HIGHWAY RESEARCH
CIRCULAR

Number 37 | Subject Area: Exploration-Classification (Soils), Foundations (Soils), Mechanics (Earth Mass), Soil Science, Construction, General Materials, Photogrammetry, Highway Design, Pavement Design, Bridge Design | August 1966

COMMITTEE ACTIVITY
Committee on Research Needs
Department of Soils, Geology and Foundations
Highway Research Board

REPORT ON RESEARCH NEEDS

Research Problem Statements

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Introduction

The initiation of the National Cooperative Highway Research Program by the American Association of State Highway Officials created a need for the development of a comprehensive listing of problems in the entire field of transportation. To develop such a listing, the Highway Research Board requested the various departments of the Board to prepare research problem statements within the areas of interest of each department.

The research problem statements contained in this edition of the Highway Research Circular have been prepared by the Department of Soils, Geology and Foundations. Each member of each committee within the Department was solicited for research problem statements within the scope of the committee of which he was a member. It was hoped that this procedure would assure that the problem statements submitted would be a complete representation of the problems in the need of solution through research in the field of soils, geology and foundations as related to transportation.

Prior to submission to the Board, the research problem statements were assembled and reviewed by the Committee on Research Needs of the Department. Due to the wide variety of subjects covered, the committee felt it necessary to fit the problem statements into a structure consisting of three broad problem areas. These problem areas were:

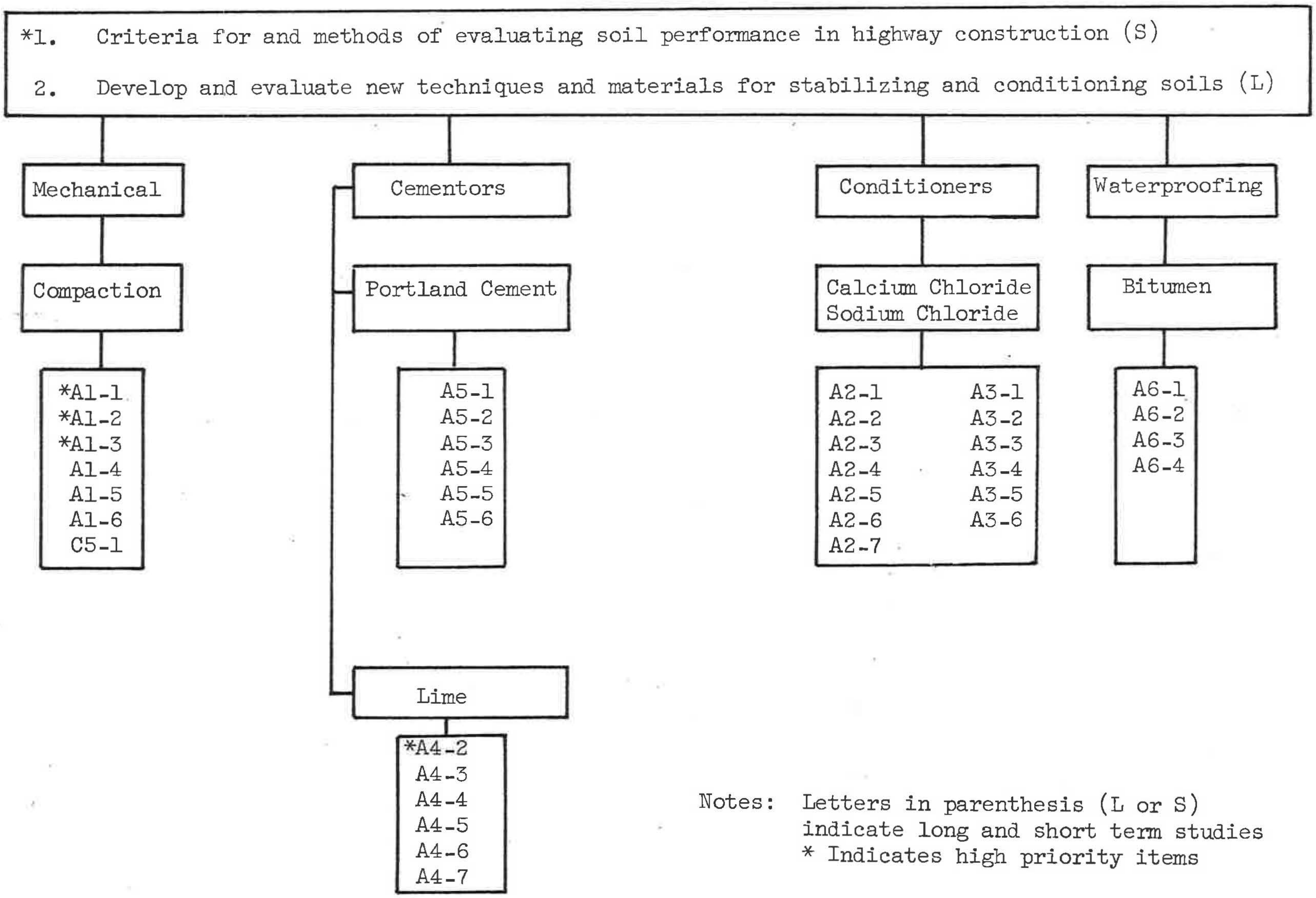
I Optimization of the Processing of Soil Systems
II Mechanics of Soil Systems
III Factors Influencing Soil Systems

Within these broad problem areas the committee further grouped the research efforts into studies of short duration and of long duration. The committee has also indicated the problems that it believed to be most urgent and, therefore, should be given highest research priority.

It is hoped that this structure will present a comprehensive overview of research needs in the field of soils, geology and foundations as related to highway transportation.

PROBLEM AREA NO. I

OPTIMIZATION OF THE PROCESSING OF SOIL SYSTEMS



Notes: Letters in parenthesis (L or S) indicate long and short term studies
* Indicates high priority items

PROBLEM AREA NO. II

MECHANICS OF SOIL SYSTEMS

1. Development of theories and methods for the analyses of soil masses and soil-structure interactions (L)

PAVE	MASSES	FOUND.	STRUCT.	DRAIN
B5-1	*B5-4	B3-2	*B4-1	B6-5
B5-2		B3-3	*B4-3	
B5-3		*B3-8	B4-4	
B5-5		B3-12	B4-5	
B5-6				

*2. Validation of analytical solutions by model and prototype measurements (S)

PAVE	MASSES	FOUND.	STRUCT.	DRAIN.
*A4-1	B3-1	B2-2	*B3-7	B2-1
B1-1		B3-4	B4-6	B6-1
B1-5		B3-5		B6-2
B1-8		*B3-6		B6-3
		*B3-9		B6-4

Notes: Letters in parenthesis (L or S) indicate long and short term studies
*Indicates high priority items

PROBLEM AREA NO. III

FACTORS INFLUENCING BEHAVIOR OF SOIL SYSTEMS, ROCK SYSTEMS AND SOIL ROCK SYSTEMS

1. The development of areal relationships of material properties including compilation of existing data (L)

B3-11
C1-1
C1-2
C1-3
C1-4
C1-5
C1-6
C1-8
C1-9
C2-7
C6-1
C6-2
C6-3
C6-4
C6-5
C6-6

2. Define and measure the critical properties and relationships governing soil and rock behavior (L)

B1-2	C3-1
B1-3	C3-2
B1-4	C3-3
B3-10	C3-4
B4-2	*C3-5
C1-7	C3-6
C1-10	C4-3
C2-1	C4-4
C2-2	C4-6
C2-3	
C2-4	
C2-5	
C2-6	
C2-8	
C2-9	
C2-10	

*3. Determine the detrimental effects of environmental factors, including frost and moisture, on pavement, soil and rock behavior (S)

B1-6
B1-7
C4-1
C4-2
C4-5
C4-7
C5-2
*C5-3
*C5-4

Notes: Letters in parenthesis (L or S) indicate long and short term studies
* Indicates high priority items

Research Problem Statements

A1-1 Problem: TO PREVENT THE CONSOLIDATION OR EXPANSION OF SOILS AND RELATED MATERIALS ADJACENT TO STRUCTURES.

Problem Area: The consolidation (settlement) or expansion of soils adjacent to structures with a resultant subsidence or raising of the pavement is almost universal. This requires costly traffic disrupting maintenance which often has to be repeated numerous times before the soil structure reaches a state of equilibrium.

Objectives: (a) To determine the state of density and moisture to which foundation and embankment soils adjacent to structures must be compacted to insure that no detrimental densification or expansion of the soil structure will develop in service.

(b) To determine types of soils that are most suited for backfilling operations, in order that they may be selected and used for that purpose when available.

(c) To develop economical methods of treating soils that are not ideally suited for backfilling adjacent to structures. There will, no doubt, be many areas where soils meeting the requirements determined under (b) will not be available.

(d) To determine the effect of construction procedures and specifications on the consolidation or expansion of soils and related materials adjacent to structures.

(e) To determine the magnitude of stresses including drag against abutments (or structures) caused by compacting close to the structure.

Urgency: From the standpoints of safety and economy in maintenance this problem is considered to be most urgent.

A1-2 Problem: TO DETERMINE THE BEST WAY TO COMPACT COHESIONLESS SOILS. It is generally known that good compaction to high density is the best way of stabilizing cohesionless soil subgrades, subbase courses and base courses for highways. However, even after much research and the development of good field procedures, contractors are still having difficulty obtaining satisfactory densities especially with particular soils.

Problem Area: This problem pertains to the compaction of cohesionless soils wherever encountered in construction processes.

Objective: The object of this research would be to evaluate all of the parameters affecting the compaction of cohesionless soils and analyze them on a dimensional basis so that the most efficient method for compacting cohesionless soils may be established. Previous research has identified several but not all of the parameters while few of these have been evaluated for their relative effects on compaction.

References: "Stabilization of Beach Sand by Vibrations," Gomes and Graves, HRB Bulletin 325.

"Compaction of Sands by Vibration Alone," Honigs, Valente and Graves, Highway Research Record No. 22.

"Variables Affecting the Vibratory Compaction of Sands," Honigs, unpublished M.S. Thesis, University of Notre Dame Library.

Urgency: Highways are costing more and highway soils are getting less compaction than they should because this knowledge is not available.

A1-3 Problem: TO ESTABLISH A COMPARISON OF THE ENGINEERING PROPERTIES OF LABORATORY COMPACTED SPECIMENS WITH THE ENGINEERING PROPERTIES OF THE FIELD COMPACTION OF THE SAME SOIL. Standard laboratory compaction tests are used to evaluate the adequacy of soils compacted in the field. The standard test is a dynamic test developed empirically. It is necessary to know to what extent laboratory test specimens reflect the properties of soil compacted in the field.

Problem Area: The problem pertains to all situations for which compacted soil may be used, e.g., highways, airports, backfilling, foundations for structures, etc.

Objectives: Up to the present time, no comprehensive evaluation of the properties of soils compacted in the field in relation to the properties of samples compacted by standard laboratory tests has been made. Many types of compactors are now being used in the field and their methods of compaction are quite different. As a result, the structure of the soil varies with the type of compactor used.

It is generally recognized that the properties of compacted soil vary with the structure of the soil. This fact is not taken into consideration in compaction specifications. Research is required to ascertain the harm done by neglecting the differences cited above. This would lead to a better understanding of the field compaction process and to a better method of specifying compaction.

References: "The Structure of Compacted Clay," T. W. Lambe, J. Soil Mech. and Found. Div., ASCE, Vol. 84, No. SM-2, Part I, p. 1654-1, May 1958.

"The Engineering Behavior of Compacted Clay," T. W. Lambe, J. Soil Mech. and Found. Div., ASCE, Vol. 84, No. SM-2, Part I, p. 1655-1, May 1958.

"Structure and Strength Characteristics of Compacted Clays," H. B. Seed and C. K. Chan, J. Soil Mech. and Found. Div., ASCE, Vol. 85, No. SM-5, pp. 87-128, October 1959.

Urgency: Such a program is basic to development of a capability for reliably predicting the properties of soil compacted in the field from laboratory compaction test results.

A1-4 Problem: TO DETERMINE THE EFFECTIVENESS OF VARIOUS TYPES OF COMPACTION EQUIPMENT WITH RESPECT TO ACHIEVING DESIGN STRENGTH OR STABILITY. Historically, density tests have been employed to measure the effectiveness of the compactive effort applied to embankment soils, subbase, base and bituminous surface course materials, even though it is the load carrying capacity rather than the density that is of concern. The density tests are being used as a substitute for strength tests on the assumption that strength and density are directly and linearly related. It is well established that this assumption is in error in that the strength-density relationship is affected by moisture content, particle size distribution, aggregate shape factor and particle orientation. It is also well established that the different types of compaction equipment have decidedly different effects on the moisture-density relationship (and therefore on the strength-density relationship) for different soils. The actual effect on the strength or load-carrying characteristics of various materials compacted with different types of equipment is not known. Direct measurements on strength are not normally made because existing procedures are excessively time consuming and expensive.

Problem Area: The problem pertains to determining the true effectiveness of various types of compaction equipment on a wide range of soil types so that proper consideration of obtainable strength might be used in the design processes.

Objectives: Using established procedures, such as seismic or sonic modulus determinations, evaluate the effectiveness of various types of compaction equipment on several typical soils and relate the measurements to obtained strength and performance.

References: See list of references included in "A Study of Earthwork Compaction" by A. W. Johnson and John W. Guinnee of the Highway Research Board. Part IV, Soil Properties Effected by Compaction and Effecting Compaction. Section VI, VII and VIII.

Urgency: In order to insure that highways being built under our accelerated construction program meet the minimum standards of strengh assumed in our design criteria, and that this strength is achieved as economically as possible, it is important that we have more direct understanding of the effectiveness of various types of equipment with respect to achieving this strength.

A1-5 Problem: TO DEVELOP TEST ROLLING CRITERIA FOR VARIOUS SOIL TYPES AND CONDITIONS.

Problem Area: The problem is common to all locations where test rolling (proof rolling) is being used to secure uniform subgrade of adequate supporting capability.

Objectives: To develop criteria needed for test rolling soils of different types and varying conditions to insure uniform subgrade of adequate supporting capability and to establish a correlation between these data and subgrade bearing values used in the design of pavement. These criteria should develop the proper desirable number of coverages, tire pressures, and wheel loads to be required.

References: "A List of References Under Study with Regard to Soil Compaction, Its Effects on Soil Properties and Its Use in Design and Construction," Part I and Part II, A. W. Johnson and J. W. Guinnee, Highway Research Board, May 1964.

Urgency: It is considered this program should proceed as quickly as possible to permit the findings to be put to use at an early date.

A1-6 Problem: TO DETERMINE PROPER COMPACTION REQUIREMENTS TO PREVENT DETRIMENTAL POST CONSTRUCTION CONSOLIDATION. It is not known what degree of compaction is necessary to insure that soil embankments will not consolidate in service. Some specifications set different compaction requirements for different soil types, while others require the same compaction for all soil types. Some specifications set different requirements for embankments of different height, while others require the same compaction for embankments of all heights. Some embankments may not be adequately compacted. Others may be compacted more than necessary.

Problem Area: The problem involves all highway embankments of all heights and all soil types at all geographical locations.

Objectives: The objective is to determine the proper compaction requirement, for various soil types and for various heights of embankment, to insure that highway embankments will not consolidate by detrimental amounts while supporting the pavement in service.

References: "Factors That Influence Field Compaction of Soils," A. W. Johnson and J. R. Sallberg, Highway Research Board, Bulletin 272, 1960.

"Factors Influencing Compaction Test Results," A. W. Johnson and J. R. Sallberg, Highway Research Board, Bulletin 319, 1962.

"A List of References Under Study with Regard to Soil Compaction, Its Effects on Soil Properties and Its Use in Design and Construction," A. W. Johnson and J. W. Guinnee, Highway Research Board, May 1964.

Urgency: Highway soil embankments are currently being constructed on a large scale throughout the country, with specifications for compaction in general use. Improved information on compaction required is of immediate importance to insure satisfactory performance, with the economy possible by not compacting to requirements higher than necessary.

A2-1
A3-1
Problem: TO DETERMINE THE EFFECTS OF CALCIUM CHLORIDE OR SODIUM CHLORIDE ON THE PERFORMANCE OF SOIL-AGGREGATE UNPAVED ROADS. There is a definite need for quantitative information relative to the advantages and limitations of the use of calcium chloride or sodium chloride as an additive in soil-aggregate mixtures.

