ENGINEERING BULLETIN

H IGHWAY
E XTENSION
AND
R ESEARCH
P ROJECT
FOR
I NDIANA
C OUNTIES

# Field Investigation of County Road Bases and Subgrades

PURDUE UNIVERSITY—ENGINEERING EXPERIMENT STATION

in cooperation with

THE COUNTY COMMISSIONERS OF INDIANA

COUNTY HIGHWAY SERIES—No. 14

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# HIGHWAY EXTENSION AND RESEARCH PROJECT FOR INDIANA COUNTIES

The Highway Extension and Research Project for Indiana Counties (HERPIC) was organized at Purdue in 1959 to implement legislation by the Indiana General Assembly authorizing programs of extension and research for county highway departments throughout the state.

The financial support for these programs of extension and research is derived from one-eighth of one percent of the funds made available to the 92 counties from gas taxes and license fees collected by the state of Indiana. The legislation by the General Assembly also designated Purdue University through its Engineering Experiment Station and School of Civil Engineering to develop and coordinate these programs.

The HERPIC program of extension and research provides for the preparation of manuals and bulletins setting forth recommended procedures and for regional workshop conferences with county road officials throughout the state to review typical road problems for their area. All of these activities are designed to assist and guide county highway officials in their problems of management, planning, design, and operation of county highway departments.

The HERPIC project operates as a cooperative effort between the county commissioners of Indiana and Purdue University. The program of extension and research is guided and approved by a 12-man advisory board, consisting of six county commissioners from over the state and six members from the staff of the Purdue's School of Civil Engineering. The current membership of the HERPIC advisory Board is listed below.

## HERPIC Advisory Board
## (July 1975 June 1977)

COUNTY HIGHWAY SERIES

# field investigation of county road bases and subgrades

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# FIELD INVESTIGATION AND TESTING OF COUNTY ROAD BASES AND SUBGRADES

## I. INTRODUCTION

County road officials generally recognize that the maintenance of blacktop roads is a major item of expense in their annual highway maintenance budget. This high maintenance cost for blacktop roads comes about for several different reasons. The main problem is the steadily rising costs—cost of materials, labor and equipment in recent years.

Another reason for high maintenance costs is the increase in volume of both normal traffic and truck traffic on county roads.

Still another reason for exorbitant maintenance costs is that many blacktop roads were not built by plan and design, but, simply, gravel roads were "blacktopped" to satisfy popular demand. Usually little attention was given to the quality of subgrade soils or the depth and quality of base to sustain traffic.

As a result, blacktop improvement often had a short life. Maintenance, and sometimes extensive maintenance, was required much too soon.

All of this suggests a maxim for county highway departments:

*Pavement maintenance is an expensive operation*

- Maintenance done right requires a concentration of manpower, equipment, and materials
- Maintenance done wrong wastes all three

Pavement design reduces maintenance costs.

While the above message may not receive universal adoption by county road officials as a policy and procedure tenet, it does capsulize something of the underlying purpose and objective of this bulletin.

### Evolution of Unpaved County Roads

The sampling and testing of unpaved county roads should not be viewed as a lofty exercise that increases construction costs. In fact it saves. It reduces the costs of maintenance at a later date. Perhaps if we would review the stage development of our county road system, we could better appreciate the need to examine the various parts or elements that make up a pavement structure, before scarce highway dollars are committed to the road improvement.

Some 50-60 years back, the complaint from the rural areas was to get the roads out of the mud. Gradually, little by little, and by painfully stretching the scarce road dollars of the era, the mud problem began to diminish. Gravel from local deposits and crushed stone from local quarries was hauled and spread on the road, usually for one-lane traffic, to provide a base that would support the light traffic and minimize mirings in the subgrade.

As traffic loads and volume increased so likewise was the need to perform surface maintenance on these unpaved roads. The thickness of the wearing surface was increased by adding additional gravel or crushed stone to those areas that rutted during the spring-thaw period. Gravel spreading was then usually followed by drag maintenance to smooth the surface.

In the development of our unpaved road surfaces, the addition of gravel and stone to fill up the ruts and to give added strength to the road surface has been done largely on an as-needed basis and as visual inspection indicated a need.

Even today, maintenance programs for unpaved county roads are still based largely on visual inspection of what is needed to accommodate local traffic. This is still the most practical and economical method of surface maintenance of unpaved roads.

