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A QUESTIONNAIRE-AIDED ASSESSMENT
OF THE STATE OF THE ART FOR
COMPACTED SHALE EMBANKMENTS

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IDIANA STATE HIGHWAY COMMISSION

Technical Paper

A QUESTIONNAIRE-AIDED ASSESSMENT OF THE STATE OF THE ART
FOR COMPACTED SHALE EMBANKMENTS

TO: J. F. McLaughlin, Director   December 17, 1974
        Joint Highway Research Project

                                                  Project: C-36-5L

FROM: H. L. Michael, Associate Director
        Joint Highway Research Project   File: 6-6-12

        The attached Technical Paper, "A Questionnaire-Aided
Assessment of the State of the Art for Compacted Shale Embankments",
has been authored by D. R. Chapman and L. E. Wood of our staff.
The paper has been accepted for presentation at the annual meeting
of the Transportation Research Board in Washington, D. C. in
January 1975.

        The paper presents information obtained by a questionnaire
to state highway departments, Federal Highway Administration
Officers, U.S. Army Corps of Engineers and others relating to
the State of the Art in constructing embankments from compacted
shale. This activity is a part of the active HPR Study titled'
"Design and Construction Guidelines for Shale Embankments."

        The paper is presented to the Board for approval of presentation
and publication by the TRB. If approved, copies will also be sent
to the ISHC and FHWA for similar approval inasmuch as the content
of this product of the HPR study has not been previously approved
by FHWA.

                        Respectfully submitted,

                        Harold L. Michael

                        Harold L. Michael
                        Associate Director

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Technical Paper

A QUESTIONNAIRE-AIDED ASSESSMENT OF THE STATE OF THE ART FOR COMPACTED SHALE EMBANKMENTS

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The contents of this report reflect the views of the author
who is responsible for the facts and the accuracy of the data
presented herein. The contents do not necessarily reflect the
official views or policies of the Federal Highway Administration.
This report does not constitute a standard, specification, or
regulation.

Prepared for Presentation at the Annual Meeting of the Transportation
Research Board in Washington, D. C., January, 1975.

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December 17, 1974

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ABSTRACT

To aid in assessing the State of the Art with respect to design
and construction of shale embankments, a questionnaire was formulated.
All phases of activity were investigated; site investigation, sampling,
testing, specification of compaction, excavation, degradation,
compaction methodology, and field compaction control.

Fifty-two questionnaire responses indicated experience with shales.
Sheepsfoot rollers are the most popular for compacting shales, being
used by 88% of the responding agencies. A need for research by means of
field testing on test strips is indicated, with less than 30% of those
responding having investigated any compaction variables in the field.

Information concerning selected phases of the design and construc-
tion process is given in the form of percentages. Explanatory comments
are made concerning the content and purpose of some of the questions.
It is concluded that the information derived from this study is a
substantial, but not exhaustive assessment of the State of the Art.

INTRODUCTION

Background

As a part of a study entitled "Design and Construction Guidelines for Shale Embankments" currently in progress at Purdue University, a questionnaire was compiled to elicit information concerning the State of the Art in constructing embankments from compacted shale.

Because of the wide spectrum of earth materials which bear the name "shale", and the great variability in properties which exists within a given geologic unit of shale, the technology in this area is highly variable and seemingly quite poorly developed. In most cases, soil specifications are applied to softer shales, which are placed as a rolled embankment. Some shales degrade readily in the process of excavation, hauling and placement. Others are durable enough to remain in large chunks under the same action of equipment. In spite of this apparent durability, this same shale may slake and break up into smaller pieces in the in-service environmental conditions of moisture and temperature changes, etc. Some shales are acceptable materials for rockfill embankments, whereas others may require several passes of heavy compaction equipment to degrade the shale into an essentially soil-size mixture. Placing a soft shale as a soil fill can prevent in-service degradation and resulting settlements.

In Indiana, a major portion of the spectrum of durabilities exists. The behavior of Indiana shales has been quite variable, and found to not follow the trend of the oldest deposits being the most durable. One of the most serious embankment failures occurred in an Ordovician formation,

while some of the younger shales are much harder, and more durable.

An earlier study at Purdue by P. Deo (1)[1] developed a rating system for shales. Selected laboratory tests were used to provide quantitative predictors of shale behavior, and a classification system was proposed. Four simple tests give index values, which are then used to describe the shale as "soil-like", "intermediate 1 or 2," or "rock-like". Fifteen shales were tested and rated.

As a result of some failures of shale embankments on I-74 in Dearborn County, Indiana, and Deo's study, the present project was undertaken. It is hoped that it will generate guidelines for design and construction which are sufficient for the efficient and economical use of the whole range of shales. Ultimately, results will be quickly determined from simple laboratory tests which will give the engineer information and insight into the expected behavior of the shale in the long-range condition. As this expertise develops, shale can be used more extensively as an economical borrow material than is the case today.

<h2 style="text-align:center">Objectives of the Questionnaire</h2>

The questionnaire was compiled to survey the current State of the Art with respect to embankments constructed from compacted shale. It was formulated with the intent of obtaining as much information as possible about all phases of design and construction with compacted shale. Topics covered by the questionnaire included: geologic investigation and identification of shale deposits, extent of usage of

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1. Numbers in parenthesis refer items in the Bibliography.

shale materials in construction, problems encountered in using com-
pacted shale, guidelines and criteria for acceptance or rejection of
shale as compacted fill, laboratory tests for determination of shale
properties, current construction techniques applied to compacting shale,
and current design guidelines for shale embankments.