Problem Area: These salt additives are used in an attempt to improve many of the thousands of miles of unpaved roads throughout the nation. Research is needed to improve the economic utilization of this method and to establish design criteria.

Objectives: (a) To determine the effects of the chemicals on density, compaction, and other engineering properties of the treated material as related to traffic volume and climate.

(b) To determine the uses and limitations of these salt additives and develop the economic advantages in reducing dust and improving (maintaining) strength and density.

(c) To develop the economics of stage construction using these salt additives during the first stage.

Urgency: Thousands of tons of these salt additives are being used each year and the development of criteria for economic use is urgently needed.

A2-2
A3-2
Problem: TO DETERMINE THE EFFECTS OF CALCIUM CHLORIDE OR SODIUM CHLORIDE ON THE RATE OF ROAD WEAR.

Problem Area: New unsurfaced roads are being constructed continuously. Many are programmed for paving at some later time, but most must be maintained as all weather unpaved roads in the meantime. The material comprising these unpaved roads is lost through several mechanisms such as grinding by traffic, surface erosion by water, wind, and leaching.

Objectives: (a) To develop a quantitative measuring rate of road wear for unpaved roads both untreated and treated.

(b) Establish the economic criteria for first application rate of these salt additives and for maintenance rates and intervals.

Urgency: Hundreds of miles of new unpaved roads are constructed each year and the development of criteria for economic use is urgently needed.

A2-3 A3-3 Problem: TO DETERMINE THE EFFECTS OF CALCIUM CHLORIDE OR SODIUM CHLORIDE ON THE PERFORMANCE OF SHOULDERS.

Problem Area: There is a general need to evaluate the variables which influence the performance of various shoulder types as well as to establish criteria needed for economic design and selection of type.

Objectives: (a) To determine how the addition of these salts improves the desirable design characteristics, e.g., geometry, aggregate type or gradation, compaction, and drainage.

(b) To determine the effects of these salts on the performance of shoulders either paved or unpaved, under differing environmental factors and varying traffic volumes and speeds.

Urgency: Many miles of shoulders are yet to be constructed on the Interstate and Primary systems and thousands of miles of existing shoulders need improving to meet the needs of today's high speed traffic.

A2-4 A3-4 Problem: TO DETERMINE THE EFFECTS OF CALCIUM CHLORIDE OR SODIUM CHLORIDE ON THE PERFORMANCE OF GRANULAR BASES UNDER FLEXIBLE PAVEMENTS.

Problem Area: The AASHO Road Test established the need for improving the uniformity of compaction and of strength of flexible pavement subsurface materials to minimize differential settlement along the wheelpaths. Difficulties in obtaining competent compaction during construction and increasing maintenance costs are part of this problem.

Objectives: (a) To determine the effects of these salts on the compaction characteristics of various types of granular base courses at various levels of compactive effort.

(b) To determine the effect of various traffic densities and loads on the performance of treated base courses.

Urgency: Driving over some of the nation's newly constructed flexible pavements is mute evidence of the urgency of this study.

A2-5 A3-5 Problem: TO DETERMINE EFFECTS OF CALCIUM CHLORIDE AND SODIUM CHLORIDE ON MINERALS OF ROAD CONSTRUCTION. The clay minerals of a soil are often called the active portion of the soil. The complete exchange of calcium or sodium ions for the naturally occurring ions on clay minerals is known to profoundly change the properties of the clay. There also seems to be some evidence of a reaction between the chlorides and other minerals, notably limestone. These reactions need study in light of their obvious effects on binding and cementation.

Problem Area: The determination of the basic phenomena whereby the minerals used in road construction are altered by the addition of calcium chloride or sodium chloride is necessary for any understanding of how they are effective. Only with this knowledge can a rational approach be made to optimizing this method of improving quality and performance.

Objectives: (a) To determine the basic phenomena involving the alteration of clay minerals by the chlorides.

(b) To determine the phenomena which applies to the reactions of large mineral aggregates with the chlorides.

(c) To determine the effect on binding, cementation, and moisture retention and the extent of permanence of the effects.

Urgency: This knowledge is needed to provide a basis for a full evaluation of the process of dust treating and stabilizing with calcium chloride or sodium chloride.

A2-6
A3-6 Problem: TO DEVELOP LABORATORY TESTS TO EVALUATE EFFECTS OF CALCIUM CHLORIDE AND SODIUM CHLORIDE.

Problem Area: The area of chloride stabilization is lacking in basic research on the mechanism, economics, and effectiveness. The mechanisms of chloride stabilization require laboratory study to better understand and thereby determine the most efficient usage in the improvement of engineering soil properties. Laboratory tests would need to be correlated through controlled field test installation in normal road sections.

Objective: To develop laboratory tests to indicate both qualitative and quantitative improvement of engineering properties of soil materials due to stabilization with chlorides.

Urgency: This test development is needed to provide a means of evaluating the difference brought about by the addition of calcium chloride or sodium chloride.

A2-7 Problem: TO DETERMINE EFFECTS OF USE OF CALCIUM CHLORIDE IN CEMENT-, LIME- OR LIME-FLY ASH-TREATED SOIL AGGREGATE BASE OR SUBBASE COURSES.

Problem Area: Difficulties with the construction of cement-, lime- or lime-fly ash-treated soil aggregate base or subbase courses many times occur toward the end of the construction season. This makes desirable a means of accelerating strength gains. Some hot weather projects are faced with the problem of rapid evaporations and need a means of achieving and maintaining optimum moisture and uniform density. Some stabilized base courses evidence contraction cracks which reflect through the flexible surface. There is a definite need to reduce this cracking and its attendant problems.

Objectives: (a) To determine the effects of an admixture of calcium chloride on cement-, lime-, or lime-fly ash-treated aggregate base or subbase courses in accelerating strength gains.

(b) To determine the effects of the admixture in achieving and maintaining optimum moisture and uniform density.

(c) To determine the effects of the admixture in reducing reflective cracking.

Urgency: The continuing efforts to improve the secondary and tertiary road systems will continue to result in thousands of miles of flexible pavements, and this knowledge is needed to facilitate construction and reduce maintenance.

A4-1 Problem: TO DETERMINE THE LOAD-DEFLECTION CHARACTERISTICS OF SOIL-LIME FOUNDATION LAYERS. Soil-lime, a compacted mixture of pulverized soil, hydrated lime and water, is frequently used as a base or foundation for roads, parking areas, runways and/or shoulders. Although used extensively, only a limited amount of data is available relating to the development of compressive strength, flexural strength and reduction in plasticity for various amounts of lime additive and the time required for the development of these characteristics for specified soils.

Problem Area: The problem pertains to the supporting ability of subsurface strata of pavement components for various loads and the allowable limit of deflection for standard type surfaces.

Objectives: (a) To evaluate the above variables affecting the load-deflection behavior of soil-lime test sections.

(b) To develop an equation, using the variables, for establishing a relationship of load and deflection.

(c) To determine effectiveness of varying the lime content on physical and chemical characteristics of lime treated soils.

(d) To compare strength and service characteristics of soil-lime mixtures with other conventional methods of stabilization.

Pioneer work to establish the trend of the objectives should consist of laboratory static loadings and testing, while subsequent verification should consist of dynamic loadings on full scale test sections.

Reference: "Load-Deflection Characteristics of Soil-Cement Pavements," P. J. Nussbaum and T. J. Larsen, Portland Cement Association, Research and Development Laboratories Series 1065-1, 1964.

Urgency: This basic knowledge of the structural interaction of the soil-lime strata is currently needed for the application in design methods on various soil types to carry maximum loads with minimum distress and distortion.

A4-2 Problem: THE DETERMINATION OF UNIFORM TEST PROCEDURES FOR QUALITY CONTROL AND DURABILITY OF LIME- OR LIME-FLY ASH-TREATED SOILS AND AGGREGATES: At the present time, tests which were developed for other materials, such as soil-cement stabilization, are being used for lime stabilization. There is a lack of uniformity in testing procedures among the various States. Correlation data with field performance is quite limited. Consequently, some highway designers are pessimistic about the use of lime- or lime-fly ash stabilized soils for bases and subbases.

Problem Area: The problem pertains to the design and construction of lime- and lime-fly ash stabilized stoils.

Objectives: The primary object would be to find the most suitable tests for evaluating the strength and durability of lime- or lime-fly ash stabilized soils and aggregates. This will involve a review of current tests being used by various highway departments, universities, and other agencies. Of particular importance will be data which shows correlation between laboratory tests and field performance.

References: Manuals of Testing Procedures--All highway departments which use lime treatment.

Urgency: Lime treatment has now been used sufficiently long in the United States to permit a good evaluation of field performance and thereby provide a basis for determining the adequacies or deficiencies of current test methods.

A4-3 Problem: TO DETERMINE APPLICABLE METHODS OF SOIL-LIME CONSTRUCTION CONTROL TESTING.

Problem Area: The problem of controlling the pulverization of the soil, distribution and mixing of the lime, proper amounts of moisture, and compaction of the mix is one which is subject to many and varied specification and control methods. Standard control tests are needed to insure construction performance compatible with design requirements.

Objective: To improve and standardize tests for controlling construction of lime-stabilized soil.

Urgency: Thousands of tons of lime and lime slurry are being used each year and these tests are needed to produce an economical and efficient construction process.

A4-4 Problem: TO DETERMINE WHETHER NEW PROCEDURES AND NEW EQUIPMENT ARE NEEDED TO PROVIDE AN ECONOMICAL PROCESS FOR SOIL-LIME CONSTRUCTION.

Problem Area: Demands for speeding up the processing of soil-lime construction make it necessary to investigate new methods and equipment to be sure that satisfactory results are obtainable.

Objective: To develop improved soil-lime construction procedures.

Urgency: To meet the modern demand for more production speed it is urgent that new procedures and equipment be studied to insure continued high quality production.

A4-5 Problem: TO DEVELOP A RATIONAL DESIGN PROCEDURE FOR SOIL-LIME MIXTURES.

Problem Area: General design criteria for base and subbase courses needs to be developed to insure rational design procedures for pavements.

Objective: To produce a rational thickness and strength design procedure for soil-lime mixtures.

Urgency: Rational methods are needed to insure adequate but not overdesigned pavement sections.

A4-6 Problem: TO DETERMINE THE RELATIONSHIPS BETWEEN THE CHEMICAL PROPERTIES OF SOILS AND THE REACTION WITH LIME OR LIME-FLY ASH.

Problem Area: An understanding of the basic reactions including the properties of the reaction products is essential to a rational approach to economic design, construction, and testing procedures.

Objective: To develop a rational basis for the design of soil-lime mixes based on the chemical properties of the soil.

Urgency: A more rational design basis would result in an economy of materials and labor.

A4-7 Problem: TO DEVELOP FIELD TECHNIQUES FOR STABILIZATION OF SOFT SOILS BY DEEP INJECTION OF LIME. The necessity of constructing highway embankments on soft compressible soils has increased over the past decade. The present methods of treating foundations and/or designing highway embankments across soft areas are not entirely satisfactory since they are sometimes very costly and, therefore, impractical. Some of these methods are: displacement or excavation of soft soils, counterweights adjacent to embankments, sand drains beneath embankments, lightweight embankment construction, and construction of embankments at a specified rate of time.

Field lime stabilization of subgrades for roadbeds and experimental laboratory studies on lime-soil mixtures indicate that the strength of clay soils increases with the addition of lime. With these encouraging results, the process of injecting a lime slurry into the subsurface to stabilize soils is worthy of further research. Although some preliminary work has been completed in the field of soil stabilization by pressure injection, the need for more extensive practical experience with high pressure deep injection under a greater variety of situations is needed. More research in this field will enable the practicing highway engineer to use this process with confidence.

Problem Area: This problem pertains to means of obtaining stabilization of deep soft compressible inorganic soils beneath highway embankments.

Objectives: (a) At selected field locations using known equipment, information must be obtained to determine how the following variables affect the distribution and penetration of a lime slurry injected into soft soil deposits.

(1) hole spacings and patterns
(2) injection at various depths
(3) injection pressures
(4) chemical additives and/or catalysts
(5) quantities of lime slurry per injection
(6) lime-water slurry composition

(b) The magnitude and time of strength increases of the in-situ soils must be studied and the results compared to related laboratory samples.

Reference: Interim Report Lime Stabilization by Pressure Injection Phase II, Swindell-Dressler Company, Pittsburgh, Pennsylvania.

Urgency: Methods currently being used are often time consuming. A more rapid but yet reliable method is desired so that it is urgent that this proposed method be studied for feasibility and economy.

A5-1 Problem: TO DETERMINE APPLICABLE METHODS OF SOIL-CEMENT CONSTRUCTION CONTROL TESTING.

Problem Area: The problem of controlling the pulverization of the soil, distribution and mixing of the cement, proper amounts of moisture, and compaction of the mix is one which is subject to many and varied specification and control methods. Standard control tests are needed to insure construction performance compatible with design requirements.

Objective: To improve and standardize tests for controlling construc-struction of cement-stabilized soil.

Urgency: Thousands of tons of cement and cement slurry are being used each year and these tests are needed to produce an economical and efficient construction process.

A5-2 Problem: TO DETERMINE WHETHER NEW PROCEDURES AND NEW EQUIPMENT ARE NEEDED TO PROVIDE AN ECONOMICAL PROCESS FOR SOIL-CEMENT CONSTRUCTION.

Problem Area: Demands for speeding up the processing of soil-cement construction make it necessary to investigate new methods and equipment to be sure that satisfactory results are obtainable.

Objective: To develop improved soil-cement construction procedures.

Urgency: To meet the modern demand for more production speed it is urgent that new procedures and equipment be studied to insure continued high quality production.

A5-3 Problem: TO DEVELOP A RATIONAL DESIGN PROCEDURE FOR SOIL-CEMENT MIXTURES.

Problem Area: General design criteria for base and subbase courses needs to be developed to insure rational design procedures for pavements.

Objective: To produce a rational thickness and strength design procedure for soil-cement mixtures.

Urgency: Rational methods are needed to insure adequate but not over-designed pavement sections.

A5-4 Problem: TO RE-EVALUATE SOIL-CEMENT TEST METHODS AND CRITERIA.

Problem Area: Continuing efforts to improve test methods and criterias are needed to meet the challenge of modern day construction.

Objectives: (a) Re-evaluate present test methods and criteria for determining cement requirements for soil-cement mixes.

(b) Recommend changes and/or devise new test methods and criteria that determine cement requirement within one week's time.

Urgency: Modern construction methods and the demands for speed of testing will require radical improvements in current methods to meet the needs.

A5-5 Problem: TO DETERMINE THE RELATIONSHIPS BETWEEN THE CHEMICAL PROPERTIES OF SOILS AND THE REACTION WITH SOIL-CEMENT.

Problem Area: An understanding of the basic reactions including the properties of the reaction products is essential to a rational approach to economic design, construction, and testing procedures.

Objective: To develop a rational basis for the design of soil-cement mixes based on the chemical properties of the soil.

Urgency: A more rational design basis would result in an economy of materials and labor.

A5-6 Problem: TO DETERMINE VOLUME CHANGE AND SHRINKAGE CRACKING RELATIONSHIPS IN SOIL-CEMENT MIXTURES.

Problem Area: Reflection cracking through the bituminous surface contributes to added maintenance costs and hastens the loss of stability.

Objective: Devise practical means of reducing or eliminating the reflection of shrinkage cracks through the bituminous surface on soil-cement base courses.

Urgency: Reflection cracks are showing up early in the life of these pavements, adding to their cost through increased maintenance.

A6-1 Problem: TO DETERMINE APPLICABLE METHODS OF SOIL-BITUMINOUS CONSTRUCTION CONTROL TESTING.

Problem Area: The problem of controlling the pulverization of the soil, distribution and mixing of the bituminous materials, proper amounts of moisture, and compaction of the mix is one which is subject to many and varied specification and control methods. Standard control tests are needed to insure construction performance compatible with design requirements.

Objective: To improve and standardize tests for controlling soil-bituminous construction.

Urgency: Thousands of tons of soil-bituminous materials are being used each year and these tests are needed to produce an economical and efficient construction process.

