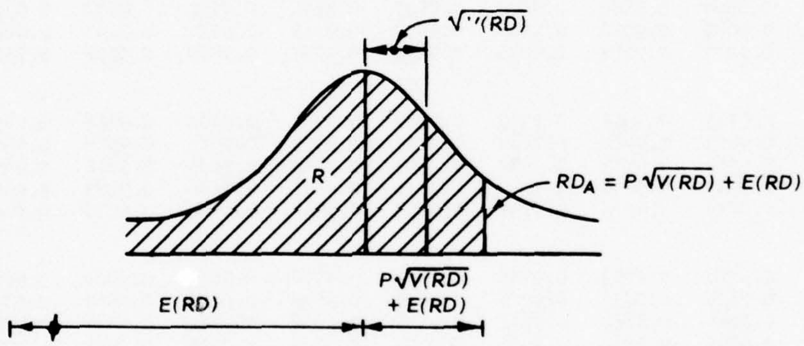

FIG. 20. STANDARD NORMAL DISTRIBUTION CURVE ILLUSTRATING $E(RD)$, $\sqrt{V(RD)}$, and RD_A

In order to determine reliability R from Table 4 or, that is, the area under the distribution curve defined by E(RD) and V(RD) and to the left of maximum rut depth RD_A , enter the table with the value of P determined previously and read the area under the distribution curve that is the reliability. As an illustrative example, assume the following values:

TABLE 4.--NORMAL DISTRIBUTION FUNCTION

F(P) = R

P	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.0	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998

$$RD_A = 3 \text{ in.}$$

$$E(RD) = 2 \text{ in.}$$

$$V(RD) = 1 \text{ in.}$$

then $P = \dfrac{RD_A - E(RD)}{\sqrt{V(RD)}} = \dfrac{3 - 2}{\sqrt{1}} = \dfrac{1}{1} = 1$. If Table 4 is entered with a value of 1 in the left-hand column, interpolation is not necessary. Also, it can immediately be seen that $R = 0.8413$, which means that there is a probability of 0.8413 that the rut depth will not exceed a predetermined maximum value of 3 in. Table 4 is typical of similar tables found in most statistics textbooks. Details for the operation of the computer programs are presented in Appendix IV.

DIFFERENTIAL ANALYSIS SYSTEM

Description

Fig. 21 gives a logic diagram of DAS as defined in this document. The system provides for a utilization of the rutting models to determine the rate of deterioration and/or reliability of any of the four types of facilities described in terms of rutting. The term "differential" has been given to the computational system to emphasize the fact that differences in results caused by changes in input can be determined by the user in any assessment of damage caused by various vehicle types or the effects of changes in the structure. The DAS, as shown in Fig. 21, provides for one automatic iteration of the computational processes. Differential analysis as described above can be achieved simply by repeated iterations of the system while changing any variable or variables desired. The system as shown is adequate for limited use where the various models apply and is adequate to develop the original hypothesis that life-cycle management can be achieved through deterioration and reliability concepts.

The DAS is programmed for computer solution. The program listing, input listing, output listing, instructions for use, and some example problems are given in Appendix IV. Appendix IV should be utilized by any reader concerned with operating the system. The following is a description of the DAS (Fig. 21). Block numbers identify the particular block in the logic diagram being discussed.

1. Blocks 1 and 2.--Blocks 1 and 2 provide for input of data describing each independent variable considered. The data can be entered in deterministic single-value form but should be entered in terms

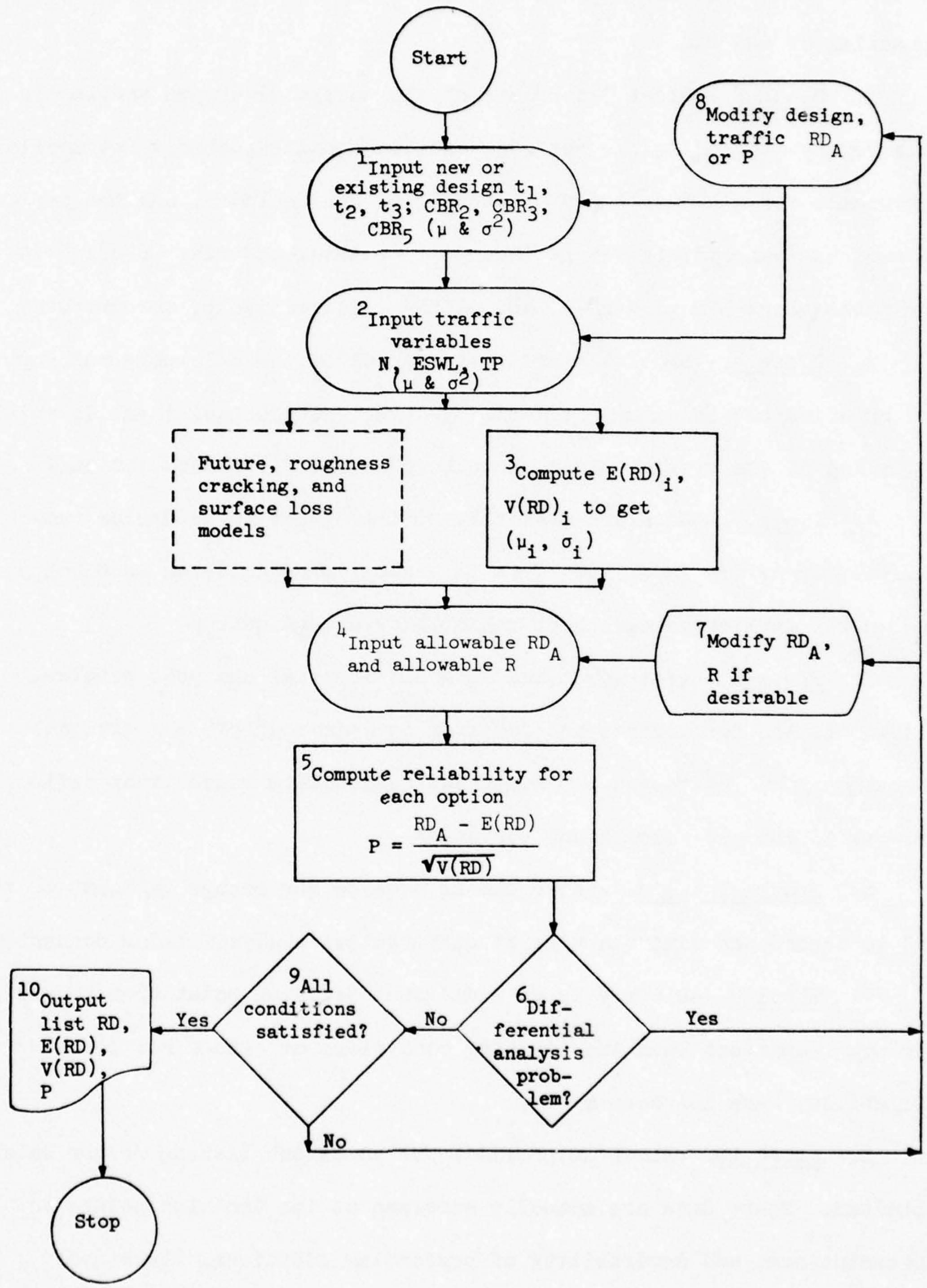

FIG. 21.--DIFFERENTIAL ANALYSIS SYSTEM (DAS), LOGIC DIAGRAM (STAGE 1)

of the mean and variance of a group of data in order to fully utilize the potential of the DAS.

2. Block 3.--Block 3 consists of the models developed earlier in this report, including the rutting, variance, and expected value models. The models for all four types of structures are included, and the selection of the appropriate set is incumbent to using the DAS. Block 3 is the point where RD , V(RD) , and E(RD) , respectively, are computed.

3. Block 4.--Block 4 provides for input of the allowable rut depth and an allowable (minimum) reliability level. The actual input is at the beginning of the system but is shown here as its first point of use.

4. Block 5.--Data are available at this point to determine the reliability of the facility. This is accomplished as shown in Block 5 and in the earlier paragraph on reliability determination.

5. Block 6.--If the problem is a differential analysis problem, Block 6 is the point where the decision is made to perform additional iterations and obtain new rut depth and reliability values that reflect effects of changes made in any variables.

6. Blocks 7 and 8.--These blocks provide for change in input to the DAS in accordance with the type of differential analysis being conducted.

7. Block 9.--Block 9 is an additional decision point that provides for new iterations when the limiting conditions of either rut depth or reliability have not been met.

8. Block 10.--Block 10 provides for an output listing of the data obtained. These data are actually accessed at the decision points to determine need and desirability of performing additional iterations.

Fig. 22 shows the logic of an expanded differential analysis system that considers surface loss, roughness, and cracking as well as rutting.

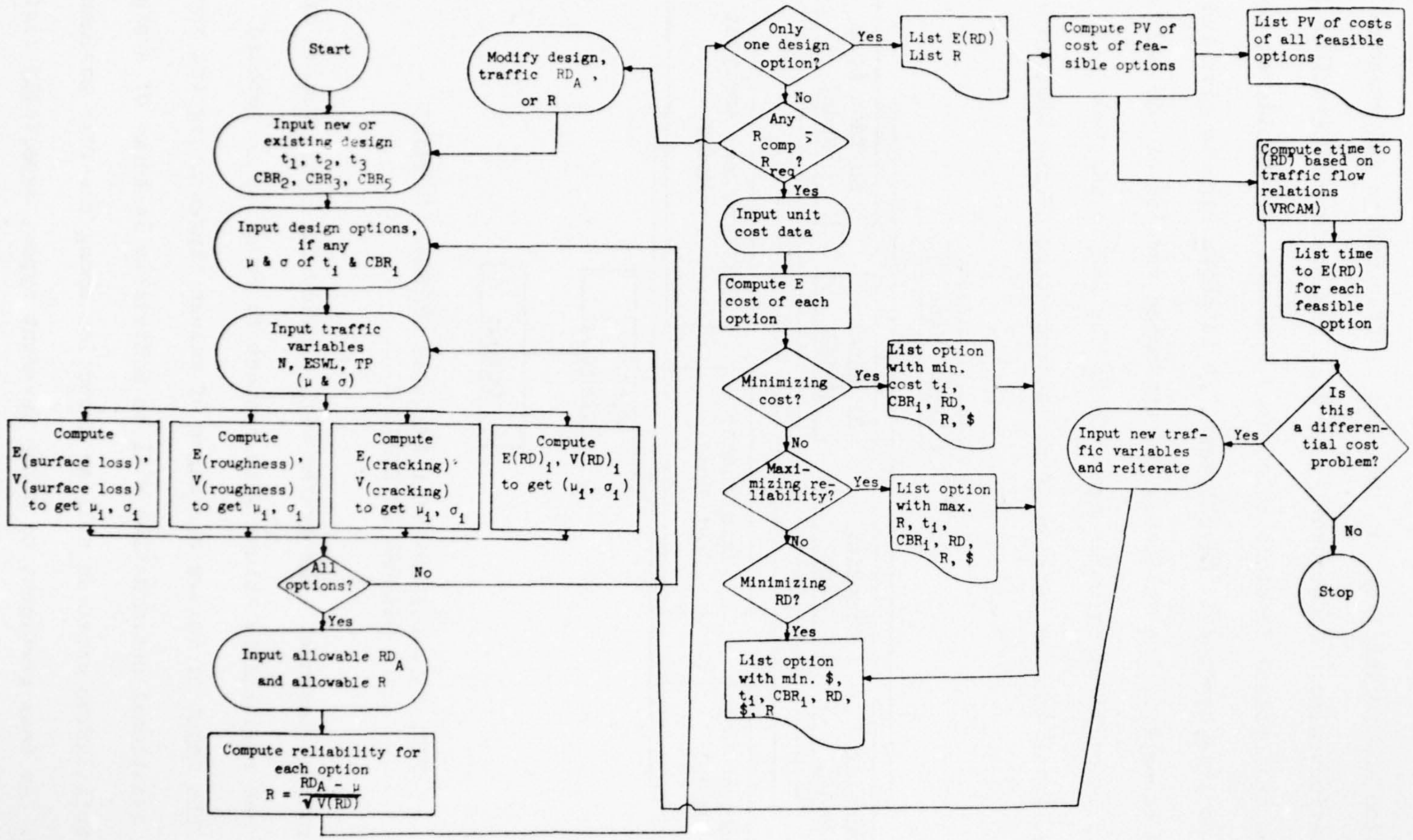

FIG. 22.--DIFFERENTIAL ANALYSIS SYSTEM (DAS), STAGE 2

It uses the same logic as the system shown in Fig. 21 in determining deterioration and reliability but includes traffic design and economic considerations also. Consequently, it will require more iterations to determine the optimal feasible solution. Although not considered essential to this hypothesis development, it is shown here to give the reader a concept of the validated and automated version of the DAS that will only be utilized by other agencies as the DAS is adopted.

Fig. 23 is another version of the second stage of the DAS, showing

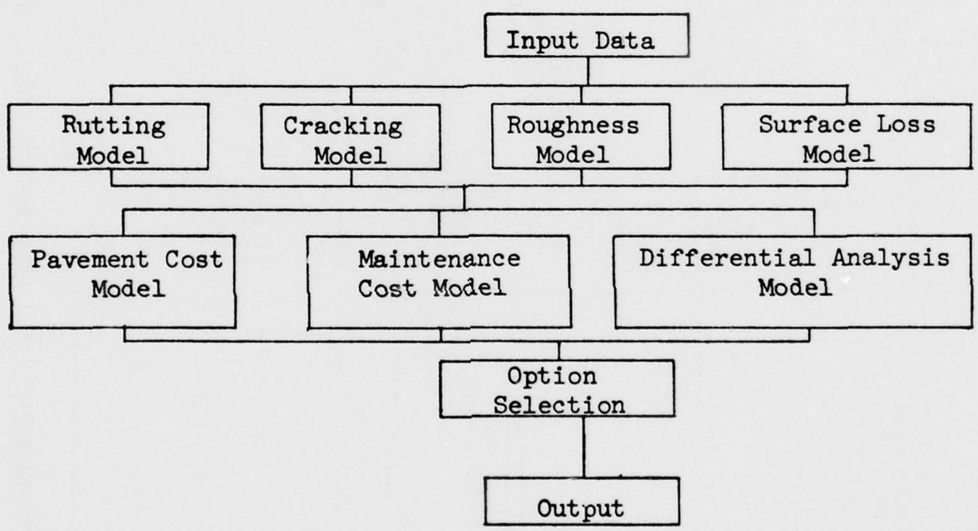

FIG. 23.--DIFFERENTIAL ANALYSIS SYSTEM. SUMMARY DIAGRAM OF STAGE 2

the essential elements. The system will provide for optimization of rutting and reliability values with respect to constraints imposed through the input of values or ranges of values representing the variables. Additional optimization will be achievable in terms of design and rehabilitation costs as well as selection among the four pavements options. As data pertinent to other pavement types, especially rigid pavements and selected hybrid pavements, become available, models will be included for their analysis.

Range and Distribution of Variables

The DAS is considered to be applicable to design and evaluation problems where normally encountered values of the variables are utilized. The range of applicability of any computational system which uses empirical formulas as developed herein is constrained by, if not limited to, the range of observed data upon which it is based.

Figs. 24-55 graphically portray the range and distribution of variables upon which the DAS is based. As can be seen, the boundaries will normally encompass most vehicle and road characteristics to be input as variables.

The data are not normally distributed in most cases as was indicated in tests for normality. However, it was realized that the data collected and utilized were not intended to group about any particular value as a whole. Instead, the data shown in Appendix I group about various values within each given series of tests in a normal manner. For this reason, normal distribution is assumed in determining reliability as has previously been discussed. Validation of the DAS for use by various agencies will necessarily include tests for normality or determination of the nature of statistical distribution for the purpose of more succinctly determining reliability. In general, the DAS is applicable within data ranges and especially where data are concentrated.