Especially emphasized in the questionnaire were specific items in
the construction process, such as excavation and degradation techniques
and the several variables in the compaction process. Since compacted
fills in shale involve the placing of a quasi-rock material as a soil,
the method of breakdown or degradation prior to compaction is extremely
important. Since the compaction variables are so numerous, and shale
is not strictly a soil, the important variables for shale may be some-
what different than for soil.

Information was sought concerning: type of compactor which had
been used, optimum number of passes to obtain satisfactory densities,
maximum allowable lift thickness and chunk size, homogeneity and
gradation of the compacted mix, addition of water to aid in degrading
and densifying the shale, current density standards for compacted shale,
and methods of field compaction control as they apply to shales. The
use of test fills or test strips to investigate the interrelationships
of the different compaction variables, and which variables have been
examined to date were also surveyed.

From the information obtained through the questionnaire survey,
sources of expertise in this area can be identified and contacted for
further information.

Introduction to the Questionnaire

The questionnaire was separated into 3 sections. Section A, "Occurrence and Performance of Shale Materials," contains questions 1 through 6 and investigated the extent to which the agencies contacted had dealt with shale as a compacted fill. The second section, "State of the Art" consisting of questions 7 through 26, sought information concerning the techniques of sampling, testing, analysis, design, and construction in use by the agencies at present. The final section, "Research", inquired if any organized research had been carried out on shale as an embankment material, and if so, what variables had been examined. The question numbers in this report apply to those in the questionnaire.

The questionnaire was sent to the highway departments of each state (except Hawaii), Federal Highway Administration Regional Offices, U. S. Army Corps of Engineers Districts, Canadian provincial highway departments, and a few other selected sources. Of the 85 questionnaires which were returned, 52 indicated experience, and were included in the tabulation. Of these, 33 were state highway departments, and 19 were other agencies.

RATIONALE FOR FORMULATION OF THE QUESTIONNAIRE AND PRESENTATION AND ANALYSIS OF RESULTS

The following section contains an explanation of the nature of some of the problems as understood when the questionnaire was compiled, intending to convey to the reader a perspective as to the type of information sought. In addition, the data obtained are plotted,

analyzed, and summarized, as appropriate.

Section A - Occurrence and Performance of Shale Materials

Section A deals with the qualitative aspects of the use of shale. How often does shale occur in practice? How is it classified, how are its properties determined, what uses are made of it, and how has it performed? The questions are either stated or paraphrased below.

1. What exactly is your criteria for classifying a geologic member as a shale; that is to distinguish it from other similar formations such as mudstone, or siltstone?

2. Approximately what percentage of your projects encounter shale materials?

    a) 0-25%   b) 25-50%   c) 50-100%

3. To what extent, if any, does your organization analyze the engineering and construction properties of shales?

    a) Not at all
    b) Some consideration
    c) Special consideration and/or a routine testing program

4. This question concerned modes of shale usage, and whether it was used never, sometimes, or commonly. The modes investigated were: rockfill, compacted fill, subgrade, subbase, base, wearing surface, and shoulders.

5. Please indicate the problems which have been encountered in the use of shales as embankment materials.

    a. Degradation of softer shales, reversion to clay, causing excessive settlement.
    b. Obstruction or failure of drainage structures.
    c. Failure of embankment slopes.
    d. Interbedding of shale with more resistant rocks such as limestone - causing difficulty in obtaining a homogeneous compacted mass.

Question 1

The first question stems from the lack of agreement over exactly which sedimentary rocks should be named shale. To some, shale is any

argillaceous sedimentary rock. Approximately 25% of the responses
reflected this approach to shale classification. A more rational
method, as reflected in 75% of the responses, is to use the general
term "mudrocks", reserving the term shale for rocks with laminated
structures, or fissility.

Questions 2 and 3

The degree to which shales have presented problems in the practice
of any given agency can be understood through the answers to these
questions, summarized in Figures 1 and 2. Nearly 50% of the agencies
contacted had encountered shale on more than 25% of their projects, and
58% give shales special consideration. As expected, the responses in
general showed that agencies encountering shale on a large percentage of
projects have developed a larger body of specialized shale technology
than those who encounter it only rarely.

Question 4

Because of varying shale durabilities and the differing needs for
construction materials depending on the locale, shale is put to different
uses, as indicated in Figure 3. Compacted fill and subgrade are the
most common uses, responses indicating 100% and 85%, respectively, with
61% using shale as rockfill. Where shale occurs in proximity to readily
available granular materials, the shale would not be used in pavement
bases or subbases. Shale would however, be used in rolled embankments
where encountered in excavation or convenient in borrow, provided that
suitable design and construction techniques had been developed. In
other regions, it may be necessary to use selected shales as base and

subbase materials as well as in embankments, because gravel and/or
crushed rock are not available.