A6-2 Problem: TO DETERMINE WHETHER NEW PROCEDURES AND NEW EQUIPMENT ARE NEEDED TO PROVIDE AN ECONOMICAL PROCESS FOR SOIL-BITUMINOUS CONSTRUCTION.

Problem Area: Demands for speeding up the processing of soil-bituminous construction make it necessary to investigate new methods and equipment to be sure that satisfactory results are obtainable.

Objective: To develop improved soil-bituminous construction procedures.

Urgency: To meet the modern demand for more production speed it is urgent that new procedures and equipment be studied to insure continued high quality production.

A6-3 Problem: TO DEVELOP A RATIONAL DESIGN PROCEDURE FOR SOIL-BITUMINOUS MIXTURES.

Problem Area: General design criteria for base and subbase courses needs to be developed to insure rational design procedures for pavements.

Objective: To produce a rational thickness and strength design procedure for soil-bituminous mixtures.

Urgency: Rational methods are needed to insure adequate but not over-designed pavement sections.

A6-4 Problem: TO RE-EVALUATE SOIL-BITUMINOUS TEST METHODS AND CRITERIA.

Problem Area: Continuing efforts to improve test methods and criterias are needed to meet the challenge of modern day construction.

Objectives: (a) Re-evaluate present test methods and criteria for determining bituminous requirements for soil-bituminous mixes.

(b) Recommend changes and/or devise new test methods and criteria that determine bituminous requirement within one week's time.

Urgency: Modern construction methods and the demands for speed of testing will require radical improvements in current methods to meet the needs.

B1-1 Problem: TO DETERMINE STRENGTH AND DEFORMATION PROPERTIES OF MACADAM BASES. The existing theories of pavement behavior deal with certain constant or equivalent deformation moduli or Poisson's ratios for each pavement layer. However, it is known that the deformation moduli of macadam bases greatly vary with the stress level and the relative magnitude of shear (deviator stress) with respect to (octahedral) normal stress applied. Systematic studies are needed to clarify the fundamental properties of macadam bases as materials.

Problem Area: Mechanical behavior of highway materials.

Objectives: To define, by high-pressure triaxial testing on a number of selected macadam bases, the strength and deformation characteristics as functions of the stress level and stress path (or deviatoric stress ratio). To correlate these characteristics with some equivalent characteristics that can be obtained by plate-load or dynamic tests for use in pavement design.

References: "Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements," A. S. Vesic and L. Domaschuk, National Cooperative Highway Research Program, Report 10, Washington, D. C., 1965.

"On Shear Strength of Sand at Very High Pressures," A. S. Vesic and R. D. Barksdale, American Society for Testing and Materials, Symposium on Laboratory Shear Strength Testing of Soils, Ottawa, Canada, 1963.

Urgency: This research should furnish the answer to the fundamental problem: whether and to what extent can the behavior of macadam bases be simulated by simple schemes such as those offered by the classical theory of elasticity.

B1-2 Problem: DETERMINATION AND ISOLATION OF INDIVIDUAL STRUCTURAL LAYER BEARING MODULI BY NON-DESTRUCTIVE MEANS.

Problem Area: Structural characteristics of pavements.

Objectives: To determine individual in situ layer moduli by measurement of the deflection profile using the Benkelman beam or electronic devices (LVDT) and by expansion of present mathematical analysis of layered system response, to deduce equivalent layer moduli. A possible alternate to proposed dynamic testing procedure.

Reference: "Evaluation of Cement Stabilized Bases in Alberta," B. P. Shields and B. G. Hutchinson, Proc. Canadian Good Roads Association, 1961.

Urgency: Fundamental to any proposed extension of AASHO Road Test findings.

B1-3 Problem: TO DETERMINE REALISTIC LABORATORY TESTING AND EVALUATION PROCEDURES FOR SURFACING AND SUBSURFACING ELEMENTS, DIRECTLY RELATED TO THE FIELD LOADING ENVIRONMENT.

Problem Area: Correlation of specific layer attributes to total system response, for design and evaluation purposes.

Objectives: Studies of this nature would be extensions of present strength/deformation criteria, into the stress and deformation regions to which surfacing materials are subjected in situ. This would include establishing new strength testing procedures for the high frequency-low strain domain (conditions equivalent to field loading), with emphasis on the effects of repeated loadings. Correlation to composite field performance.

References: "The Effect of Resilience - Deflection Relationship on the Structural Design of Asphaltic Pavements," F. N. Hveem, E. Zube, R. Bridges, and R. Forsyth, Proceedings, International Conference on the Structural Design of Asphalt Pavements, 1962, University of Michigan, 1963, pp. 649-666.

"Prediction of Pavement Deflections from Laboratory Repeated Load Tests," H. B. Seed, F. G. Mitry, C. L. Monismith and C. K. Chan, Report No. TE-65-6 (to NCHRP, HRB) University of California, Berkeley, 1965.

"Rheologic Behavior of Asphalt Concrete," C. L. Monismith, R. L. Alexander, and K. E. Secor, Proceedings, Association of Asphalt Paving Technologists, Vol. 35, 1966.

Urgency: A thorough review and critique of current procedures would appear necessary as a first step prior to embarking on development programs.

B1-4 Problem: TO ESTABLISH A DETAILED TECHNIQUE FOR TRIAXIAL TESTING OF GRANULAR MATERIAL. Triaxial testing has long been recognized by many pavement designers and researchers as the most fundamental testing technique available for use in evaluating granular materials. In spite of this recognition the use of triaxial testing has not spread as rapidly as might be expected due to the time and cost involved in current testing techniques. Furthermore, even where such tests are used the procedures involved are not standardized to any reasonable degree.

Problem Area: The codification of triaxial testing techniques is a specific part of the overall problem associated with establishing adequate methods of evaluating paving materials including granular and stabilized materials for use in pavement sections. This is in turn a part of the overall problem of developing more rational and thus better methods of correctly designing highway pavements.

Objectives: To establish detailed criteria and techniques for the triaxial evaluation of paving materials.

References: At least three states currently use some form of triaxial procedure in some phase of pavement design. The Texas Highway Department utilizes a 6" x 8" triaxial specimen which is treated with a prescribed set of mechanical manipulations prior to testing. The Kansas Highway Department uses a triaxial procedure of a completely different type. Finally, the California Highway Department uses a closed system triaxial test, the so-called R-value or stabilometer in evaluating materials as to their paving quality. Other small studies associated with triaxial testing have been made particularly with relation to fundamental properties of clays and other materials; however, no other large schedule of triaxial tests in evaluation of pavements is known.

Urgency: This project is an essential building block which must be completed in order to build the necessary foundation for adequate pavement design across the nation. This adequate design will result in substantial savings of time, money and human resources by providing longer pavement life, better pavement performance, lower pavement maintenance costs.

B1-5 Problem: TO CODIFY THE EXISTING METHODS OF MEASUREMENT FOR STRUCTURAL PAVEMENT VARIABLES. In the past several years a great deal of money has been spent in studying pavement performance and other methods of improving pavement design methods. In many cases these studies have been accomplished without significant attention to the mechanistic behavior of pavement sections and the constituent materials. At the present time the NCHRP is conducting several small projects aimed at various segments of this problem. Included among these projects is a project for the "Development of Measurements Teams for Pavement Satellite Studies." It is not clear at this point that significant study has been given on a coordinated basis to the specific measurements which should be included in any pavement satellite study to provide methods of quantifying the structural variables described in NCHRP Report No. 2A, "Guidelines for Satellite Studies of Pavement Performance."

Problem Area: This problem is a part of the overall pavement design and evaluation of the problem area. There is certainly a need to continue theoretical studies into the design of pavement sections and into new methods for evaluating the material property which are required to make the theories compatible. There is a more immediate need, however, of a taking of stock of existing methods and the codification of these methods into a proposed approach on the pressing problems of pavement satellite studies.

Objectives: To properly evaluate the existing materials testing techniques for all structural variables in the pavement section to establish criteria for material property evaluation to be used in the nationwide satellite road test studies.

References: The work done by the HRB in preparing NCHRP Reports Nos. 2 and 2A, "Guidelines for Satellite Studies of Pavement Performance," provides the general basis for the project suggested herein. These reports, it might be said, define the problem. A second NCHRP project being conducted by Texas A&M University concerns measurement teams to be used in studies of road test satellite pavement performance. Other work with a direct bearing on this problem involves every state which is currently conducting some sort of pavement evaluation program, whether or not it is considered to be a so-called satellite study. A brief list of these states includes Texas, Alabama, Florida, Minnesota, Missouri, and Colorado, among others.

Urgency: If the thirty odd million dollars spent on the AASHO Road Test, as well as the many millions of dollars being spent on satellite studies, is to have its greatest possible impact on improvement of pavement design techniques with a resulting savings in money due to improved pavement performance, lower maintenance cost, and extended pavement life, as well as better service to the pavement user; it is essential that the research described herein be accomplished in some expeditious manner so as to provide the necessary basis for extending the road test findings in the near future.

B1-6 Problem: TO DETERMINE THE EFFECT OF WATER CONTENT AND DENSITY ON THE STRENGTH OF GRANULAR MATERIALS IN PAVEMENT SECTIONS. Although much attention has been given in the past few years to the measurement of water content and density in soil and granular material sections, little specific information is available concerning the effect of these water content and density deviations on strength of the pavement section. Certainly we know that high water content and low density can be equated with low strength. The relative magnitude of these variations, however, in various materials is quite another matter.

Problem Area: The load carrying capacity or strength as it is often termed as well as the deformation characteristics of granular layers in pavement sections is essential in the ultimate solution of the pavement design problem. The problem stated here, then, is a part of the overall pavement design problem area.

Objectives: The specific objectives of this research can be stated as follows:

(a) Determine the effect of varying water content on the strength and deformation characteristics of a variety of granular materials.

(b) Determine the effect of variations in density on the strength and deformation characteristics of soil and granular materials in pavement sections.

Reference: "Prediction of Pavement Deflections From Laboratory Repeated Load Tests," H. B. Seed, F. G. Mitry, C. L. Monismith and C. K. Chan, Report No. TE-65-6 (to NCHRP, HRB) University of California, Berkeley, 1965.

Urgency: This research is one of the building blocks which must form a part of the ultimate pavement design procedures. In the recently run AASHO Road Test $30,000,000 was spent in evaluating pavement performance of approximately 850 different pavement sections. It has not been possible to fully analyze the data from this road test partly because complete information is not available as to the evaluation of variations in water content and density in granular materials. It is essential then that this problem be solved before we can ultimately solve the pavement design and evaluation problem.

B1-7 Problem: THE ROLE OF MICRO-CLIMATE AS A FACTOR IN PAVEMENT PERFORMANCE CHANGES.

Problem Area: Permanent, non-recoverable deformation in pavements are, in many cases, more a function of micro-climatic features than structural response to imposed loadings, resulting in performance loss.

Objectives: Present climatic indices (total annual precipitation, freezing index, etc.) serve merely as broad geographic classifiers. An assessment of micro-climate would concentrate on temperature and precipitation fluctuations at selected test areas within regions, with correlation to subsurface thermal and moisture regime measurements taken on a periodic basis. Where known performance-age relationships occur for existing pavements, together with meteorological records of sufficient extent, analysis of the latter might result in more significant parameters than currently employed.

Urgency: These studies are primarily of a long-term basis, and of importance in those areas where the major detractor from pavement performance is not the loading history.

B1-8 Problem: FIELD VERIFICATION OF LAYERED SYSTEM BEHAVIOR. In order that research will have engineering application, it is important that field performance under well-controlled test conditions be obtained.

Problem Area: Field verification for theories of layered systems is needed to justify changes in design.

Objectives: (a) To apply the theory of layered systems to an analysis of existing test road and test tract data, such as the results of the AASHO and WASHO Road Tests and Corps of Engineers test sections.

(b) To evaluate in situ equipment
  (1) Pressure cells--over- and under-registration due to arching resulting from cell deformation
  (2) Deflection and strain indication

(c) Correlation of theoretical development with actual performance criteria. This latter is extremely important so that the preceding determinations are not merely academic exercises.

Urgency: This information is needed to form a competent basis for continuing study and development of layered systems theory.

B2-1 Problem: TO DETERMINE THE EFFECT OF VERTICAL SAND DRAINS, INCLUDING COMPARISON OF VARIOUS METHODS OF INSTALLATION. The installation of vertical sand drains has considerable effect on the engineering characteristics of the material into which the drains are placed. Some of this effect may be detrimental to the efficiency of the sand drains. The effects are also greatly dependent on the methods, equipment and procedures of installation.

Problem Area: This problem lies within the scope of the design, construction and performance of embankments on soft, compressible foundation soils.

Objectives: To investigate by field tests and observations on various construction projects throughout the country, the actual and practical effects of the installation of sand drains, including the effects of various methods of installation, in order that rational design and construction procedures be evolved.

References: "Treatment of Soft Foundations for Embankments," M. N. Sinacori, W. P. Hofmann and A. H. Emery, Highway Research Board Proceedings, Vol. 31, pp. 601-621, 1952.

"Vertical Sand Drains for Stabilization of Embankments," Highway Research Board Bulletin No. 115, 1955.

"An Appraisal of Sand Drain Projects," New York State Department of Public Works, Physical Research Project No. 5, 1966.

"Method of Installation as a Factor in Sand Drain Stabilization Design," Richard E. Landau (to be published in a Research Record).

"Experimental Sand Drain Fill at Napa River," William G. Weber, Jr. (to be published in a Research Record).

"Summary of Treatments for Highway Embankments on Soft Foundations," Lyndon H. Moore (to be published in a Research Record).

Urgency: Many millions of linear feet of sand drains have already been installed in various sections of the U. S. A. Properly conducted, this investigation requires field studies during and after the construction of projects utilizing vertical sand drains. Each project that is completed without adequate observations in relation to this problem represents a waste of valuable data that could have been acquired from a full scale model.

B2-2 Problem: INVESTIGATION OF SECONDARY COMPRESSION CHARACTERISTICS OF ORGANIC DEPOSITS. Embankments, fills and structures constructed on or over organic foundation soils undergo long-time post-construction settlements that are often detrimental to the performance of the embankment, fill and/or structure. A large portion of the settlement can be attributed to the "secondary" consolidation characteristics of the organic deposit.

Problem Area: This problem lies within the scope of study of the design, construction and performance of embankments on soft foundations, including the treatment of marsh deposits, for the support of embankments and fills.

Objectives: Basic information on the consolidation properties of organic soils is required in order to evolve the most economical and satisfactory methods of stabilizing such deposits. The objectives are:

(a) By means of laboratory investigations, to determine the settlement characteristics of various types of organic soils, including the limitations of applying the present "primary" and "secondary" consolidation concept to organic soils, and the ability to predict the long-time "secondary" with reasonable certainty. New test procedures and equipment may be required.

(b) To compare the results of observations and measurements of long-time settlements of embankments and fills constructed on organic deposits with laboratory test data and assumptions used in design.

References: The highway departments of New Jersey, New York, California, Michigan, and the Port of New York Authority have constructed a considerable number of projects on organic deposits.

"Summary of Treatments for Highway Embankments on Soft Foundations," Lyndon H. Moore (to be published in a Research Record).

"Experimental Sand Drain Fill at Napa River," William G. Weber, Jr. (to be published in a Research Record).

"Construction on Marshland Deposits: Treatment and Results," Martin S. Kapp, D. L. York, A. Arónowitz and H. Sitomer (to be published in a Research Record).

"Observational Approach and Instrumentation for Construction on Compressible Soils," Yves Lacroix (to be published in a Research Record).

Urgency: In some parts of the U. S. A., especially in the vicinity of urban areas, the only land areas remaining for the location of new highways and other engineering works are the swamps and marshes. This is particularly true in the coastal areas. Removal of the organic material requires areas for disposal and sources of suitable borrow for backfill purposes. Such areas are becoming less available at reasonable cost with the passage of time. Thus the utilization of the organic deposit as a foundation material has become economically imperative in many sections of the country. The sooner significant data on the solution of this problem is made available to the profession, the sooner savings in cost of the utilization of such sites will be realized.