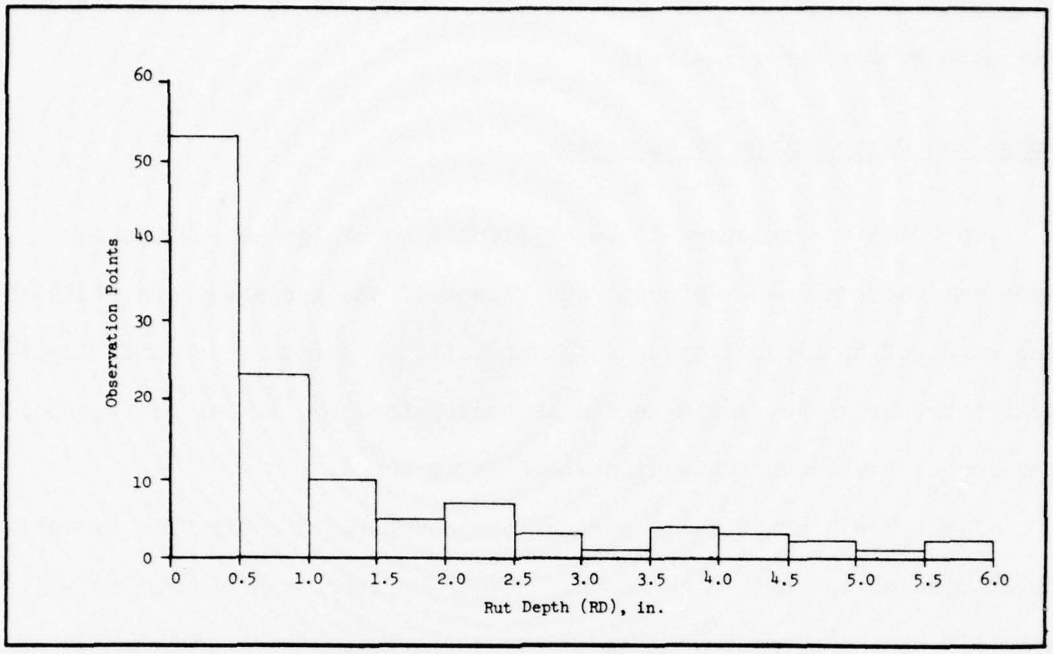

FIG. 24.--UNSURFACED FACILITY, RUT DEPTH DISTRIBUTION

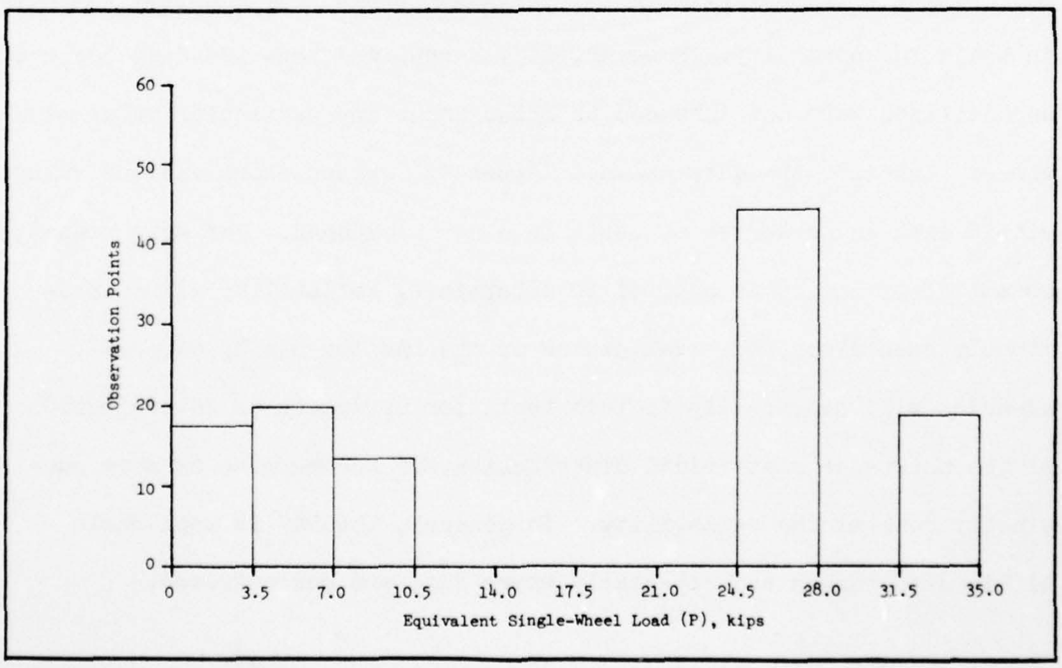

FIG. 25.--UNSURFACED FACILITY, LOAD DISTRIBUTION

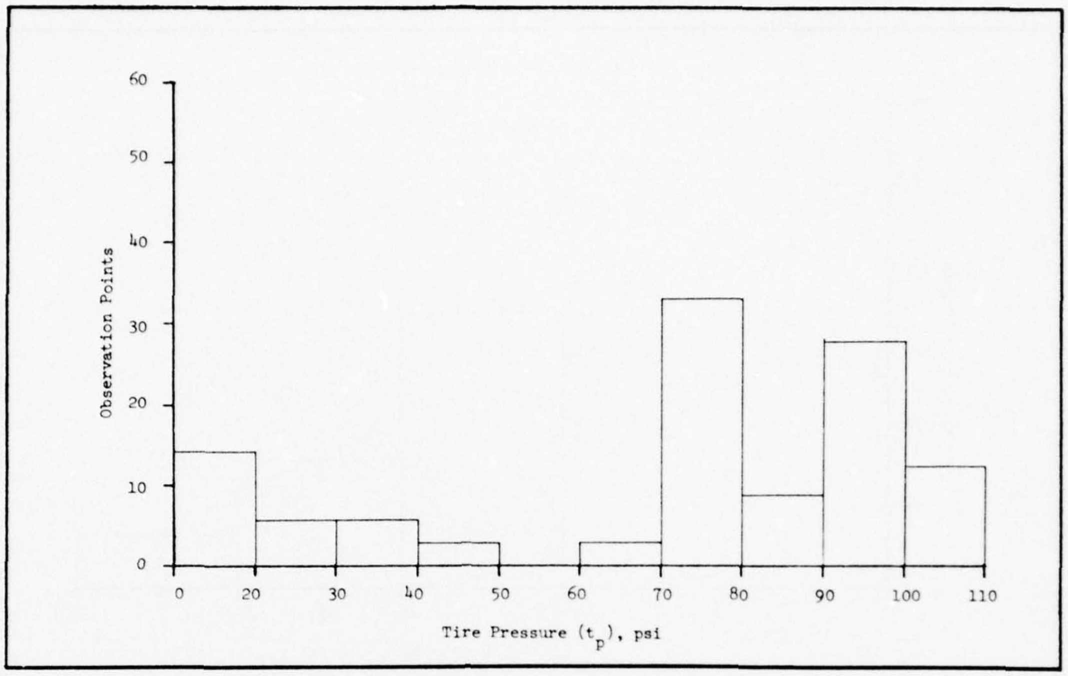

FIG. 26.--UNSURFACED FACILITY, TIRE PRESSURE DISTRIBUTION

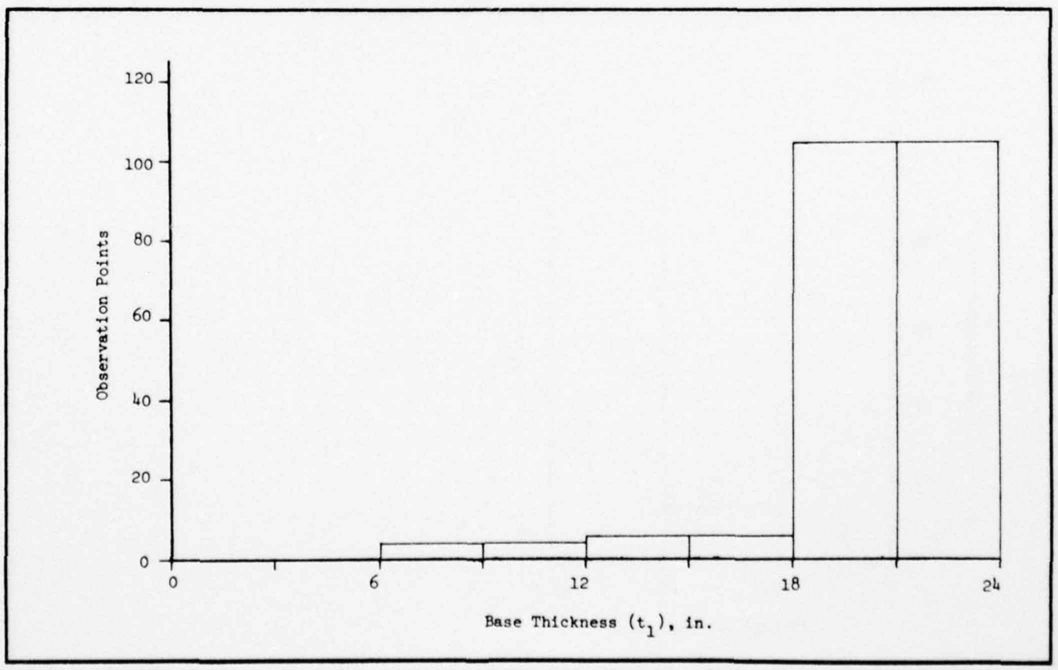

FIG. 27.--UNSURFACED FACILITY, GRAVEL THICKNESS DISTRIBUTION

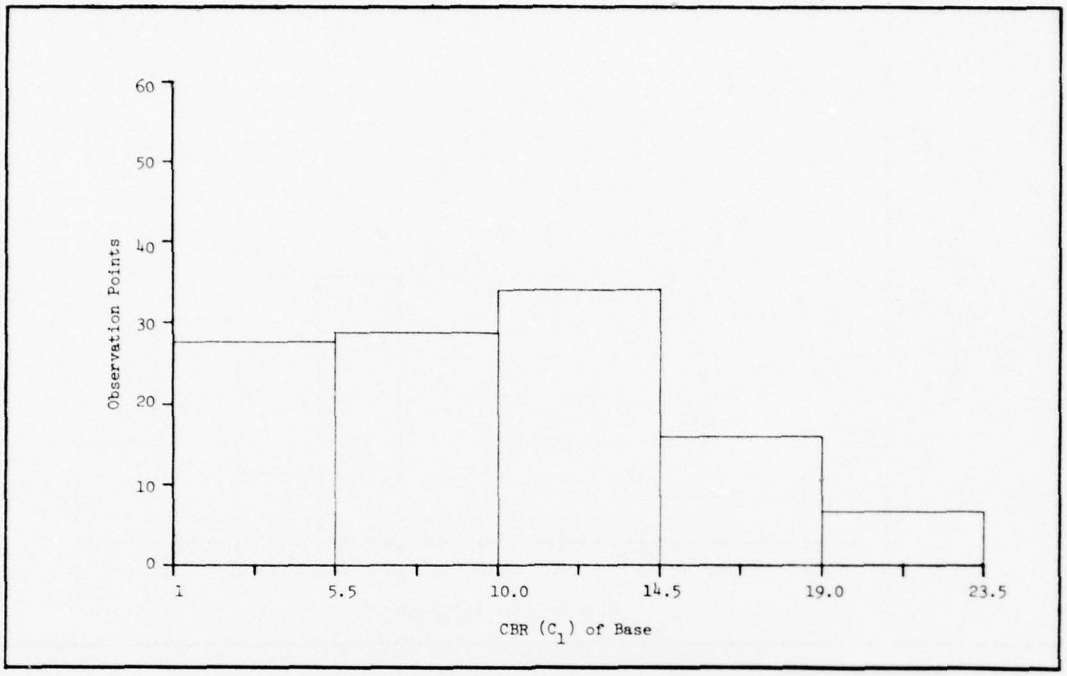

FIG. 28.--UNSURFACED FACILITY, BASE CBR DISTRIBUTION

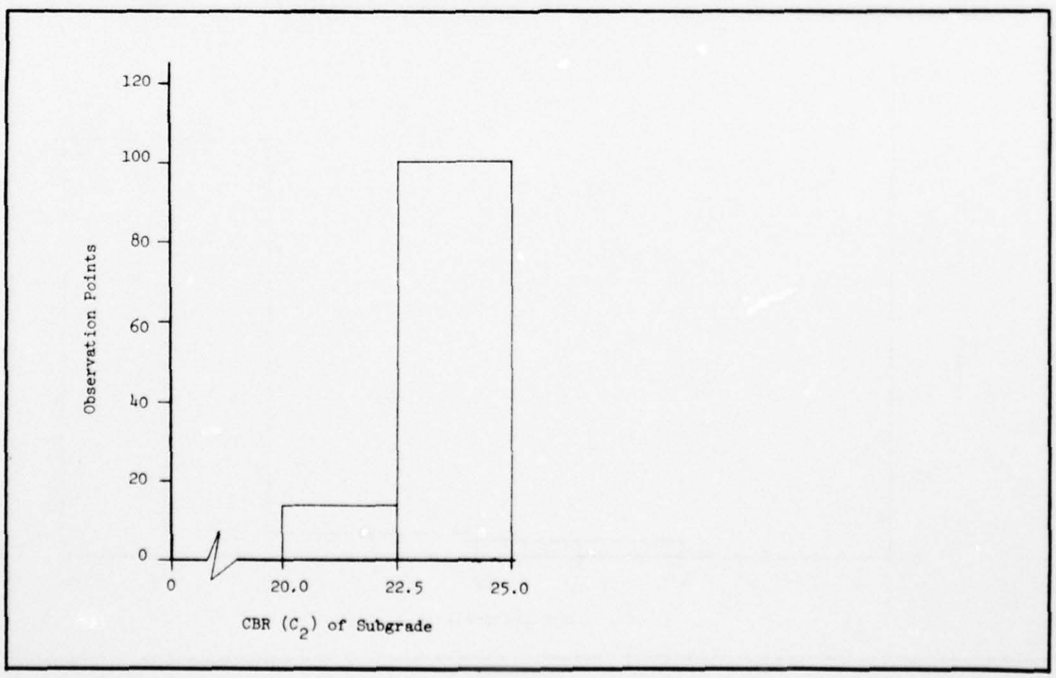

FIG. 29.--UNSURFACED FACILITY, SUBGRADE CBR DISTRIBUTION

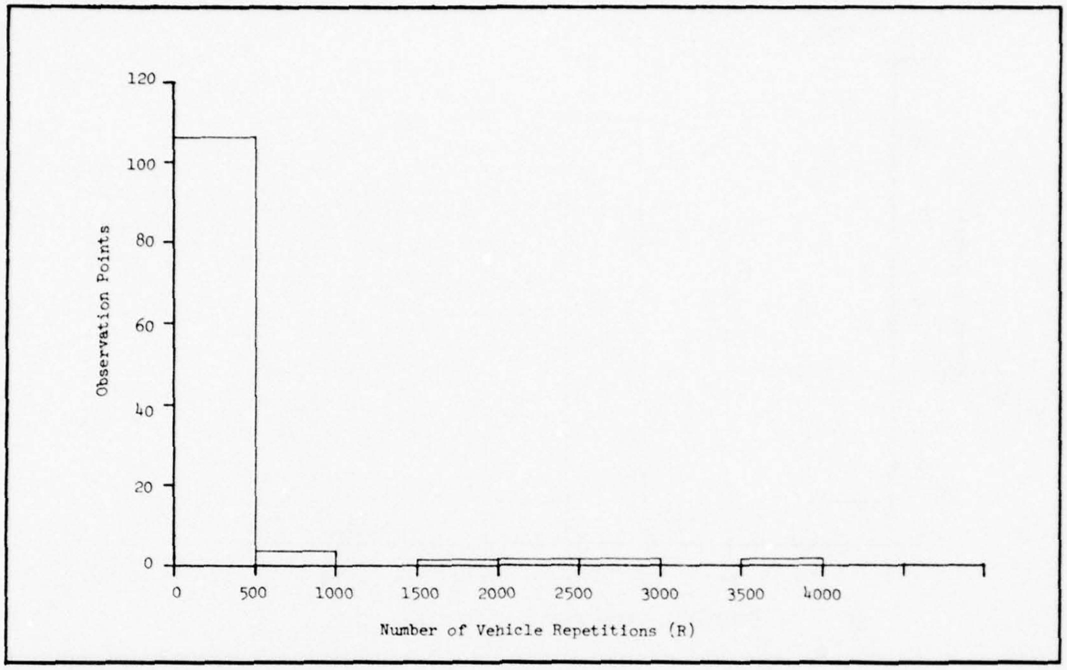

FIG. 30.--UNSURFACED FACILITY, REPETITION DISTRIBUTION

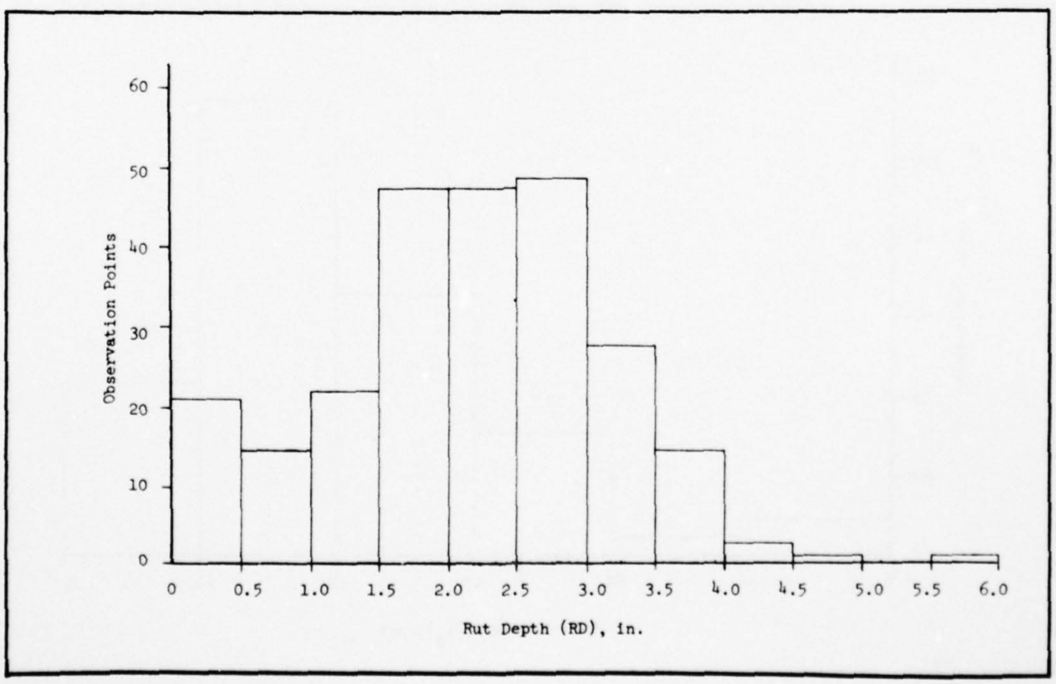

FIG. 31.--GRAVEL-SURFACED FACILITY, RUT DEPTH DISTRIBUTION

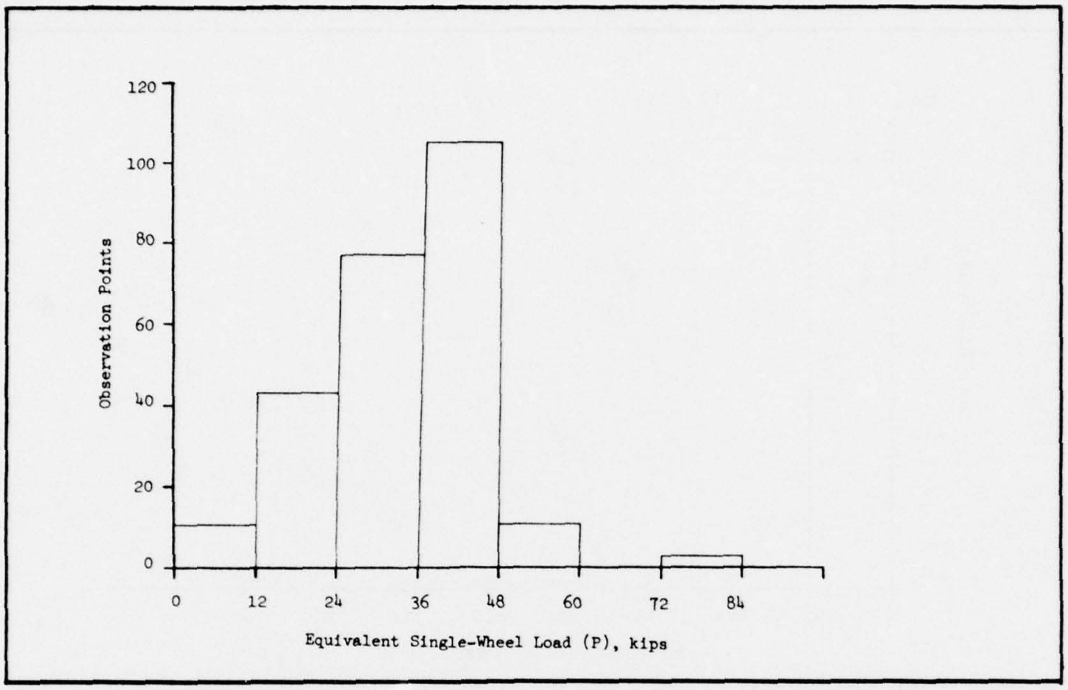

FIG. 32.--GRAVEL-SURFACED FACILITY, LOAD DISTRIBUTION

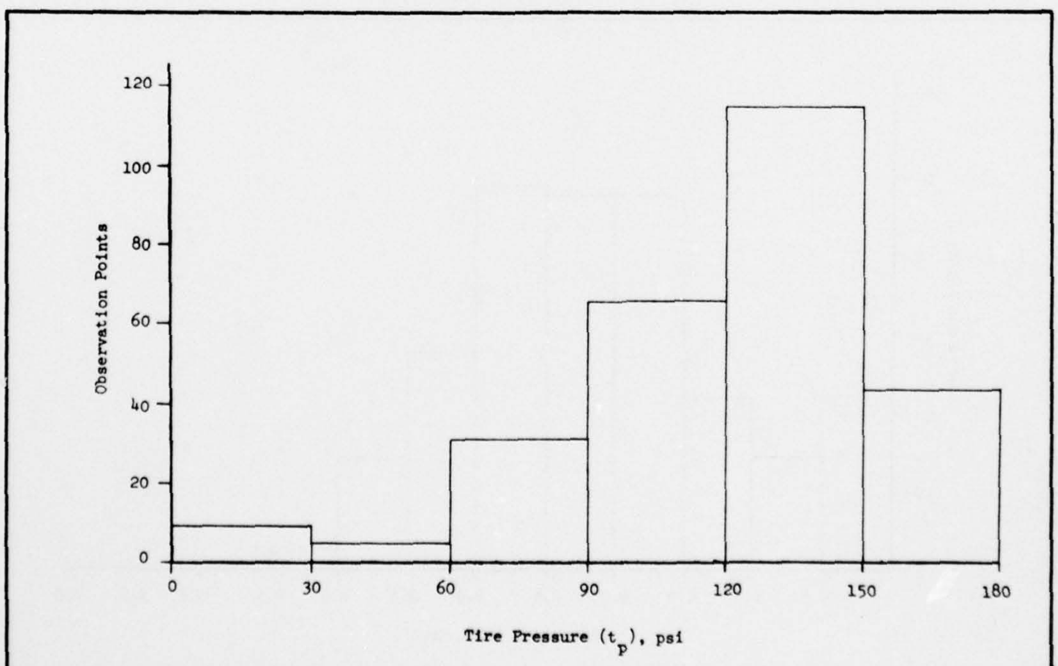

FIG. 33.--GRAVEL-SURFACED FACILITY, TIRE PRESSURE DISTRIBUTION

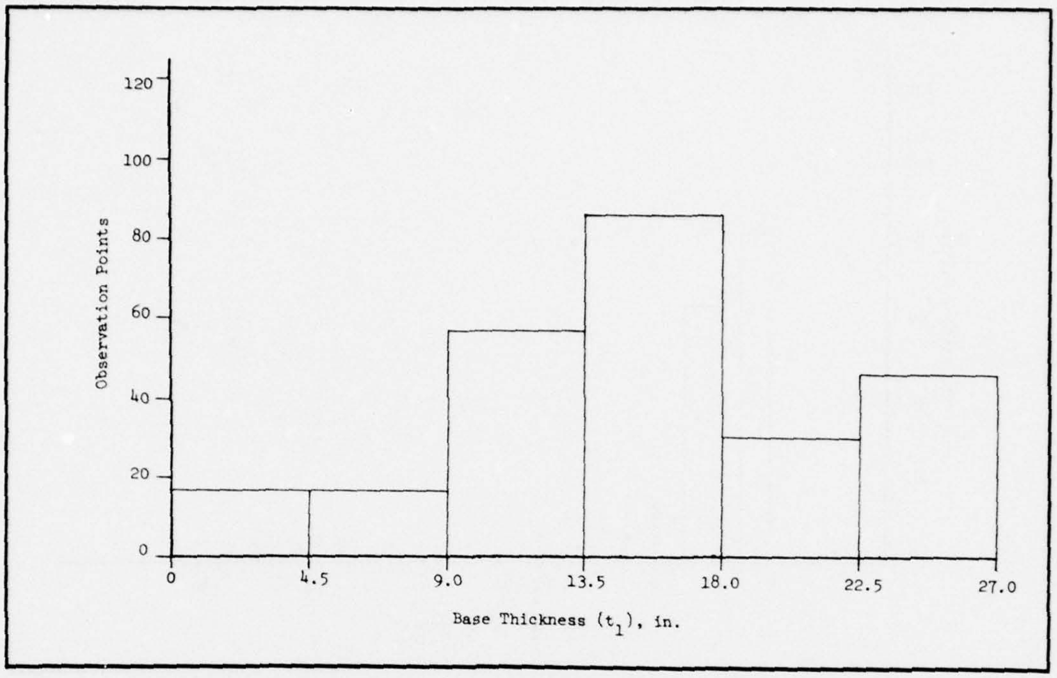

FIG. 34.--GRAVEL-SURFACED FACILITY, GRAVEL THICKNESS DISTRIBUTION

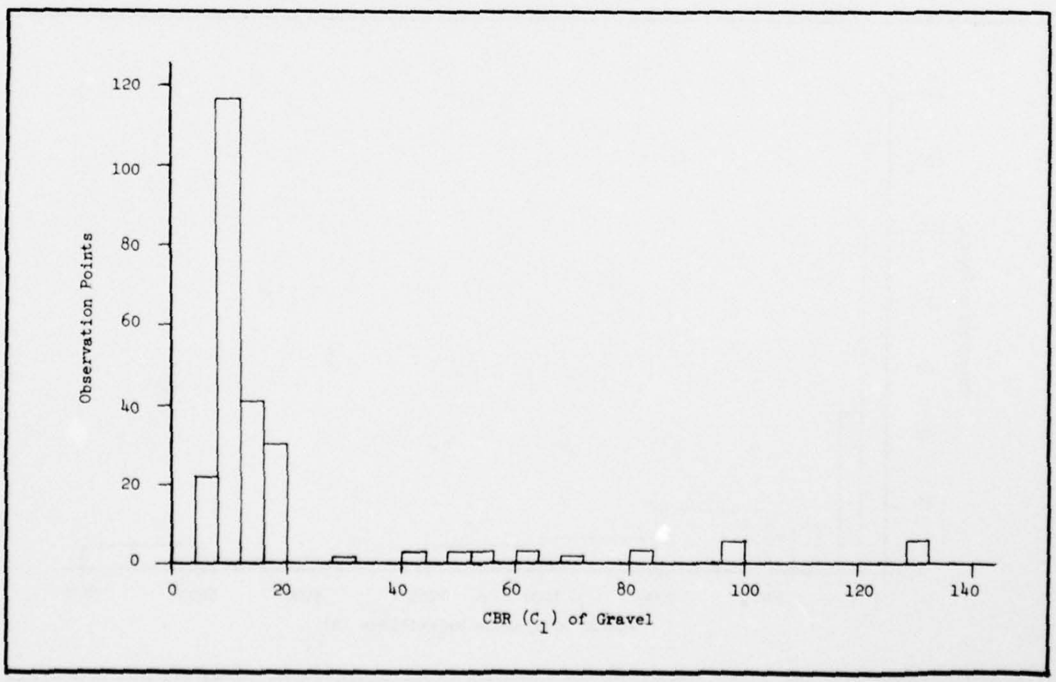

FIG. 35.--GRAVEL-SURFACED FACILITY, GRAVEL CBR DISTRIBUTION

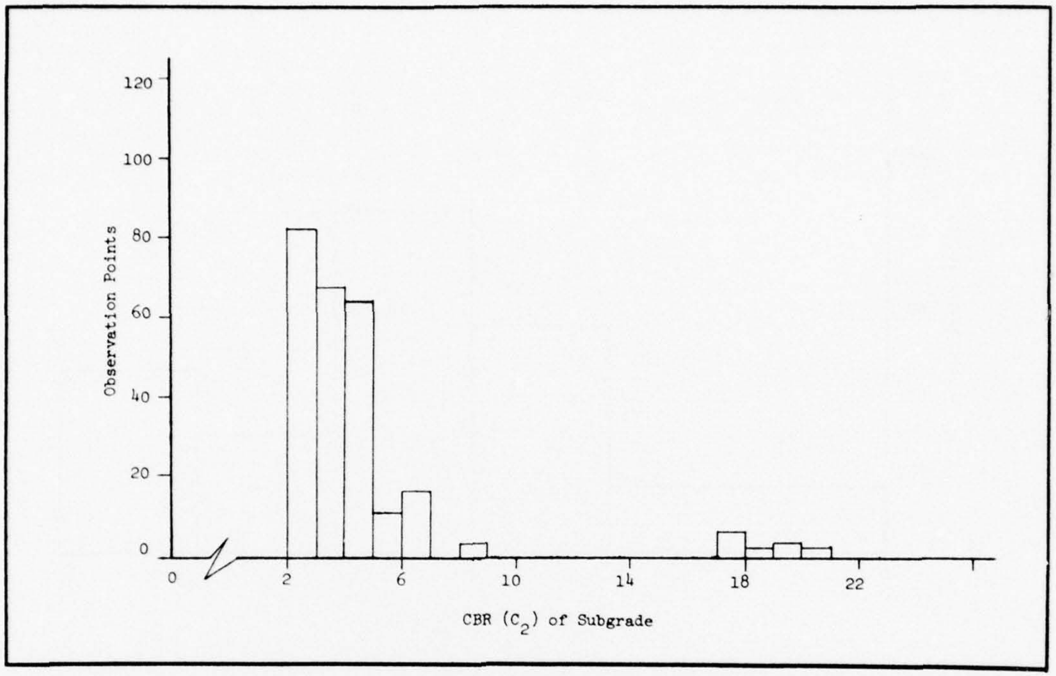

FIG. 36.--GRAVEL-SURFACED FACILITY, SUBGRADE CBR DISTRIBUTION