Question 5

A spectrum of problems have been contended with in the performance
of shale embankments, attributable in part to the variabilities of
shales in durability and weathering characteristics. If shales having
a tendency to slake are placed in thick lifts as rockfill, the shale
may degrade and fall into the relatively large internal voids, resulting
in settlements of large magnitudes. This particular problem can be
accentuated if a more competent rock such as limestone is interbedded
with the shale. Excessive settlements may also disrupt the drainage
structures, that are conventionally placed in embankments to prevent
water from accumulating, and cause slope failures. Problems reported
in the questionnaire ranged from minor sloughing of side slopes to major
slope failures. From the responses (Figure 4), 52% have experienced
slope failures, 50% have experienced slaking and degradation problems,
and 20% to 33% have experienced drainage obstruction and interbedding
related problems.

Section A of the questionnaire showed that a majority of those
surveyed give special consideration to shales encountered on construction
projects, analyzing some of their properties for use in design.

Section B - State of the Art

In this section, questions are directed to each step in the
construction process, from identification of a shale stratum, through
sampling, laboratory testing, analysis and design, specifications,

construction, and field control. Given below are questions or

paraphrased questions which evoked responses which were helpful in

assessing the current State of the Art.

8. How much attention is given to identification of the shale
    by its geologic age and formation? None, some, or a great
    deal.

9. How much shale is sampled for laboratory testing, and in what
    condition is it required to be? i.e. weathered, unweathered?
    Is an attempt made to preserve the natural moisture content?

10. How is the breakdown of shales effected in the laboratory in
    preparation for laboratory testing?

11. Please indicate if any of the following laboratory test
    procedures are used to determine shale properties such as:
    degradation characteristics, Atterberg limits, grain size
    analysis, specific gravity, absorption, abrasion, compaction,
    load-deformation, or any others not mentioned.

15. Please indicate which methods are used to excavate shales.

16. Please indicate which of the following problems have been
    encountered in the compaction process on shales

    a. The material is too hard to be sufficiently broken down
       by a normal compaction process.

    b. Difficulty in achieving a homogeneous compacted mix, i.e.,
       compaction sometimes results in sorting of sizes.

    c. Difficulty in incorporating water into the mix in a
       manner that results in a uniform water content.

17. What processes are carried out to prepare the shale for
    compaction, e.g. prewatering in the cut, disking, or
    adding water?

18. What types of compactors have produced the best results in
    degrading and densifying shales?

25. If any of these special precautions are taken to protect shales
    from weathering, degradation, etc., in embankments, please
    indicate them below.

    a. Encasement of shale with soil for protection of the shale.
    b. Stabilization with lime or cement to combat excessive
       plasticity.

            c. Inclusion of a certain percentage of sand, gravel, or
               crushed stone in the compacted mix.
            d. Protection of the shale with bituminous material to
               prevent water from entering the embankment.

    26. Are drainage structures conventionally incorporated into
        shale embankments to help minimize the harmful effects of
        water upon shale?

Question 8

Geologic identification and classification of shale strata should

occupy an important place in the design and construction process. The

importance of geological background work in solving geotechnical

problems in a rational manner cannot be over-emphasized. The tone of

the responses to the questionnaire reflected the cognizance of the

agencies questioned with respect to geologic investigation. Only 10%

of the responses indicated no attention in this area (Figure 5), the

other 90% indicating that shale strata are identified by a geologist or

an engineer with some stratigraphic capability.

Question 9

Should shale for laboratory testing be stored at natural moisture

content, or allowed to dry?

Although some differences in test results have been observed by

the Division of Materials and Tests of the Indiana State Highway

Commission due to drying of shale (4), information presently available

is insufficient to predict the magnitude or probable engineering

significance of this effect. Sampling and subsequent storage of shale

was an area of variability in the questionnaire responses, often

varying even within the practice of one agency. About 60% (Figure 6)

attach no importance to the condition of the shale when sampled, and

only 21% specify storage at the natural moisture content. It is hoped
that current research will determine the effects of drying on the
various laboratory tests performed on shale.

Question 10

Although a soft rock, shale can present an extreme problem in
preparation of samples for grain size and Atterberg limits tests
(3, 5). Consisting basically of silt and clay sizes cemented together,
shales can be quite resistant to degradation to ultimate particle size.

A majority of agencies questioned prepare samples by crushing with
mortar and pestle and/or mechanical crushers. A few combined slaking
with grinding for more effective degradation. Ultrasonic equipment,
used by a very few, has been investigated for its effectiveness (3),
but is not standard equipment in geotechnical laboratories.

Question 11

A variety of tests have been performed on shales, with the
intention of finding qualitative predictors which are suitable to
describe shale behavior. As data are amassed, it is expected that
simple tests will be identified which will predict shale properties
with sufficient accuracy for design.

As shown in Figure 7, most agencies employ standard soil-type
identification tests (90%) and compaction and load-deformation tests
(65%). Approximately 50% assess the degradation characteristics
through slaking-type tests and nearly 25% use aggregate type tests on
shale. 10% make some measure of breaking characteristics or fissility.

Question 15

The method of excavation is generally the contractor's choice, and is therefore chosen by economical considerations, the optimum method being dictated by the hardness of the shale and the extent of the cut.