B3-1 Problem: TO DEVELOP A MEANS OF DETERMINING LATERAL EARTH PRESSURES AGAINST WALLS AND PILES, ON THE "ACTIVE" SIDE AND ON THE "PASSIVE" SIDE. At present it is customary to design bridge abutments and retaining walls supported by piles to resist conventionally determined active lateral earth pressures acting only against the abutment or wall proper; active lateral earth pressures transmitted by underlying soft plastic clays to piles below the heel of the abutment or wall are usually ignored, although there is reason to believe that appreciable bending stresses can then be induced in such piles by active lateral earth pressures against them. Some unpublicized failures of abutments and walls on long slender piles may be attributed to this cause.

Similarly, batter piles under the toe of an abutment also may be subjected to additional bending stresses. Arbitrarily assigned values of passive resistance are sometimes specified, but no reliable experimental data is available concerning the resulting stresses in such piles.

Problem Area: The problem pertains to the assumptions on which the design of bridge abutments has to be based, specifically to the interaction between the structural elements of a bridge abutment and the surrounding soil.

Objectives: Determination of the "active" and of the "passive" lateral earth pressures against walls and against the piles supporting them. These might be done by study of properties of various types of soils, by laboratory and field tests with proper instrumentation, by theoretical analyses and by combinations of the above.

References: "Retaining Structures," Gregory P. Tschebetarioff, pp. 490-496 of Chapter 5 in FOUNDATION ENGINEERING, G. Leonards, Editor, McGraw-Hill Book Co., 1962, 1136 pp.

"Applied Soil Mechanics," K. Terzaghi and R. Peck, Art. 46, pp. 312-329.

Urgency: Without comprehensive experimental research on this subject the design assumptions for this type of bridge abutment will continue to be based on pure speculation. "Standard Specifications for Highway Bridges," of AASHO, has an oversimplified treatment of these pressures.

B3-2 Problem: TO DETERMINE THE EFFECTS OF PILE DRIVING ON SOIL ADJACENT TO THE PILES AND NEARBY STRUCTURES, INCLUDING TEMPORARY LIQUEFACTION. Many highway bridge structures must be constructed over deep layers of soft compressible soil. The foundations at such locations are generally constructed on piles. Piles are used to transfer the foundation loads either to a competent layer, or they distribute the load through friction along their shafts into the surrounding soil. The soils in which piles are generally used are either loose to medium dense sands and silts or very soft to stiff clays. They have a relatively low shear strength. When the piles are driven into the ground, the soil is displaced and remoulded. Compression and shear takes place in a certain zone around the pile, resulting in temporary excess pore water pressures. The remoulding in sensitive soils brings about a considerable decrease in shear strength, with potential danger to the stability of any structure, slope or embankment in the proximity of the pile driving operations.

With the passage of time the remoulded soil regains its strength. There is evidence that some soils eventually acquire a higher strength than they originally had, and therefore, the piles have a bearing capacity in excess of that theoretically computed using the original soil strength parameters. However, not enough evidence and theoretical explanation are available to make reasonably accurate predictions.

On the other hand, in some medium to stiff clays, piles never acquire the bearing capacity computed by using the original soil shear strength parameters. Apparently, full mobilization of soil shear strength along the pile shaft never occurs. There is also evidence that with some types of piles the agreement with the theoretical prediction is reasonably good.

Problem Area: The problem area pertains to the change in the physical properties of the soil around the pile, brought about by pile driving operations.

Objectives: The prediction of the bearing capacity of friction piles is rather unreliable because of the lack of understanding and knowledge of what is actually happening while the pile is being driven into the ground and the manner in which the soil behaves. The build-up and subsequent dissipation of pore pressures, the loss and subsequent regain of shear strength, the eventual partial or full mobilization of wall friction along the pile shaft, the increase of shear strength above original value, and the time required to achieve these, all require further systematic studies and explanations.

Only when these phenomena are understood and explained can a rational attempt to predict the behaviour of friction piles be attempted.

References: "The Structure of Clay and Its Importance in Foundation Engineering," A. Casagrande, Journal, Boston Society of Civil Engineers, 1932.

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"The Adhesion of Piles Driven in Clay Soils," M. J. Tomlinson, Proc. 4th Int. Conf. on Soil Mech. & Found. Engr., London, 1957, Vol. II.

"Comparison of the Extent of Disturbance Produced by Driving Piles into Plastic Clay to the Disturbance Caused by an Unbalanced Excavation," G. Tschebotarioff and J. R. Schuyler, Proceedings, 2nd Int. Conf. on Soil Mechanics and Found. Engr., Rotterdam, 1948, Vol. II.

"Pile Loading Tests in Stiff Clays," R. Woodward and J. Boitano, Proceedings, 5th Int. Conf. on Soil Mechanics & Found. Engr., Paris, 1961, Vol. II.

Urgency: A better understanding of the changes in the physical properties of the soil and the zone of influence of the changes brought about by pile driving operations would lead to more economical and safer designs.

B3-3 Problem: THE DETERMINATION OF SKIN FRICTION VALUES OF VARIOUS SOILS ON PILES. Pile bearing capacities are usually evaluated by dynamic formulae which vary markedly from capacities determined in pile load tests. Estimating lengths prior to contract is usually somewhat empirical. It is reasonable that type of soil, texture, density, sensitivity, moisture, stratification, as well as pile material, taper, displacement and shape can influence pile support value from friction. In the present state of the art, skin friction values are neither known on a broad scale nor determined with sufficient accuracy.

Problem Area: This problem pertains to friction piles and involves the frictional action of soil along piles.

Objectives: There should be properties of soil and soil-pile contact that should define friction developed between soil and pile. These should be defined in parameters of water table, soil properties and stratification, and pile material and geometry to predetermine pile lengths required to support given structure loads. The object of this research would be to determine these relationships.

This study should be aimed primarly at the single pile with group action to be considered separately.

References: "A Study of the Comparative Behavior of Friction Piles," Special Report 36, Highway Research Board.

"Friction Pile Load Test Records," Special Report 67, Highway Research Board.

"Timber Friction Pile Foundations," F. M. Masters, Transactions of ASCE, Paper 2174, Vol. 108, 1943.

"Pile Loading Tests, Morganza Floodway Control Structure," Mansor and Focht, Transactions of ASCE, Paper 2810, Vol. 121, 1956.

"The Action of Soft Clay Along Friction Piles," Seed and Reese, Transactions of ASCE, Paper 2882, Vol. 122.

"Group Pile Loads in Plastic Soils," H. G. Schlitt, Proceedings of HRB, Vol. 31, 1952.

"On the Bearing Capacity of Piles," J. Jaky, Proceedings of the Second International Conference on Soil Mechanics, Vol. 1, 1948.

(All references noted contain extensive bibliographies of pertinent material.)

Urgency: No rational predetermination of pile lengths can be made without a reasonable estimate of soil friction values along piles. Basic research is needed to evaluate this soil property.

B3-4 Problem: DETERMINING THE AMOUNT OF NEGATIVE SKIN FRICTION (DRAG-DOWN) OF PILES AND SUBSTRUCTURES. When the ground surrounding piles or substructures settles, a drag-down force is exerted on these elements. There are many different approaches to estimating these drag-down forces, but none of them appear to be truly satisfactory.

Problem Area: The problem pertains to piles or substructures buried in or through compressible layers that will settle at some future time.

Objectives: The amount of drag-down on piles and substructures appears to be related to the shear strength of the material surrounding these elements, the dimensions and arrangement of these elements, the rate of settlement, etc. The object of this research would be to run both small scale and full size tests under controlled conditions in areas where full test data is available on the underlying soils. In this way, present theories available for determining drag-down forces can be validated or new theories proposed.

References: Gant, Stephens, Moulton, Highway Research Board Bulletin No. 173.

"Reduction of Point Bearing Capacity of Piles Because of Negative Friction," L. Zeevaert, Proceedings, 1st Pan American Conference, 1959, Vol. III, p. 1145.

Urgency: Since more and more construction is now taking place in areas of highly compressible soils, it is imperative that information concerning validated methods of estimating drag-down forces be made available as soon as possible.

B3-5 Problem: SETTLEMENTS AND LATERAL MOVEMENTS OF PILE SUPPORTED STRUCTURES. Despite the use of accepted pile driving formulae and related criteria developed both theoretically and empirically, pile supported structures have been known to settle and move laterally. Such movements have been generally found to occur where compressible strata underlie the structure and consolidation of the soil is induced by surface loading; however, similar movements have been found to occur in instances where no specific surface loading is applied. Although it is reasonable to assume that some of the vertical movement is due to the effects of pile "drag" which may not have completely been evaluated, the occurrence of lateral movements cannot be readily related to such effects.

Problem Area: The problem relates to pile supported structures of all types, and is principally related to instances where a compressible stratum is penetrated by the piling.

Objectives: It is the purpose of the proposed research to compile available experience and data relative to the occurrence of settlement and movements of pile supported structures, and the soil conditions involved in each case. A questionnaire would be prepared to initially establish which public and private organizations have recorded instances of such settlements and movements, and to what extent detailed information may be available. Because organizations involved in this type of work may not be readily able to compile and present the required information, the initial questionnaire may serve as an indicator of the extent of the problem and the awareness of its occurrence.

After a review of the initial inquiry and the information developed thereby, it would be the objective of further investigation to establish the need for and desirability of field instrumentation of specific pile supported structures under construction by public and/or private organizations, as a means of establishing the influence of soil type, pile type and length, and related factors, on the magnitude of post construction movement.

Reference: "Study of Comparative Behavior of Friction Piles," R. B. Peck, HRB Abstracts, Vol. 29, No. 4, 1958.

Urgency: A considerable amount of money is often invested in pile foundations to arrest post-construction settlements, only to find that such settlements may nevertheless occur. If the occurrence of such movements can be predicted, and the means to insure its avoidance established, maintenance of the construction can be either anticipated or avoided at the discretion of the designer. Without the proposed research, the problem of the settlement of pile supported structures cannot be readily investigated.

B3-6 Problem: THE DETERMINATION OF THE STRUCTURAL ASPECTS AND PERMISSIBLE TOLERABLE UNIFORM AND DIFFERENTIAL SETTLEMENTS OR MOVEMENTS OF BRIDGE STRUCTURES. Bridge foundations are generally designed with the concept that foundation movement will be negligible. Most modern highway bridge structures are not designed to be rigid but are yielding to permit redistribution of loads and pressures. Therefore, it is reasonable that the substructure be designed to be compatible with the superstructure and designed to be as economical and yet safe as possible. In most design practices, permissible foundation movement is not considered since permissible values are not taken into consideration.

Definite design data should be set forth depicting permissible tolerable uniform and differential settlements for various types of foundations, span lengths, widths, heights, etc. It is reasonable that the type of structure will govern the permissible settlements or movements of its foundation.

Problem Area: The problem pertains specifically to highway bridges, an area commonly referred to as "Soil Structure Interaction."

Objectives: The objectives of this research problem are:

(a) Theoretically determine permissible tolerable uniform and differential settlements or movements of bridge structures and plot design aids and charts for various structure types, spans, etc.

(b) Research various selected structures by instrumentation and periodic checks of the movements of foundations and inspection relative to structure condition.

(c) By determining theoretical permissible movements and actual permissible movements, refine design aids for the selection of foundation type, span lengths, etc.

(d) Research high volume change soil materials as related to foundations for wet and dry seasons, droughts, or other moisture-changing conditions.

References: "Foundation Engineering," Gerald Leonards; "Soil Mechanics in Engineering Practice," Terzaghi-Peck; "Theoretical Soil Mechanics," Terzaghi.

Urgency: Economies in foundations may be realized provided the relationship of superstructure and substructure are correlated with permissible foundation movements by basic field research.

B3-7 Problem: SCOUR AT STRUCTURE FOUNDATIONS. The supports of structures built across flowing water are subject to a complex array of stresses. A major stress that is recognized, mostly when the structure support is weakened, is the lateral pressure of moving water when it has suddenly become greater than that pressure for which the support was designed. The support is either (1) completely removed, (2) partially removed, or (3) warped out of position. This destruction of structural support is recognized as being caused by the removal of foundation material around and beneath a foundation support by the eroding and carrying capacity of flowing water. Very little knowledge has been obtained concerning the quantitative capacities of these eroding properties of flowing water. Laboratory studies have established certain rules governing the relationships between obstructions and stream flow, but very little beyond some localized empirical prototype relationships have become commonly known to the engineering profession. It is the quantitative relationships between stream flow (gradient, velocity, volume, etc.), obstruction type and sediment carrying capacity of the flow that should be sought in order that public monies may be spent as economically as possible.

Problem Area: The problem pertains to the determination of the depth of maximum scour or streambed removal in the vicinity of obstructions placed in the stream area.

Objectives: Changes in a streambed, as measured by vertical distances during extreme velocities of flow, is a primary objective for streambed scour study. Water turbidity, rapidly moving objects of massive size, vibration of structures from which measurements may be made, all prevent actual measurement of maximum streambed scour. Topographic feature interrelationship in the area upstream from the structure is complex and not easily subject to quantitative evaluation. The shape and location of the stream flow obstructions on a miniature scale have received considerable study and their effects upon scour action are becoming understood.

Model studies, while fundamental in determining basic hydraulic relationships, do not develop quantitative field or prototype relationships.

The objectives of this study are therefore limited to a development of the relationship between measurable topographic features upstream from the structure, such as (1) topographic relief classifications, (2) volume of stream flow, (3) gradient of streambed, (4) horizontal stream configuration, and (5) drainage area, potential rainfall and surface water developed upstream from the structure and actual scour as measured at structures as soon after maximum flood periods as possible.

Reference: "Report on Investigation of Scour at Bridges Caused by Floods of 1955," Moulton, Belcher and Butler, HRB Abstracts, September 1957.

Urgency: The history of the destruction of bridges in the Pacific Northwest during the winter of 1964-1965 and the several millions of dollars required to rebuild these structures so as to restore communications between communities is reason enough to initiate a continuing study of this problem.

B3-8 Problem: THE DETERMINATION OF THE RELATIONSHIP OF FOUNDATIONS FOR OVERHEAD SIGNS TO FACTORS WHICH SHOULD BE CONSIDERED IN THEIR ECONOMICAL DESIGN. Foundations for overhead signs are presently being designed with about the same factors of safety, calculation of dead and live loads, and method of load transfer to the soil, as that for other more important structures. Due to the nature of the overhead sign structure, engineers recognize its greater tolerance to settlement and consequent potential saving in design. Types of foundations and methods of load transfer characteristics of each need to be studied and analyzed in order to arrive at more realistic design concepts.

Problem Area: The problem pertains to the type of foundation used as determined by the soil materials present, namely piling, drilled shafts or spread footings.

Objectives: (a) To test load and utilize instrumentation capable of measuring load distribution and earth pressure distribution about the type of foundation under consideration.

(b) On the basis of field measurements with this instrumentation and on the basis of certain laboratory and field soil exploration tests, to develop methods by which the bearing capacity of the foundation under test can be predicted from results of soil tests.

(c) To develop design criteria relative to factor of safety, variable wind and dead load and methods of load transfer.

(d) To develop refined design procedures commensurate with overhead signs, necessary design aids, charts, etc.

References: Texas Highway Department, South Dakota Highway Department, Ohio Highway Department with Union Metal Mfg. Co., Prof. Kondner at Northwestern, Prof. Graves at Notre Dame.

Urgency: More realistic and economical design of foundations for overhead signs may be realized by performing basic research specifically for signs.

B3-9 Problem: TO IMPROVE METHODS OF PILE LOAD TESTING, INCLUDING QUICK LOAD TESTS. Test loading piles in the field is considered the most reliable method of determining actual pile bearing capacity. Unfortunately, there is a wide difference of opinion on testing procedures. The most significant problem in evaluating load tests, that of correlating test results with existing soil conditions and determining the true behavior of a pile foundation, is not considered in determining load testing procedure. One standard procedure is generally established by each specifying agency and is used regardless of soil conditions which often makes test results meaningless. Since load testing of piles is expensive and time consuming, research on when piles should be tested, significant testing procedures based on soil conditions, acceptable equipment and rational analysis of results is needed.

Problem Area: The problem is to obtain pile foundations with an adequate factor of safety during the life expectancy of the structure at the most economical cost. Load testing of piles should be conducted in such a manner that results obtained will be significant in evaluating both the ultimate capacity of the pile foundation and the most economical type of foundation.