While this approach has proven effective as long as the road surface remains, it is an unwise approach for a county blacktop paving program. It is unwise mainly because of the variations in quality, depth, and width of the unpaved surfacing materials that will serve as a base for the blacktop pavement. It also is unwise because of the variations in the quality of the subgrade materials.

### Purpose and Scope

With the mounting needs for upgrading county roads, along with declining revenues, there is a continuing need to make the most efficient use of available funds. Therefore, this bulletin focuses on the investigation, sampling, and testing of in-place wearing surface materials, in-place base materials, and in-place subgrade materials in advance of paving. This is especially important the first time the road is to be blacktopped. However, the investigation and testing methods suggested herein are equally applicable to existing blacktop pavements needing reconstruction.

The test methods focus on two quick field tests that have been developed through research to measure equivalent CBR values. CBR is a measure of the load-carrying capacity of base or subgrade materials.

The methods and procedures set forth in this bulletin should go far in helping county road officials plan for a better, more efficient use of county highway construction funds.

## II. SUMMARY OF FIELD INFORMATION REQUIRED

In the interest of economy, the reconstruction of a county road to a higher surface-type should, where practical, make effective use of existing in-place materials. This is generally an important consideration where an asphalt or concrete pavement surface is to be constructed over a previously unpaved gravel or crushed stone wearing surface.

The in-place materials, however, are often subject to wide variations in both quality and quantity. Therefore, to assure reasonable pavement life, and to make effective use of the in-place materials, it is *necessary* to determine the quality and quantity of the in-place base materials—along with the quality of the underlying subgrade soils.

Field investigation and testing of in-place base materials and subgrade soils should be a standard procedure for all county roads that are to be paved the first time. To gamble scarce county road dollars against the unknown is risky.

Factors for quantity of wearing surface (or base) materials include: (1) thickness (2) uniformity of thickness (3) average thickness (4) width (5) uniformity of width (6) average width and (7) length (project length).

Factors for quality of the wearing surface, or base, and subgrade materials include (1) percent of gravel, sand and fines (2) gradation (if predominantly coarse-grained) (3) plasticity of fines and (4) CBR (California Bearing Ratio—a load-capacity-indicator figure). The first three items can be used to determine the soil classification from which considerable information can be gained on the soil properties, including an approximate CBR value.

## Quantity of Aggregate in Wearing Surface or Base

The quantity of material in the road-wearing surface will ordinarily be the volume of material or its depth times width times length. Quantity of in-place material by total volume, however, is not very informative. The depth or thickness of material is the significant factor. The load-carrying capacity of a road is directly related to the thickness of the aggregate over the subgrade. As the aggregate thickness increases the load-carrying capacity increases.

Thus, over the length of a project, numerous thickness measurements should be made to determine an average thickness. This is primary information. Equally important are the variations in thickness. There may be some specific sections of roadway where the aggregate thickness is considerably less than others—and it may be necessary to add aggregate to these locations to provide for better uniformity in load-carrying capacity.

Similarly, enough soundings or borings should also be made to determine the average width and variations in the aggregate width in the roadway. If a bituminous pavement is to be laid, it is desirable to have aggregate materials to extend at least one or two feet beyond the pavement edge to prevent edge failures. Aggregate width measurements also supply shoulder and general drainage information.

The spacing and total number of thickness and width measurements are determined by: (1) relative importance of the project (2) length of the project, and (3) uniformity of the findings. Recommended locations and spacing of test points along the road will be discussed later. The use of power augers or hand tools is probably the most efficient means of making thickness measurements and sampling.

### Quality Factors for Wearing Surface and Subgrade Materials

The simplest way to determine the general quality of wearing-surface, or base materials, and subgrade materials is to identify and classify the materials into one of various soil groups in the Unified Soil Classification System (USCS). Once a soil, including aggregates, has been identified and classified according to this classification system, much information on the soil's properties, behavior and quality becomes immediately available from previous experience and recorded data.

Another method of gauging the general quality of wearing-surface matetерials (but not subgrade materials), is to determine the composition of the in-place materials, namely gradation and plasticity of fines. Then this field data should be compared to similar data in specifications for base aggregate materials—either gravel or crushed stone.

### Quality Factors to Measure or Test In the Field

In the evaluation of materials for quality, either by classification or by comparing gradation and plasticity of fines to specification data, the three most important factors are: (1) percent gravel, sand and fines (2) gradation (if coarse-grained) and (3) plasticity of fines.