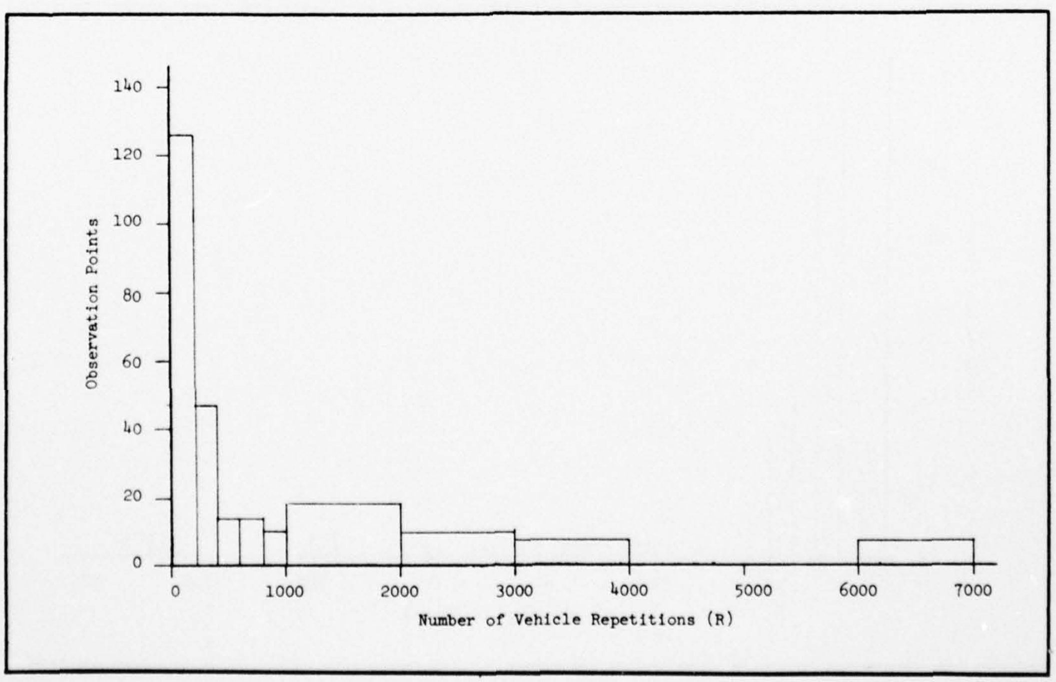

FIG. 37.--GRAVEL-SURFACED FACILITY, REPETITION DISTRIBUTION

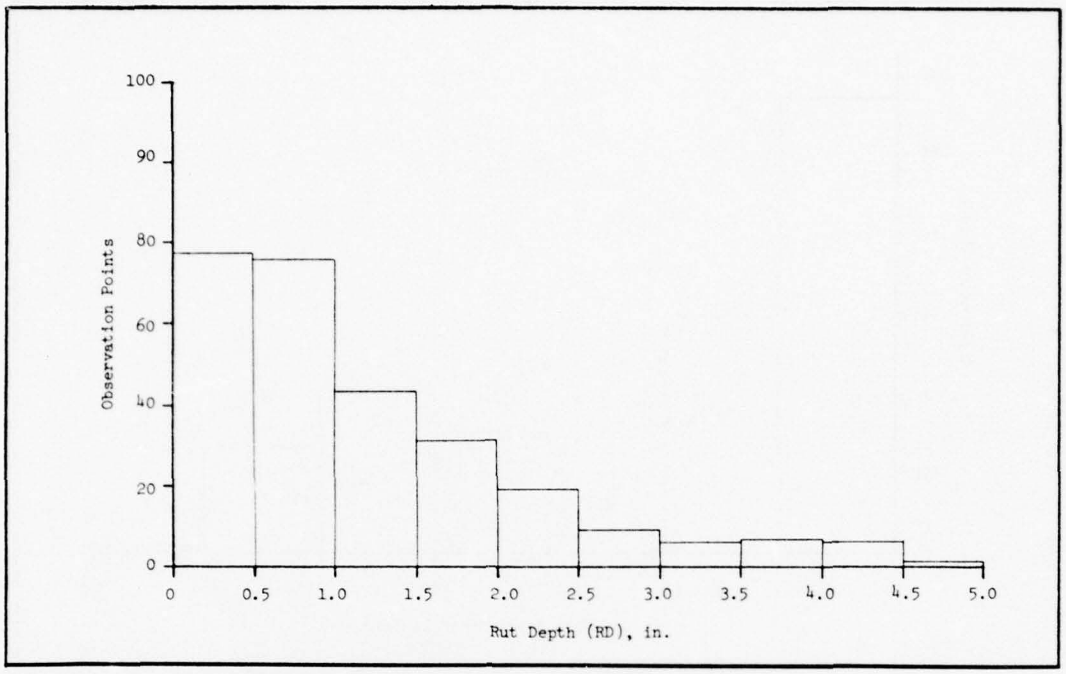

FIG. 38.--TWO-LAYER FLEXIBLE PAVEMENT, RUT DEPTH DISTRIBUTION

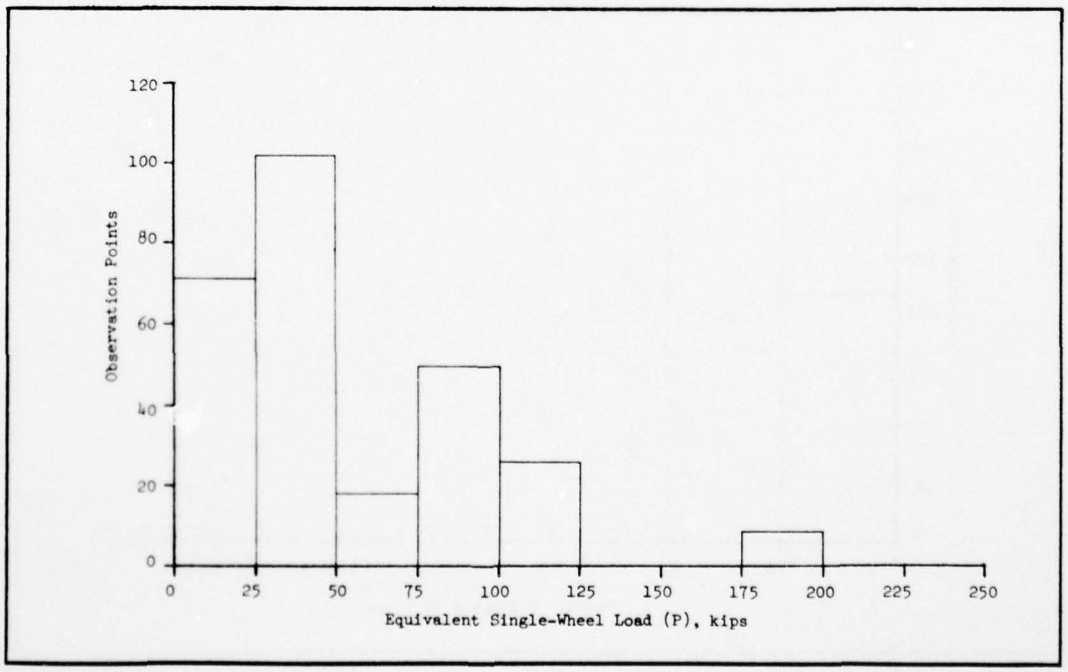

FIG. 39.--TWO-LAYER FLEXIBLE PAVEMENT, LOAD DISTRIBUTION

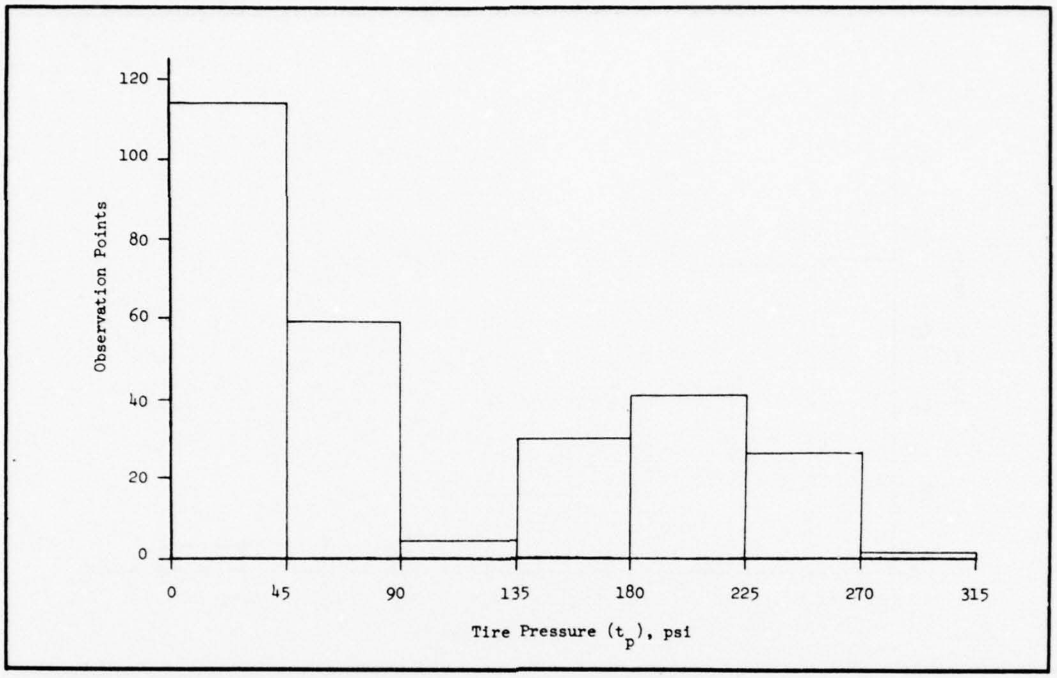

FIG. 40.--TWO-LAYER FLEXIBLE PAVEMENT, TIRE PRESSURE DISTRIBUTION

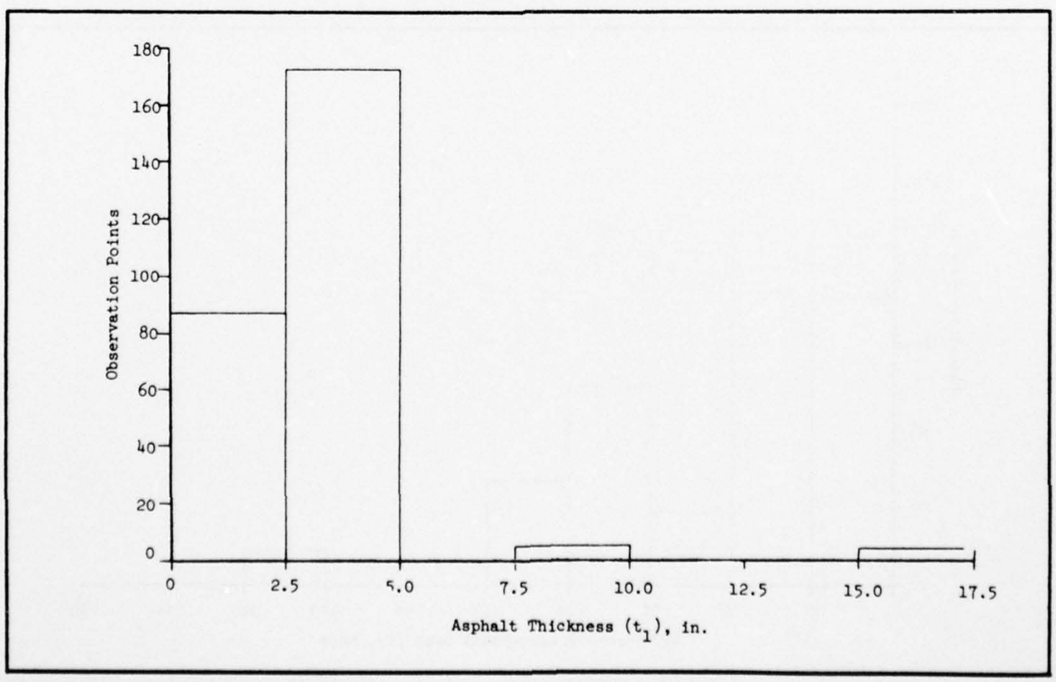

FIG. 41.--TWO-LAYER FLEXIBLE PAVEMENT, ASPHALT THICKNESS DISTRIBUTION

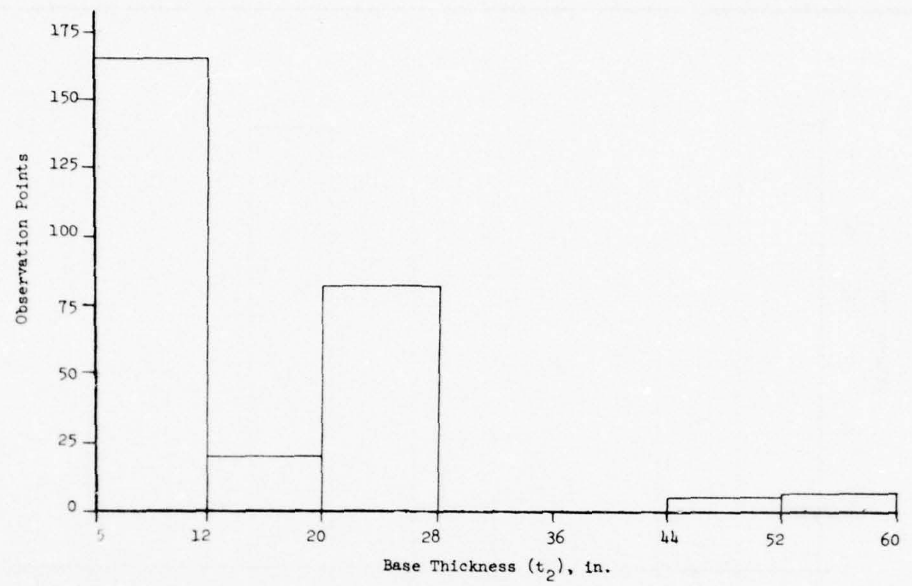

FIG. 42.--TWO-LAYER FLEXIBLE PAVEMENT, BASE THICKNESS DISTRIBUTION

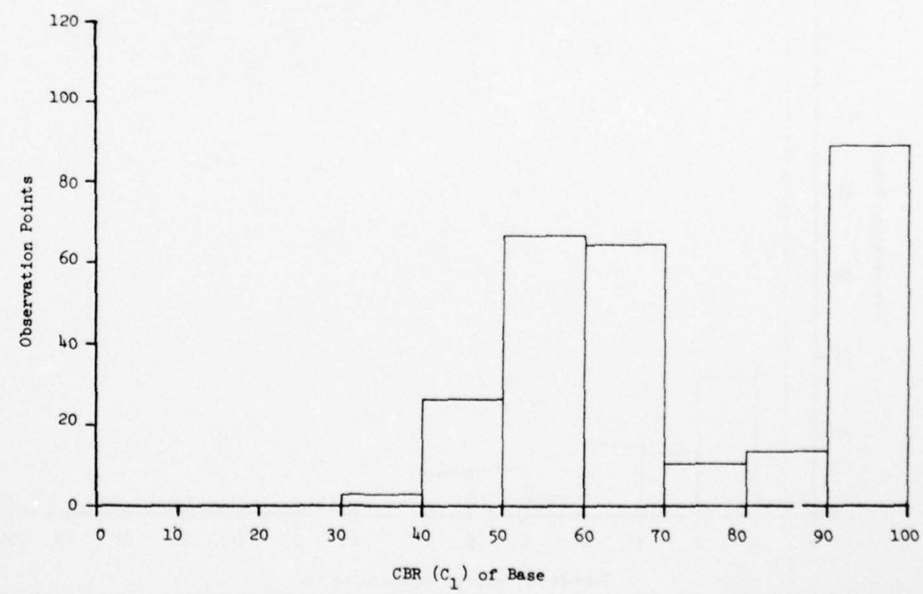

FIG. 43.--TWO-LAYER FLEXIBLE PAVEMENT, BASE CBR DISTRIBUTION

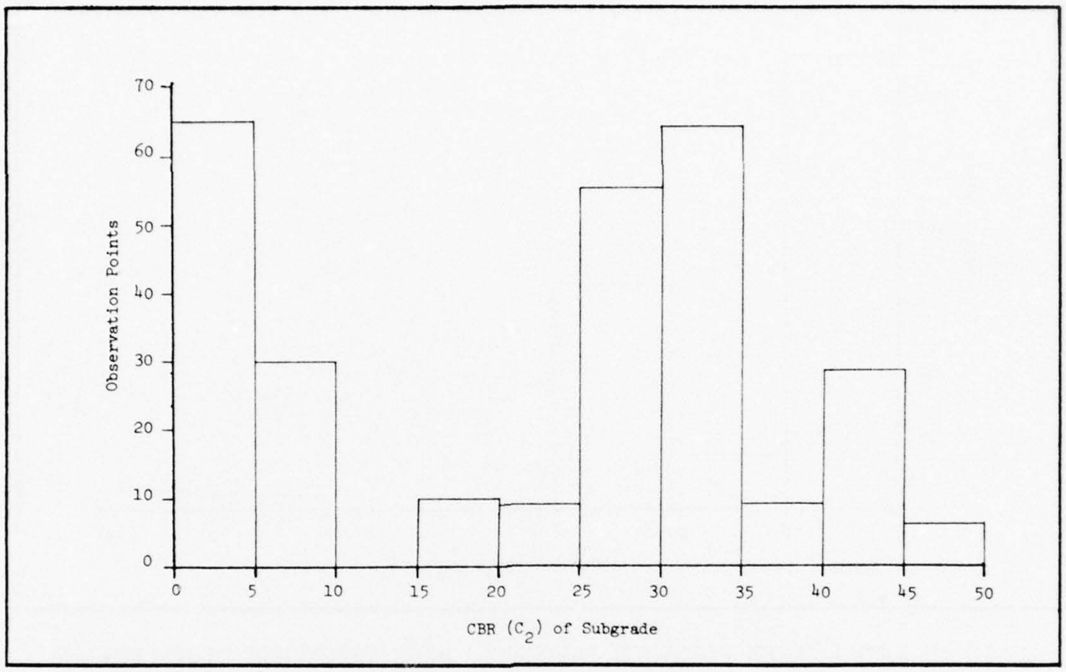

FIG. 44.--TWO-LAYER FLEXIBLE PAVEMENT, SUBGRADE CBR DISTRIBUTION

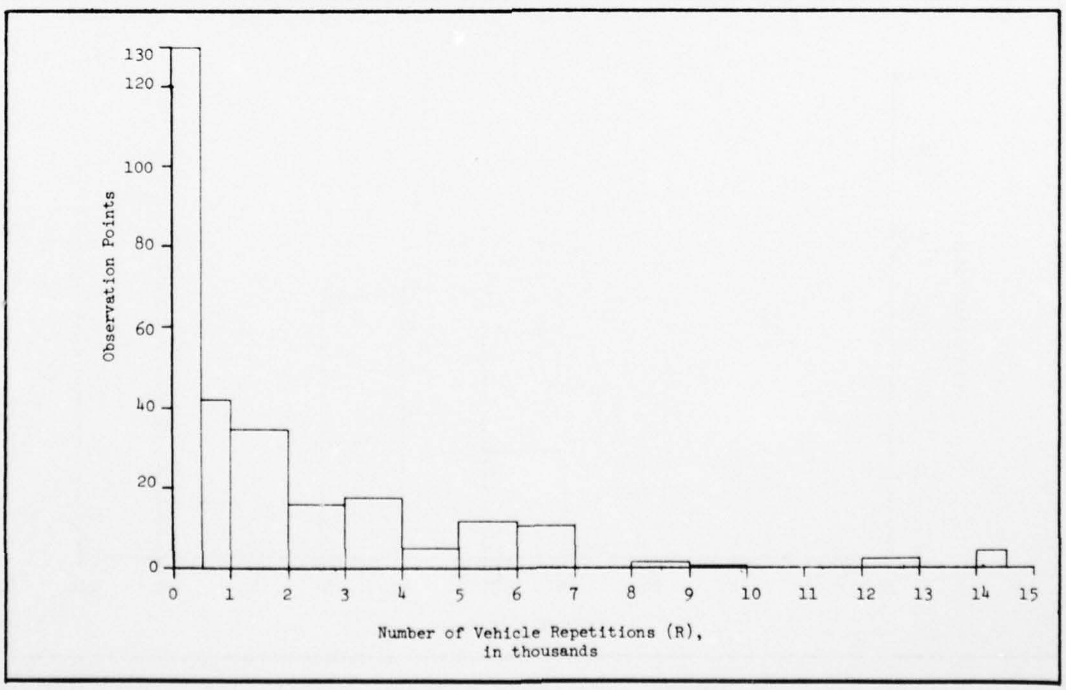

FIG. 45.--TWO-LAYER FLEXIBLE PAVEMENT, REPETITION DISTRIBUTION

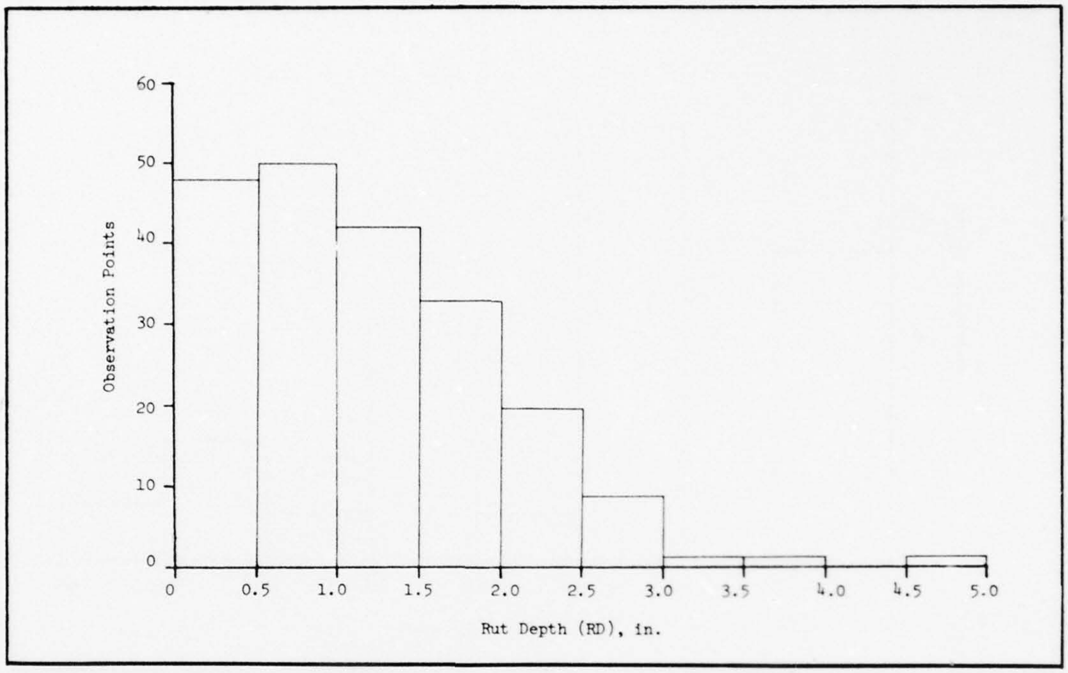

FIG. 46.--THREE-LAYER FLEXIBLE PAVEMENT, RUT DEPTH DISTRIBUTION

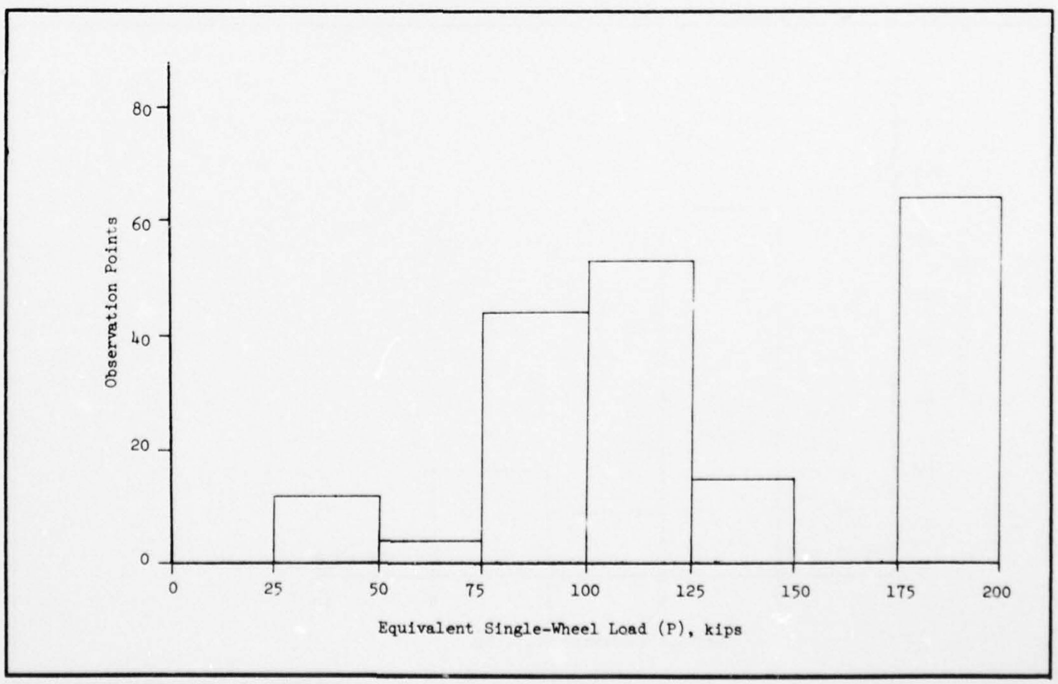

FIG. 47.--THREE-LAYER FLEXIBLE PAVEMENT, LOAD DISTRIBUTION

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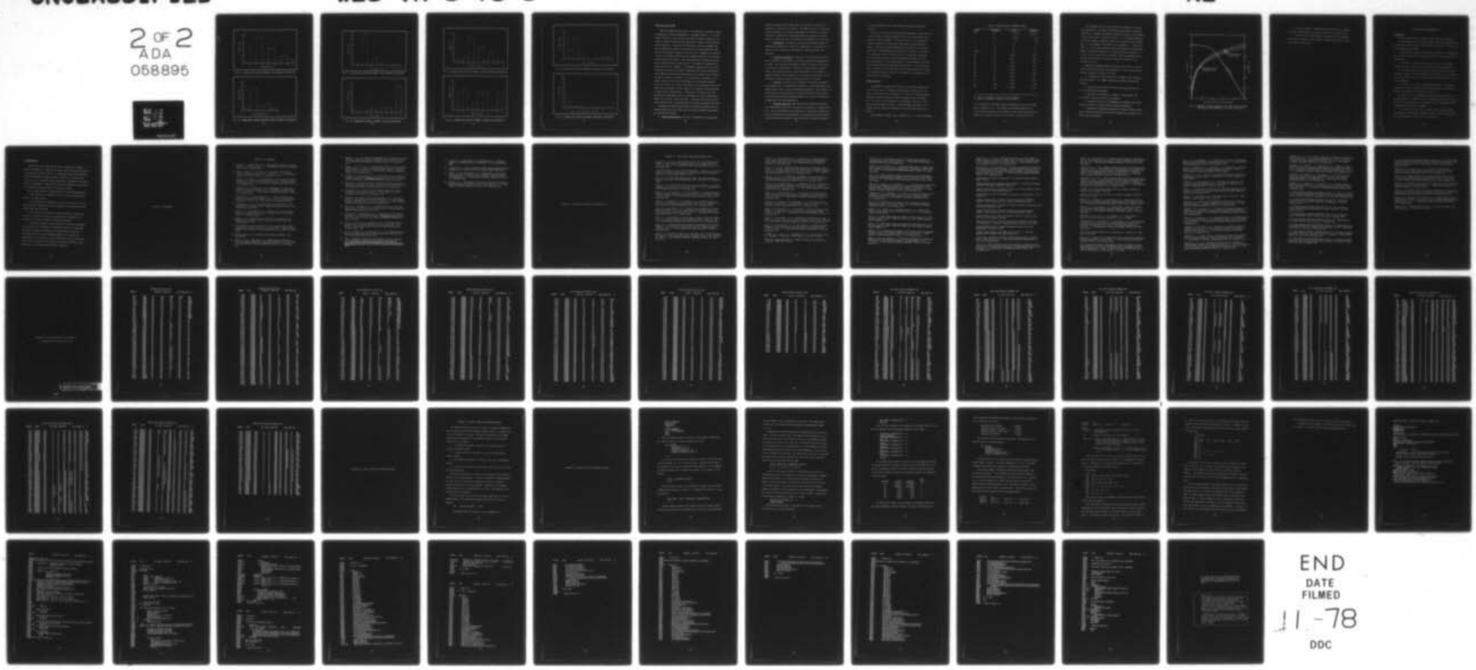