Objectives: To obtain, through research, load testing procedures for different soil conditions that will more accurately reflect ultimate capacity of piles; to obtain through research more factual approach to the capacity of friction piles in groups and the capacities of batter piles; to improve load testing by use of recommended equipment; to reduce costs by determining proper effective sizes of load increments and significant time duration of load increments; to endeavor to standardize on load testing procedures so that field information may be better correlated and improve our knowledge of the subject.

References: ASTM Designation: D1143 "Load-Settlement Relationship for Individual Piles."

"Construction and Material Specifications - Jan. 1, 1963," State of Ohio, Department of Highways, Item S-17 Pile Test Load, p. 247.

"Public Works Specifications, Jan. 2, 1957," State of New York, Department of Public Works, Division of Construction, Item 88P, Load tests for Piles, p. 392.

"Steel and Timber Pile Tests - West Atchafalaya Floodway," American Railway Engineering Association, Bulletin 489, September-October 1950.

"Group Pile Loads in Plastic Soils", by Henry G. Schlitt, Highway Research Board Proceedings, Vol. 31, 1952.

"A Study of the Comparative Behavior of Friction Piles," Highway Research Board Special Report 36.

Urgency: Pile load tests are being conducted every day. If testing procedures can be improved, so that more significant results are obtained, or testing costs reduced, the results would have an immediate effect.

B3-10 Problem: THE ELECTRO-CHEMICAL CORROSION OF STEEL PILING. The electro-chemical corrosion of metals is usually not considered during foundation investigations unless a history of failures exists in the same general area. In virgin areas this may lead to serious post-construction problems endangering the structure. After-the-fact solutions to such problems are tremendously complex and expensive. In contrast, where the controlling factors governing corrosion are identified during design, expedients are usually available to prevent serious corrosion in a given environmental situation and at reasonable cost by comparison.

Problem Area: The problem pertains to the foundations of structures and the subsurface investigation for design thereof. The disciplines of electro-chemistry and related fields fully deal with the many factors involved. Certain of these determine the "tendency" of a metal to corrode in a given environment. Whether it will depends upon certain other factors determining the "rate" of corrosion. This rate is influenced by the development of resistance to continued corrosion reactions by the build-up of certain corrosion by-products. Accurate assessment of an environment as active or passive must deal with both "rate" and "tendency" to avoid needless expenditures for protection where it is not necessary.

Objectives: The objectives of this research will be to apply existing interdisciplinary knowledge to the problem to establish a rational method for the foundation engineer to properly assess the potential corrosivity of a soil/water environment throughout the profile. Certain minimal analyses are required to establish a tendency for corrosion. If a tendency is demonstrated, other analyses will produce further definition of problems vs. non-problems to permit intelligent selection of alternate materials, coatings, or modification in structural details, as tailored to meet the problem. Problems of unusual complexity, such as requiring expert judgment, should also be delineated if no simple means can be applied to solve them. The research should include applied working theory, sampling and testing procedures, a methodology of interpreting results and preventative measures.

References: "Corrosion: Causes and Prevention," Speller, McGraw-Hill.

"Corrosion and Preservation of Iron and Steel," Cushman and Gardner, McGraw-Hill.

"The Corrosion Handbook," Uhlig, John Wiley and Sons.

"Underground Corrosion," M. Romanoff, NBS Circular 579 (1957).

"Corrosion of Steel Pilings in Soils," M. Romanoff, Journ. Res. NBS 66C, 223 (July-Sept. 1962).

"Underground Corrosion, Cathodic Protection and Required Field Measurement," National Academy of Sciences-National Research Council, BRAB Publ. 991 (1962).

Urgency: In virgin areas, where there is no existing structure to serve as a yardstick for corrosive attack, the foundation engineer has only conflicting data, half-truths and folklore on which to base a decision. Whichever way he moves, he remains uncertain. It is reasonable that danger to the foundation of a structure from corrosion should be investigated and determined with the same degree of precision as the other fundamental components of the structure. Obviously, the urgency is great.

B3-11 Problem: TO DETERMINE THROUGH GEOLOGICAL FACTORS THE PROPER DRILLING AND BLASTING METHODS TO BE CONSIDERED WHEN BRIDGE PIERS, ABUTMENTS AND RETAINING WALLS ARE FOUNDED DIRECTLY UPON BEDROCK. Although "bedrock" might generally be regarded as the finest foundation for bridge piers and abutments, there may arise situations in which, due to some geological factor(s) or inadequate drilling and blasting methods, or both, bedrock may "fail" or yield under the load imposed by such structures. Further, certain bedrock conditions, if overlooked, may bring about exceedingly high construction costs through such media as "overbreakage," needless or excessive grouting, etc. Too many times, "solid rock" is simply taken for granted, probably more through ignorance than through carelessness.

Problem Area: This is one of the important features connected with the proper treatment of bedrock in highway design, construction and maintenance.

Objectives: (a) A symposium on bedrock geology problems associated with foundations, and/or -

(b) A manual prepared specifically for use by highway engineers and geologists to enable them to better recognize and evaluate potentially detrimental characteristics of bedrock foundations, and to use proper drilling and blasting techniques.

References: Publications on Engineering Geology of Geological Society of America.

The Mechanics of Rock Breakage, Richard Ash, "Pit and Quarry," Aug., Sept., Oct., Nov., 1963.

Colorado School of Mines Quarterly Symposia, on Rock Mechanics, Drilling, and Blasting.

Rock Blasting, U. Langefors and B. Kihlstrom, John Wiley and Sons, Inc., 1963.

Four Methods of Controlled Blasting, E. I. duPont deNemours and Co., 1964.

Pre-Split Blasting, Paine, R. S.; Holmes, D. K.; and Clark, H., The Explosives Engineer, May-June 1961.

Pre-Splitting, Hercules Powder Co., 1962.

Urgency: The ideas projected in this proposal might better be categorized in terms of usefulness rather than urgency. It is felt that an accumulation of information relating engineering geology of bedrock to foundations of highway structures would be extremely beneficial to highway engineers.

B3-12 Problem: COFFERDAMS AND DE-WATERING MEASURES FOR FOUNDATION EXCAVATION. Cofferdam design and de-watering method is the responsibility of the designing engineers or the contractor performing the construction. In both instances their success depends on the reliability and the adequacy of the information on subsoil conditions, on the selection of the proper type of cofferdam, its economical design, and above all on the correct evaluation of lateral pressures, supplemented with rational solution of the seepage pattern and of the potential hydrostatic uplift below the foundation slab. Dependable estimate of the anticipated volume of seepage through and under the cofferdam as well as of the future pumping rate are also essential requirements. Tremie concrete seals are often used for shallow excavations when not needed and are often needlessly thick when bond to piles and sheeting are ignored.

Problem Area: The problems involved include, besides proper field investigation, the area of lateral soil and hydraulic pressure, two-dimensional permeability study of soil in situ and the area of fluid mechanics (flow through granular media, both laminar and turbulent) and close prediction of the flow patterns and hydrostatic uplift.

Objectives: The future research should broaden the knowledge of the mechanics of lateral pressures, their evaluation for various soil conditions, the control of soil pressure and the seepage and the factors affecting the uplift pressures with measures to counteract them effectively.

References: Many difficulties and some failures of cofferdams have been recorded in the literature, often attributing the cause to the underestimated lateral pressure, seepage forces, flotation phenomenon or uplift pressure action. White and Prentis: "Cofferdams," and many others.

Urgency: Adequate reliable data for the design and the construction of cofferdams as well as their successful de-watering are not readily available to the profession, and thus rational research in above mentioned fields would greatly enhance the solution of these problems.

B4-1 Problem: THE DETERMINATION OF THOSE SOIL PROPERTIES WHICH AFFECT THE STRUCTURAL PERFORMANCE OF BURIED STRUCTURES. In the past, soil loads on buried structures have generally been determined under the assumption that the buried structure is perfectly rigid. Many modern structures are not rigid and thoughtful designers recognize that the yielding structures tend to relieve soil loads and redistribute soil pressures on the structure. It is reasonable that the type of soil (degree of compaction, etc.) can influence soil pressures against flexible buried structures. In most design practices, the soil properties are not considered simply because pertinent soil properties are not known.

Problem Area: The problem pertains to buried flexible structures, an area commonly referred to as "Soil Structure Interactions."

Objectives: If soil were homogeneous and elastic, but if it were nonisotropic in the horizontal directions compared to the vertical direction, then four soil properties would be required to analyze a soil-structure interaction problem: two moduli of elasticity (one vertical and one horizontal) and two Poisson's ratios (one horizontal in terms of vertical and the other vertical in terms of horizontal). For most buried structure investigations, these properties might well be written in terms of easily measured and commonly understood soil properties such as compressibility, soil friction angle, etc. The object of this research would be to determine these relationships.

The objectives of this research problem are limited to static loads and pressures. Additional soil properties are required if dynamic loads are to be considered.

Reference: "Stresses and Displacements in Cross-Anisotropic Soil," L. Barden, Geotechnique, Volume XIII, No. 3, September 1963.

Urgency: No application of design methods to soil structure interaction problems can be reasonably made without some of this basic research on fundamental soil properties.

B4-2 Problem: THE DETERMINATION OF THE EFFECTS OF CONDUIT STRETCHING DUE TO SETTLEMENT AND TO STRESS RELAXATION.

Problem Area: Maintenance problems with long conduits which stretch under high fills and heavy loads becoming cracked and displaced have increased along with the increasing number of such fills being constructed. Repair and realignment are expensive and fill washout may occur if these are neglected.

Objectives: (a) To determine the extent of this problem and relate it to the various factors of soil type, conduit type, and construction practices.

(b) Develop design criteria dependent upon soil type, fill load, and geometrics, so that conduit rupture can be prevented.

Urgency: Repair of such structures is expensive while neglect can be dangerous. It would therefore be safer and more economical to design against this occurrence.

B4-3 Problem: THE DISTINCTION BETWEEN RING CRUSHING AND SNAP-THROUGH IN BUCKLING FAILURE OF BURIED CONDUITS.

Problem Area: The solution of this problem would lead to a more economical design method.

Objective: To develop studies which would lead to such a distinction.

Urgency: The development of the more economical approach would provide safer structures while saving money.

B4-4 Problem: TO DETERMINE THE EFFECTS OF NONSYMMETRICAL SURFACE LOADS OVER BURIED FLEXIBLE CONDUITS.

Problem Area: Information is needed for proper design to withstand the effects of the nonsymmetrical surface loads. These loads are especially important when the flexible conduit is near the surface.

Objectives: (a) To determine the effects of the nonsymmetrical surface loads and their relationship with depth of cover over the buried flexible conduit.

(b) To develop design criteria to insure proper functioning of the conduits.

Urgency: The effectiveness of buried flexible conduits is decreased if they are crushed or distorted. Proper design and construction will result in an economy.

B4-5 Problem: SOIL PRESSURE ON BORED-INTO-PLACE CONDUITS.

Problem Area: The use of bored-into-place or jacked-into-place culvert and pipes under roadways is increasing. Little is known about soil pressures on these conduits; therefore a proper and adequate design cannot be made.

Objective: To develop studies to determine the pressures and effective stress on the bored-into-place or jacked-into-place conduits.

Urgency: Some of the conduits so installed are of pedestrian or vehicular size and placed in very tight quarters with little over-conduit clearance. Failure of such conduits could be dangerous if not disastrous. Safety and economy make this study urgent.

B4-6 Problem: MEASUREMENTS OF SETTLEMENT RATIO OF BURIED RIGID CONDUITS IN FIELD INSTALLATIONS.

Problem Area: Proper design of buried rigid conduits is dependent upon an appreciation of differential settlements and settlement ratios.

Objective: To determine the magnitude of settlements and settlement ratios as related to soil type and construction specifications.

Urgency: This information is needed for an economical and effective design of buried rigid conduits.

B5-1 Problem: INVESTIGATIONS OF INERTIAL EFFECTS IN PAVEMENT BEHAVIOR. Practically all the analyses of stresses and deformation of pavement systems are performed for static or quasi-static loading conditions, ignoring inertial effects. Often this approach provides an overly conservative design. On the other hand, there are cases (as in braking) where the ignorance of inertial effects provides an underdesigned pavement. For the proper understanding and interpretations of pavement behavior, it is essential to consider the effect of actual pavement loads and inertial effects.

Problem Area: Dynamics of pavements.

Objectives: To develop solutions of basic problems of stress distribution and pavement displacements under the action of moving loads.

References: "Deplacements produits sur un semi-espace elastique par une charge en mouvement rectiligne uniforme," J. Mandel and A. Avramesco, Annales des Ponte et Chaussees, pp. 147-158, 1963.

Urgency: This problem is of great significance in evaluation of equivalent weighed axle applications, as well as for interpretation of many stress and deformation measurements.

B5-2 Problem: ANALYSES OF NON-HOMOGENEOUS AND ANISOTROPIC SEMI-INFINITE AND LAYERED SYSTEMS. Analyses of stresses and displacements within pavement systems are usually based on very simplifying assumptions that the pavement materials and underlying soils are isotropic and linearly deformable in the classical sense (elastic constants E and ν are independent of stress level). However, most pavement materials and many soils are anisotropic and exhibit an increase of modulus of deformation E with the increase of stress level. For a better understanding of pavement behavior under load it is vital to develop the theoretical analyses of semi-infinite and layered media consisting of ideal materials whose elastic constants are functions of applied stress and/or direction of material element considered.

Problem Area: Stress distribution in pavement systems.

Objectives: To solve the problem and evaluate the solutions for stress distribution due to surface loads . . . would include as a start, considerations of stress distribution due to surface loads, when the entire loaded mass or particular layers are:

(a) orthotropic solids (elastic constants differing in two perpendicular directions)

(b) hexagonally anisotropic solids (material with one axis of symmetry). This material description is representative of natural soils in which the modulus and Poisson's ratio differ in each horizontal direction.

(c) bilinear solids (elastic constants differing in tension and compression).

(d) granular solids (elastic constants varying with stress level).

References: "Stress Distribution in a Homogeneous, Anisotropic, Elastic Semi-Infinite Solid," H. Koning, Proceedings, Fourth Int. Conf. Soil Mech. and Found. Engrg., London, Vol. 1, pp. 335-338, 1957.

"Mechanics of Granular Matter," H. Deresiewicz, Advances in Applied Mechanics, 5, Academic Press, New York, 1958.

Urgency: It is considered that no significant advancement of the elastic theories of pavement behavior is possible unless the effect of anisotropy and stress level are classified.

B5-3 Problem: ANALYSIS OF MULTI-LAYER VISCOELASTIC SYSTEMS. Pavement materials and soils have time-dependent behavior which can be represented by visco-elastic relationships. There are, at present, few solutions available which can be applied for the evaluation of research findings and/or for direct use in design. This type of analysis would be useful in evaluating cumulative deformation data of pavements under repetitive loads, the effect of static wheel loads and the effect of temperature changes.

Problem Area: Stress distribution in pavement systems.

Objectives: This project should eventually embrace a very broad scope, similar to that proposed for multi-layer elastic systems. The specific objective is to determine the time history of stresses and displacements in multi-layered visco-elastic systems to include:

(a) effect of moving loads, including multiple loads
(b) effect of frictional forces between the tire and the pavement
(c) effect of braking and acceleration
(d) effect of wheel indentations
(e) effect of seasonal temperature changes
(f) effect of time-dependent, stress-transfer conditions of the interface between layers.

References: "Analysis of Visco-elastic Pavements Subjected to Moving Loads," K. S. Pister and R. A. Westmann, Proceedings, Int. Conf. Struct. Design Asphalt Pavements, Ann Arbor, Mich., pp. 522-529, 1962.

"Viscoelastic Behavior of Asphalt Concrete Pavements," C. L. Monismith and K. E. Secor, Proc. Int. Conf. Struct. Design Asphalt Pavement, Ann Arbor, Mich., pp. 476-498, 1962.

"The Response of Linear Viscoelastic Materials in the Frequency Domain with Emphasis on Asphaltic Concrete," H. S. Papazian, Proc. Int. Conf. Struct. Design Asphalt Pavements, Ann Arbor, Mich., pp. 454-463, 1962.

Urgency: In view of increased research efforts in this area, the work on developing visco-elastic solutions can be considered as very urgent.