A fourth measure of quality of roadway aggregate materials is called the CBR (California Bearing Ratio), which is a measure of load-carrying capacity. The CBR value (ranging from 0 to 100) reflects (1) aggregate composition, (2) aggregate particles interactions, (3) aggregate thickness, (4) moisture content, and (5) the degree of construction and traffic compaction (in-place wearing surface materials). The CBR value of subgrade soils (usually fine-grained) mainly reflects their composition, moisture content, and compaction.

Therefore, the four most important factors that measure the general quality of in-place wearing-surface materials and subgrade materials are:

1. Percent gravel, sand and fines;
2. Gradation (if predominantly coarse-grained);
3. Plasticity of fines; and
4. CBR

These four items and soil classifications are briefly discussed below and in greater detail under the heading of field testing.

### The Unified Soil Classification System

The Unified Soil Classification System, suggested for Indiana county roads is the simplest system for classifying soils and aggregates and for making subsequent quality determinations. The system along with detailed descriptions of visual means and simple field tests to determine particle percentages, gradation, and plasticity of fines, are described in HERPIC Bulletin No. 13, *Field Identification of Soils and Aggregates for County Highways*. The tests procedures are also summarized in a later section of this bulletin.

Use of the Unified Soil Classification System is also recommended because its classification requirements for each soil group, namely the gravel and sand groups, can be used as general specifications for bases and wearing surfaces. Therefore, using these soil group classifications as specifications, field data on in-place materials can be compared to this specification data to evaluate the quality of the in-place materials and to determine any deficiencies or needs. Use of the USCS soil group classifications as specifications for bases and wearing surface are discussed further in a subsequent section on specifications.

### CBR Determinations

CBR, California Bearing Ratio, is a measure of load-carrying capacity. CBR test values are widely used by highway and airport authorities as a basis for designing the thickness requirements of flexible pavements. The state highway departments in all 50 states recognize the CBR as a standard test procedure, and some 20 state highway departments use the CBR test exclusively for their flexible pavement design procedure. A number of select publications on the use and application of the CBR test results are discussed later.

By the CBR test, the load-carrying capacity of various subgrade and base-type materials are compared with that of a high-quality crushed stone base material. Quality of material is determined by measuring and comparing the force required to push a piston (nearly 2 in. in diameter) into the high-quality crushed stone base material with the force required to push the piston into the material under test. If the force required to push the piston 0.1 in. into the strong crushed stone base is 1000 psi (a standard value) and if only 100 psi is required to push a similar piston into a sandy clay, the CBR of the sandy clay si 10 (100 psi is 10 percent of 1000 psi). CBR values of subgrades and bases generally range from 0 to 100.

The standard ASTM or AASHTO test procedures for CBR are complex, time-consuming, and costly. Samples must be brought in from the field, recompacted to field density, and tested with special equipment under rigorous specifications. This bulletin, therefore, recommends the use of two simple, portable penetrometers (probes or push-rods) that have been correlated with CBR test values and can thus be used to determine equivalent CBR values for in-place subgrade and base materials. See Figures 1 and 2.

The CBR (or its equivalent) of roadway aggregate or subgrade materials may therefore be determined by either of several test methods, each testing at a certain level of accuracy. Two methods already mentioned were: (1) standard ASTM or AASHTO tests, which are most accurate, and (2) heavy-