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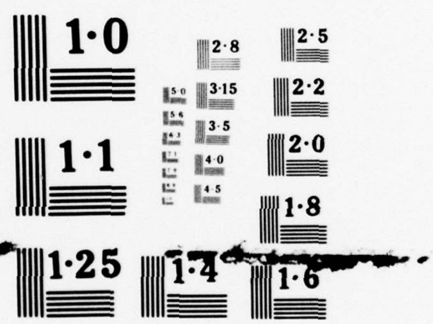

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MICROCOPY RESOLUTION TEST CHART

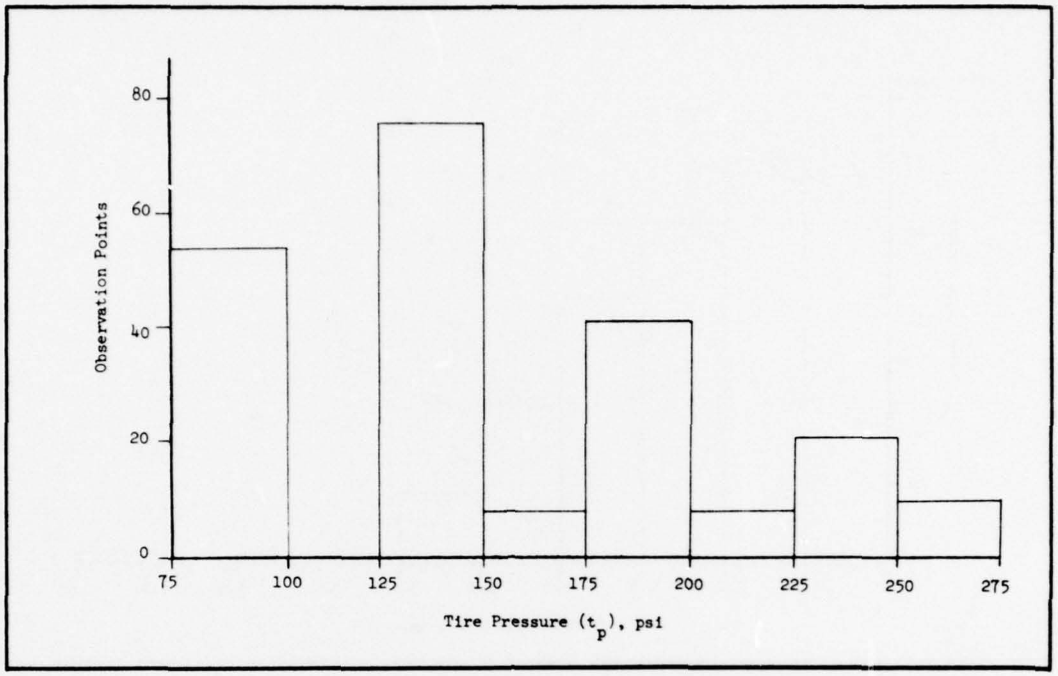

FIG. 48.--THREE-LAYER FLEXIBLE PAVEMENT, TIRE PRESSURE DISTRIBUTION

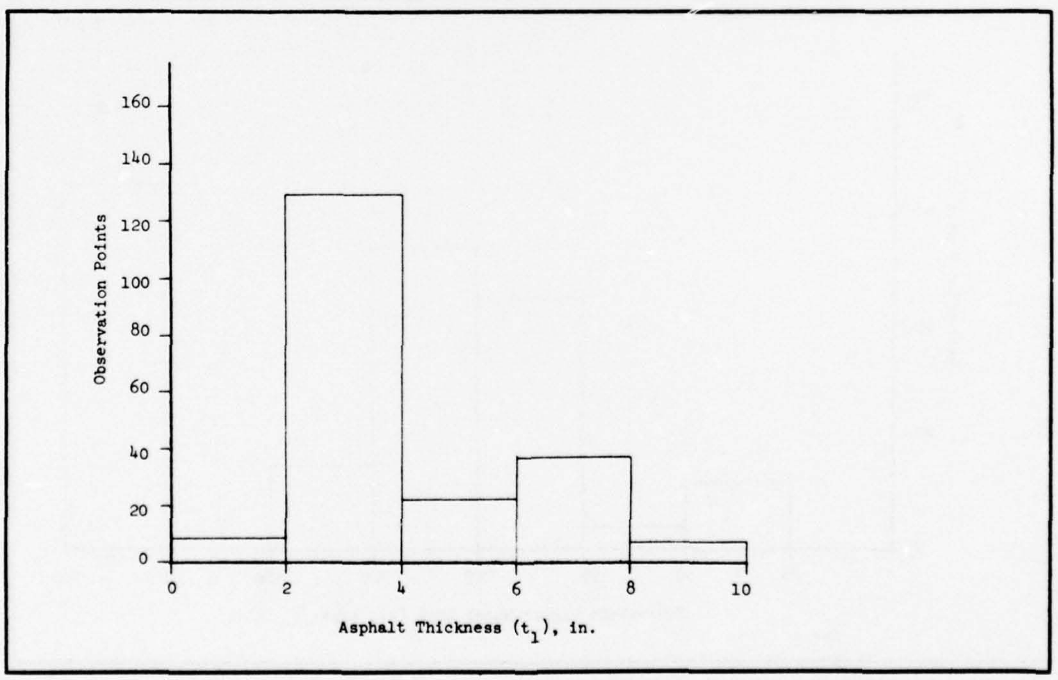

FIG. 49.--THREE-LAYER FLEXIBLE PAVEMENT, ASPHALT THICKNESS DISTRIBUTION

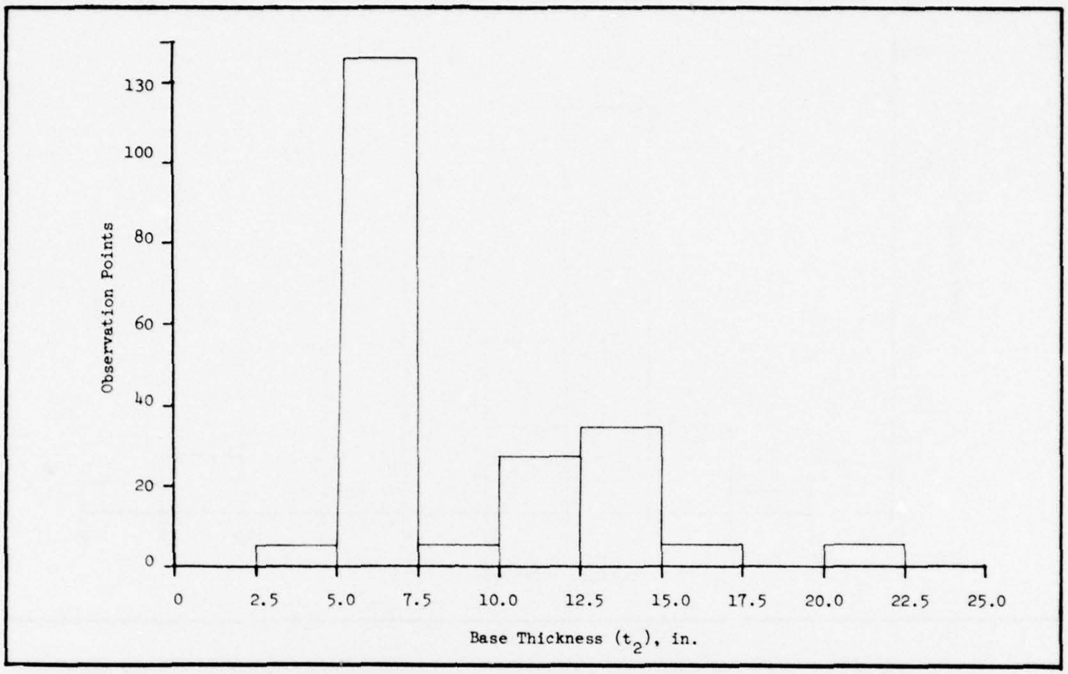

FIG. 50.--THREE-LAYER FLEXIBLE PAVEMENT, BASE THICKNESS DISTRIBUTION

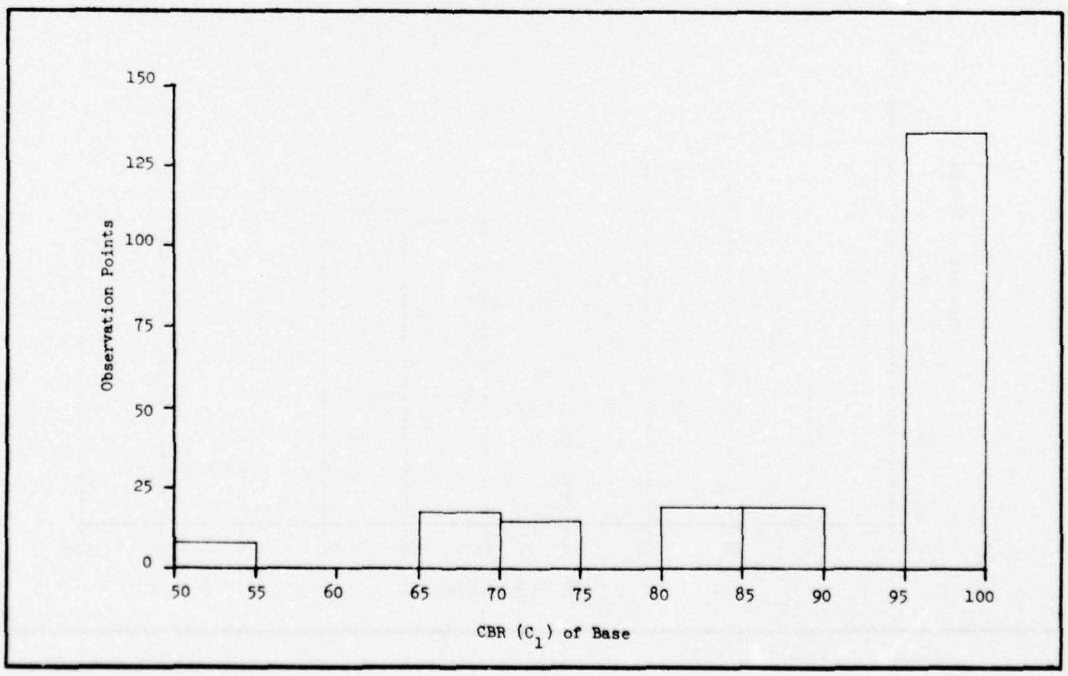

FIG. 51.--THREE-LAYER FLEXIBLE PAVEMENT, BASE CBR DISTRIBUTION

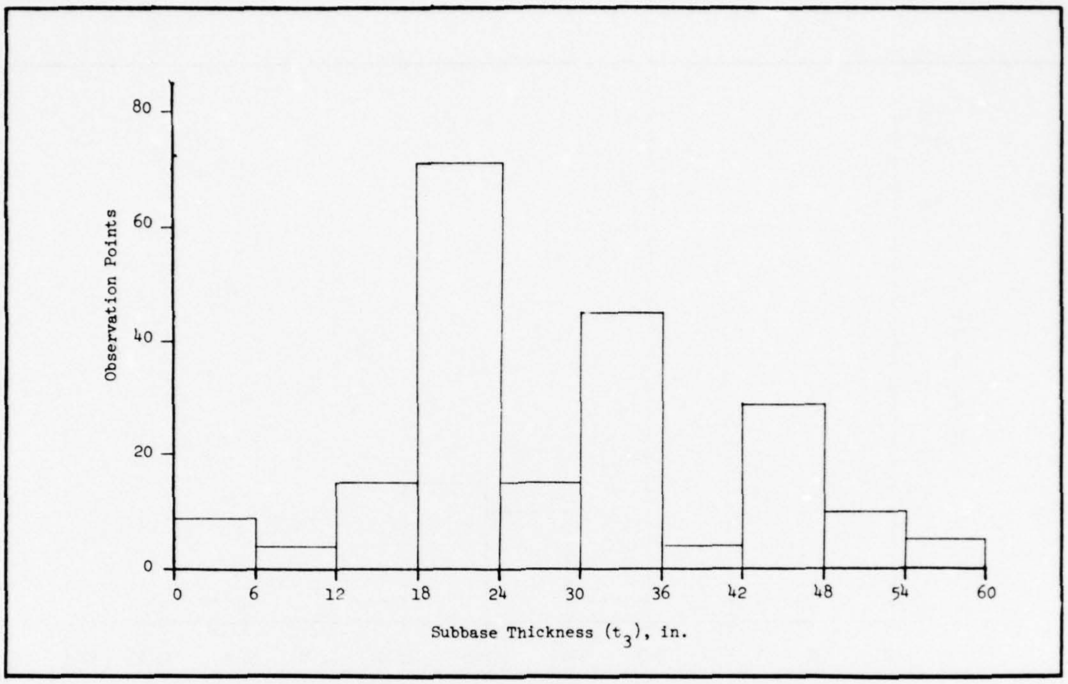

FIG. 52.--THREE-LAYER FLEXIBLE PAVEMENT, SUBBASE THICKNESS DISTRIBUTION

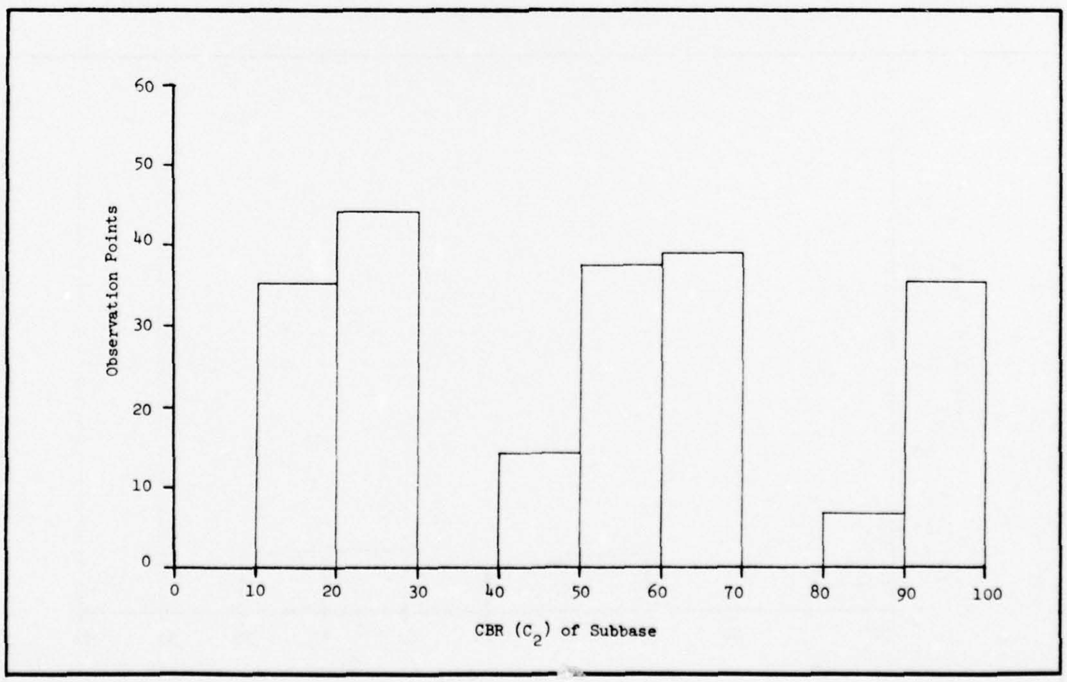

FIG. 53.--THREE-LAYER FLEXIBLE PAVEMENT, SUBBASE CBR DISTRIBUTION

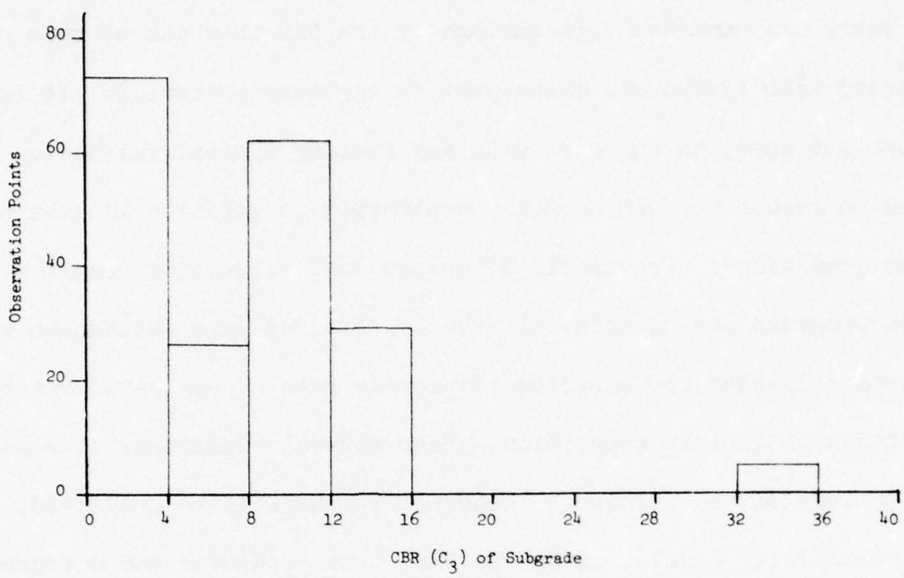

FIG. 54.--THREE-LAYER FLEXIBLE PAVEMENT, SUBGRADE CBR DISTRIBUTION

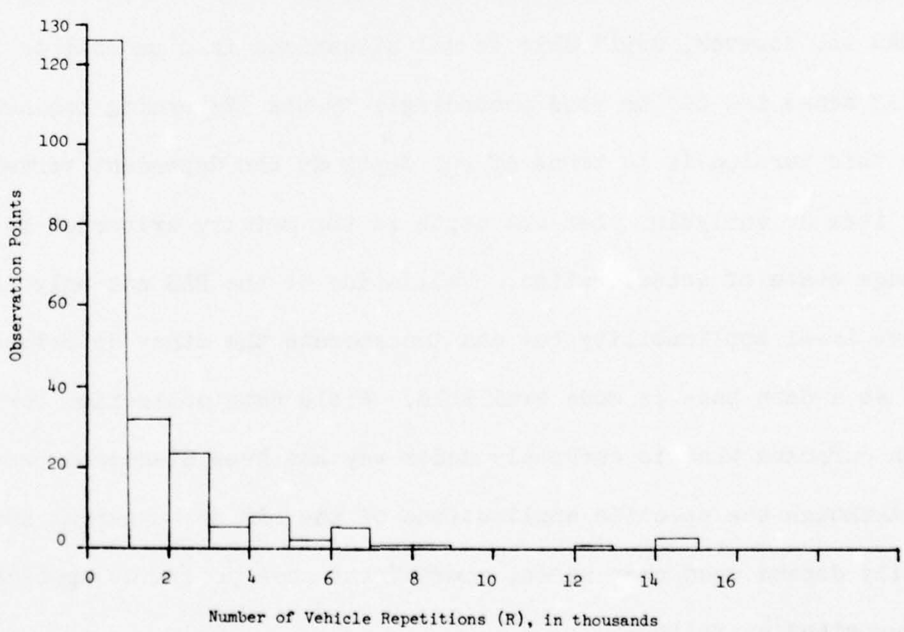

FIG. 55.--THREE-LAYER FLEXIBLE PAVEMENT, REPETITION DISTRIBUTION

Utilization of the DAS

There are numerous applications of the DAS that can be made by those concerned with life-cycle management or any aspect thereof. It is again pointed out that, as the case with any similar system, validation is required to render the DAS directly applicable to specific locales having unique conditions. Previously discussed data collection programs that are in progress are expected to provide data for this validation effort. The data collected are expected to provide rate of change in rut depth as a function of vehicle repetitions under several conditions of road types, traffic levels, and climate. These rut depths will be predicted, along with reliability levels, using the DAS. The predicted and measured rut depth values will be compared. An acceptable comparison will constitute validation, but lack of acceptable comparison will dictate modification of the expected value and variance models for use under those conditions. The DAS is, however, applicable to all situations in a general or stochastic sense and can be used accordingly by the discerning engineer. Since this version is in terms of rut depth as the dependent variable and major item of analysis, then rut depth is the primary criterion by which to judge state of deterioration. Validation of the DAS not only can achieve local applicability but can incorporate the other deterioration modes as a data base is made available. Field data collection for validation purposes that is currently under way has been discussed previously.

Although the specific applications of the DAS are numerous and necessarily depend upon user needs, some of the more prominent applications are described as follows:

1. Design and Evaluation.--The DAS is applicable to CE design and

evaluation problems in the same sense as are current criteria due to similarity in data bases and results. The added features of the DAS are namely the ability to (a) modify limiting failure criteria (rut depth), (b) adjust conservatism to any desired degree by imposing a required degree of reliability, and (c) determine the reliability of a facility.

2. Optimization.--Iterations of the DAS while making changes in appropriate variables can provide for optimization of a design with respect to cost, reliability, serviceability, layer properties, and materials.

3. Differential Analysis.--Iterations of the DAS provide directly for the analysis of the effects of different quantities and magnitudes of loads. The equivalent single-wheel concept (12) makes this possible by providing the capability to incorporate various vehicle configurations. This feature provides a quantitative basis for assessment of damages caused by various categories of vehicles and, when used on a relative basis, would not require locality validation of the DAS.

4. Planning.--The DAS can be considered an effective stochastic-type planning tool for quantitative estimation of future maintenance and repair needs as well as time-to-maintenance estimation. This feature, in connection with such procedures as Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT), can be used to effectively program work loads and expenditures.

5. Military Operations.--The tactical and logistical operations that could benefit from use of the DAS are too numerous to mention in detail. Such considerations as optimization of construction capabilities by constructing facilities having only a required reliability and using facility reliability concepts to aid in tactical planning and maneuvers

are key considerations that could be better quantified using DAS concepts.

The use of the DAS as it exists herein necessarily includes use of the CBR method of strength evaluation, which is in itself not a true physical material parameter. This feature is not to be considered a deterrent, however, to prospective users bound to other design procedures. Material strength parameters can be stated in any suitable terms where a sufficient data base exists for validation. True material parameters, such as Poisson's ratio (μ) and elastic properties (E), in various forms can be utilized and would provide for a more rational approach to the overall operation. Other methods of portraying strength can be used where data are available. In all cases, any bias is removed in the actual correlation indicated during the validation stage and should be the basis of judgment as to whether a particular procedure is employed.

Example Problem

The examples in Appendix IV illustrate the computer program and show how it is used. An example is given here to illustrate the concepts of deterioration and reliability. A "type 1" or gravel-surfaced facility is selected having a surface CBR greater than the subgrade CBR. The values of the variables are arbitrarily selected for illustration and are shown in Table 5. In this example, the object is to evaluate the rut depth and reliability at all repetition levels up to 10,000.

The allowable rut depth, RD_A , selected is 2 in. Eleven iterations

TABLE 5.--VARIABLES USED IN EXAMPLE PROBLEM

Index	Variables	Mean	Variance
1*	P	15 kips	423,333
2	t_P	70 psi	58.33
3	t	9 in.	1.21
4	C_1	25	6
5	C_2	10	2
6a**	R_1	100	10
6b	R_2	1,000	100
6c	R_3	2,000	200
6d	R_4	3,000	300
6e	R_5	4,000	400
6f	R_6	5,000	500
6g	R_7	6,000	600
6h	R_8	7,000	700
6i	R_9	8,000	800
6j	R_{10}	9,000	900
6k	R_{11}	10,000	1,000

* Values of variables 1-5 used for all iterations.
** Value of variable 6 changed for each iteration.

of the problem are performed, each time changing the value of the number of repetitions, R . The results are portrayed graphically in Fig. 56, where the values of rut depth in inches and the reliability are shown as a continuous function of the number of 15-kip repetitions.

The information shown in Fig. 56 gives the designer or evaluator an illustration of the effect of repetitions upon both rut depth and reliability. Although the maximum allowable rut depth is not exceeded, it has an associated reliability of only 0.5. If a higher reliability level were required, structural change in the facility would be necessary. In this example, an increase in the thickness, t, and/or the CBR, C_1, of the gravel-surfaced course would bring about the desired change. Additional iterations of the problem using new values of t and C_1 would be required for evaluation. The data generated would provide for additional rut depth and reliability relations to be plotted on Fig. 56.

Although this example problem illustrates how the rate of deterioration and the reliability can be evaluated, it also illustrated the overall potential of the DAS, as follows:

1. A quantitative time and use rate of change is developed such that the engineer is no longer constrained by failure point design criteria.

2. Limiting serviceability criteria can be selected that best suit an engineering requirement.

3. Any level of reliability, or degree of conservatism, can be selected to meet the needs of the designer.

4. Quantitative bases for programming of maintenance and repair exist as a result of the deterioration analysis capability.

5. Quantitative differential analysis is possible because the degree of deterioration induced by different quantities and types of vehicles can be determined.