As shown in Figure 8, ripping is the most common technique of excavation, used by 100% of those questioned. Blasting is required at least sometimes by 83%, a scraper is used by 81%, and a shovel by 40%. For cuts of large extent, ripping is the most economical method for all but the most durable shales.

Question 16

Varying durabilities of shales can give rise to a number of different problems in the compaction process. Some of these problems were listed with the question earlier in the report.

Of those surveyed, 48% have experienced difficulty in incorporating the proper amount of water uniformly into a lift of shale to be compacted. 50% have found that a normal amount of compactive effort would not sufficiently degrade a shale, and 44% indicate that compacting shale has resulted in a sorting of sizes within any given lift. This information is shown graphically in Figure 9.

Question 17

Since shale presents problems in compacting, any process which assists in degrading the shale during excavation, hauling, or placement is desirable, assuming it is to be placed as a soil-like fill.

Most prevalent is addition of water to the shale, generally to some approximate value of standard Proctor optimum moisture content. This practice is followed by 73% of those questioned (Figure 10). Disking the shale to further reduce chunk sizes is practiced by 44%. One additional method, employed by 4% of the agencies is to prewater the shale in conjunction with ripping. This method is unpopular with contractors (4), and probably impractical for general use.

Question 18

The choice of a compactor is often left to the contractor, allowing him to meet specifications as he chooses. A heavy roller will probably achieve the best results.

The survey showed (Figure 11) that sheepsfoot compactors are preferred for shale, reflected by 88% of the responses. Smooth-wheel rollers are used by 38%, and rubber tired rollers by 25%. In each of these classes, static rollers were preferred to vibratory by substantial margins.

Question 25

Because of the special weathering properties of shale, it is often desirable to attempt to protect it from direct weathering in some manner. One relatively economical means of accomplishing this is to encase the embankment with 2 to 4 feet of soil. This practice is employed by 33% of those questioned (Figure 12). 15% use bituminous encasement of the top and sides of the embankment in special locations.

Lime stabilization, used to combat plasticity of compacted shales is used by 25% of those questioned, presumably as a means of stabilizing

subgrades.

Question 26

It is impractical if not impossible to prevent all water from
entering an embankment, and therefore, drainage structures are commonly
built into embankments to remove infiltrating water (2). Some examples
of these are pervious blankets, horizontal drains, vertical relief
wells, and interceptors. 81% of the responses indicated that one or
more types of drainage structures were used in their embankments
(Figure 13).

Section C - Research

27. Do you feel that the current techniques and guidelines for
handling shales in the construction of embankments are
adequate or inadequate?

28. Please indicate which of the following items discussed in
the past few questions have been investigated for
optimization with the use of test strips, or have been
performance tested in the field.

   a. Type of compactor
   b. Preparation for compaction to assist in degradation
   c. Lift thickness and maximum size
   d. Gradation characteristics
   e. Water content specification
   f. Homogeneity of mixture

Question 27

The general trend of the responses was that those who had no
experience or very limited experience believe that the present technology
is adequate. Agencies who frequently encounter shales and are often
faced with solving shale problems are more likely to feel that research
in this area is warranted. Numerically, the responses were equally
divided between the two alternatives.

Question 28

Current guidelines for soils may not be entirely applicable to shales. It may be necessary to investigate properties and formulate guidelines and specifications through construction of and experimentation with test fills. Approximately 70% of those questioned had never built any test fills with shale, and of the 30% who responded positively, several were actually referring to the same individual piece of work. This is an area where research effort is needed, at least until sufficient information becomes available to evaluate conventional laboratory and field testing methods as they apply to shale, and to modify them as necessary.

General

In addition to the information given in the question summaries, a great deal of information of a general nature was obtained. Much of it merely reflected that in many areas, standard soil practice is applied to shale. Such categories include shear strength determination, lift thickness and maximum size criteria, water content specifications, field compaction control, and standard side slopes for embankments.

CONCLUSIONS

A large amount of information was gained from the questionnaire, which can be extremely useful to those faced with the use of shale in the construction of highway embankments. Through such appresentation of facts, successful innovations and techniques can be identified and brought into wider usage. Research needs can also be identified.

A questionnaire of this sort is not without some rather obvious limitations. It is impossible to identify every source of expertise; thus, some experience is omitted from the survey. It is very difficult to obtain all the desired information through short-answer questions. It would be advantageous to ask for discussion and comments from those who respond, if this is practical, in view of the busy schedule of engineers in the agencies contacted.

From the responses, sources of expertise have been identified, and can be contacted for additional information, leading to a more complete State of the Art report.

ACKNOWLEDGEMENTS

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    Prof. L. E. Wood at Purdue University, W. Lafayette, Indiana.