B5-4 Problem: STRESSES AND DISPLACEMENTS IN HIGH FILLS AND EMBANKMENTS. Present practices often require high fills and embankments (over 100 feet). There are, at present, no rational methods for predicting the stresses and displacements within the fill and/or embankment. It is necessary, to be able to predict the construction stresses and displacements as well as long term developments of stresses and displacements including conditions leading to potential failure of high fills and embankments.

Problem Area: Stress distribution in earth masses.

Objectives: To develop basic solutions that would enable predictions of complete stress fields, including neutral stresses and failure criteria, in a high embankment constructed of soil, as well as in the underlying strata. Particular considerations include:

(a) elastic stresses and displacements within high fills and embankments

(b) long term (visco-elastic) stresses and displacement within, and underlying high fills and embankments

(c) development of displacement fields within high fills and embankments due to the development of plastic yielding of portions of the fill or embankment

(d) contained plastic flow of material underlying fill and embankment

(e) the development of excess pore pressures in foundation soil at the edges of fills and embankments. This study would be necessary to permit field predictions of potential toe failure conditions.

References: "Stress Distribution in Wedges with Arbitrary Boundary Forces," J. H. A. Brahtz, Physics, Vol. 4, pp. 56-65, 1933.

"Analysis of Contained Plastic Flow in Plane Solids," A. H. S. Ang and G. N. Harper, Journal of the Engineering Mechanics Division, ASCE, 90, No. EM-5, Paper 4113, pp. 397-418, 1964.

"Stability of a Bank on a Thin Peat Layer," W. H. Ward, A. Penman and R. E. Gibson, Geotechnique, 5, pp. 154-163, 1955.

Urgency: This subject is of great interest for prediction of settlements of highway embankments and fills.

B5-5 Problem: MECHANISMS OF FAILURE OF MULTI-LAYER SYSTEMS UNDER LOAD. There exists a body of opinion among highway engineers that a rational design method for pavement systems should include considerations at failure as well as under normal working conditions. There exists, at present, very little knowledge concerning the actual mechanisms and causes of plastic failure of flexible pavements.

Problem Area: Mechanics of pavement failure.

Objectives: It is desired to obtain theoretical and experimental information on patterns of displacements and slip surfaces under different load conditions and in varied geometrical and relative strength situations of pavement layers.

Reference: "Some Basic Problems in Flexible Pavement Design," N. W. McLeod, Proceedings, Highway Research Board, No. 32, pp. 90-118, 1955.

Urgency: The information of this kind is necessary for the establishment of adequate ultimate strength criteria for pavement design. It will help explain different causes of mechanical pavement failures, and may contribute to the improvement of techniques of pavement construction.

B5-6 Problem: ANALYSES OF MULTI-LAYER ELASTIC SYSTEMS. The existing solutions of the problem of a multi-layer elastic system are far from complete to satisfy the needs of current research and engineering practice. Also, many solutions that exist have not been numerically evaluated in sufficient detail to permit a convenient use in current computations.

Problem Area: Stress distribution in pavement systems.

Objectives: The existing analyses of multi-layer elastic-isotropic systems should be extended to include at least the following:

(a) stress and deformation at any point within the layered system. The mathematical complexity of this problem area requires the extensive use of large computing systems. The development of stress and displacement data should be considered as a computing system.

(b) effect of stress-transfer conditions at the interface between layers.

(c) stress and deformation resulting from other shapes of loaded areas (e.g., ellipse) and pressure conditions other than uniform.

(d) effect of multiple loads, e.g., dual wheels and tandem axles.

(e) effect of shear stresses induced by braking and acceleration.

(f) effect of finite rather than infinite boundary conditions (e.g., loading conditions near edge of portland cement concrete slab or in outer wheel path of asphalt concrete pavement adjacent to unpaved shoulder).

(g) effect of pore pressures in saturated and partially saturated subgrades and bases.

(h) effect of seasonal temperature changes.

In addition, practical solutions should be made available for an elastic system consisting of four or more layers and include the factors noted above for the three-layer system. This project would of necessity require extensive use of electronic computers.

References: "The General Theory of Stresses and Displacements in Layered Systems," D. M. Burmister, Journal of Applied Physics, Vol. 16, pp. 296-302, 1945.

"General Analysis of Stresses and Displacements in Layered Elastic Systems," R. L. Schiffman, Proceedings, Int. Conf. Struct. Design Asphalt Pavements, Ann Arbor, Mich., pp. 365-375, 1962.

Urgency: Many of the evaluations and solutions mentioned are needed daily by the researchers in this area.

B6-1 Problem: SURVEY EFFECTIVENESS OF EXISTING SUBSURFACE DRAINAGE INSTALLATIONS. Considerable evident lack of adequate subsurface drainage shows need for study of installations. Review of original condition, design of drainage, construction and maintenance records, and present condition would provide data for improving design of subsurface drainage to maintain pavement stability. On new work, record pertinent data while construction is under way, and develop long time records of maintenance and performance.

Problem Area: Pavement performance is related to the effectiveness of subsurface drainage in certain soil types.

Objective: Develop design criteria for effective installation of subsurface drainage installations.

Urgency: Increasing maintenance costs and smoothness requirements demand closer attention to proper design and installation procedures.

B6-2 Problem: DETERMINE PROPERTIES OF SUBSURFACE DRAINAGE CONDUITS. To aid in selecting the best conduit for a particular situation, an inventory is needed of engineering properties of conduits of various materials and configurations. These properties include cost, strength, durability, installation, and characteristics of flow into and through them.

Problem Area: Economics and maintenance.

Objective: To develop criteria for the proper selection of subsurface drainage conduits in relation to the various properties.

Urgency: Economy is based on intelligent selection.

B6-3 Problem: DETERMINE DRAINABILITY OF SOILS, BASES, AND SUBBASES. Study by full-scale tests and other appropriate methods the effectiveness of various materials and geometry for stabilizing soil and pavement under various typical situations of soil and water.

Problem Area: Effective drainage is necessary to provide stability to many sites involving high fills, deep cuts, and side hill cuts in seepage areas.

Objective: To establish standard methods for determining drainability of soils so as to provide engineering criteria for design.

Urgency: Improvement for economic design procedures.

B6-4 Problem: REFINE CRITERIA FOR FILTER MATERIAL IN SUBDRAINS. Although criteria for selecting one-size materials for filters are well established, tests and criteria are needed to better specify the use of widely graded materials against soil and adjacent to perforations or joints between pipes. Examinations should be made from the standpoint of the drainpipes as well as from the standpoint of the material surrounding the pipes.

Problem Area: Effective drainage of subsurface soils.

Objectives: (a) To develop the criteria necessary to specify filter materials for use with subsurface drains.

(b) Relate these criteria to properties of drainage conduits.

Urgency: Effectiveness of drainage systems is dependent upon effectiveness of filter courses.

B6-5 Problem: APPLICATION OF THE FLOW NET THEORY TO DESIGN OF SUBDRAINAGE SYSTEMS.

Problem Area: Need for designing drainage systems with adequate discharge capacities.

Objectives: To develop design criteria assuring the construction of drainage systems capable of permanently protecting roads from water damage.

Urgency: Considerable pavement deterioration and economic loss is occurring due to inadequate subdrainage systems.

C1-1 Problem: RESEARCH IN PHOTO INTERPRETATION TECHNIQUES OF INFRARED PHOTOGRAPHY. Infrared aerial photography has been found useful in many fields, but has yet to be fully exploited for use in interpretation of soils.

Problem Area: This problem belongs in the broad area of airphoto interpretation of soils.

Objectives: The objective is to develop the technique of interpreting infrared aerial photographs and evaluate their use for highway soil engineering purposes, including the evaluation of photography taken at different seasons and with different filters. This research should be conducted to determine the limitations and the advantages of this type of photography as compared to conventional panchromatic aerial photography and should include a study of filters to use with the infrared emulsions.

References: Some work has been accomplished at Ohio State University, Project EES 196-B. The work involves a study of film filter scale season combinations over soft soil and landslide-susceptible terrain.

Urgency: The rapid pace of new highway construction requires improved shorter methods of conducting soils surveys and materials exploration.

C1-2 Problem: AIRPHOTO INTERPRETATION THROUGH USE OF MULTIBAND SENSING. Airphoto interpretation of soils and terrain has been severely limited in capabilities due to the limitations of the generally available photography. This is usually limited to one emulsion type (panchromatic).

Problem Area: This problem belongs in the broad area of airphoto interpretation of soils.

Objectives: To develop techniques of airphoto interpretation of soils by utilizing two or more different photographic types (such as panchromatic, infrared and color). To develop best film-filter combinations to obtain maximum information content on aerial photography.

Reference: The USAF Cambridge Research Laboratories, Bedford, Massachusetts, has developed a nine lens camera using three film types with different filter types to study this same problem.

Urgency: This is the most important research that can be conducted to improve airphoto interpretation of soils and geologic features.

C1-3 Problem: INVESTIGATION OF PHOTOGRAPHIC-SPECTRAL RANGE TO IMPROVE AIR-PHOTO INTERPRETATION TECHNIQUES. Aerial photography available and that being made available utilizes broad portions of the visible spectrum and, therefore, often does not differentiate between features that have different reflective characteristics in narrow portions of the spectrum.

Problem Area: This problem belongs in the broad area of airphoto interpretation of soils.

Objective: To increase soils and terrain information from airphoto interpretation by developing the best film-filter combinations utilizing narrow portions of the spectral response. Research should be conducted utilizing conventional aerial photographic emulsions and narrow band filters. Available spectrophotometer data should be used to select filters.

Reference: Some work has been accomplished at Ohio State University, Project EES 196-B. This work has utilized conventional emulsions with several filters over limited soils conditions.

Urgency: This is a required step in improving airphoto interpretation techniques for soils surveys and materials exploration.

C1-4 Problem: THE EFFECT ON PHOTO INTERPRETATION OF VARIANCE IN QUALITY OF COLOR AERIAL PHOTOGRAPHY. In using color aerial photography for photo interpretation, extreme variation in quality of photography is often noted when conditions of exposing, processing or storage are allowed to vary. This difference in quality most often is evidenced by a change in hue of the color images of an object presented in different photographs. Study is needed of the effect this variance in color quality has on optimum use of color aerial photography for photo interpretation. It is known that several variables have a definite effect on quality of the photography, but exactly what effect they have is not always clear, and little is known of the effect these variables have on the quality of photo interpretation that can be accomplished from the photographs.

Problem Area: This problem belongs in the broad area of airphoto interpretation of soils.

Objectives: The objectives are to study the effects on quality of color aerial photography of such variables as: (1) type of color film, (2) methods of processing, (3) color prints versus transparencies, (4) time and conditions of exposure, (5) time of day of photography, (6) time of year of photography, and (7) fading of photographs under different storage conditions; and more significantly, to determine the relationship between each of these variables and the quality of photo interpretation obtained from color aerial photography.

References: "Application of Color Aerial Photography to Geologic and

Engineering Soil Mapping," J. P. Minard and J. P. Owens, HRB Bulletin 316, 1962, pp. 12-22.

"A Preliminary Evaluation of Color Aerial Photography in Materials Surveys," J. R. Chaves, R. L. Schuster and R. J. Warren, HRB Proc., Vol. 41, 1962, pp. 611-620.

"The Use of Aerial Color Photography in Materials Surveys," J. R. Chaves and R. L. Schuster, HRB, Highway Research Record No. 63, 1964, pp. 1-9.

"Aerial Photography and Photogrammetry in the Coast and Geodetic Survey," L. W. Swanson, Photogrammetric Engineering, Vol. XXX, No. 5, Sept. 1964, pp. 699-726.

Urgency: Color aerial photography has shown great promise but little use has been made of this photography for photo interpretation. This is an important step in increasing the capability of photo interpretation of soils and materials exploration. New methods are required to assist in finding scarce material sources.

C1-5 Problem: RESEARCH IN INTERPRETATION OF INFRARED THERMAL IMAGERY. Infrared aerial imagery has been found useful in terrain studies but has not been exploited in soils investigations.

Problem Area: This problem belongs in the category of airphoto interpretation of soils.

Objectives: The objectives are to develop techniques of interpreting infrared thermal imagery and to evaluate the usefulness of these techniques for highway soil engineering purposes. This research should be conducted to determine the advantages and limitations of this type of aerial photography.

References: Some work has been accomplished at the U. S. Army Cold Regions Research and Engineering Laboratory, University of Michigan, University of California, Texas Instruments, etc.

Urgency: There are certain latent terrain conditions that cannot be fully detected by conventional photography, such as poorly drained soils; new highway construction requires early detection of poor foundation soils areas and improved methods of conducting soil surveys and materials exploration.

C1-6 Problem: EVALUATION OF EQUIPMENT AND PROCEDURES FOR SAMPLING SAND AND GRAVEL DEPOSITS. The problems seem to fall under several headings. They are as follows:

1. Sorting of material by the sampling equipment
    a. Samples coarser than the average source material
    b. Samples finer than the average source material
    c. Segregation or loss of intermediate sized

2. Contamination by overburden material as sample is brought to the surface.

3. Inability of equipment to bring samples to the surface. This occurs most frequently when the bed lies below the water table.

Problem Area: The difficulties encountered in attempting to obtain accurate representative samples of cohesionless or nearly cohesionless sands and gravels have been recognized for many years by those responsible for locating suitable natural sources of these materials.

Objectives: The objectives are to determine the effectiveness of presently available equipment to obtain accurate samples of sands and gravels above and below the water table. To develop, if possible, new equipment and techniques that will be capable of taking accurate samples of sand and gravel under all conditions.

Urgency: The problem is considered to be urgent in the area of soil exploration.

C1-7 Problem: EVALUATION OF GEOPHYSICAL APPARATUS AND ITS APPLICATIONS IN HIGHWAY SUBSURFACE EXPLORATIONS. The problem areas may be grouped as follows:

A. Analysis and comparison of methods and new instruments.

B. Analysis and comparison of interpretive techniques.

Problem Area: There have been numerous developments in geophysical instrumentation related to subsurface explorations during the past 30 years. Some of the equipment now available has been tested in some detail over a variety of geologic conditions. Other more recently developed apparatus has had a minimum of field testing in establishings its probable usefulness or limitation.

Objectives: The objective is to determine the usefulness of new geophysical equipment in a variety of subsurface explorations and compare it with other exploration equipment with regard to its cost and effectiveness.

References: "Geophysics Efficient in Exploring the Subsurface," R. Woodward Moore, Journal of the Soil Mechanics and Foundation Division, A.S.C.E., June 1961, pp. 69-100.

"Geophysical Methods and Statistical Soil Surveys in Highway Engineering," HRB, Highway Research Record No. 81, 1965, pp. 1-48.

Urgency: The problem is considered to be of continuing interest and urgent in the area of soil exploration.

C1-8 Problem: CORRELATION OF AASHO SOIL CLASSIFICATION AND BEARING CAPACITY OR STRENGTH OF SOIL AND AGGREGATE MATERIALS. There is a need for a correlation between the soil classification systems and the strength properties.

Problem Area: There is considerable published information on the various soil classification systems and on the various tests to determine strength or bearing capacity of soil and aggregate materials. There is, however, a noticeable lack of information relating these classification systems with strength parameters.

Objectives: The objective is to develop the relationship between the AASHO Soil Classification System and bearing capacity or strength of soils as determined by CBR, triaxial compression, unconfined compression, R-value, etc.

References: "Predicting the California Bearing Ratio from Compaction and Classification Data," J. L. Jorgenson, presented at 45th Annual Meeting, HRB, Jan. 1966.

Urgency: The problem is considered to be urgent in the area of relating the performance of subgrade materials with soil classification systems and in the area of pavement design.

C1-9 Problem: CLASSIFICATION OF ORGANIC SOILS. An investigation is needed to determine the relationship between amount and type of organic matter present in organo-mineral soils (natural or artificial mixture) and the physical properties of the soil as measured by Atterberg limits, compressibility, moisture-density relations and some appropriate strength parameter.

Problem Area: There is no quantitative basis for defining organic soils. Casagrande and others have indicated that organic soils (such as OL or OH) can be identified by first determining the liquid limit of a soil in its natural moisture conditions (without first air drying), then performing the same test on air-dry material (standard test method). A major reduction in liquid limit indicates an organic soil. This criterion is not really satisfactory since certain clay minerals and hydrous oxides also have irreversible structures. The liquid limit of such clay minerals will also decrease considerably upon oven drying. The literature contains only a few publications which deal with the effect of organic material on the engineering properties of soils. Furthermore, in the present AASHO Soil Classification System, no allowance is provided for the classification of soils containing appreciable organic matter.