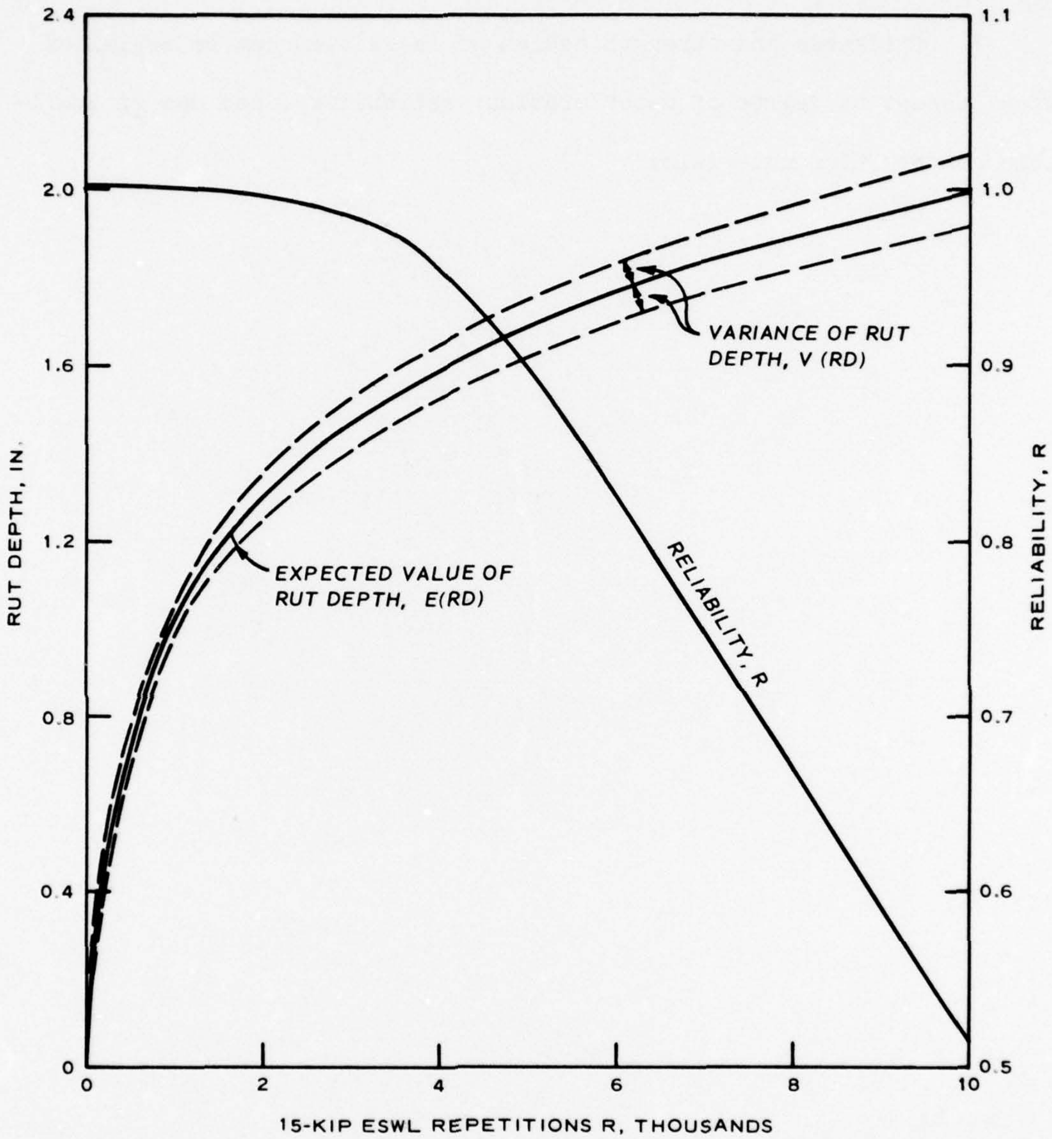

FIG. 56.--EXPECTED VALUE AND VARIANCE OF RUT DEPTH, AND ASSOCIATED RELIABILITY VERSUS NUMBER OF 15-KIP ESWL REPETITIONS

6. Military planning is enhanced through the ability to quantify the state of deterioration at any anticipated level of traffic usage.

7. Thickness and strength design of facilities can be optimized with respect to degree of deterioration, reliability, and use of available construction materials.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The conclusions drawn as a result of this study are as follows:

1. The hypothesis that effective pavement life-cycle management can be achieved through the use of deterioration and reliability concepts has been investigated and proven.

2. Models were developed that effectively portray the deterioration of a facility and assess its reliability in terms of the rutting mode of deterioration.

3. The DAS is a first-generation system that can be considered validated for use to the extent of the current CE design procedure.

4. The deterioration and reliability models show high correlation and small residual error and, therefore, when combined to form the heart of the DAS, should provide for effective rut depth prediction and reliability assessment.

5. The DAS can be used for design and evaluation , optimization, differential analysis, planning, and military operations as described in the section entitled "Utilization of the DAS."

6. The DAS, as a first-generation system, provides a basis for the development of a complete life-cycle management system for all modes of deterioration pertinent to all pavement types through expansion and validation as data are made available.

7. The DAS can be used in its present form for relative differential analysis on roads where damage incurred by various vehicle types must be determined as a basis for cost assessment.

Recommendations

The scope of this study and the results obtained are limited in terms of intended use. Although the results can be directly utilized for some purposes, the basic intent is to establish the fact that deterioration and reliability concepts can play a vital role in improving the state of the art in pavement design, evaluation, maintenance, and overall life-cycle management. Additional validation and expansion are required for verification and improvement of the overall system.

The following specific recommendations are considered appropriate:

1. The DAS should be validated for use in terms that satisfy the needs of the using agency.

2. The DAS should be employed on a trial basis by the CE, FS, and other appropriate agencies to increase awareness and determine possible benefits that can be derived.

3. The current field evaluation programs should be continued and improved to provide more closely controlled data and expanded to incorporate all of the more important deterioration modes.

4. The present research programs should be continued and expanded in scope and level of intensity to effectively provide for development of a fully validated and comprehensive system within this decade. A significant portion of these expanded programs should include the investigation of the effects of vehicle dynamics as well as the investigation of the correlation among steady state tangent operations, curve operations, and acceleration-deceleration operations.

APPENDIX I.--REFERENCES

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1. Ahlvin, R. G., and Brown, D. N., "Combined CBR Criteria," Technical Report No. 3-495, Mar 1959, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

2. Pereira, Taboza A., "Procedures for Development of CBR Design Curves," Instruction Report S-77-1, June 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

3. Barber, V. C., Odom, E. C., and Patrick, R. W., "Pavement Deterioration Analysis for Design and Evaluation Systems," Technical Report S-76-15, Dec 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

4. Barker, W. R., and Brabston, W. N., "Development of a Structural Design Procedure for Flexible Airport Pavements," Technical Report S-75-17, Sep 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

5. Carmichael, R. F., and McCullough, B. F., "Rigid Pavement Design Systems, Input Guide for Program RPS 2 in Use by the Texas Highway Department," Report 123-21, 1973, Center for Highway Research.

6. Castleberry, J. P., II, "An Engineering Geology Analysis of Home Foundations on Expansive Clays," unpublished Master's Thesis, Texas A&M University, Aug 1974.

7. Darter, M. I., and Hudson, W. R., "Probabilistic Design Concepts Applied to Flexible Pavement System Design," Report 123-18, 1973, Center for Highway Research.

8. Debuse, D. A., "Variable Selection Procedure, Implementing the Hocking-La Motte-Leslie Method," Institute of Statistics, Texas A&M University, 1970.

9. Della-Moretta, L., and Sullivan, E., "U. S. Forest Service Vehicle Operating Cost Model," prepared for Presentation to Transportation Research Board Workshop on Low-Volume Roads, Boise, Idaho, 16-19 Jun 1975.

10. Forest Service-Corps of Engineers Inter-Agency Agreement, 1974, unpublished.

11. Hall, J. W., Jr., and Elsea, D. R., "Small Aperture Testing for Airfield Pavement Evaluation," Miscellaneous Paper S-74-3, Feb 1974, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

12. Hammitt, G. M., II, "Thickness Requirements for Unsurfaced Roads and Airfields: Bare Base Support," Technical Report S-70-5, Jul 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

13. Hammitt, G. M., II, et al., "Multiple-Wheel Heavy Gear Load Pavement Tests, Volume IV: Analysis of Behavior Under Traffic," Technical Report S-71-17, Nov 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

14. Hocking, R. R., and Leslie, R. N., "Selection of the Best Subset in Regression Analysis," Technometrics 9, American Society for Quality Control and American Statistical Association, 1967, pp 531-540.

15. Hudson, W. R., "State-of-the-Art in Predicting Pavement Reliability from Input Variability," Contract Report No. S-75-7, Aug 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

16. Hutchinson, R. L., "Basis of Rigid Pavement Design for Military Airfields," Miscellaneous Paper No. 5-7, May 1966, Ohio River Division Laboratories, CE, Cincinnati, Ohio.

17. Kennedy, T. W., Hudson, W. R., and McCullough, B. F., "State-of-the-Art in Variability of Material Properties for Airport Pavement Systems," Contract Report No. S-75-6, Aug 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

18. Kher, R. K., and Darter, M. I., "Probabilistic Concepts and Their Applications to ASSHO Interim Guide for Design of Rigid Pavements," Highway Research Record No. 466, 1973.

19. La Motte, L. R., and Hocking, R. R., "Computational Efficiency in the Selection of Regression Variables," Technometrics 12, American Society for Quality Control and American Statistical Association, 1970, pp 83-93.

20. Lu, D. Y., Lytton, R. L., and Moore, W. M., "Forecasting Serviceability Loss of Flexible Pavements," Research Report No. 57-1F, Nov 1974, Texas Transportation Institute, Texas A&M University, College Station, Tex.

21. Lu, D. Y., Shih, C. S., and Scrivner, F. H., "The Optimization of a Flexible Pavement System Using Linear Elasticity," Report 123-17, 1973, Texas Transportation Institute.

22. Lumb, P. (editor), "Statistics and Probability in Civil Engineering," Proceedings of the First International Conference on Applications of Statistics and Probability to Soil and Structural Engineering, Hong Kong, 13-16 Sep 1971, Hong Kong University Press, 1972.

23. Lytton, R. L., McFarland, W. F., and Schafer, D. L., "Systems Approach to Pavement Design," NCHRP Report 160 (with Appendixes), 1975.

24. Orellana, H. E., "FPS-11 Flexible Pavement System Computer Program Documentation," Report 123-15, 1972, Texas Highway Department.

25. Parker, F., Jr., and Gunkel, R. C., "Development of a Structural Design Procedure for Rigid Airport Pavements," Technical Report (in preparation) U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

26. Webster, S. L., "Determination of In-Place Moisture and Density by Nuclear Methods," Instruction Report S-74-1, Apr 1974, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

APPENDIX II.--PUBLICATIONS CONTAINING REFERENCE DATA

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Ahlvin, R. G., et al., "Multiple-Wheel Heavy Gear Load Pavement Tests, Volume I: Basic Report," Technical Report S-71-17 (AFWL-TR-70-113), Vol I, Nov 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

"Airfield Runways; Surface Profile Measurements: Comparison of the Multi-Wheeled Profilometer Test Reports ("q" Values) and Check Measurements Made with a 10-ft Straight Edge," TL 725.

Boyer, R. E., "Predicting Pavement Performance Using Time-Dependent Transfer Functions," Information Report, 1977, TE7 P8T No. 32, Technical Paper.

Brown, D. N., "A Limited Study of Effects of Mixed Traffic on Flexible Pavements," Technical Report 3-587, Jan 1962, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Brown, D. N., and Ahlvin, R. G., "Revised Method of Thickness Design for Flexible Highway Pavements at Military Installations," Technical Report 3-582, Aug 1961, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Brown, D. N., Hammitt, G. M., and Ladd, D. M., "Flexible Pavement for Tomorrow's Major Airports," Miscellaneous Paper S-69-33, Aug 1969, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Brown, D. N., and Vedros, P. J., "Evaluation of Applicability of AASHO Road Test Results to Corps of Engineers Flexible Pavement Design Criteria," Technical Report 3-721, Nov 1966, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Burns, C. D., "Validation of Soil-Strength Criteria for Aircraft Operations on Unprepared Landing Strips," Technical Report 3-554, Jul 1960, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Burns, C. D., "Total Thickness and Compaction Requirements for Flexible Pavements to be Subjected to Channelized Traffic," Technical Report 3-610, Nov 1962, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Burns, C. D., "Airfield Operations on Unsurfaced Soil, Soil Measurements and Analysis Project Rough Road Alpha," Technical Report 3-624, Jun 1963, Jun 1963, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Burns, C. D., and Brabston, W. N., "Evaluation of Surfacing Materials for Firm Base Tactical Airfields; Bare Base Support," Miscellaneous Paper S-69-10, Mar 1969, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Burns, C. D., et al., "Multiple-Wheel Heavy Gear Load Pavement Tests, Volume II: Design, Construction, and Behavior Under Traffic," Technical Report S-71-17 (AFWL-TR-70-113), Vol II, Nov 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Burns, C. D., et al., "Comparative Performance of Structural Layers in Pavement Systems, Volume I," Technical Report S-74-8, Jun 1974, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Burns, C. D., and Hutchinson, R. L., "Demonstration Test of Performance of Heavy-Load Airfield Pavements; Kelly AFB, San Antonio, Texas," Technical Report 3-459, Jun 1957, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Burns, C. D., and Hutchinson, R. L., "Proof-Test Section Columbus Air Force Base, Structural Investigation of Pavements," Technical Report 3-533, Dec 1959, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Burns, C. D., Joseph, A. H., and Womack, L. M., "Proof-Test Section, Columbus Air Force Base," Technical Report 3-490, Dec 1958, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Burns, C. D., and McCall, J. L., "Evaluation of Load Distributing Capability of T17 Membrane in Road Construction," Miscellaneous Paper S-68-10, Jul 1968, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Burns, C. D., and Womack, L. M., "Pavement Mix Design Study for Very Heavy Gear Loads: Pilot Test Section," Technical Report 3-594, Feb 1962, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Chou, Y. T., and Ledbetter, R. H., "The Behavior of Flexible Airfield Pavements Under Loads--Theory and Experiments," Miscellaneous Paper S-7-66, Jul 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Coffman, B. S., Ilves, G. J., and Edwards, W. F., "The Fatigue of Flexible Pavements: Final Report," EES 296B-1; PB 204 080, Feb 1971.

"Deflection Survey Technique for Pavement Evaluation in Developing Countries," TRRL Report LR 525.

Fenwick, W. B., "F-5A Austere Field Test Landing Strip Evaluation," Miscellaneous Paper 4-701, Aug 1965, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Foster, C. F., and Sale, J. P., "Accelerated Proof-Tests of Runway Pavement, Columbus Air Force Base, Mississippi," Miscellaneous Paper 4-303, Jan 1959, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Fry, Z. B., "Investigation of Behavior of Flexible Airfield Pavements, Effect of Channelized Heavy-Aircraft Traffic," Technical Report 3-548, Jun 1960, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Frye, F. J., Leese, G. W., and Tucker, S. G., "Prefabricated Airfield and Road Surfacing Membrane Investigation: Engineering Tests July 1953-December 1954," Technical Report 3-492, Report 1, Feb 1959, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Geymayer, H. G., and McDonald, J. E., "Short and Long Time Deflections of Reinforced Concrete Flat Slabs (AD No. 704 333)," Technical Report C-70-1, Feb 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Grau, R. W., "Evaluation of Structural Layers in Flexible Pavement," Miscellaneous Paper S-73-26, May 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Haines, R. M., Leslie, D. D., and Middlebrooks, T. A., "Accelerated Traffic Tests; Langley Field, Virginia," Jun 1945, U. S. Army Engineer District, Norfolk, Va.

Hall, A. W., "Three-Track Runway and Taxiway Profiles Measured at International Airports E and F," NASA TN D-6567, Nov 1971, Langley Research Center, Hampton, Va.

Hall, A. W., "Three-Track Runway and Taxiway Profiles Measured at International Airports G and H," NASA TN D-6680, Apr 1972, Langley Research Center, Hampton, Va.

Hammitt, G. M., "Comparative Performance of Structural Layers in Pavement Systems, Volume III," Technical Report S-74-8, Dec 1974, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Hammitt, G. M., and Aspinall, W., "Thickness Requirements for Unsurfaced Roads and Airfields; Bare Base Support," Technical Report S-70-5, Jul 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Hammitt, G. M., II et al., "Multiple-Wheel Heavy Gear Load Pavement Tests, Volume IV: Analysis of Behavior Under Traffic," Technical Report S-71-17 (AFWL-TR-70-113), Vol IV, Nov 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Hendrickson, C. L., and Schiele, J., "Project Rough Road Alpha Take-Off and Landing Capabilities of C-130B, JC-130B, NC-130B (BLC), C-123B, and YC-123H Aircraft on Off-Runway (Unprepared) Surfaces," Technical Documentary Report 63-8, Apr 1963, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Highway Research Board, Proceedings of the Eighteenth Annual Meeting - 1938: Part I.

Highway Research Board, Indexes (Titles Scanned). 1950-1955; 1956-1959; 1960-1962; 1963-1965; 1966-1968; 1969-1972.

Highway Research Board, "Design and Testing of Flexible Pavement," 1955, HRB Bulletin 114 (34th Annual Meeting).

Highway Research Board, Proceedings, Thirty-Sixth Annual Meeting - 1957, Volume 36.

Highway Research Board, "Concrete Pavement Design and Performance Studies: 1960," HRB Bulletin 274 (39th Annual Meeting), 1960.

Highway Research Board, "Pavement Performance Concepts," HRB Bulletin 250 (39th Annual Meeting), 1960.

Highway Research Board, "Flexible Pavement Design and Performance Studies - 1962," HRB Bulletin 321 (41st Annual Meeting), 1962.

Highway Research Board, "Flexible Pavement Design" (5 Reports), HRB No. 13, 1963, 42nd Annual Meeting.

Highway Research Board, "Pavement Slipperiness, Roughness, and Condition Evaluation" (7 Reports), Highway Research Record No. 311, 1970.

Highway Research Board, "Pavement Slipperiness Factors and Their Measurement," HRB Bulletin 186.

Highway Research Board, "The WASHO Road Test; Part 2: Test Data, Analyses, and Findings," HRB Special Report 22.

Irick, Paul, "Statistical Analyses of Trafficability Data," Contract Report 3-108, Nov 1953, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Ladd, D. M., "Soil Strength Criteria for Operation of Fighter Aircraft on Unsurfaced Airfields; Bare Base Support," Miscellanecus Paper S-70-24, Sep 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Ladd, D. M., and Ulery, H. H., "Aircraft Ground-Flotation Investigation, Part I: Basic Report" (all 19 parts reviewed), Technical Report 3-737, Aug 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Ledbetter, R. H., et al., "Multiple-Wheel Heavy Gear Load Pavement Tests, Volume III, Part A: Presentation and Initial Analysis of Stress-Strain Deflection and Vibratory Measurements; Instrumentation," Technical Report S-71-17 (AFWL-TR-70-113), Vol IIIA, Nov 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Ledbetter, R. H., et al., "Multiple-Wheel Heavy Gear Load Pavement Tests; Volume III, Part B: Presentation and Initial Analysis of Stress-Strain Deflection and Vibratory Measurements, Data and Analysis," Technical Report S-71-17 (AFWL-TR-70-113), Vol IIIB, Nov 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Lindsey, H. E., "Accelerated Traffic Tests on Pavement Overlays at MacDill Field, Florida," Aug 1946.

Lister, N. W., "Deflection Criteria for Flexible Pavements," TRRL Report LR 375, 1972.

Maxwell, A. A., Ahlvin, R. G., and Brown, D. N., "Controlled Tests of Mixed Loads on Flexible Pavements," Miscellaneous Paper 4-486, Apr 1962, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Maxwell, A. A., and Joseph, A. H., "Measurement of Effects of Traffic with the Shell Road Vibration Machine," Miscellaneous Paper 4-347, Jul 1959, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Mellinger, F. M., Sale, J. P., and Wathen, T. R., "Heavy Wheel Load Traffic on Concrete Airfield Pavements," TL 726, Jan 1957.

Middlebrooks, T. A., Turnbull, W. J., and Taylor, D. W., "Investigations of Pressures and Deflections for Flexible Pavements; Report No. 1: Homogeneous Clayer-Silt Test Section," Technical Memorandum 3-323, Mar 1951, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Ohio River Division Laboratories, "Lockbourne No. 1 Test Track: Final Report," Mar 1946.

Redus, J. F., "Study of Soil-Cement Base Courses on Military Airfields," Miscellaneous Paper 4-253, Jan 1958, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

"Rigid Pavement Laboratory Investigation Design of Pavement for Track-Type Landing Gear: Report of Traffic Tests with Track-Type and Tire Mounted Landing Gear: Report of Traffic Tests with Track-Type and Tire Mounted Landing Gear on C-82a Aircraft," Aug 1949.

Rula, A. A., and Blackmon, C. A., "Evaluation of Airstrip at Bihn Hung, South Vietnam," Miscellaneous Paper 4-549, Feb 1963, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Seed, H. B., Monismith, C. L., and Chan, C. K., "Prediction of Flexible Pavement Deflection from Laboratory Repeated-Load Tests," Report 35, 1967, National Cooperative Highway Research Program.

Sherman, G. B., et al., "Deflection Studies Performed on El Centro Road (03-SAC-99); Ten Year Report: Interim Report," Jun 1970, Highway Research Board.

Shifley, L. H., and Monismith, C. L., "Test Road to Determine the Influence of Subgrade Characterisitcs on the Transient Deflections of Asphalt Concrete Pavements," TE 68-5, Aug 1968.

Smith C. J., "Evaluation of Mo-Mat 158 as Light-Duty Landing Mat," Miscellaneous Paper S-72-5, Feb 1972, Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Thomas, J. J., and Vyce, J. M., "Flexible Pavement Deflection: Three Studies," Research Report 68-10, Dec 1968.

Thompson, A. B., "Tests of Vinyl Membrane as Surfacing for Airplane Landing Facilities," Technical Memorandum 3-416, Nov 1955, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Thompson, A. B., and Burns, C. D., "Criteria for Designing Runways to be Surfaced with Landing Mat and Membrane-Type Materials," Technical Report 3-539, Apr 1960, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Tucker, S. G. and Vollor, T. W., "Engineering Tests of T17 Membrane Used as All-Weather Surfacing for Two-Way Military Roads," Technical Report 3-772, Aug 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Turnage, G. W., and Brown, D. N., "Prediction of Aircraft Ground Performance by Evaluation of Ground Vehicle Rut Depths," Miscellaneous Paper M-73-16, Dec 1973, U. S. Arny Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Turnbull, W. J., et al., "Effects of Traffic with Small High-Pressure Tires on Asphalt Pavements," Technical Memorandum 3-314, Jun 1950, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Turnbull, W. J., et al., "Design of Flexible Airfield Pavements for Multiple-Wheel Landing Gear Assemblies; Report No. 1: Test Section with Lean Clay Subgrade," Technical Memorandum 3-349, Sep 1952, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Turnbull, W. J., et al., "Design of Upper Base Courses for High-Pressure Tires; Report No. 1: Base Course Requirements as Related to Contact Pressure," Technical Memorandum 3-373, Dec 1953, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Turnbull, W. J., Foster, C. R., and Ahlvin, R. G., "Design of Flexible Airfield Pavements for Multiple-Wheel Landing Gear Assemblies; Report No. 2: Analysis of Existing Data," Technical Memorandum 3-349, Jun 1955, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Turnbull, W. J., Foster, C. R., and Maxwell, A. A., "Relationship Between Tire Pressure and Marginal-Road Deterioration, Pilot Tests," Miscellaneous Paper 4-220, May 1957, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Turnbull, W. J., Maxwell, A. A., and Burns, C. D., "Strength Requirements in Unsurfaced Soils for Aircraft Operations," Miscellaneous Paper 4-394, May 1960, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

U. S. Army Engineer Waterways Experiment Station, CE, "Results of Traffic Tests on Various Combinations of Light Bar and Rod Airplane Landing Mats and Base Courses," Technical Memorandum 212-1, Aug 1944, Vicksburg, Miss.

U. S. Army Engineer Waterways Experiment Station, CE, "Accelerated Traffic Test, Grenier Field, Manchester, New Hampshire," Dec 1944, Vicksburg, Miss.

U. S. Army Engineer Waterways Experiment Station, CE, "Accelerated Traffic Tests; Natchitoches Municipal Airport, Louisiana," Dec 1944, Vicksburg, Miss.

U. S. Army Engineer Waterways Experiment Station, CE, "Accelerated Traffic Tests; Eglin Field, Florida," Jan 1945, Vicksburg, Miss.

U. S. Army Engineer Waterways Experiment Station, CE, "Summary Report: Accelerated Traffic Tests," Feb 1947, Vicksburg, Miss.

U. S. Army Engineer Waterways Experiment Station, CE, "Investigation of the Design and Control of Asphalt Paving Mixtures," Technical Memorandum 3-254, Vols 1-3, May 1948, Vicksburg, Miss.

U. S. Army Engineer Waterways Experiment Station, CE, "Airfield Pavement Evaluation; Travis Air Force Base, Fairfield, California," Miscellaneous Paper 4-312, Jun 1958, Vicksburg, Miss.

U. S. Army Engineer Waterways Experiment Station, CE, "Airfield Pavement Evaluation; Altus Air Force Base, Altus, Oklahoma," Miscellaneous Paper 4-352, Aug 1959, Vicksburg, Miss.

U. S. Army Engineer Waterways Experiment Station, CE, "Airfield Pavement Evaluation; Altus Air Force Base, Altus, Oklahoma (Detailed Report Complete with Supporting Data)," Miscellaneous Paper 4-353, Aug 1959, Vicksburg, Miss.