David R. Chapman, L. E. Wood

QUESTION #2

EXTENT OF SHALE OCCURRENCE

A. 0-25% SHALE

B. 25-50% SHALE

C. 50-100% SHALE

D. NO REPLY

0   20   40   60   80   100
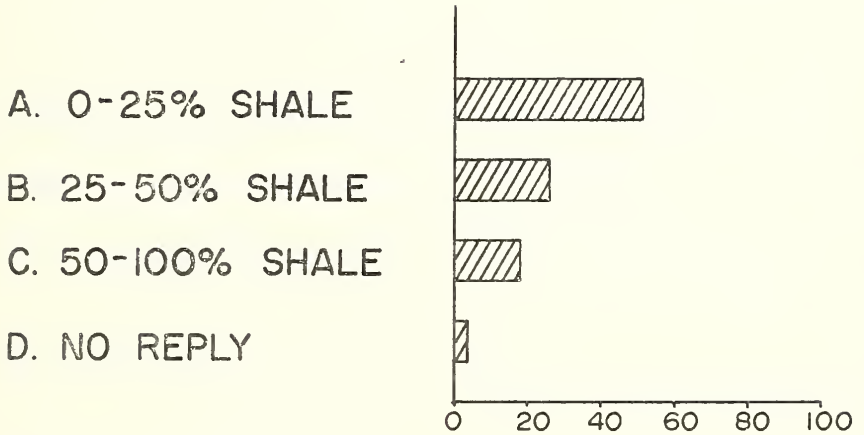
FIGURE 1

QUESTION #3

EXTENT OF SHALE PROPERTY ANALYSIS

A. SPECIAL CONSIDERATION

B. SOME CONSIDERATION

C. NO CONSIDERATION

D. NO ANSWER

0   20   40   60   80   100

FIGURE 2

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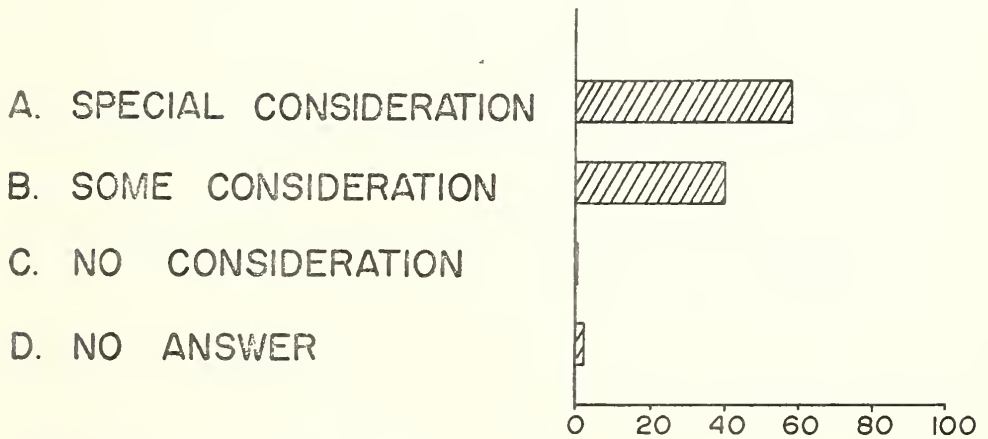
QUESTION #4

MODES OF SHALE USAGE
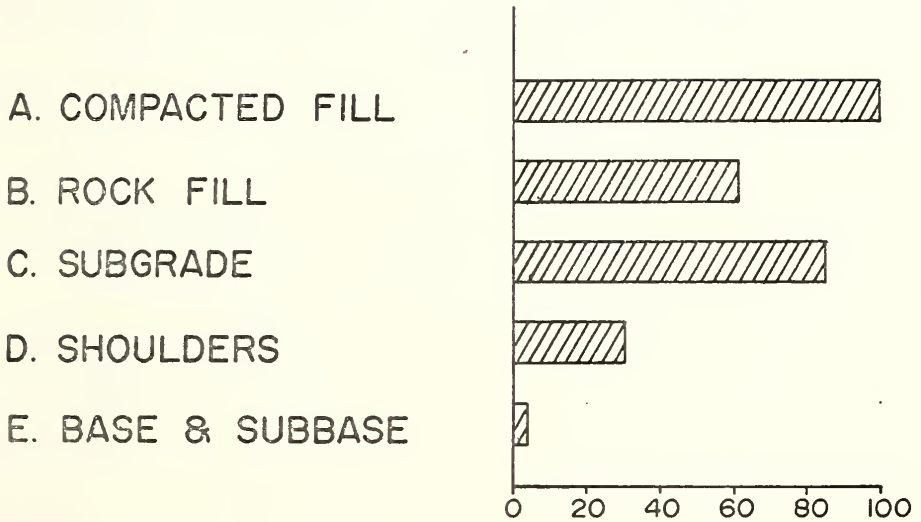
FIGURE 3
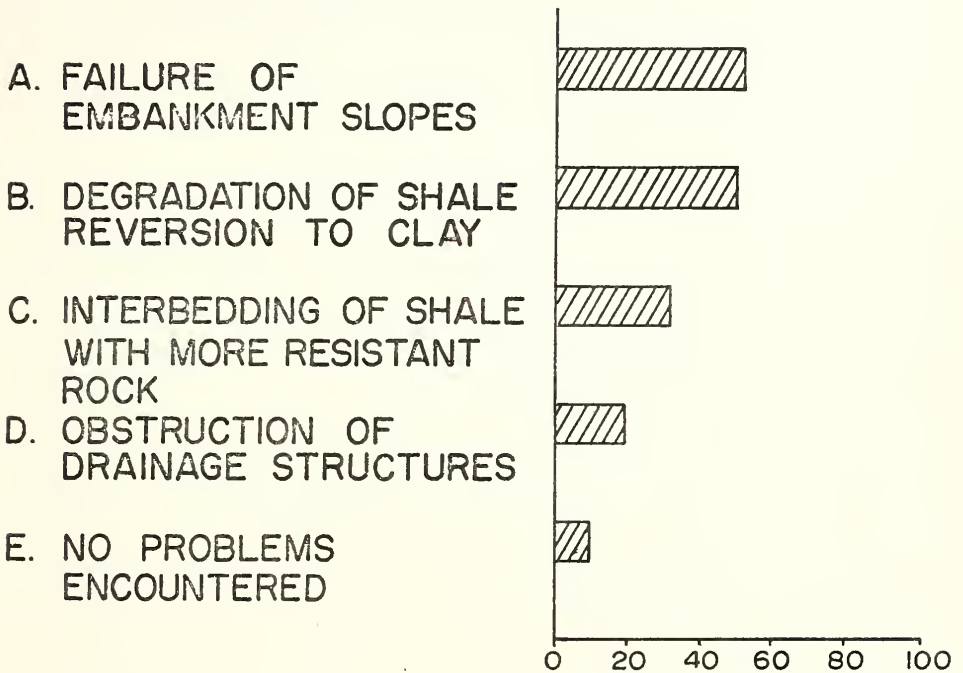
FIGURE 4