Objective: The objective is to develop a rational basis for identification and classification of organic and organo-mineral soils which can be related to their probable engineering performance.

Urgency: The problem is considered to be very urgent in the area of classifying organic soils.

C1-10 Problem: REVISION OF THE AASHO SOIL CLASSIFICATION SYSTEM. The AASHO Soil Classification System should be reevaluated, based on the experience gained in its use by the state highway departments and other agencies and on the most recent knowledge of the performance of subgrade materials.

Problem Area: Based on the returns to a questionnaire sent out to the state highway departments and other agencies by the HRB, there appears to be a need for the revision of the AASHO Soil Classification System. Particular attention needs to be given to the soils having group indices of zero and those having values of twenty.

Objective: The objective is to determine the revisions that should be made in the AASHO Soil Classification System as determined by experience gained in its use by the state highway departments and so that it will more accurately reflect the performance of subgrade materials.

References: "A Review of Engineering Soil Classification Systems," T. K. Liu, presented at 45th Annual Meeting, HRB, Jan. 1966.
"Standard Recommended Practice for the Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes," AASHO Designation: M 145-49, Standard Specifications for Highway Materials and Methods of Sampling and Testing, Part I, 9th ed., AASHO, 1965.

Urgency: The problem is considered to be of concern in the area relating the performance of subgrade materials with engineering soil classifications.

C2-1 Problem: STABILITY ANALYSIS OF ROCK CUTS.

Problem Area: The methods available for selecting safe slopes for rock cuts are unreliable. They are either general methods that do not account for geologic defects adequately or they are specific procedures whose limitations are not defined.

Objective: Develop analytical methods to evaluate stability of rock cuts that can consider the geometry, instrinsic stresses, rock type, geological defects, and the effects of ground water and gain or loss of moisture content on exposure.

Urgency: High priority. Badly needed to increase safety and reduce costs of rock cuts.

C2-2 Problem: MECHANICS INVOLVING ROCK STRESSES IN DEEP CUTS.

Problem Area: Some deep rock cuts have evidenced disturbance in the rock remaining due to the relief of restrain brought on by the cut. This disturbance has caused the popping out of rocks along the lower exposed faces, sometimes causing a traffic hazard.

Objective: To develop the mechanics involved to the extent that prediction of this action can be made in order to design restraint or protection devices.

Urgency: Will grow more urgent as these deep cuts become more common with modern design and construction.

C2-3 Problem: STRESS TRANSMITTAL FROM END BEARING PILES OR CAISSONS.

Problem Area: The assumptions on stress transmittal from end bearing piles or spread foundations need both qualitative and quantitative substantiation. Many times designs are more costly than need be because of unrealistic assumptions of load transfer.

Objectives: (a) To develop design criteria for load transfer from end bearing piles and caissons to the underlying rock.

(b) To establish test methods to substantiate or disprove the proposed criteria.

Urgency: Many more dry land bridges will be constructed under the modern highway program with limited accesses. The economy which could evolve will be of growing importance.

C2-4 Problem: TO DEVELOP CRITERIA FOR PRESPLITTING.

Problem Area: Presplitting of rock faces in cut excavations is becoming more and more common because of the reduction in overbreakage and therefore construction costs. Post construction maintenance costs are decreased since clearing of rock fall is reduced. The additional hazard of rock in the roadway is reduced also.

Objective: Evaluate the effectiveness of criteria for presplitting in relation to rock type, geological conditions, and height of cut.

Urgency: This information is needed to make competent designs of rock cuts with economical specifications and controls.

C2-5 Problem: MECHANICS OF ROCK SWELL AND CREEP.

Problem Area: Movements of massive rock cuts against bridge abutments, etc., has caused structural distress involving expensive maintenance and repair. Rock swell into the bottom of some cuts has caused dangerous pavement damage, again leading to expensive maintenance or repair.

Objectives: (a) To develop measuring device and system to follow accurately the incremental rock swell or creep.

(b) To develop the mechanics of rock swell and creep so that accurate predictions of movement may be made dependent upon rock type and stratigraphy.

(c) To develop criteria for use in design.

Urgency: The problem, while not a major one at this time, will increase in importance as Interstate and Primary road systems are constructed in mountainous country.

C2-6 Problem: MEASUREMENT OF ROCK PROPERTIES OF CONCERN IN HIGHWAY CONSTRUCTION.

Problem Area: There are no standardized tests for most physical properties of rock, and many of the existing tests are either time-consuming, expensive, or difficult to interpret.

Objective: To develop standard tests that are rapid and economical and still permit a high-confidence level in prediction of abrasion resistance, strength, porosity, absorption, density, and other rock properties that would be of use to highway engineers. To develop petrographic microscope analyses that would minimize or eliminate extensive laboratory testing of the aforenoted properties.

C2-7 Problem: USE OF GEOPHYSICAL AND OTHER NON-DESTRUCTIVE MEASUREMENTS.

Problem Area: Geophysical techniques have been used in highway investigations to locate bedrock and, occasionally, to determine the depth and thickness of soil types that have distinctly definable signatures for the type of instrumentation used. These investigations generally are accompanied by extensive drilling and core sampling with subsequent laboratory tests. Considerable judgment still is required in deciding the most efficient method of excavating and processing the rock.

Objective: Information that can be used to ascertain the most efficient method for rock excavation; for example, whether (1) high or low energy chemical explosives will be most efficient, (2) draglines can be used, or (3) rippers will perform efficiently.

C2-8 Problem: RAPID EXCAVATION OF ROCK IN OPEN CUTS AND TUNNELS.

Problem Area: Present rock and soil excavation methods are not always compatible with the rapid progress desired in building Interstate highways. Also, most of the rock excavation methods require high-energy explosives that could damage structures adjacent to those stretches of highways especially in the vicinity of urban areas. Furthermore, the feasibility of proposals to place Interstate highways underground through dense urban areas and to construct underground parking complexes is dependent on new and highly efficient methods of rapid rock excavation; such methods also will have to minimize possibility of structural damage to overlying buildings.

Objective: To develop methods not dependent upon conventional high explosives for excavating of all types of rock, such as full-face tunnel boring machines, thermal jets, lasers, high-frequency electrical arcs, and chemical explosives more controllable than those available today.

Urgency: There is a high priority on the development of such methods. It would open up new vistas for construction of high-speed transportation systems.

C2-9 Problem: METHODS OF DRILLING HOLES FOR EXPLOSIVES.

Problem Area: The currently used methods are founded on rotary, percussive, and rotary-percussive principles that have hardly changed for several decades. Conventional methods of excavating rock (drilling, blasting, and mucking) include a time-cycle that is controlled by the time required to get a drilling machine (or machines) into place, drill the hole, clean it, load it, and then remove the machine prior to blasting.

Objective: Development of very rapid hole-drilling methods that would use light-weight, easily and rapidly movable equipment, and maintain a clean hole during the entire drilling cycle.

Urgency: Large economic benefits would construe in many aspects of highway construction, including rock cuts, production of aggregates, etc.

C2-10 Problem: PREDICTION AND CONTROL OF PORE PRESSURE IN ROCK MASSES.

Problem Area: Little is known about the relation between rock type and structure and the development of internal pore pressures in the rock; the same problem occurs where there is movement of water through rock masses. Water pressures can result in destruction of retaining walls (by uplift or by high back pressures caused by drainage from adjacent rock banks), unexpected movement of embankments founded on rock, undesirable deflection of concrete structures such as bridge abutments and the like.

Objective: Development of an analytical and experimental technique to predict pore pressure and ground water movement in all types of rock and geological situations.

Urgency: High priority. Badly needed to increase safety and reduce costs of rock cuts.

C3-1 Problem: FUNDAMENTAL RESEARCH INTO PHYSICO-CHEMICAL PROPERTIES OF SOILS.

Problem Area: A widespread lack of understanding of the physical-chemical properties of soils has led to some significant errors in concept of the solution of problems in soil engineering.

Objectives: (a) To develop systematic relationships between physico-chemical properties of soils and the engineering properties of soils.

(b) Develop means for the adequate dissemination of this information with competent instruction where needed.

References: "The Application of Base Exchange and Soil Physics to Problems of Highway Construction," Proceedings, Soil Science Society of America, Vol. 1, pp. 93-99, 1937.

"Surface-Chemical Factors Influencing the Engineering Properties of Soils," Proceedings, HRB, Vol. 16, pp. 293-308, 1937.

"A Study of Changes in Physical Properties of Putnam Soil Induced by Ionic Substitution," Proceedings, HRB, Vol. 21, pp. 415-435, 1941.

"Physico-Chemical Properties of Soils," Proceedings, 2nd Int. Conf. Soil Mechanics and Foundation Engineering, Vol. 1, pp. 8-12, Rotterdam, Netherlands, 1948.

Urgency: This information is needed to help avoid costly errors in soil engineering.

C3-2 Problem: DEVELOP PHYSICO-CHEMICAL INDICATOR TESTS TO PREDICT PERFORMANCE.

Problem Area: The decision as to what physico-chemical property is indicative of an engineering property is closely allied to the physico-chemical indicator test used and properly conducting and interpreting such a test.

Objectives: (a) Develop standards for the indicator tests.

(b) Develop diagnostic procedures and guides for the use of such tests.

Reference: "Physico-Chemical Testing of Soils and the Application of Results in Practice," Proceedings, HRB, Vol. 20, pp. 798-806, 1940.

Urgency: These methods and guides are needed to aid in the proper usage of the physico-chemical properties of soils in predicting engineering performance.

C3-3 Problem: DEVELOP PRACTICAL RELATIONSHIPS OF PHYSICO-CHEMICAL PROPERTIES WITH MOISTURE MIGRATION.

Problem Area: Excessive soil moisture generally results in loss of strength in soil structures. Moisture migration many times extends over long periods of time before the accumulation is sufficient to cause troubles. There is a relation between the physico-chemical properties of the soil and its propensities to accumulate excessive moisture. Prediction of ultimate moisture through negative pressure tests are time consuming and laborious. It is thought that accurate predictions could be based on physico-chemical tests.

Objective: To develop physico-chemical tests which would be suitable for prediction of ultimate subgrade moisture under inservice conditions.

References: "Water Conduction in Soils," Highway Research Board Special Report 40, 1958, also Bulletin 287, 1961.

"Climate and Highways," Transactions, AGU, 1944, pp. 405-411.

Urgency: Proper design of flexible pavement is dependent upon an estimate of inservice strength of the subgrade soil which in turn is dependent upon a proper estimate of ultimate moisture content under the inservice conditions. More rational and therefore more economic flexible pavement design will be possible with this information.

C3-4 Problem: DEVELOP PHYSICO-CHEMICAL INDICATOR TESTS TO PREDICT SUITABILITY OF A SOIL FOR STABILIZATION.

Problem Area: Much time and effort through empirical performance testing goes into the study of a soil to see whether or not it is suitable for stabilization. This is very costly, especially when there are several soil types to be considered.

Objectives: (a) Develop appropriate physico-chemical tests of the soil so that those soils definitely unsuitable for any current type of stabilization will be eliminated from further study.

(b) Develop appropriate physico-chemical tests which would serve as indicator as to which common type of stabilizer (aniline-furfural, cement, lime, asphalt, phosphoric acid, etc.) might be most promising to study further.

(c) Develop indicator tests that suggest the appropriate range of amounts of additive to study.

References: "Principles and Practice of Soil Stabilization," Colloid Chemistry, Theoretical and Applied (Editor, Jerome Alexander), Vol. VI, pp. 459-492, Reinhold Publishing Corp., New York, 1948.

"Soil and Soil Aggregate Stabilization," Highway Research Board, Bulletin 108, 1955.

"Surface-Chemical Factors of Importance in Bituminous Soil Stabilization," Proceedings, A.A.P.T., Vol. 11, pp. 204-257, 1940.

"Soil Stabilization," Proceedings, 2nd Int. Conf. Soil Mechanics and Foundation Engineering, Vol. 5, pp. 209-215, Rotterdam, Netherlands, 1948.

"Surface-Chemical Factors of Importance in the Hardening of Soils by Means of Portland Cement," Proceedings, HRB, Vol. 22, pp. 385-414, 1942.

"Beach Sand Stabilization Research 1947-1949," NOy-15087 Bureau of Yards and Docks, Department of the Navy (reprinted by the U. S. Dept. of Commerce) 564 pages, 1949.

"Fundamental Approach to the Stabilization of Cohesive Soils," Proceedings, HRB, Vol. 28, pp. 415-422, 1948.

Urgency: Thousands of tons of additives are being used to stabilize subgrades to improve their performance. The selection of kind and amount is time consuming and costly. The information obtained here would greatly reduce the cost and time.

C3-5 Problem: FUNDAMENTAL RESEARCH ON THE EFFECT OF TEMPERATURE ON SOIL PROPERTIES AND BEHAVIOR.

Problem Area: Although temperature affects most engineering properties of soils, their interaction with water and stabilizing chemicals and the rate of air and moisture transportation processes in soils, all of which are of great importance in construction, maintenance and in service quality and life of highways, very few dependable data are available concerning the temperature effect.

Objectives: (a) To develop systematic data concerning the effect of temperature on the commonly used subgrade soil constants as well as on such soil mechanics tests as compressibility, shear resistance, permeability, etc., of cohesive soils of various mineralogic and pedologic characteristics.

(b) To develop and evaluate data concerning the effect of temperature on the rates of reaction of cohesive soils with common and uncommon stabilizing materials.

(c) To coordinate the information obtained into a useful and thermodynamically correct guide for soil engineering at various temperature levels.

Urgency: Absence of this information has led to great loss of construction money especially in regions different from those in which project engineers have acquired their practical experience. This information is required to help soil engineering and especially soil stabilization and low cost road construction take another step toward being a practical science applicable to all climates and soils of this earth.

C3-6 Problem: LIFE EXPECTANCY OF SOIL AGGREGATION STABILITY.

Problem Area: Agronomists are presently using empirical techniques for measuring the stability of soil aggregation. There are no tests to predict the degree of permanency of the stability.

Objectives: (a) Develop tests to assess and determine the life expectancy of both micro- and macro-aggregation.

(b) Develop diagnostic procedures and guides for the use of such tests.

References: "Techniques for the Determination of the Stability of Soil Aggregates," Soil Science Vol. 101, pp. 157-163, 1966.

"Mechanism of Water Attack on Dry Cohesive Soil Systems," Soil Science, Vol. 54, No. 4, October 1942.

"Importance of Volume Relationships in Soil Stabilization," Proceedings, HRB, Vol. 29, pp. 553-560, 1949.

Urgency: Should such tests be developed, the effectiveness of the various methods of soil stabilization can be included in the economic optimization techniques used for any design and feasibility study.

C4-1 Problem: DENSITY OF VARIOUS SOIL TEXTURES WHICH WILL RESIST FROST HEAVING WHEN SLOW FROZEN IN A NEAR SATURATED CONDITION.

Problem Area: In frost-susceptible soils in Northern United States.

Objectives: If densification can be used to retard or resist frost heaving then soil compaction becomes a major factor in highway construction in the frost areas of the United States.

Urgency: Frost heaving in subgrades is a serious highway problem and anything that can be done to improve the situation should be encouraged.

C4-2 Problem: A STUDY OF SHRINKAGE OF SOILS AND BASE COURSES DUE TO FROST ACTION.

Problem Area: It has been observed that soils and bases which do not otherwise exhibit detrimental effects of frost action do quite often show transverse cracking as a result of prolonged freezing. As this cracking appears to be the origin of distress to flexible pavement surfaces, some study of this problem is required. It should be pointed out that this phenomena apparently occurs most extensively on pavement base and soil combinations that are least susceptible to frost action in the form of heaving and loss of bearing capacity upon thawing.

Objectives: The objective of this research is to determine the conditions under which transverse contraction cracking takes place.

References: No references are known regarding transverse cracking. Longitudinal cracking, due to another cause, has been documented to some extent in the literature.