Watkins, J. E., and Hill, W. J., "Ground-Flotation Investigation of Model Wide Tire," Miscellaneous Paper 4-948, Sep 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Wismer, R. D., "Performance of Soils Under Tire Loads; Tests in Clay Through November 1962," Technical Report 3-666, Report 3, Feb 1966, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Womack, L. M., "Traffic Evaluation Tests of Rogers Dry Lake, California," Miscellaneous Paper 4-365, Nov 1959, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Womack, L. M., "Traffic Tests to Determine the Benefits of Vegetation in Increasing Traffic Coverages," Miscellaneous Paper 4-769, Dec 1965, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Womack, L. M., Mathews, M. J., and Fry, Z. B., "Field Moisture Content Investigation; November 1952-May 1956 Phase," Technical Memorandum 3-401, Report 3, May 1961, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Zimpfer, W. H., "Strength Characteristics of Pavement Materials (Base Course Materials)," TE 210 F54, Jun 1970.

APPENDIX III.--DATA SELECTED FOR DEVELOPMENT OF DETERIORATION AND RELIABILITY MODELS

UNSURFACED FACILITY DATA

UNSURF 12:28:13 04/21/78 FILE PAGE NO. @ 1

RUT	ESWL	TP	TH1	CBR1	CBR2	REP
0.7	4800	70	10	20	21	920
0.9	4800	70	10	20	21	2940
0.3	5920	20	10	19	21	1800
0.35	5920	20	10	19	21	2940
4.8	4800	70	24	4.3	21	140
2.2	5920	20	24	4.3	21	400
5.5	5920	20	24	4.3	21	800
2.6	8000	20	24	4.3	21	200
0.2	5920	20	18	11	21	200
0.4	8000	20	18	11	21	120
0.8	8000	20	18	11	21	400
0.9	8000	20	18	11	21	800
2.2	8000	20	18	11	21	2400
3.0	8000	20	18	11	21	4000
0.14	1780	30	24	9	25	4
0.17	1780	30	24	9	25	12
0.19	1780	30	24	9	25	20
0.54	1780	30	24	2.5	25	4
1.04	1780	30	24	2.5	25	12
1.42	1780	30	24	2.5	25	20
0.03	3368	39	24	12	25	4
0.06	3368	39	24	12	25	12
0.07	3368	39	24	12	25	20
0.69	3368	39	24	2.5	25	4
1.10	3368	39	24	2.5	25	12
1.86	3368	39	24	2.5	25	20
0.14	3864	74	24	14	25	4
0.17	3864	74	24	14	25	12
0.16	3864	74	24	14	25	20
0.19	3864	74	24	9	25	4
0.28	3864	74	24	9	25	12
0.31	3864	74	24	9	25	20
1.56	3864	74	24	2.5	25	4
2.80	3864	74	24	2.5	25	12
3.62	3864	74	24	2.5	25	20
1.56	3864	74	24	2.5	25	4
4.39	3864	74	24	2.5	25	12
5.82	3864	74	24	2.5	25	20
3.69	7635	98	24	2.5	25	4
0.25	7635	98	24	8.5	25	4
0.42	7635	98	24	8.5	25	12
0.53	7635	98	24	8.5	25	20
0.10	7635	98	24	12	25	4
0.15	7635	98	24	12	25	12
0.21	7635	98	24	12	25	20
0.59	2698	45	24	2.5	25	2
1.06	2698	45	24	2.5	25	6
1.38	2698	45	24	2.5	25	12
.30	1573	18	24	3	25	4
.46	1573	18	24	3	25	12
.57	1573	18	24	3	25	20
0.18	35000	75	24	9	25	2
0.40	35000	75	24	9	25	10
0.55	35000	75	24	9	25	20

0.88	35000	75	24	9	25	50
1.22	35000	75	24	9	25	100
0.07	35000	75	24	14	25	2
0.18	35000	75	24	14	25	10
0.26	35000	75	24	14	25	20
0.35	35000	75	24	14	25	50
0.22	35000	100	24	13	25	2
0.59	35000	100	24	13	25	10
0.86	35000	100	24	13	25	20
1.28	35000	100	24	13	25	50
1.77	35000	100	24	13	25	100
0.18	35000	100	24	16	25	2
0.35	35000	100	24	16	25	10
0.41	35000	100	24	16	25	20
0.61	35000	100	24	16	25	50
0.81	35000	100	24	16	25	100
3.03	25000	75	24	3	25	1.1
4.60	25000	75	24	3	25	2
0.29	25000	75	24	8	25	2
0.68	25000	75	24	8	25	10
0.93	25000	75	24	8	25	20
1.50	25000	75	24	8	25	50
2.10	25000	75	24	8	25	100
0.13	25000	75	24	14	25	2
0.24	25000	75	24	14	25	10
0.28	25000	75	24	14	25	20
0.39	25000	75	24	14	25	50
0.50	25000	75	24	14	25	100
3.73	25000	100	24	3	25	1.1
5.73	25000	100	24	3	25	2
0.71	25000	100	24	9	25	2
1.55	25000	100	24	9	25	10
2.14	25000	100	24	9	25	20
4.25	25000	100	24	9	25	50
0.23	25000	100	24	14	25	2
0.32	25000	100	24	14	25	10
0.43	25000	100	24	14	25	20
0.62	25000	100	24	14	25	50
0.80	25000	100	24	14	25	100
4.40	25000	90	24	3	25	1.1
0.84	25000	90	24	7	25	2
2.28	25000	90	24	7	25	10
3.68	25000	90	24	7	25	20
0.08	25000	90	24	16	25	2
0.18	25000	90	24	16	25	10
0.34	25000	90	24	16	25	20
0.60	25000	90	24	16	25	50
1.07	25000	90	24	16	25	100
0.45	25000	110	24	9	25	2
1.29	25000	110	24	9	25	10
2.17	25000	110	24	9	25	20
0.30	25000	110	24	15	25	10
0.47	25000	110	24	15	25	20
0.95	25000	110	24	15	25	50
2.01	25000	110	24	15	25	100
0.07	25000	110	24	23	25	2
0.15	25000	110	24	23	25	10
0.22	25000	110	24	23	25	20
0.37	25000	110	24	23	25	50
0.50	25000	110	24	23	25	100

GRAVEL-SURFACED FACILITY DATA

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RUT	ESWL	TP	TH1	CBR1	CBR2	REP
0.5	4680	100	4.5	81	19.5	920
1.0	4680	100	4.5	81	19.5	3240
1.2	4680	100	4.5	81	19.5	6760
0.6	4800	70	4.5	69	18.5	3400
0.7	4800	70	4.5	69	18.5	6480
0.2	5440	40	4.5	64	18	1080
0.5	5440	40	4.5	64	18	3800
0.6	5440	40	4.5	64	18	6800
0.2	5920	20	4.5	50	17.5	1160
0.45	5920	20	4.5	50	17.5	2660
0.5	5920	20	4.5	50	17.5	6120
0.5	5440	40	10	29	21	1880
0.6	5440	40	10	29	21	2940
0.4	5920	20	4.5	55	9	800
0.6	5920	20	4.5	55	9	4000
0.8	5920	20	4.5	55	9	6400
0.2	8000	20	4.5	44	7	120
0.8	8000	20	4.5	44	7	800
1.6	8000	20	4.5	44	7	4000
2.5	25000	100	12	5.3	4.7	17
3.2	25000	100	12	5.3	4.7	30
2.0	25000	100	12	8	5.3	17
2.2	25000	100	12	8	5.3	30
2.4	25000	100	12	8	5.3	43
2.0	25000	100	12	7	4.9	17
2.4	25000	100	12	7	4.9	30
2.7	25000	100	12	7	4.9	43
2.75	15000	150	6	9	3.2	91
3.84	15000	150	6	9	3.2	108
4.91	15000	150	6	9	3.2	133
1.16	15000	150	12	7.5	3.5	41
1.52	15000	150	12	7.5	3.5	66
2.02	15000	150	12	7.5	3.5	108
2.47	15000	150	12	7.5	3.5	133
3.00	15000	150	12	7.5	3.5	158
3.60	15000	150	12	7.5	3.5	199
1.04	15000	150	18	9	3.7	41
1.12	15000	150	18	9	3.7	66
1.47	15000	150	18	9	3.7	108
1.75	15000	150	18	9	3.7	133
1.88	15000	150	18	9	3.7	199
2.92	15000	150	18	9	3.7	291
3.10	15000	150	18	9	3.7	332
3.48	15000	150	18	9	3.7	365
1.55	15000	150	24	7.6	3.2	41
1.13	15000	150	24	7.6	3.2	66
1.52	15000	150	24	7.6	3.2	108
1.53	15000	150	24	7.6	3.2	133
1.82	15000	150	24	7.6	3.2	199
2.57	15000	150	24	7.6	3.2	291
2.53	15000	150	24	7.6	3.2	332
2.97	15000	150	24	7.6	3.2	365
1.85	25000	115	12	7.5	3	29
3.70	25000	115	12	7.5	3	109

GRAVEL-SURFACED FACILITY DATA

GSURF CONT 11:45: 2 04/21/78 FILE PAGE NO. 2

1.79	25000	115	18	8.2	3.3	29
1.96	25000	115	18	8.2	3.3	57
2.86	25000	115	18	8.2	3.3	109
3.86	25000	115	18	8.2	3.3	144
1.39	25000	115	24	9	3.1	29
1.21	25000	115	24	9	3.1	57
1.50	25000	115	24	9	3.1	109
2.31	25000	115	24	9	3.1	144
3.37	25000	115	24	9	3.1	333
1.00	40000	80	12	11	3.7	11
2.29	40000	80	12	11	3.7	56
3.61	40000	80	12	11	3.7	90
1.72	40000	80	18	9.3	3.4	187
2.22	40000	80	18	9.3	3.4	262
2.84	40000	80	18	9.3	3.4	337
3.75	40000	80	18	9.3	3.4	449
1.66	40000	80	6	9	3.7	8
3.47	40000	80	6	9	3.7	17
1.16	40000	80	12	11	2.9	17
1.85	40000	80	12	11	2.9	55
2.44	40000	80	12	11	2.9	76
3.54	40000	80	12	11	2.9	98
0.82	40000	80	18	9.7	3.6	17
0.94	40000	80	18	9.7	3.6	55
1.57	40000	80	18	9.7	3.6	76
1.81	40000	80	18	9.7	3.6	98
2.10	40000	80	18	9.7	3.6	157
2.82	40000	80	18	9.7	3.6	212
2.78	40000	80	18	9.7	3.6	233
2.91	40000	80	18	9.7	3.6	254
3.25	40000	80	18	9.7	3.6	297
1.22	40000	80	24	9.7	4.3	212
1.19	40000	80	24	9.7	4.3	233
1.16	40000	80	24	9.7	4.3	254
1.32	40000	80	24	9.7	4.3	297
1.62	40000	80	24	9.7	4.3	424
1.72	40000	80	24	9.7	4.3	636
2.25	40000	80	24	9.7	4.3	848
2.57	40000	80	24	9.7	4.3	1060
2.66	15000	165	6	11	4.4	8
3.36	15000	165	6	11	4.4	16
1.33	15000	165	12	10	3.8	8
1.48	15000	165	12	10	3.8	16
0.59	15000	165	18	13	4.5	8
0.85	15000	165	18	13	4.5	16
1.16	15000	165	18	13	4.5	56
1.56	15000	165	18	13	4.5	80
2.41	15000	165	18	13	4.5	127
2.97	15000	165	18	13	4.5	159
3.25	15000	165	18	13	4.5	175
0.65	15000	165	24	11	4.1	8
0.97	15000	165	24	11	4.1	16
1.35	15000	165	24	11	4.1	56
1.97	15000	165	24	11	4.1	80
2.56	15000	165	24	11	4.1	127

2.72	15000	165	24	11	4.1	159
3.07	15000	165	24	11	4.1	175
2.63	40000	120	6	13	3.5	13
3.90	40000	120	6	13	3.5	17
1.65	40000	120	12	12	4	17
3 78	40000	120	12	12	4	76
1.31	40000	120	18	11	4.7	17
2.28	40000	120	18	11	4.7	76
2.47	40000	120	18	11	4.7	127
2.81	40000	120	18	11	4.7	170
3.20	40000	120	18	11	4.7	212
0.88	40000	120	24	11	5.1	17
1.53	40000	120	24	11	5.1	76
1.65	40000	120	24	11	5.1	127
2.04	40000	120	24	11	5.1	170
2.57	40000	120	24	11	5.1	212
2.66	40000	120	24	11	5.1	254
2.75	40000	120	24	11	5.1	297
3.25	40000	120	24	11	5.1	339
0.78	26600	120	12	10	4.3	5
1.88	26600	120	12	10	4.3	49
1.97	26600	120	12	10	4.3	82
2.50	26600	120	12	10	4.3	114
3.38	26600	120	12	10	4.3	147
1.31	26600	120	18	9.9	4.1	49
1.57	26600	120	18	9.9	4.1	114
1.97	26600	120	18	9.9	4.1	147
2.28	26600	120	18	9.9	4.1	196
2.29	26600	120	18	9.9	4.1	245
2.47	26600	120	18	9.9	4.1	293
2.78	26600	120	18	9.9	4.1	342
3.16	26600	120	18	9.9	4.1	391
1.57	26600	120	24	11	4.4	49
1.66	26600	120	24	11	4.4	114
1.94	26600	120	24	11	4.4	147
2.07	26600	120	24	11	4.4	196
1.94	26600	120	24	11	4.4	245
2.00	26600	120	24	11	4.4	293
2.16	26600	120	24	11	4.4	342
2.72	26600	120	24	11	4.4	391
2.50	26600	120	24	11	4.4	440
3.52	26600	120	24	11	4.4	473
2.38	25000	125	15	18	2.7	431
2.63	25000	125	15	18	2.7	545
2.94	25000	125	15	18	2.7	689
3.56	25000	125	15	18	2.7	861
4.06	25000	125	15	18	2.7	941
2.19	25000	125	18	17	2.9	712
2.69	25000	125	18	17	2.9	861
2.81	25000	125	18	17	2.9	941
2.65	25000	125	18	17	2.9	1091
2.85	25000	125	18	17	2.9	1538
3.00	25000	125	18	17	2.9	1722
3.25	25000	125	18	17	2.9	1866
4.00	25000	125	18	17	2.9	2003

GRAVEL-SURFACED FACILITY DATA

GSURF CONT 11:45: 2 04/21/78 FILE PAGE NO. 4

1.69	25000	125	21	17	2.6	1866
1.63	25000	125	21	17	2.6	2003
1.56	25000	125	21	17	2.6	2153
1.66	25000	125	21	17	2.6	2296
1.69	25000	125	21	17	2.6	2440
1.75	25000	125	21	17	2.6	2583
1.81	25000	125	21	17	2.6	2727
1.88	25000	125	21	17	2.6	2870
2.06	40000	125	15	15	2.4	42
2.48	40000	125	15	15	2.4	85
2.83	40000	125	15	15	2.4	127
3.93	40000	125	15	15	2.4	170
2.12	40000	125	18	15	2.9	42
2.43	40000	125	18	15	2.9	85
3.00	40000	125	18	15	2.9	127
3.31	40000	125	18	15	2.9	170
3.62	40000	125	18	15	2.9	233
1.87	40000	125	21	14	2.6	233
2.13	40000	125	21	14	2.6	276
2.13	40000	125	21	14	2.6	318
2.38	40000	125	21	14	2.6	424
2.44	40000	125	21	14	2.6	530
2.69	40000	125	21	14	2.6	636
2.81	40000	125	21	14	2.6	742
2.81	40000	125	21	14	2.6	848
2.87	40000	125	21	14	2.6	954
2.87	40000	125	21	14	2.6	1060
2.94	40000	125	21	14	2.6	1166
3.00	40000	125	21	14	2.6	1272
3.25	40000	125	21	14	2.6	1484
3.13	40000	125	9	12	2.4	11
5.62	40000	125	9	12	2.4	19
2.13	40000	125	12	13	2.3	11
2.62	40000	125	12	13	2.3	19
3.25	40000	125	12	13	2.3	37
1.75	40000	125	15	16	2.2	37
2.75	40000	125	15	16	2.2	75
3.06	40000	125	15	16	2.2	105
3.31	40000	125	15	16	2.2	116
2.06	40000	125	18	14	2.9	116
2.13	40000	125	18	14	2.9	150
2.25	40000	125	18	14	2.9	187
2.25	40000	125	18	14	2.9	224
2.50	40000	125	18	14	2.9	262
2.62	40000	125	18	14	2.9	299
2.75	40000	125	18	14	2.9	337
2.81	40000	125	18	14	2.9	374
2.87	40000	125	18	14	2.9	411
2.94	40000	125	18	14	2.9	486
3.08	40000	125	18	14	2.9	524
3.20	40000	125	18	14	2.9	561
3.08	40000	125	18	14	2.9	598
3.31	40000	125	18	14	2.9	636
3.50	40000	125	18	14	2.9	673
1.75	40000	125	21	17	2.4	673

GRAVEL-SURFACED FACILITY DATA

GSURF CONT 11:45: 2 04/21/78 FILE PAGE NO. 5

1.78	40000	125	21	17	2.4	748
1.88	40000	125	21	17	2.4	860
1.98	40000	125	21	17	2.4	935
2.08	40000	125	21	17	2.4	1047
2.09	40000	125	21	17	2.4	1103
2.13	40000	125	21	17	2.4	1167
2.22	40000	125	21	17	2.4	1290
2.31	40000	125	21	17	2.4	1403
1.3	25000	123	12	10	4.3	57
2.2	25000	123	12	10	4.3	115
2.6	25000	123	12	10	4.3	172
3.3	25000	123	12	10	4.3	230
3.8	25000	123	12	10	4.3	287
1.5	25000	123	12	10	3.9	57
2.1	25000	123	12	10	3.9	115
2.4	25000	123	12	10	3.9	172
3.2	25000	123	12	10	3.9	230
4.5	25000	123	12	10	3.9	287
2.3	25000	123	12	10	3.8	115
2.7	25000	123	12	10	3.8	172
3.4	25000	123	12	10	3.8	230
4.1	25000	123	12	10	3.8	287
0.11	10000	100	8	100	6.2	35
0.19	10000	100	8	100	6.2	141
0.21	10000	100	8	100	6.2	353
0.23	10000	100	8	100	6.2	706
0.29	10000	100	8	100	6.2	3530
0.70	10000	100	8	100	6.2	6001
0.12	10000	100	11	132	6.2	35
0.15	10000	100	11	132	6.2	141
0.20	10000	100	11	132	6.2	353
0.20	10000	100	11	132	6.2	706
0.19	10000	100	11	132	6.2	1765
0.20	10000	100	11	132	6.2	3530
0.30	10000	100	11	132	6.2	6001

TWO-LAYER FLEXIBLE PAVEMENT DATA

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RUT	ESWL	TP	TH1	TH2	CBR1	CBR2	REP
.20	20000	50	3	22	54	6.5	254
.90	20000	50	3	22	54	6.5	1247
1.10	20000	50	3	22	54	6.5	8951
1.20	20000	50	3	22	54	6.5	12700
.20	20000	50	3	17	53	5.5	254
.80	20000	50	3	17	53	5.5	1247
1.30	20000	50	3	17	53	5.5	8951
1.60	20000	50	3	17	53	5.5	12700
.40	20000	50	3	11	51	4	254
1.00	20000	50	3	11	51	4	790
1.60	20000	50	3	11	51	4	1247
.72	77400	100	3	21	84	4.6	85
.96	77400	100	3	21	84	4.6	170
1.68	77400	100	3	21	84	4.6	1222
2.16	77400	100	3	21	84	4.6	4080
1.68	87000	180	3	21	73	3.9	1036
2.52	87000	180	3	21	73	3.9	1647
.43	75000	290	3	21	100	4.2	137
1.44	75000	290	3	21	100	4.2	328
.50	200000	150	9.5	55.5	65	10	10
1.00	200000	150	9.5	55.5	65	10	50
1.55	200000	150	9.5	55.5	65	10	210
2.10	200000	150	9.5	55.5	65	10	530
2.50	200000	150	9.5	55.5	65	10	2100
.40	200000	150	16	50	65	10	20
1.00	200000	150	16	50	65	10	110
2.40	200000	150	16	50	65	10	1060
2.40	200000	150	16	50	65	10	2100
.43	64000	200	1	14	100	47	628
.52	64000	200	1	14	100	47	1727
.83	64000	200	1	14	100	47	3925
1.04	64000	200	1	14	100	47	6280
1.16	64000	200	1	14	100	47	9420
1.19	64000	200	1	14	100	47	14353
.14	15000	45	2	10	35	5	24
.24	15000	45	2	10	35	5	48
.46	15000	45	2	10	35	5	299
.55	15000	45	2	10	35	5	538
.81	15000	45	2	10	35	5	777
.91	15000	45	2	10	35	5	992
.40	94000	190	3	25	100	5.4	74
.60	94000	190	3	25	100	5.4	592
.80	94000	190	3	25	100	5.4	2553
1.30	94000	190	3	25	100	5.4	4625
1.60	94000	190	3	25	100	5.4	6771
.30	94000	190	3	25	100	5.4	74
.70	94000	190	3	25	100	5.4	592
1.20	94000	190	3	25	100	5.4	6771
.30	94000	190	3	25	100	3.8	74
.60	94000	190	3	25	100	3.8	592
1.00	94000	190	3	25	100	3.8	2553
1.20	94000	190	3	25	100	3.8	4625
1.30	94000	190	3	25	100	3.8	6771
1.40	94000	190	3	25	100	3.8	14467

TWO-LAYER FLEXIBLE PAVEMENT DATA

.30	94000	190	3	25	100	3.8	74
.80	94000	190	3	25	100	3.8	592
1.10	94000	190	3	25	100	3.8	2553
1.40	94000	190	3	25	100	3.8	4625
1.[illegible]0	94000	190	3	25	100	3.8	6771
1.90	94000	190	3	25	100	3.8	14467
.40	94000	190	3	25	100	3.8	74
.70	94000	190	3	25	100	3.8	592
1.00	94000	190	3	25	100	3.8	2553
1.40	94000	190	3	25	100	3.8	4625
1.40	94000	190	3	25	100	3.8	6771
1.80	94000	190	3	25	100	3.8	14467
.40	94000	190	3	25	96	4.9	74
.80	94000	190	3	25	96@	4.9	592
1.50	94000	190	3	25	96	4.9	2553
.30	94000	190	3	25	96	4.9	74
.80	94000	190	3	25	96	4.9	592
1.30	94000	190	3	25	96	4.9	2553
.30	94000	190	3	25	96	4.9	74
.60	94000	190	3	25	96	4.9	592
1.10	94000	190	3	25	96	4.9	2553
.40	113000	250	3	25	100	4	74
.40	113000	250	3	25	100	4	222
.70	113000	250	3	25	100	4	592
.40	113000	250	3	25	100	4	74
.70	113000	250	3	25	100	4	222
1.20	113000	250	3	25	100	4	592
.50	113000	250	3	25	100	4	74
.80	113000	250	3	25	100	4	222
1.40	113000	250	3	25	100	4	592
.40	113000	250	3	25	100	3.2	74
.60	113000	250	3	25	100	3.2	222
1.10	113000	250	3	25	100	3.2	592
1.90	113000	250	3	25	100	3.2	1147
.40	113000	250	3	25	100	3.2	74
.70	113000	250	3	25	100	3.2	222
1.30	113000	250	3	25	100	3.2	592
2.50	113000	250	3	25	100	3.2	1147
.40	113000	250	3	25	100	3.2	74
.80	113000	250	3	25	100	3.2	222
1.20	113000	250	3	25	100	3.2	592
1.90	113000	250	3	25	100	3.2	1147
.90	113000	250	3	25	100	5.2	74
1.70	113000	250	3	25	100	5.2	222
.80	113000	250	3	25	100	5.2	74
1.60	113000	250	3	25	100	5.2	222
.80	113000	250	3	25	100	5.2	74
.15	15000	45	1.5	6.5	55	35	20
.20	15000	45	1.5	6.5	55	35	40
.25	15000	45	1.5	6.5	55	35	100
.30	15000	45	1.5	6.5	55	35	190
.40	15000	45	1.5	6.5	55	35	380
.50	15000	45	1.5	6.5	55	35	960
.55	15000	45	1.5	6.5	55	35	1910
.60	15000	45	1.5	6.5	55	35	3820