QUESTION #8
GEOLOGIC IDENTIFICATION

A. NONE

B. SOME

C. A GREAT DEAL

0   20   40   60   80   100
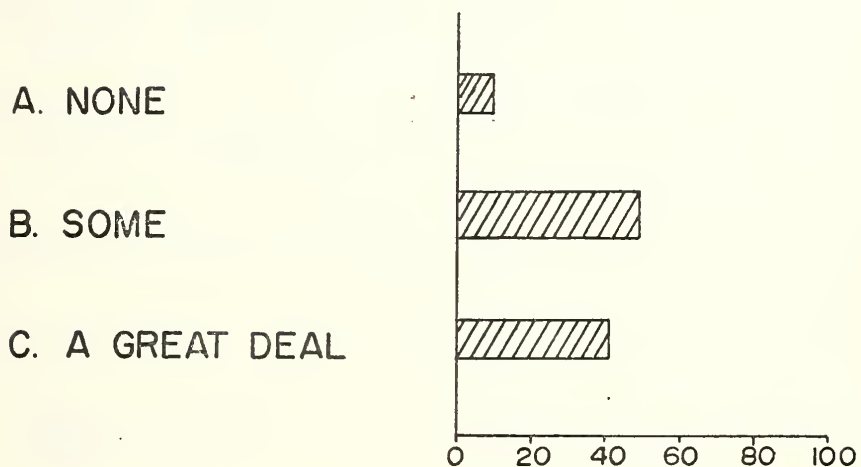
FIGURE 5

QUESTION #9

SAMPLING & STORAGE OF SHALE

A. STORE AT NATURAL MOISTURE CONTENT

B. WEATHERED OR UNWEATHERED

C. UNWEATHERED ONLY

D. VARIES

E. NOT TESTED REGULARLY
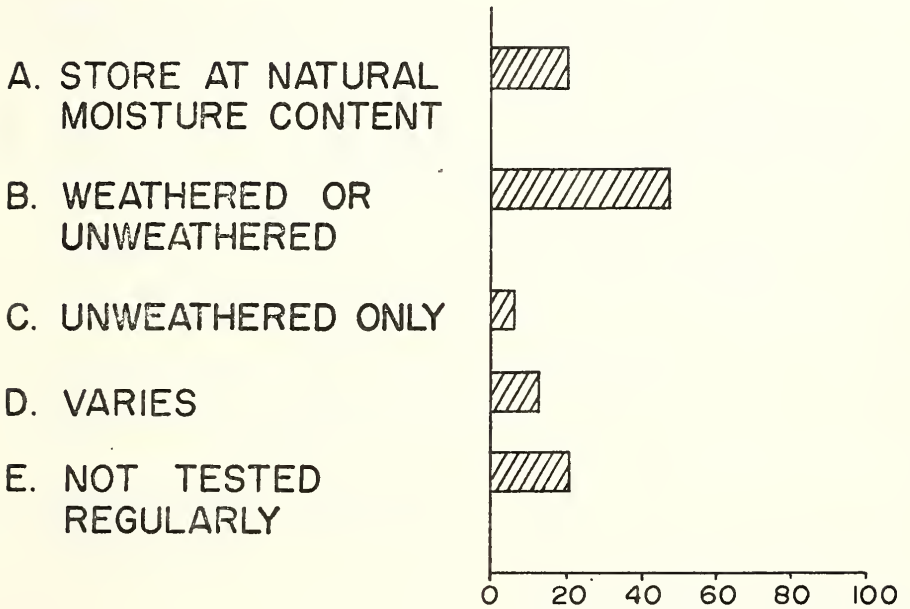
FIGURE 6

QUESTION #11

LABORATORY TESTS COMMONLY PERFORMED

A. DEGRADATION TESTS - SLAKING, ETC.