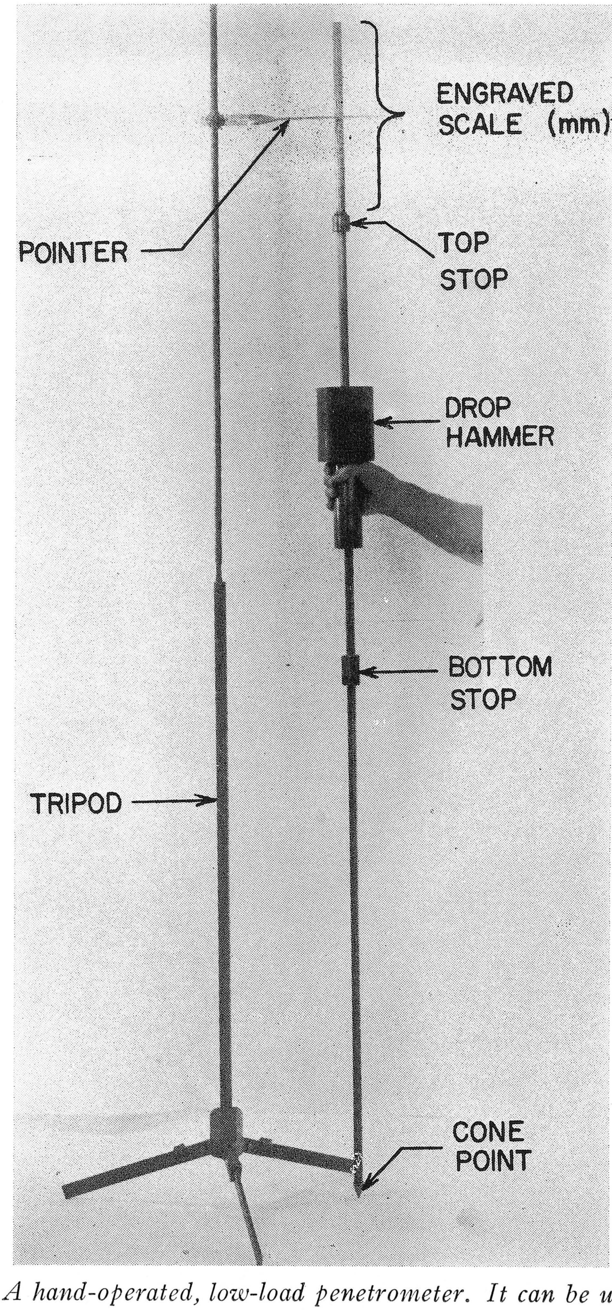



*Figure 1. A hand-operated, low-load penetrometer. It can be used to determine the CBR of clays, silts, fine, and medium sands. The drop hammer causes the cone point to penetrate a soil a few millimeters. From the amount of each penetration, and a penetration (mm)-CBR chart, the CBR is determined.*

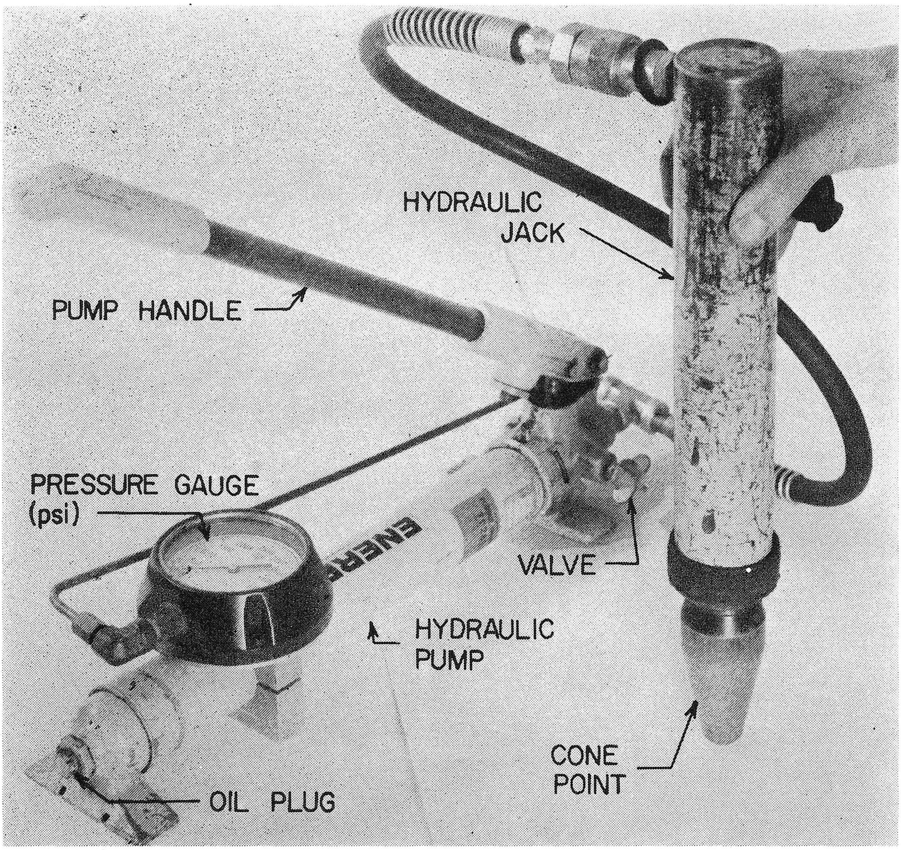



*Figure 2. A hydraulically-operated, high-load penetrometer. It can be used to determine the CBR of compacted granular materials. The cone point of the jack is driven into a material by pressure from the hydraulic pump. CBR of the material is determined from the pressure required and a pressure (psi)-CBR chart.*

duty and light-duty penetrometers, which are quite accurate. A third method is by soil (or aggregate) classification and the use of soil-CBR charts. This equivalent CBR method is approximate.