.65	15000	45	1.5	6.5	55	35	5690
.15	15000	45	1.5	6.5	53	29	20
.20	15000	45	1.5	6.5	53	29	40
.35	15000	45	1.5	6.5	53	29	100
.50	15000	45	1.5	6.5	53	29	190
.60	15000	45	1.5	6.5	53	29	380
.85	15000	45	1.5	6.5	53	29	960
1.05	15000	45	1.5	6.5	53	29	1910
1.25	15000	45	1.5	6.5	53	29	3820
1.40	15000	45	1.5	6.5	53	29	6690
.15	15000	45	3	5	59	27	20
.25	15000	45	3	5	59	27	40
.45	15000	45	3	5	59	27	100
.55	15000	45	3	5	59	27	190
.75	15000	45	3	5	59	27	380
1.00	15000	45	3	5	59	27	960
1.25	15000	45	3	5	59	27	1910
1.50	15000	45	3	5	59	27	3820
1.55	15000	45	3	5	59	27	6690
.15	15000	45	3	5	55	35	20
.20	15000	45	3	5	55	35	40
.20	15000	45	3	5	55	35	100
.25	15000	45	3	5	55	35	190
.25	15000	45	3	5	55	35	380
.35	15000	45	3	5	55	35	960
.40	15000	45	3	5	55	35	1910
.45	15000	45	3	5	55	35	3820
.45	15000	45	3	5	55	35	6690
.10	15000	45	3	5	77	38	20
.10	15000	45	3	5	77	38	40
.15	15000	45	3	5	77	38	100
.20	15000	45	3	5	77	38	190
.25	15000	45	3	5	77	38	380
.50	15000	45	3	5	77	38	960
.55	15000	45	3	5	77	38	1910
.70	15000	45	3	5	77	38	3820
.85	15000	45	3	5	77	38	6690
.35	15000	45	1.5	6.5	61	44	20
.45	15000	45	1.5	6.5	61	44	40
.50	15000	45	1.5	6.5	61	44	100
.65	15000	45	1.5	6.5	61	44	190
.95	15000	45	1.5	6.5	61	44	380
1.20	15000	45	1.5	6.5	61	44	960
1.50	15000	45	1.5	6.5	61	44	1910
1.80	15000	45	1.5	6.5	61	44	3820
2.00	15000	45	1.5	6.5	61	44	6690
.20	37000	45	1.5	8.5	60	34	15
.45	37000	45	1.5	8.5	60	34	30
.60	37000	45	1.5	8.5	60	34	80
.95	37000	45	1.5	8.5	60	34	160
1.20	37000	45	1.5	8.5	60	34	320
1.55	37000	45	1.5	8.5	60	34	800
1.90	37000	45	1.5	8.5	60	34	1590
2.25	37000	45	1.5	8.5	60	34	3180
2.50	37000	45	1.5	8.5	60	34	5570

TWO-LAYER FLEXIBLE PAVEMENT DATA

.25	37000	45	3	7	88	32	15
.40	37000	45	3	7	88	32	30
.60	37000	45	3	7	88	32	80
.90	37000	45	3	7	88	32	160
1.05	37000	45	3	7	88	32	320
1.50	37000	45	3	7	88	32	800
1.80	37000	45	3	7	88	32	1590
2.10	37000	45	3	7	88	32	3180
2.45	37000	45	3	7	88	32	5570
.50	37000	45	1.5	8.5	63	44	15
.85	37000	45	1.5	8.5	63	44	30
1.45	37000	45	1.5	8.5	63	44	80
1.95	37000	45	1.5	8.5	63	44	160
2.50	37000	45	1.5	8.5	63	44	320
3.00	37000	45	1.5	8.5	63	44	800
3.50	37000	45	1.5	8.5	63	44	1590
4.00	37000	45	1N5	8.5	63	44	3180
4.15	37000	45	1.5	8.5	63	44	5570
.20	37000	45	3	7	60	34	15
.35	37000	45	3	7	60	34	30
.50	37000	45	3	7	60	34	80
.75	37000	45	3	7	60	34	160
1.00	37000	45	3	7	60	34	320
1.45	37000	45	3	7	60	34	800
1.60	37000	45	3	7	60	34	1590
2.00	37000	45	3	7	60	34	3180
2.10	37000	45	3	7	60	34	5570
.65	37000	45	1.5	8.5	41	29	30
1.20	37000	45	1.5	8.5	41	29	80
1.85	37000	45	1.5	8.5	41	29	160
2.15	37000	45	1.5	8.5	41	29	320
2.85	37000	45	1.5	8.5	41	29	800
3.15	37000	45	1.5	8.5	41	29	1590
3.55	37000	45	1.5	8.5	41	29	3180
3.90	37000	45	1.5	8.5	41	29	5570
.40	37000	45	3	7	48	27	8
.90	37000	45	3	7	48	27	15
1.35	37000	45	3	7	48	27	30
2.10	37000	45	3	7	48	27	80
2.80	37000	45	3	7	48	27	160
3.35	37000	45	3	7	48	27	320
4.00	37000	45	3	7	48	27	800
4.50	37000	45	3	7	48	27	1590
4.95	37000	45	3	7	48	27	3180
5.05	37000	45	3	7	48	27	5570
.25	50000	50	1.5	8.5	65	34	15
.40	50000	50	1.5	8.5	65	34	30
.65	50000	50	1.5	8.5	65	34	80
1.00	50000	50	1.5	8.5	65	34	160
1.30	50000	50	1.5	8.5	65	34	320
1.60	50000	50	1.5	8.5	65	34	800
2.00	50000	50	1.5	8.5	65	34	1590
2.45	50000	50	1.5	8.5	65	34	3180
2.55	50000	50	1.5	8.5	65	34	5570
.50	50000	50	1.5	8.5	58	44	8

TWO-LAYER FLEXIBLE PAVEMENT DATA

.75	50000	50	1.5	8.5	58	44	15
1.15	50000	50	1.5	8.5	58	44	30
1.55	50000	50	1.5	8.5	58	44	80
2.00	50000	50	1.5	8.5	58	44	160
2.50	50000	50	1.5	8.5	58	44	320
3.00	50000	50	1.5	8.5	58	44	800
3.50	50000	50	1.5	8.5	58	44	1590
4.00	50000	50	1.5	8.5	58	44	3180
4.40	50000	50	1.5	8.5	58	44	5570
.65	50000	50	1.5	8.5	52	29	8
1.00	50000	50	1.5	8.5	52	29	15
1.45	50000	50	1.5	8.5	52	29	30
1.95	50000	50	1.5	8.5	52	29	80
2.45	50000	50	1.5	8.5	52	29	160
2.80	50000	50	1.5	8.5	52	29	320
3.50	50000	50	1.5	8.5	52	29	800
4.00	50000	50	1.5	8.5	52	29	1590
4.50	50000	50	1.5	8.5	52	29	3180
4.75	50000	50	1.5	8.5	52	29	5570
.15	50000	50	3	7	65	34	8
.25	50000	50	3	7	65	34	15
.45	50000	50	3	7	65	34	30
.60	50000	50	3	7	65	34	80
.95	50000	50	3	7	65	34	160
1.15	50000	50	3	7	65	34	320
1.55	50000	50	3	7	65	34	800
1.95	50000	50	3	7	65	34	1590
2.25	50000	50	3	7	65	34	3180
2.55	50000	50	3	7	65	34	5570
.90	50000	50	3	7	41	27	15
1.40	50000	50	3	7	41	27	30
2.00	50000	50	3	7	41	27	80
2.40	50000	50	3	7	41	27	160
2.80	50000	50	3	7	41	27	320
3.45	50000	50	3	7	41	27	800
3.80	50000	50	3	7	41	27	1590
4.20	50000	50	3	7	41	27	3180
4.50	50000	50	3	7	41	27	5570
.30	72000	140	3	17	100	19	298
.45	72000	140	3	17	100	19	596
.45	72000	140	3	17	100	19	894
.45	72000	140	3	17	100	19	1192
.50	72000	140	3	17	100	19	1490
.50	72000	140	3	17	100	19	1788
.55	72000	140	3	17	100	19	2086
.60	72000	140	3	17	100	19	2384
.70	72000	140	3	17	100	19	2682
.70	72000	140	3	17	100	19	2980
.40	79500	140	3	23	100	21	298
.60	79500	140	3	23	100	21	596
.75	79500	140	3	23	100	21	894
.65	79500	140	3	23	100	21	1192
.80	79500	140	3	23	100	21	1490
.70	79500	140	3	23	100	21	1788
.80	79500	140	3	23	100	21	2086
1.00	79500	140	3	23	100	21	2682
.90	79500	140	3	23	100	21	2980

THREE-LAYER FLEXIBLE PAVEMENT DATA

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RUT	ESWL	TP	TH1	TH2	CBR1	TH3	CBR2	CBR3	REP
.31	112610	266	4	11	100	23	30	10	163
.47	112610	266	4	11	100	23	30	10	408
.60	112610	266	4	11	100	23	30	10	652
.70	112610	266	4	11	100	23	30	10	978
.77	112610	266	4	11	100	23	30	10	1467
.87	112610	266	4	11	100	23	30	10	1793
1.01	112610	266	4	11	100	23	30	10	3097
1.10	112610	266	4	11	100	23	30	10	4727
1.15	112610	266	4	11	100	23	30	10	5461
1.21	112610	266	4	11	100	23	30	10	8150
.25	89000	200	5	22	100	25	45	34	2591
.50	89000	200	5	22	100	25	45	34	5552
.75	89000	200	5	22	100	25	45	34	7615
1.00	89000	200	5	22	100	25	45	34	9891
1.50	89000	200	5	22	100	25	45	34	14130
.36	77400	100	3	6	100	15	61	5.0	80
.96	77400	100	3	6	100	15	61	5.0	160
.36	77400	100	3	6	100	15	100	4.7	83
.60	77400	100	3	6	100	15	100	4.7	165
1.08	77400	100	3	6	100	15	100	4.7	1087
.80	94500	100	3	6	82	24	18	3.6	355
1.40	94500	100	3	6	82	24	18	3.6	821
1.80	94500	100	3	6	82	24	18	3.6	1275
2.40	94500	100	3	6	82	24	18	3.6	1897
2.60	94500	100	3	6	82	24	18	3.6	2701
1.40	94500	100	3	6	82	24	18	3.6	355
1.80	94500	100	3	6	82	24	18	3.6	821
2.00	94500	100	3	6	82	24	18	3.6	1275
2.50	94500	100	3	6	82	24	18	3.6	1897
3.00	94500	100	3	6	82	24	18	3.6	2701
1.00	94500	100	3	6	82	24	18	3.6	355
1.30	94500	100	3	6	82	24	18	3.6	821
1.40	94500	100	3	6	82	24	18	3.6	1275
1.80	94500	100	3	6	82	24	18	3.6	1897
2.10	94500	100	3	6	82	24	18	3.6	2701
.40	94500	100	3	6	66	24	27	3.0	103
.80	94500	100	3	6	66	24	27	3.0	362
1.70	94500	100	3	6	66	24	27	3.0	1282
2.00	94500	100	3	6	66	24	27	3.0	1904
3.00	94500	100	3	6	66	24	27	3.0	2708
.60	94500	100	3	6	66	24	27	3.0	103
1.10	94500	100	3	6	66	24	27	3.0	362
1.80	94500	100	3	6	66	24	27	3.0	1282
2.10	94500	100	3	6	66	24	27	3.0	1904
3.10	94500	100	3	6	66	24	27	3.0	2708
.50	94500	100	3	6	66	24	27	3.0	362
1.00	94500	100	3	6	66	24	27	3.0	829
1.20	94500	100	3	6	66	24	27	3.0	1282
2.10	94500	100	3	6	66	24	27	3.0	1904
.40	109800	100	3	6	96	33	24	2.8	162
1.00	109800	100	3	6	96	33	24	2.8	836
1.10	109800	100	3	6	96	33	24	2.8	1290
1.30	109800	100	3	6	96	33	24	2.8	1912
1.80	109800	100	3	6	96	33	24	2.8	2712

THREE-LAYER FLEXIBLE PAVEMENT DATA

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.60	109800	100	3	6	96	33	24	2.8	162
1.40	109800	100	3	6	96	33	24	2.8	836
1.40	109800	100	3	6	96	33	24	2.8	1290
1.90	109800	100	3	6	96	33	24	2.8	1912
2.10	109800	100	3	6	96	33	24	2.8	2712
.80	109800	100	3	6	96	33	24	2.8	836
1.10	109800	100	3	6	Y6	33	24	2.8	1290
1.30	109800	100	3	6	96	33	24	2.8	1912
1.70	109800	100	3	6	96	33	24	2.8	2712
.40	50000	165	3	6	73	15	14	3.9	93
1.90	50000	165	3	6	73	15	14	3.9	546
.50	50000	165	3	6	73	15	14	3.9	93
2.10	50000	165	3	6	73	15	14	3.9	546
.40	50000	165	3	6	73	15	14	3.9	93
2.30	50000	165	3	6	73	15	14	3.9	546
1.30	146400	225	3	6	71	33	24	3.2	74
3.80	146400	225	3	6	71	33	24	3.2	518
1.00	146400	225	3	6	71	33	24	3.2	74
2.50	146400	225	3	6	71	33	24	3.2	518
1.10	146400	225	3	6	71	33	24	3.2	74
2.30	146400	225	3	6	71	33	24	3.2	518
.70	30000	100	3	6	55	6	11	3.3	202
1.90	30000	100	3	6	55	6	11	3.3	328
.60	30000	100	3	6	55	6	11	3.3	202
1.30	30000	100	3	6	55	6	11	3.3	328
.60	30000	100	3	6	55	6	11	3.3	202
1.70	30000	100	3	6	55	6	11	3.3	328
1.30	200000	150	7	15	100	21.5	53	8	110
2.40	200000	150	7	15	100	21.5	53	8	320
2.60	200000	150	7	15	100	21.5	53	8	740
2.90	200000	150	7	15	100	21.5	53	8	1060
.10	200000	150	7	15	100	24.5	53	9	10
.50	200000	150	7	15	100	24.5	53	9	68
2.00	200000	150	7	15	100	24.5	53	9	330
2.90	200000	150	7	15	100	24.5	53	9	965
2.90	200000	150	7	15	100	24.5	53	9	2100
.20	200000	150	6.5	13.5	100	31	53	8	68
1.40	200000	150	6.5	13.5	100	31	53	8	330
1.60	200000	150	6.5	13.5	100	31	53	8	965
1.60	200000	150	6.5	13.5	100	31	53	8	2100
.30	200000	150	6.5	15	100	39	53	6	10
.70	200000	150	6.5	15	100	39	53	6	68
1.70	200000	150	6.5	15	100	39	53	6	965
1.90	200000	150	6.5	15	100	39	53	6	2100
.30	200000	150	7	14.5	100	45	53	10	330
.90	200000	150	7	14.5	100	45	53	10	1060
.90	200000	150	7	14.5	100	45	53	10	2100
.10	200000	150	6	12	100	42.5	14	14	2
.30	200000	150	6	12	100	42.5	14	14	10
.70	200000	150	6	12	100	42.5	14	14	20
2.30	200000	150	6	12	100	42.5	14	14	50
.30	200000	150	6.5	14	100	45.5	16	16	10
1.20	200000	150	6.5	14	100	45.5	16	16	50
2.30	200000	150	6.5	14	100	45.5	16	16	110
2.90	200000	150	6.5	14	100	45.5	16	16	130

THREE-LAYER FLEXIBLE PAVEMENT DATA

THREEL CONT 15: 6:32 04/21/78 FILE PAGE NO. 3

1.50	200000	150	6.5	14.5	100	2	87	13	110
4.00	200000	150	6.5	14.5	100	2	87	13	530
5.10	200000	150	6.5	14.5	100	2	87	13	700
.30	200000	150	7	14	100	9	87	13	10
.60	200000	150	7	14	100	9	87	13	110
1.80	200000	150	7	14	100	9	87	13	1060
2.40	200000	150	7	14	100	9	87	13	2100
.30	200000	150	4	5.5	100	55	65	10	10
.40	200000	150	4	5.5	100	55	65	10	50
1.10	200000	150	4	5.5	100	55	65	10	210
1.50	200000	150	4	5.5	100	55	65	10	530
1.70	200000	150	4	5.5	100	55	65	10	3180
.30	200000	150	6	4.5	100	54	65	14	10
.85	200000	150	6	4.5	100	54	65	14	110
1.55	200000	150	6	4.5	100	54	65	14	530
1.80	200000	150	6	4.5	100	54	65	14	1060
1.95	200000	150	6	4.5	100	54	65	14	2100
.10	200000	150	4.5	9	100	49	65	8	10
.60	200000	150	4.5	9	100	49	65	8	110
1.10	200000	150	4.5	9	100	49	65	8	530
1.40	200000	150	4.5	9	100	49	65	8	1060
1.70	200000	150	4.5	9	100	49	65	8	3180
.25	200000	150	9.5	5.5	100	48	65	13	50
1.75	200000	150	9.5	5.5	100	48	65	13	530
1.90	200000	150	9.5	5.5	100	48	65	13	1060
1.90	200000	150	9.5	5.5	100	48	65	13	3180
.15	200000	150	4.5	16.5	100	43	65	10	3
.20	200000	150	4.5	16.5	100	43	65	10	10
.55	200000	150	4.5	16.5	100	43	65	10	210
1.20	200000	150	4.5	16.5	100	43	65	10	1060
1.25	200000	150	4.5	16.5	100	43	65	10	3180
.15	200000	150	7	14.5	100	45	65	11	2
.60	200000	150	7	14.5	100	45	65	11	210
.80	200000	150	7	14.5	100	45	65	11	420
1.10	200000	150	7	14.5	100	45	65	11	530
1.25	200000	150	7	14.5	100	45	65	11	2100
.30	200000	150	10	12	100	45	65	8	10
.70	200000	150	10	12	100	45	65	8	110
1.60	200000	150	10	12	100	45	65	8	530
2.00	200000	150	10	12	100	45	65	8	2100
.20	104000	190	3	6	88	24	94	5.6	74
.50	104000	190	3	6	88	24	94	5.6	592
.80	104000	190	3	6	88	24	94	5.6	2553
1.20	104000	190	3	6	88	24	94	5.6	4625
1.40	104000	190	3	6	88	24	94	5.6	6771
.30	104000	190	3	6	88	24	94	5.6	74
.40	104000	190	3	6	88	24	94	5.6	592
.70	104000	190	3	6	88	24	94	5.6	2553
1.00	104000	190	3	6	88	24	94	5.6	4625
1.30	104000	190	3	6	88	24	94	5.6	6771
.20	104000	190	3	6	88	24	94	5.6	74
.40	104000	190	3	6	88	24	94	5.6	592
.60	104000	190	3	6	88	24	94	5.6	2553
.90	104000	190	3	6	88	24	94	5.6	4625
1.00	104000	190	3	6	88	24	94	5.6	6771

THREE-LAYER FLEXIBLE PAVEMENT DATA

THREEL CONT 15: 6:32 04/21/78 FILE PAGE NO. 4

.40	124000	190	3	6	100	33	52	4	74
1.00	124000	190	3	6	100	33	52	4	592
1.70	124000	190	3	6	100	33	52	4	2553
2.10	124000	190	3	6	100	33	52	4	4625
.80	124000	190	3	6	100	33	52	4	74
1.50	124000	190	3	6	100	33	52	4	592
2.30	124000	190	3	6	100	33	52	4	2553
2.80	124000	190	3	6	100	33	52	4	4625
.50	124000	190	3	6	100	33	52	4	74
1.10	124000	190	3	6	100	33	52	4	592
1.90	124000	190	3	6	100	33	52	4	2553
2.50	124000	190	3	6	100	33	52	4	4625
.40	125000	250	3	6	100	24	100	4.4	74
.70	125000	250	3	6	100	24	100	4.4	222
.90	125000	250	3	6	100	24	100	4.4	592
1.90	125000	250	3	6	100	24	100	4.4	1110
.60	125000	250	3	6	100	24	100	4.4	74
.70	125000	250	3	6	100	24	100	4.4	222
1.30	125000	250	3	6	100	24	100	4.4	592
2.10	125000	250	3	6	100	24	100	4.4	1110
.30	125000	250	3	6	100	24	100	4.4	74
.50	125000	250	3	6	100	24	100	4.4	222
.80	125000	250	3	6	100	24	100	4.4	592
1.10	125000	250	3	6	100	24	100	4.4	1110
.80	149000	250	3	6	100	33	43	4.2	74
1.20	149000	250	3	6	100	33	43	4.2	222
2.20	149000	250	3	6	100	33	43	4.2	629
.90	149000	250	3	6	100	33	43	4.2	74
1.40	149000	250	3	6	100	33	43	4.2	222
2.20	149000	250	3	6	100	33	43	4.2	629
.70	149000	250	3	6	100	33	43	4.2	74
1.00	149000	250	3	6	100	33	43	4.2	222
1.80	149000	250	3	6	100	33	43	4.2	629
.06	85000	200	1	12	100	29	92	13	63
.22	85000	200	1	12	100	29	92	13	628
.31	85000	200	1	12	100	29	92	13	6280
.42	85000	200	1	12	100	29	92	13	12560
.48	85000	200	1	12	100	29	92	13	14353
.06	75000	200	1	12	100	15	63	12	63
.29	75000	200	1	12	100	15	63	12	628
.56	75000	200	1	12	100	15	63	12	6280
.59	75000	200	1	12	100	15	63	12	14353

APPENDIX IV.--INPUT, OUTPUT, AND PROGRAM LISTINGS

APPENDIX IV.--INPUT, OUTPUT, AND PROGRAM LISTINGS

The RUTDEP program was written in Fortran IV computer language and was run using the WES 600 time-sharing computer system. A complete listing of the program is included. With minor modifications, the RUTDEP program should be adaptable to any computer system if the following conditions are satisfied:

1. A time-sharing computer system that will allow Fortran IV computer code must be used.

2. A remote terminal is necessary to access the time-sharing computer system.

3. The RUTDEP program must be stored on disc in the time-sharing system.

4. The ability to create and store input data files on disc in the time-sharing system.

When these conditions are satisfied, the program can be executed as shown in the following example. For ease in running the RUTDEP program, the input data are entered in a step-by-step process in response to questions printed by the remote terminal. Included with the example problem shown below is a discussion of each step. The responses of the computer user are underlined.

The initial step is to access the computer system and call up the RUTDEP program. With the WES 600 computer system this is done as follows:

```
*** WES-TSS NOTIFIED ***

HIS SERIES 600 ON 01/31/78 AT 10.750 CHANNEL 6575
```

APPENDIX IV.--INPUT, OUTPUT, AND PROGRAM LISTINGS

```
USER ID -ROSF111
PASSWORD--
XXXXXXXXXXX

SYSTEM ?FORTRAN
OLD OR NEW-OLD RUTDEP
READY
*RUN
```

After the RUTDEP program is called, the run command is given and the computer asks for the type of problem to be run.

```
TYPE PROBLEM:
        UNSURFACED C1>C2 = 1
        UNSURFACED C1<C2 = 2
        ASPHALT WO/SUBBASE,8 VAR. = 3
        ASPHALT W/SUBBASE,10 VAR. = 4

  =4
```

A listing of the four types of problems is printed out with an identification number (1, 2, 3, 4) for each type. The appropriate number is then entered for the type of problem the user requires. In this example an asphalt pavement with a subbase was required, so the number "4" was entered.

```
INPUT - ALLOWABLE RUT DEPTR.
= 1.0
```

The next item of input is the allowable rut depth, which is used in computing the reliability statistic. An allowable rut depth of 1.0 inch was selected.

```
INPUT MODE - FILE(1),KEYBOARD(2),COMBINATION(3)?
= 2
```

The next question asked by the computer is how the actual problem data will be entered into the computer; by a data file, by the keyboard on the terminal, or by a combination of these two. The computer user selects one of the three modes by entering the identification number (1, 2, 3).

Depending upon the mode selected the computer asks one of two questions. If all of the data are to be entered by the file mode (1) or if part of the data are to be entered by a file (3), the computer responds by asking for the name of the data file. Instructions on how to create an input data file will be discussed later. In this example, the second input mode was selected, which is input by the keyboard. Since no data file is required with this mode, the computer did not ask for a file name but went to the next step, asked for the input stat code of the variables, and listed the variables in order.

```
INPUT - STAT CODE - COMPUTED(0), GIVEN(1)
P   TP  R   T1  T2  C1  T3  C2  C3
=1  1   1   1   1   1   1   1   1
```

A zero or one should be entered on the keyboard by the user for each variable listed. The number zero instructs the computer to compute the mean and variance of the variable from the data file, while the number one tells the computer that the mean and variance will be typed in from the terminal. Since no data file was used for this example problem, the number one was entered for all nine variables. The computer then asks for the mean and variance of the first variable. The mean and variance may be separated by a comma or a space.

```
INPUT MEAN & VARIANCE FOR -  P
=18000. 500000.
```

When the data are entered for the ESWL (P) the computer asks for the input data of the second variable.

```
INPUT MEAN & VARIANCE FOR - TP
=80. 60.
```

After the user responds to this question, the computer asks for the mean and variance of the remaining variables one at a time.

```
INPUT MEAN & VARIANCE FOR -  R
=40000. 1000000.
INPUT MEAN & VARIANCE FOR -  T1
=2.5 0.5
INPUT MEAN & VARIANCE FOR -  T2
=6.,1.
INPUT MEAN & VARIANCE FOR -  C1
=50.,10.
INPUT MEAN & VARIANCE FOR -  T3
=6. 1.
INPUT MEAN & VARIANCE FOR -  C2
=25. 7.
INPUT MEAN & VARIANCE FOR -  C3
=10.,2.
```

In entering data by either a data file or by the keyboard, the ESWL (P) should always be in pounds, the tire pressure (TP) should be in psi, and all thicknesses should be in inches. After the mean and variance for the last variable is entered, the computer executes the program and lists the output.