B. SOIL TYPE STANDARD IDENTIFICATION TESTS

C. COMPACTION & LOAD - DEFORMATION TESTS

D. AGGREGATE OR MODI- FIED AGGREGATE TESTS

E. BREAKING CHARAC- TERISTICS

0   20   40   60   80   100
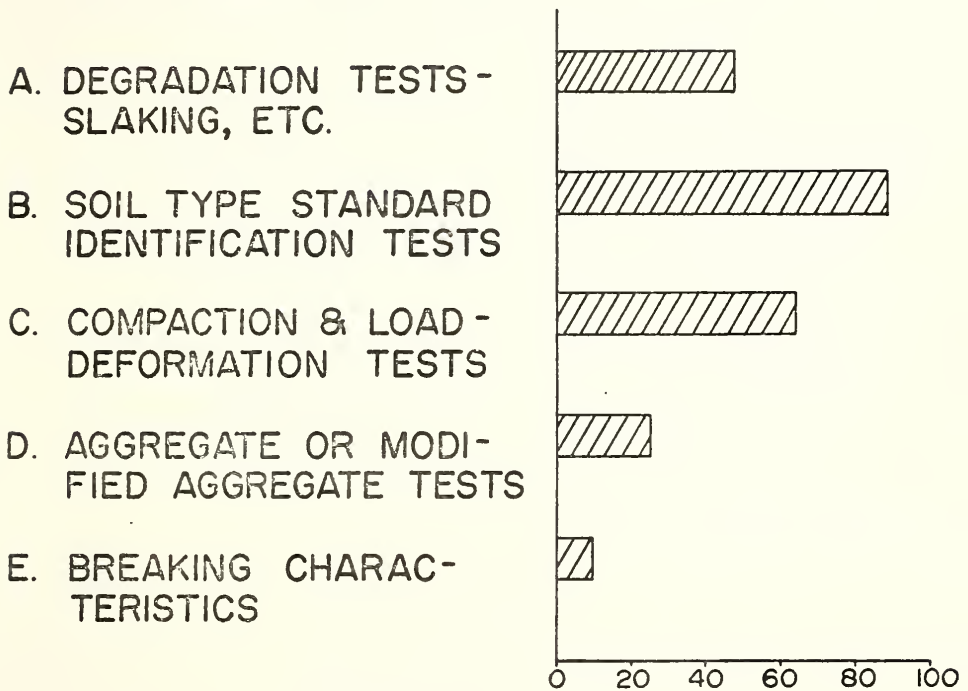
FIGURE 7

QUESTION #15

EXCAVATION METHODS

A. RIPPING

B. SOME BLASTING
    REQUIRED

C. SCRAPER

D. SHOVEL

FIGURE 8

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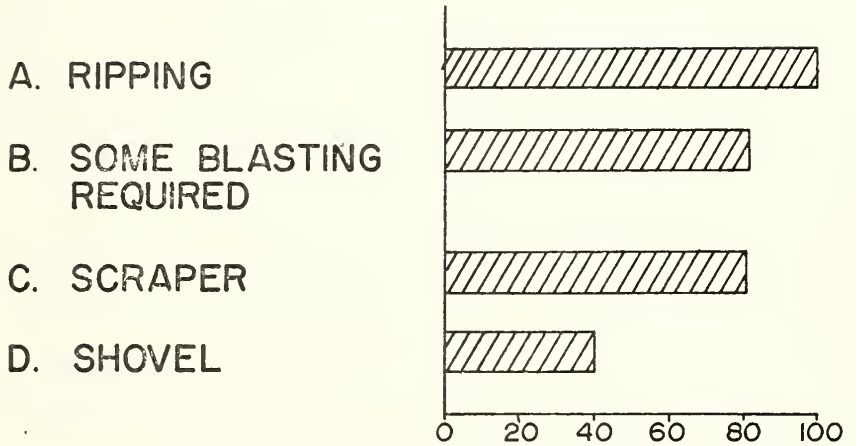
QUESTION #16