Urgency: A trend has been established for using cleaner base course materials so as to avoid the detrimental aspects of frost heaving and loss of bearing capacity. It may be that another problem is being created as a result. On the basis of limited observations thus far, the transverse cracks do not seem to occur on soils in those locations which are conducive to detrimental frost action in the form of heaving and loss of bearing capacity during the spring breakup period. Knowledge of shrinkage behavior of soils upon freezing is needed to help establish the limits of material properties for frost-resistant design.

C4-3 Problem: A STUDY OF THE EFFECT OF COMPOSITION OF THE SOIL ON ITS FROST-SUSCEPTIBILITY.

Problem Area: Although considerable research has been done on this topic, the relationship between frost-susceptibility and soil composition has been defined only within very broad limits. Further research is necessary to develop relationships that will be useful in design and selection of materials.

Objective: The objective of the proposed research is to establish clearly defined relationships between soil composition and frost-susceptibility. For the purposes of this statement, frost susceptibility includes both the effects of heaving and the loss of stability upon thawing. Also, soil composition includes mineralogical composition, grain-size or textural composition, and the presence of small quantities of organic material.

References: Publications of the U. S. Army Cold Regions Research and Engineering Laboratory, the Highway Research Board, and various Canadian agencies document the work that has been accomplished thus far. Some information is available in the literature from Western and Northern Europe.

Urgency: The margin between the supply of materials which are suitable for frost-resistant design and the demand for these materials is decreasing very rapidly with the current highway building program. As these materials constitute irreplaceable resources, they must be used in the most effective manner possible.

C4-4 Problem: LOAD SUPPORTING CAPACITY OF ROADWAY BASE COURSE MATERIALS.

Problem Area: Minor changes in the percent of fines in base course materials apparently have a great influence on the supporting capacity. The economics of this program are serious. Therefore, research is needed to guide highway engineers in preparing specifications for base materials.

Objectives: The objective of this research is to determine rather precisely the effect of these minor changes in the percent of fine material. The project would include the evaluation of the load supporting capacity of base course materials after freezing and thawing, with differing percentages of fine material, differing moisture contents, and differing rates of freezing.

References: The publications of the U. S. Army Cold Regions Research and Engineering Laboratory, and the Highway Research Board Symposium on Pavement Design in Frost Areas-Part II, Bulletin 225, contain pertinent information.

Urgency: The expansion in highway construction and the widespread area consequences of this problem indicate that it deserves immediate consideration.

C4-5 Problem: THEORETICAL AND EXPERIMENTAL STUDIES ON TEMPERATURE REGIMEN IN SOILS AROUND CULVERTS UNDER FREEZING CONDITIONS:

Problem Area: This problem pertains to the construction of artificial drainage structures on highways and of earthworks for highways and their performance under freezing conditions. It has a bearing on traffic safety and on maintenance of highways.

Objectives: The objective of this research is to arrive at a rational design of culverts which would perform satisfactorily in winter on roads which are kept free of snow for high-speed travel. This would be obtained by reducing bumps and differential heaves on roads at and/or near culverts, and founding and imbedding culverts so that they are not affected by frost action in soil.

Urgency: Traffic safety, investment and maintenance (viz repair) considerations make this problem of study urgent.

C4-6 Problem: THERMAL PROPERTIES OF SOIL AND PAVEMENT MATERIALS.

Problem Area: This problem is a part of pavement (subgrade, subbase, base, cleanliness course and pavement proper) design for its performance under freezing, but particularly under thawing conditions.

Objectives: The objective of this research is to determine the various thermal properties of soils (conductivity, diffusivity, heat capacity, for example) necessary for calculations of frost penetration and thawing depths in highway soils. This data is needed for the design of pavement drainage structures in order to carry the melted water away quickly, thus facilitating the quick return of the bearing capacity of highway soils to withstand traffic loads.

References: Laboratory research on thermal properties of soils has been performed by Dr. Miles Kersten, Professor of Civil Engineering at the University of Minnesota. His system was vertical-cylindrical with horizontal heat flux. The soil systems were "warm."

Laboratory research on thermal properties of soils was performed by A. R. Jumikis at Rutgers University. This soil system had laterally insulated upright cylinders with vertical heat flux (viz downward freezing as in nature). The soils systems were "cold" and "chilled." Due to lack of funds, the work was limited to six New Jersey soil types.

Urgency: There is a real urgent need for knowledge of the thermal properties of soil and pavement materials. Without knowing the thermal properties, no rational pavement design can even be imagined.

C4-7 Problem: SOIL MOISTURE MIGRATION UPON FREEZING, AND STRENGTH PROPERTIES OF FROZEN AND CHILLED SOILS.

Problem Area: Design of pavements and slopes of earthworks with respect to their performance under freezing conditions.

Objectives: The specific objective of this research topic is to study theoretically and experimentally the various soil moisture migration mechanisms under various freezing conditions in various types of soils, at various porosities (viz, densities) of packing, degree of saturation, position of ground water table (or perched ground water table) below ground surface, temperature regimen in freezing soil systems, driving pressures for the upward flow of soil moisture upon freezing, of frozen and chilled soils.

References: Research work on this topic has been pursued theoretically and experimentally by A. R. Jumikis at Rutgers University since 1952, especially on the amounts of soil moisture transferred to the cold front as a function of porosity of soil, and the various soil moisture transfer mechanisms acting in the various porosity ranges formulated. The methodology for such experimental studies has been worked out by the author, and basic laboratory equipment procured. At the present time, lack of funds to continue these studies has "frozen in" Jumikis' research.

Urgency: There is an urgent need for this knowledge to understand the physical processes in soil upon freezing and for the design of highways performing under freezing conditions. The repair of damage by frost to the nation's highways costs billions of dollars. Hence, frost action in highway soils is not merely a problem of academic interest but of national importance.

C5-1 Problem: PROPER COMPACTION MOISTURE CONTENT OF HIGH VOLUME CHANGE SOILS. Differential shrinkage and swell of expansive subgrade soils may adversely affect the riding quality and performance of pavements constructed on these subgrades. It has been known for some time that these soils are markedly influenced by the moisture content and density achieved during subgrade compaction. However, systematic laboratory studies are needed to learn the effects of a wide range of compaction moisture contents and compactive efforts on volume change characteristics of a wide variety of expansive soils.

Problem Area: Differential shrinkage and swell of expansive soils is most likely to occur in arid, semi-arid or subhumid climates. However, expansive subgrades can also cause unsatisfactory pavement performance in more humid areas during droughts, shorter periods of dry weather, and where soils are highly expansive.

Objectives: To determine the proper compaction moisture contents and densities to most effectively control differential volume changes in expansive subgrade soils.

References: "Report of Committee on Warping of Concrete Pavements," Proceedings of the 25th Annual Meeting, 1945, Highway Research Board, p. 199.

"Interrelationships of Load, Volume Change and Layer Thicknesses of Soils to Behavior of Engineering Structures," Chester McDowell, Proceedings of the 35th Annual Meeting, 1955, Highway Research Board, p. 754.

"Evaluating Taylor Marl Clay for Improved Use in Subgrades," Lawrence A. Dubois, Research Report 35, Texas Engineering Experiment Station, March 1952.

"Influence of Soil Volume Change and Vegetation on Highway Engineering," Earl J. Felt, Bulletin D1, Research and Development Laboratories, Portland Cement Association.

"Theoretical and Practical Treatment of Expansive Soils," Colorado School of Mines Quarterly, Vol. 54, No. 4, October 1959.

Urgency: Because of the expanded and continuing highway program the need for engineering data on the compaction of high volume change soils is urgent.

C5-2 Problem: MODEL OF MOISTURE MOVEMENTS BENEATH PAVEMENTS. The relative importance of the climatic and material factors in determining moisture movements beneath pavement surfaces, even though a great deal of theoretical work has been accomplished for unpaved areas.

Problem Area: In order to develop rational methods of pavement design some reasonable procedures for predicting ultimate or equilibrium moisture contents must be developed.

The search for such procedures would be expedited by a knowledge of which factors are the most critical in determining the movement of moisture beneath surfaces.

In the light of the work which as been accomplished in the area of soil physics, it seems likely that a mathematical model could be developed which would describe moisture movements under pavements.

Objectives: To develop a mathematical model which would describe the movement of moisture under pavement surfaces and indicate the relative importance of various climatic and material factors in controlling the ultimate moisture content of subgrade, subbase and base courses.

References: Reports of British Road Research Laboratory on moisture movement in soils under temperature and suction pressure gradients.

Investigations of moisture movements in soil under bare and cropped plots by soil physicists at Universities of Illinois, Cornell, Wisconsin, Utah, etc.

Urgency: Until the moisture equilibrium under pavement surfaces can be predicted with a reasonable degree of accuracy there will continue to be significant economic waste in pavement construction through either under design or over design.

C5-3 Problem: MOISTURE ACCUMULATION BENEATH PAVEMENTS AS INFLUENCED BY ENVIRONMENT. There is a scarcity of reliable information on the probable amount of moisture accumulation beneath pavements particularly as it is influenced by environmental conditons.

Problem Area: The stability or load supporting capacity of a soil is dependent upon its moisture content. A pavement designer needs a means of predicting the amount of moisture that will accumulate in various types of subgrade soils under different environmental conditions.

While a few pavement design systems (see reference 4 below) consider precipitation as a factor in determining pavement requirements, little information is available on the ultimate moisture state of subgrade soils.

For example, it has been reported that subgrade soils in desert areas become fully saturated within a few years after the pavement is constructed. However, it is known that in semi-arid regions loessial subgrade soils remain fairly dry, especially beneath the center one-half of the pavement while beneath the edges the moisture fluctuates with the seasons. Therefore, some relationship should be established between the ultimate moisture state of the subgrade and the environment of the road structure.

Objectives: To develop a method or methods of predicting the probable maximum moisture state which subgrade soils will reach when covered with pavement. While it is fairly well established that the moisture content of subgrades vary with seasons, the influence of all environmental factors on the moisture content of subgrade soils has not been thoroughly explored.

References: (1) WASHO Road Test
(2) AASHO Road Test
(3) Hybla Valley Road Test
(4) Highway Research Board Bulletin 8, "Design of Flexible Pavements Using the Triaxial Compression Test."
(5) "Accumulation of Moisture in Soil Under an Impervious Surface," Ph.D. Thesis by J. L. Mickle, Iowa State Univ., 1960.

Urgency: No system of pavement design will be precise enough to avoid economic waste through either under design or over design unless the ultimate moisture state as influenced by environmental conditions can be ascertained with a reasonable degree of accuracy.

C5-4 Problem: CHANGES IN SUBGRADE MOISTURE. To develop methods of evaluating the volumetric changes and the load supporting value of subgrades, due to time and the slow accumulation of moisture beneath the pavement.

Problem Area: This problem is basic to the design of all types of pavement. Since the strength of the subgrade is a major factor in design, and pavements are designed for an expected life of possibly twenty years, it is necessary to evaluate the actual minimum subgrade strength that can be expected during the lifetime for which the pavement is designed. This minimum strength is frequently far below that indicated by the laboratory tests which are generally used for pavement design. A pavement should also be designed to resist damage by volumetric change in the subgrade soils.

Objective: The objective should be to accumulate moisture data from the existing subgrades of pavements of various ages over an extended period of time. Changes in the elevation of the pavement and the pavement profile should be recorded. In the selection of the subgrades to be studied, consideration should be given to the factors which can be expected to influence volumetric changes and loss of strength. Among these factors would be type of soil, type of pavement, geology, microtopography, design of roadway, and above all, the climatic environment. The weather cycles throughout the study would be a major factor. Since much research has been done on frost and spring breakup, it is possible that the study should be confined to damage other than freezing. In some states it is the practice to reduce the allowable wheel load by one-half during the spring breakup period. This might be evidence that the upper limit of subgrade loss of strength by moisture accumulation is in the neighborhood of 50%. There are pavements in some states where freezing is not a problem, that have completely failed from excessive moisture after giving good service for as long as seven to ten years. Also, pavements have failed from excessive shrinking and swelling of the subgrade.

Reference: The Oklahoma Highway Department is starting a study with the cooperation of the Bureau of Public Roads, at Oklahoma State University, in Stillwater, Oklahoma.

Urgency: Since pavements are being constantly designed by laboratory tests which indicate a subgrade strength above that actually occuring in the field, the need for such a study is urgent. Since this is a long time project there is a great need to collect such scattered data as already exists, about variations in subgrade moisture, pavement distortion and the loss of strength of soils at various moisture contents above optimum, and make it available as soon as possible.

C6-1 Problem: STUDY RELATIVELY RAPID PHYSICAL AND CHEMICAL CHANGES IN EARTH MATERIALS.

Problem Area: Deterioration of these earth materials is a serious problem in some localities, resulting in costly repairs and maintenance.

Objectives: To determine what processes may change the properties of earth materials used in construction, within the period of useful life of the structure, so as to significantly alter their engineering behavior. Concentrate on two types of material:

(a) Volcanic rocks, which may or may not alter to clayey minerals, and

(b) shale and clayey rock, which may or may not change in physical and chemical properties, under the thermal, chemical, or stress environment in a structure that is different from the natural state.

To develop methods of halting the deterioration.

Urgency: This is a problem of great economic importance in areas where competent materials are scarce.

C6-2 Problem: PERFORMANCE RECORD OF ROCK CUTS.

Problem Area: Rock deterioration in cuts is generally unsightly and often contributes to traffic hazards. Maintenance costs money and slows down traffic as well, so that any efforts which would work toward alleviating these conditions would be beneficial.

Objectives: To determine what are the significant factors, geologic and otherwise, that affect the long-term performance of large rock cuts. By suitable choice of field study areas, attempt to isolate and quantify the variables. Use repeated ground photography to record details. Use paired cuts to estimate effect of insolation on ravelling. Evaluate effect of benching. Use maintenance records.

Urgency: Growing maintenance costs and demands for free flow of traffic make this information important.

C6-3 Problem: ANALYSIS OF STABILITY OF LARGE ROCK SLOPES.

Problem Area: Large movements of rock could cause critical damage to our national system of defense highways. Maintenance and repair costs would be very great.

Objective: (a) To determine the factors that control the stability of large artificial or natural slopes of rock; to derive means of measuring these factors, quantitatively if possible; and to relate these factors to some quantitative measure of stability.

(b) This large field should be limited, initially, to study of homogeneous geologic material with emphasis on the relation of joint systems and topographic form of stability of large masses.

(c) May include laboratory study of the mode of failure of jointed bodies and field geologic and geophysical study of the distribution and orientation of fractures.

(d) Study these factors in relation to earthquakes and shock loads.

Urgency: It is urgent that areas of potential rock movement be classified so that emergency plans can be developed.

C6-4 Problem: FORMATION OF DISINTEGRATED GRANITE.

Problem Area: A more judicious use of explosives with a consequent decrease in construction costs would result from the knowledge of the factors that control its distribution.

Objectives: (a) To determine the geologic factors that control the formation of disintegrated granite. This material often occurs irregularly within the exposed parts of large granitic masses. Its presence means easy excavation, and it is much used as granular construction material, yet it may lie adjacent to unaltered hard rock requiring blasting.

(b) Develop knowledge of the distribution as an aid both in locating road alinements and sources of granular materials.

Urgency: Increasing construction costs could be leveled off somewhat by competent use of the knowledge gained.

C6-5 Problem: TREATMENT OF HIGHWAYS OVER OLD MINE WORKINGS.

Problem Area: Existing highways over old mine workings may be unsafe as occasionally one caves in. The location of new highways over these areas is becoming increasingly more common as straight alinements are used.

Objectives: (a) To determine amount and thickness of cover needed between a highway subgrade and an old mine.

(b) Study other methods of treatment, as removal of all naturally subsided material and backfilling or filling through pumping or dumping.

Urgency: Maintenance costs and safety make it urgent to develop this information for immediate use.

C6-6 Problem: SLOPE DESIGN FOR DIFFERENTIALLY WEATHERED MATERIALS AND OTHER MIXTURES OF EARTH AND ROCK.

Problem Area: Design of safe backslopes, maintenance and economy.

Objective: Development of design criteria that would permit field personnel to design stable, yet economical, backslopes in mixtures of earth and rock. Design of slopes in earth materials is well known; design in uniformly solid rock seldom presents difficult problems. On the other hand, design of slopes in differentially weathered materials, or where rock pinnacles exist, does pose highly complex problems.

Urgency: To aid in competent design of stable backslopes.

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