VARIABLE	MEAN	VARIANCE	STAT CODE
P	18000.00	500000.00	1
TP	80.00	60.00	1
R	40000.00	1000000.00	1
T1	2.50	0.50	1
T2	6.00	1.00	1
C1	50.00	10.00	1
T3	6.00	1.00	1
C2	25.00	7.00	1
C3	10.00	2.00	1

The first item of input is a listing of the variables along with the mean and variance of each variable. The stat code listing of the output indicates if the mean and variance of each variable was computed (0) or given by the user (1).

```
MEAN VALUE OF RUT DEPTH            =    0.865862
EXPECTED VALUE OF RUT DEPTH        =    0.900146
EXPECTED VARIANCE OF RUT DEPTH     =    0.019569
RELIABILITY STATISTIC              =    0.713800
```

The remaining output completes the problem. The computer then repeats the type of problem question.

```
TYPE PROBLEM:
     UNSURFACED C1>C2 = 1
     UNSURFACED C1<C2 = 2
     ASPHALT WO/SUBBASE,8 VAR. = 3
     ASPHALT W/SUBBASE,10 VAR. = 4
=
```

If another problem is to be run, the user enters the proper identification number as before. If no more problems are to be run, the number 9 should be entered and the computer will terminate the program.

In the above example, the mean and variance data were input from the terminal keyboard. If the computer user had desired to respond to the input mode question by selecting a file input mode (1) or a combination of file and keyboard (3), then a data file must be created and stored before the RUTDEP program is run. The mean and variance is then computed from the data points in the data file. With the file mode, the data file should be created with the following format:

Line No.	N_1		
Line No.	Value (1)	Value (2)	Value (N_1)
Line No.	N_2		
Line No.	Value (2)	Value (2)	Value (N_2)

.
.
.

```
Line No.     Ni
Line No.     Value (1)     Value (2) ....... Value (Ni)
```

Where:

Line No. = Line number which is needed for each line of data in ascending order

N_i = Number of data points for i^{th} variable

Value (i) = Value of individual data point. Each value in a line of data should be separated by a comma or a space. It may require more than one line to include all of the data points for a given variable.

i = Number of dependent variables. For pavement types 1 and 2, i = 6; for pavement type 3, i = 7; and for pavement type 4, i = 9.

After the data file is created, it should be stored under a unique data file name, which may have a maximum of six alphanumeric characteristics. An example of a data file for pavement type 1 is shown below. It was stored under the file name "DATA 1."

```
*LIST DATA1

100    6
101    14000. 14400. 15000. 15300. 15300. 16000.
110    6
111    60. 60. 70. 75. 75. 80.
120    5
121    4200. 4800. 5000. 5500. 5500.
130    7
131    7.5  8.0  8.5  9.0  9.0  10.0  11.0
140    4
141    21.  25.  27.  27.
150    3
151    9.  9.  12.
```

Data points for all six dependent variables were listed with three seven points per variable.

When test data are available for only some of the variables, then a combination of file and keyboard input (input mode 3) would be required. The data file would be created in a format similar to that of input mode 1. For variables without data points, a one would be entered for

N_i , and a zero would be entered on the following line number where the values of the data points would normally be listed. An example of this type of data format, which was stored under the data file name "DATA 2," is shown below.

```
*LIST DATA2

100  6
101  14000.  14400.  15000.  15300.  15300.  16000.
200  1
201  0.
300  1
301  0.
400  7
401  7.5  8.  8.5  9.  9.  10.  11.
500  4
501  21.  25.  27.  27.
600  1
601  0.
```

Data points for the first, fourth, and fifth variables are listed, while a one and a zero are listed for the other three variables. The sequence of line numbers for file "DATA 2" is different from file "DATA 1." The sequence could have been identical if desired. The only rule that must be followed is that the line numbers must be in ascending order.

In the following examples, the three different types of input modes were used to work one problem. When the file mode input (1) and combination mode input (3) are selected, the computer asks for the data file name. In these examples, DATA 1 was given for mode 1, and DATA 2 was given for mode 3. The next question for all three modes is the stat code for all three modes. For mode 1, a zero is entered for all variables, and for mode 2, a one is entered for all variables. For mode 3, a zero is given for the variables with data points, and a one is given for the variables where the user has to type in the mean and variance.

Following the last example, the computer again asked for the type of problem. A nine was entered and the program terminated.

```
HIS SERIES 600 ON  04/21/78 AT 10.761  CHANNEL 5416

USER ID -
ILLEGAL ID-RETYPE--R0SF111
PASSWORD--
[redacted]

SYSTEM ?FORT
ALL USERS SEE INFO 7RESTORE FOR RESTORES FROM 7TRK 556BPI FILSYS SAVE TAB

OLD OR NEW-NEW
READY
*OLD WESLIB/PAGER,P@E
YOU HAVE FILE ACCESSED WITHOUT READ PERMISSION
SYSTEM ?FORT O WESLIB/PAGER,R
READY
*RUN

        04/21/78    10.798

   PROGRAM PAGER -- LISTS FROM ANY PAGE TO THE END OF THE FILE,
   WITH OR WITHOUT SPECIAL "NEW PAGE" CHARACTER.

   (PROGRAM PAGES LISTS SELECTED PAGES ONLY.)


ENTER T IF YOU WANT THE PAGED LISTING ON YOUR TIME-SHARING TERMINAL
   OR B IF YOU WANT IT ON YOUR OFFICE'S BATCH PRINTER -
    = T
ENTER CATALOG DESCRIPTION (40 CHARACTERS MAX) OR A
   "CARRIAGE RETURN" IF IT IS IN YOUR AFT OR USER
    MASTER CATALOG =
ENTER FILE NAME = RUTDEP
ENTER PAGE SIZE IN INCHES17 11
ENTER STARTING VALUE OF PAGE LOCATION NUMBER IN
   FILE TO BE LISTED = 1
ENTER STARTING VALUE FOR PAGE NUMBER TO BE PRINTED
   AT THE BOTTOM OF EACH PAGE (OMITTED IF ZERO) =
ENTER YOUR "NEW PAGE" INDICATOR CHARACTER
   OR A "CARRIAGE RETURN" TO NOT USE ONE = ^
"NEW PAGE" INDICATOR MUST BE IN FIRST 20 COLUMNS OF LINE.
```

```
C*****---PAGE 10---
C*********************************************************************
C
C      PROGRAM RUT - COMPUTES RUT DEPTH FOR FOUR POSSIBLE
C                    PAVEMENT TYPES.
C
C      CODED FOR WES 600 TIMESHARE COMPUTER SYSTEM.
C
C      CODED BY: H. R. AUSTIN
C                E. ODOM
C                SOILS & PAVEMENTS LABORATORY
C                WATERWAYS EXPERIMENT STATION
C                SEPTEMBER 1977
C
C*********************************************************************
       DIMENSION RD(300),P(300),TP(300),T1(300),T2(300),C1(300)
       DIMENSION T3(300),C2(300),C3(300),R(300)
       DIMENSION CASE(4),M(10),V(10),COMPUTE(10)
       DIMENSION SKIP(300)
       INTEGER TYPE,COMPUTE,CASE,START,STOP
       REAL MRD,MP,MTP,MT1,MT2,MC1,MT3,MC2,MC3,MR
       REAL M,K
       CHARACTER FNAME*6,FNAME2*8
       CHARACTER CASE1*2(6),CASE2*2(6),CASE3*2(7),CASE4*2(9)
       DATA CASE/6,6,7,9/
       DATA CASE1/"P ","TP","R ","T1","C1","C2"/
       DATA CASE2/"P ","TP","R ","T1","C1","C2"/
       DATA CASE3/"P ","TP","R ","T1","T2","C1","C3"/
       DATA CASE4/"P ","TP","R ","T1","T2","C1","T3","C2","C3"/
C
C
          I=0
 1010     CONTINUE
C
C      READ INPUT DATA
          GO TO 20
 1020     CONTINUE
C
C      PRINT MEAN AND VARIANCE RESULTS
          GO TO 30
 1030     CONTINUE
C
C      SELECT AND SOLVE CORRECT RUT DEPTH EQUATION AND OUTPUT RESULTS
          GO TO(41,42,43,44),TYPE
 1040     CONTINUE
C      LOOP BACK THROUGH FOR ANOTHER PROBLEM
          GO TO 1010
 1090     CONTINUE
C
C      END OF PROGRAM
          PRINT,"NORMAL TERMINATION"
          STOP
C
C*****---END OF PAGE 10---
```

```
C^    ---PAGE 20---
C
C     READ INPUT DATA
 20   CONTINUE
C
C
          I=I+1
          PRINT,"TYPE PROBLEM:"
          PRINT,"       UNSURFACED C1>C2 = 1"
          PRINT,"       UNSURFACED C1<C2 = 2"
          PRINT,"       ASPHALT WO/SUBBASE,8 VAR. = 3"
          PRINT,"       ASPHALT W/SUBBASE,10 VAR. = 4"
          READ(5,800)TYPE
C
          IF(TYPE.GT.4)GO TO 1090
          PRINT,"INPUT - ALLOWABLE RUT DEPTH."
          READ(5,800)ARD
C
C
C
          PRINT,"INPUT MODE - FILE(1),KEYBOARD(2),COMBINATION(3)?"
          READ(5,800)IO
C
C
          GO TO(11,13,11),IO
C     DATA FILE WILL BE USED
 11       CONTINUE
C
C     DATA FILE WHERE PAVEMENT DATA IS STORED
C
              PRINT,"DATA FILE NAME?"
              READ(5,1)FNAME
  1           FORMAT(A6)
              ENCODE(FNAME2L2)"/",FNAME,":"
  2           FORMAT(A1,A6,A1)
              CALL ATTACH(10,FNAME2,3,0,,)
 13       CONTINUE
              NVAR=CASE(TYPE)
C
C     TYPE A 1 IF MEAN & VARIANCE WILL BE FURNISHED FROM KEYBOARD
C     TYPE A 0 IF MEAN & VARIANCE COMPUTED IN SUBROUTINE STAT.
C
              IF(TYPE.LT.3)PRINT 821,CASE1
              IF(TYPE.EQ.3)PRINT 823,CASE3
              IF(TYPE.EQ.4)PRINT 822,CASE4
              READ(5,800)(COMPUTE(I1),I1=1,NVAR)
C
C
              DO 199 L=1,NVAR
                 L2=L
                 IF(COMPUTE(L2).EQ.0)CALL STAT(M,V,L2)
                 IF(IO.LT.3)GO TO 199
                 IF(COMPUTE(L2).EQ.0)GO TO 199
                 READ(10,800)LINENO,NONE
                 START=1
```

```
                  STOP=8
 25                   CONTINUE
                  IF(NONE-STOP)22,22,21
 22                   READ(10,800)LINENO,(SKIP(L3),L3=START,NONE)
                      GO TO 199
 21                   READ(10,800)LINENO,(SKIP(L3),L3=START,STOP)
                      START=STOP+1
                      STOP=STOP+8
                      GO TO 25
 199          CONTINUE
 800          FORMAT(V)
 821          FORMAT("INPUT - STAT CODE - COMPUTED(0),GIVEN(1)",
&                     /6(A2,2X))
 822          FORMAT("INPUT - STAT CODE - COMPUTED(0),GIVEN(1)",
&                     /9(A2,2X))
 823          FORMAT("INPUT - STAT CODE - COMPUTED(0),GIVEN(1)",
&                     /7(A2,2X))
C
C
              DO 201 L=1,NVAR
                  IF(COMPUTE(L).EQ.0)GO TO 201
                  IF(TYPE.LT.3)PRINT 824,CASE1(L)
                  IF(TYPE.EQ.3)PRINT 824,CASE3(L)
                  IF(TYPE.EQ.4)PRINT 824,CASE4(L)
 824              FORMAT("INPUT MEAN & VARIANCE FOR -     ",A2)
                  READ(5,800)M(L),V(L)
 201          CONTINUE
      GO TO 1020
C     ---END OF PAGE 20---
```

RUTDEP CONT 10:50:40 04/21/78 FILE PAGE NO. 4

```
C     ---PAGE30---
C
 30   CONTINUE
C
C     PRINT MEAN & VARIANCE RESULTS.
C
          PRINT 825
 825      FORMAT(//40X,"STAT"/,"VARIABLE      MEAN          VARIANCE"
&                ,5X,"CODE")
          DO 204 L=1,NVAR
              IF(TYPE.LT.3)PRINT 826,CASE1(L),M(L),V(L),COMPUTE(L)
              IF(TYPE.EQ.3)PRINT 826,CASE3(L),M(L),V(L),COMPUTE(L)
              IF(TYPE.EQ.4)PRINT 826,CASE4(L),M(L),V(L),COMPUTE(L)
 826          FORMAT(4X,A2,F14.2,F14.2,I8)
 204      CONTINUE
C
C     RELEASE INPUT FILE
      CALL DETACH(10,,)
C
      GO TO 1030
C
C     ---END OF PAGE 30---
```

```
C       ---PAGE 41---
C
C       C1 > C2, 7 VARIABLES
C
C
 41     CONTINUE
           MP=M(1)
           MP=MP/1000.
           VP=V(1)
           VP=VP/1000000.
           MTP=M(2)
           VTP=V(2)
           MR=M(3)
           VR=V(3)
           MT1=M(4)
           VT1=V(4)
           MC1=M(5)
           VC1=V(5)
           MC2=M(6)
           VC2=V(6)
           K=0.17410
           A=0.4707
           B=0.5695
           C=0.2476
           D=-2.0020
           E=-0.9335
           F=-0.2848
           Q1=K*MP**A*MTP**B*MR**C
           Q2=(ALOG10(MT1))**D
           Q3=MC1**E*MC2**F
           Q=Q1*Q2*Q3
           P2=(A*(A-1)*VP)/MP**2
           TP2=(B*(B-1)*VTP)/MTP**2
           R2=(C*(C-1.)*VR)/MR**2
           T12A=0.4343*D*VT1
           T12B=MT1**2*ALOG10(MT1)
           T12C=(0.4343*(D-1.))/ALOG10(MT1)
           T12=T12A/T12B*(T12C-1.)
           C12=(E*(E-1.)*VC1)/MC1**2
           C22=(F*(F-1.)*VC2)/MC2**2
           ERD=Q+(0.5*Q*(P2+TP2+R2+T12+C12+C22))
           P1=(A**2*VP)/MP**2
           TP1=(B**2*VTP)/MTP**2
           R1=(C**2*VR)/MR**2
           T11A=(0.4343*D)**2*VT1
           T11B=(MT1)**2*(ALOG10(MT1))**2
           T11=T11A/T11B
           C11=E**2*VC1/MC1**2
           C21=(F**2*VC2)/MC2**2
           VRD=Q**2*(P1+TP1+R1+T11+C11+C21)-(0.25*Q**2)*
&             (P2**2+TP2**2+R2**2+T12**2+C12**2+C22**2)
           WRITE(6,904)Q
           WRITE(6,903)ERD
           WRITE(6,902)VRD
 902       FORMAT(10X,"EXPECTED VARIANCE OF RUT DEPTH=",F16.6//)
```

```
903    FORMAT(10X,"EXPECTED VALUE OF RUT DEPTH    =",F16.6//)
904    FORMAT(//10X,"MEAN VALUE OF RUT DEPTH       =",F16.6//)
       REL=(ARD-ERD)/VRD**0.5
       WRITE(6,919)REL
919    FORMAT(10X,"RELIABILITY STATISTIC         =",F16.6//)
C
     GO TO 1040
C
C
C    ---END OF PAGE 41---
```



```
C    ---PAGE 42---
C
C   C1 < C2, 7 VARIABLES.
C
C
42   CONTINUE
       MP=M(1)
       VP=V(1)
       MTP=M(2)
       VTP=V(2)
       MR=M(3)
       VR=V(3)
       MT1=M(4)
       VT1=V(4)
       MC1=M(5)
       VC1=V(5)
       MC2=M(6)
       VC2=V(6)
       K=0.11009
       A=0.4925
       B=0.8548
       C=0.5018
       D=0.4293
       E=-1.9773
       F=-1.2015
       Q1=K*MP**A*MTP**B*MR**C
       Q2=(ALOG10(MT1))**D
       Q3=MC1**E*MC2**F
       Q=Q1*Q2*Q3
       P2=(A*(A-1)*VP)/MP**2
       TP2=(B*(B-1)*VTP)/MTP**2
       R2=(C*(C-1.)*VR)/MR**2
       T12A=0.4343*D*VT1
       T12B=MT1**2*ALOG10(MT1)
       T12C=(0.4343*(D-1.))/ALOG10(MT1)
       T12=T12A/T12B*(T12C-1.)
       C12=(E*(E-1.)*VC1)/MC1**2
       C22=(F*(F-1.)*VC2)/MC2**2
       ERD=Q+(0.5*Q*(P2+TP2+R2+T12+C12+C22))
```

```
      P1=(A**2*VP)/MP**2
      TP1=(B**2*VTP)/MTP**2
      R1=(C**2*VR)/MR**2
      T11A=(0.4343*D)**2*VT1
      T11B=(MT1)**2*(ALOG10(MT1))**2
      T11=T11A/T11B
      C11=E**2*VC1/MC1**2
      C21=(F**2*VC2)/MC2**2
      VRD=Q**2*(P1+TP1+R1+T11+C11+C21)-(0.25*Q**2)*
&         (P2**2+TP2**2+R2**2+T12**2+C12**2+C22**2)
      WRITE(6,904)Q
      WRITE(6,903) EPD
      WRITE(6,902) VRD
      REL=(ARD-EPD)/VRD**0.5
      WRITE(6,919)REL
C
   GO TO 1040
C
C
C  ---END OF PAGE 42---
```

```
C*     ---PAGE 43---
C
C ASPHALTIC CONCRETE WITHOUT SUBGRADE, 8 VARIABLES.
C
C
 43    CONTINUE
          MP =M(1)
          MP =MP/1000.
          VP =V(1)
          VP =VP/1000000.
          MTP =M(2)
          VTP =V(2)
          MR =M(3)
          VR =V(3)
          MT1 =M(4)
          VT1 =V(4)
          MT2 =M(5)
          VT2 =V(5)
          MC1 =M(6)
          VC1 =V(6)
          MC2 =M(7)
          VC2 =V(7)
          K =1.9431
          A =1.3127
          B =0.0499
          C =0.3240
          D=-3.4204
          E=-1.6877
          F=-0.1156
          Q1=K*MP**A*MTP**B*MR**C
          Q2=(ALOG10(1.25*MT1+MT2))**D
          Q3=MC1**E*MC2**F
          Q =Q1*Q2*Q3
          P2=(A*(A-1)*VP)/MP**2
          TP2=(B*(B-1)*VTP)/MTP**2
          R2=(C*(C-1.)*VR)/MR**2
          T12A =1.25**2*0.4343*D*VT1
          T12B =(1.25*MT1+MT2)**2*ALOG10(1.25*MT1+MT2)
          T12C =((0.4343*(D-1.))/ALOG10(1.25*MT1+MT2))
          T12=T12A/T12B*(T12C-1.)
          T22A =0.4343*D*VT2
          T22=T22A/T12B*(T12C-1.)
          C12=(E*(E-1.)*VC1)/MC1**2
          C22=(F*(F-1.)*VC2)/MC2**2
          ERD=Q+(0.5*Q*(P2+TP2+R2+T12+T22+C12+C22))
          P1=(A**2*VP)/MP**2
          TP1=(B**2*VTP)/MTP**2
          R1=(C**2*VR)/MR**2
          T11A =1.25**2*(0.4343*D)**2*VT1
          T11B =(1.25*MT1+MT2)**2*(ALOG10(1.25*MT1+MT2))**2
          T11=T11A/T11B
          T21A =(0.4343*D)**2*VT2
          T21=T21A/T11B
          C11=E**2*VC1/MC1**2
          C21=(F**2*VC2)/MC2**2
```

```
       VRD=Q**2*(P1+TP1+R1+T11+T21+C11+C21)-(0.25*Q**2)*
&          (P2**2+TP2**2+R2**2+T12**2+T22**2+C12**2+C22**2)
       WRITE(6,904)Q
       WRITE(6,903)ERD
       WRITE(6,902)VRD
       REL=(ARD-ERD)/VRD**0.5
       WRITE(6,919)REL
C
    GO TO 1040
C
C
C   ---END OF PAGE 43---
```

```
C^     ---PAGE 44---
C
C ASPHALTIC CONCRETE WITH SUBGRADE, 10 VARIABLES.
C
C
 44    CONTINUE
         MP=M(1)
         MP=MP/1000.
         VP=V(1)
         VP=VP/1000000.
         MTP=M(2)
         VTP=V(2)
         MR=M(3)
         VR=V(3)
         MT1=M(4)
         VT1=V(4)
         MT2=M(5)
         VT2=V(5)
         MC1=M(6)
         VC1=V(6)
         MT3=M(7)
         VT3=V(7)
         MC2=M(8)
         VC2=V(8)
         MC3=M(9)
         VC3=V(9)
         K=0.031171
         A=1.5255
         B=0.0897
         C=0.345
         D=-0.8847
         E=-0.7616
         F=-1.1674
         G=-0.5505
         H=-0.3089
         Q1=K*MP**A*MTP**B*MR**C
         Q2=(ALOG10(1.25*MT1+MT2))**D
         Q3=MC1**E*(ALOG10(MT3))**F*MC2**G*MC3**H
         Q=Q1*Q2*Q3
         P2=(A*(A-1)*VP)/MP**2
         TP2=(B*(B-1)*VTP)/MTP**2
         R2=(C*(C-1.)*VR)/MR**2
         T12A=1.25**2*0.4343*D*VT1
         T12B=(1.25*MT1+MT2)**2*ALOG10(1.25*MT1+MT2)
         T12C=((0.4343*(D-1.))/ALOG10(1.25*MT1+MT2))
         T12=T12A/T12B*(T12C-1.)
         T22A=0.4343*D*VT2
         T22=T22A/T12B*(T12C-1.)
         C12=(E*(E-1.)*VC1)/MC1**2
         T32A=0.4343*F*VT3
         T32B=MT3**2*ALOG10(MT3)
         T32C=0.4343*(F-1.)/ALOG10(MT3)
         T32=T32A/T32B*(T32C-1.)
         C22=(G*(G-1.)*VC2)/MC2**2
         C32=(H*(H-1.)*VC3)/MC3**2
```

```
        ERD=Q+(0.5*Q*(P2+TP2+R2+T12+T22+C12+T32+C22+C32))
        P1=(A**2*VP)/MP**2
        TP1=(B**2*VTP)/MTP**2
        R1=(C**2*VR)/MR**2
        T11A=1.25**2*(0.4343*D)**2*VT1
        T11B=(1.25*MT1+MT2)**2*(ALOG10(1.25*MT1+MT2))**2
        T11=T11A/T11B
        T21A=(0.4343*D)**2*VT2
        T21=T21A0T11B
        C11=E**2*VC1/MC1**2
        T31A=(0.4343*F)**2*VT3
        T31B=MT3**2*ALOG10(MT3)**2
        T31=T31A/T31B
        C21=(G**2*VC2)/MC2**2
        C31=(H**2*VC3)/MC3**2
        VRD=Q**2*(P1+TP1+R1+T11+T21+C11+T31+C21+C31)-(0.25*Q**2)*
&            (P2**2+TP2**2+R2**2+T12**2+T22**2+C12**2+T32**2+C22**2
&           +C32**2)
        WRITE(6,904)Q
        WRITE(6,903)ERD
        WRITE(6,902)VRD
        REL=(ARD-ERD)/VRD**0.5
        WRITE(6,919)REL
C
     GO TO 1040
C
     END
C
C    ---END OF PAGE 44---
```

```
C^      ---PAGE 50---
C
C       READ DATA FROM FILE. COMPUTES MEAN & VARIANCE.
C
        SUBROUTINE STAT(M,V,I)
C
C       READ DATA FROM FILE. COMPUTES MEAN & VARIANCE.
C
C
        DIMENSION VALUE(300),M(10),V(10)
        INTEGER TO,GO
        REAL MEAN,M
C
C       INPUT SCHEME FOR DATA FILE.
C
        READ(10,800)LINENO,N
        GO=1
        TO=8
   15   CONTINUE
        IF(N-TO)10,10,11
   10       READ(10,800)LINENO,(VALUE(J),J=GO,N)
  800       FORMAT(V)
            GO TO 12
   11       READ(10,800)LINENO,(VALUE(J),J=GO,TO)
            GO=TO+1
            TO=TO+8
            GO TO 15
   12   CONTINUE
C
C       CALCULATE MEAN & VARIANCE.
C
        SUMM=0.
        DO 180 J=1,N
            SUMM=VALUE(J)+SUMM
  180   CONTINUE
        MEAN=SUMM/N
        SUMV=0.
        DO 190 J=1,N
            SUMV=(VALUE(J)-MEAN)**2+SUMV
  190   CONTINUE
        IF(N.GT.30)N=N-1
        VAR=SUMV/N
        M(I)=MEAN
        V(I)=VAR
C
C       ---END OF PAGE 50---
C
        RETURN
        END
```

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Barber, Victor C

The deterioration and reliability of pavements / by Victor C. Barber, Eugene C. Odom, Robert W. Patrick. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

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References: p. 98-109.

1. Pavement design. 2. Pavement deterioration. 3. Pavements. 4. Reliability. I. Odom, Eugene C., joint author. II. Patrick, Robert W., joint author. III. United States. Army. Corps of Engineers. IV. United States. Forest Service. V. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; S-78-8.

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