PROBLEMS ENCOUNTERED IN COMPACTION

A. DIFFICULTY IN
   INCORPORATING
   WATER UNIFORMLY

B. MATERIAL TOO
   HARD TO DEGRADE

C. HOMOGENEITY
   OF MIX

0   20   40   60   80   100
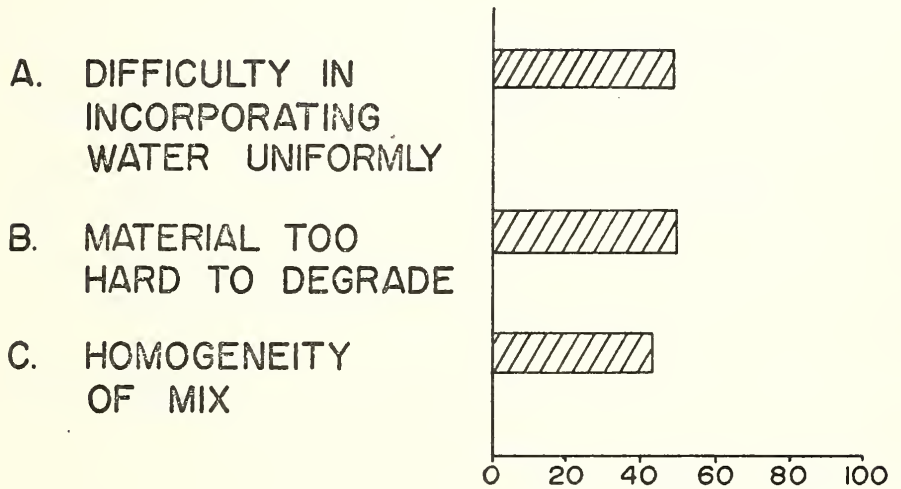
FIGURE 9

QUESTION #17

PREPARATION FOR COMPACTION

A. DISK

B. ADD WATER

C. PREWATER IN
    THE CUT

D. NONE

0   20   40   60   80   100
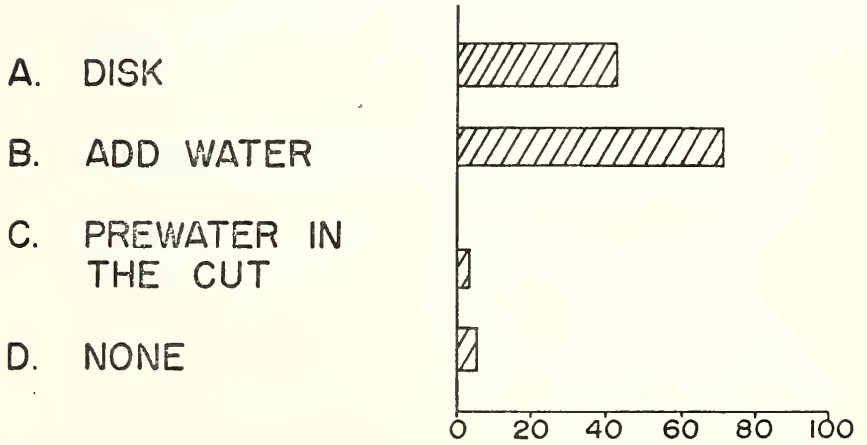
FIGURE 10

QUESTION # 18

TYPE OF COMPACTOR

FIGURE II

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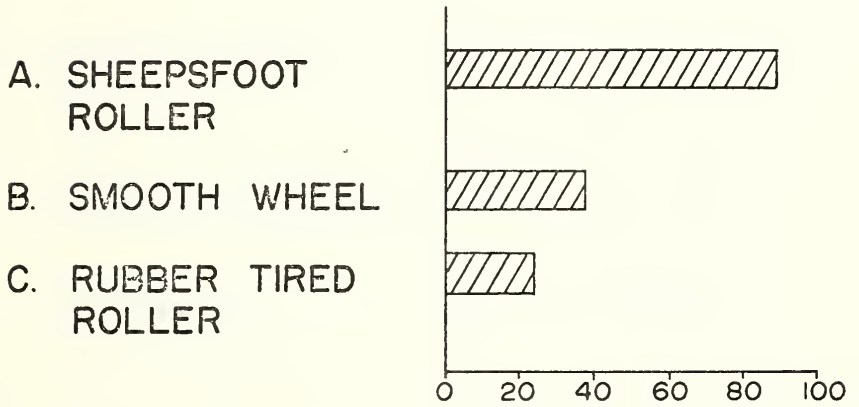
QUESTION #25

SPECIAL SHALE PROTECTION TECHNIQUES
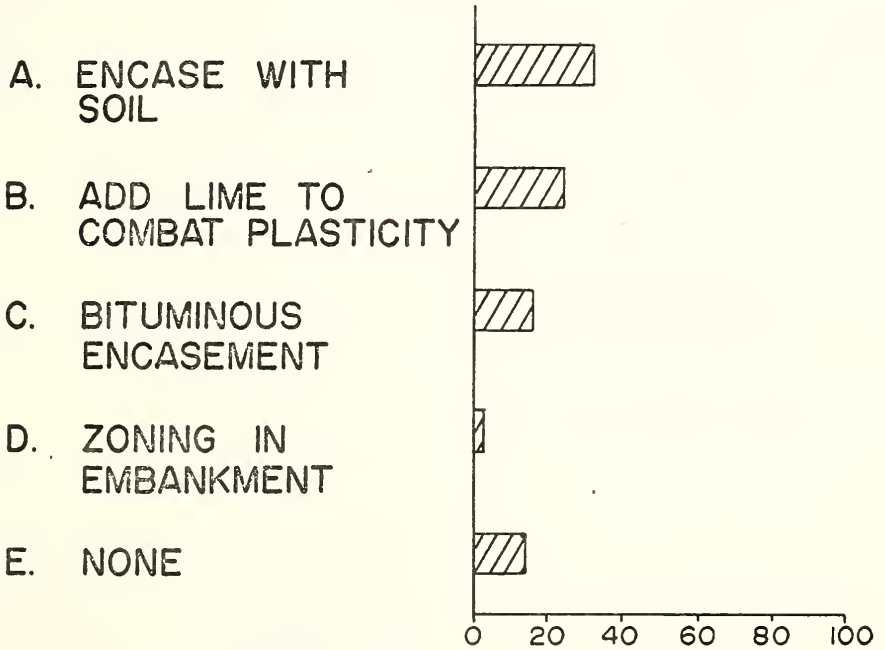
FIGURE 12

QUESTION #26

DRAINAGE OF EMBANKMENTS

A. NO DRAINAGE
   FACILITIES USED

B. SOME OR ALL
   USED

FIGURE 13