In this bulletin, the use of penetrometers are highly recommended as a compromise between cost and accuracy. Details on the penetrometers, their field use, and equivalent CBR determinations are presented in Chapter 5, "Wearing Surface and Subgrade Quality by Penetrometer Tests." If a county can not afford the use of the penetrometers, the method of soil classification using a soil-CBR chart is recommended. Ideally, both the penetrometer method and chart method should be used and results compared, especially if soil classification data is available from other testing.

## III. SPECIFICATIONS FOR WEARING SURFACES AND BASES

For the purpose of evaluating materials in existing wearing surfaces or bases, there is a need to know the requirements or specifications of high quality wearing surfaces and bases. After determining the quality factors of existing materials, i.e., their gradation, plasticity of fines, particle quality and CBR, they should be compared to standard specifications to determine the over-all quality and to determine what is needed to bring them up to the high quality indicated by standard specifications.

### Simple Specifications for Wearing Surfaces and Bases

The simplest form of specifications for a wearing surface and base would be a statement primarily of gradation requirements as indicated in the tables below. With gradation (including percent of fines) and plasticity of fines as indicated in the tables, only the requirements for particle quality and CBR need to be set forth. Particle quality could be handled with a statement that at least 95 percent of the particles should be hard, sound, and not excessively elongated, i.e., no more than 5 percent of the particles should be soft or deleterious (foreign materials like shale, coal, shells etc.). The CBR of a properly compacted aggregate base or wearing surface should be around 80 in a wet saturated condition.

**Road Wearing Surface Material (Dense-Graded)**

| | |
|---|---|
| Crushed Stone or Gravel (plus No. 4) | 40%-65% (max. size—1 in.) |
| Sand (No. 4—No. 200) | 25 -55 |
| Fines (minus No. 200) | 5 -10 (slightly plastic) |

**Base Aggregate for Flexible Pavement (Dense or Open-Graded)**

| | |
|---|---|
| Crushed Stone or Gravel (plus No. 4) | 40%-65% (Max. size—1½ in.) |
| Sand (No. 4—No. 200) | 35 -60 |
| Fines (Minus No. 200) | 0 - 5 (nonplastic) |

### Unified Soil Classification System—Gravel and Sand Groups Classification Requirements As Specifications

The Unified Soil Classification System (USCS) applies to the full range of natural soil textures, from coarse gravelly soils through sands, fine silts, and plastic clays. Thus the USCS can be used to classify aggregates for wearing surfaces and bases, as well as subgrade soil materials.*

*For the remainder of this section on USCS, the terms "gravel," "sand," etc. apply in a manner similar to crushed stone materials having corresponding size limits.

**TABLE 1. USCS Classification Requirements for Gravel and Sand Groups Along with Quality Rating of Each Group when Serving as a Base or Wearing Surface (As general specifications —read table from right to left)**

| Group[1] Symbol | % Gravel | % Sand | % Fines[3] | Gradation | Plasticity[4] | Base[6] | Wear Surf[6,7] |
|---|---|---|---|---|---|---|---|
| GW | Over 50% Coarse Grains[2] | Less than 50% Coarse Grains[2] | 0-5% | Well | Nonplastic[5] | E | F |
| GP | As above | As above | 0-5 | Poorly | Nonplastic[5] | E | — |
| GW-GC | | | 6-12 | Well | Plastic | G-P | E |
| GW-GM | | | 6-12 | Well | Nonplastic | G-F | G |
| GP-GC | | | 6-12 | Poorly | Plastic | G-P | P |
| GP-GM | | | 6-12 | Poorly | Nonplastic | G-F | P |
| GC | | | over 12 | (No effect) | Plastic | | G-F |
| GM | | | over 12 | (No effect) | Nonplastic | | |

NOTES:

1 Definition of group symbols:
G = gravel, W = well graded, P = poorly graded,
C = clay, M = silt.

2 Coarse grains are combined gravel and sand. If the headings "gravel" and "sand" were interchanged (i.e., sand predominates over gravel) the letters G (gravel) should be changed to S (sand) in the Group Symbol column.

3 Fines are combined silt and clay.

4 Plasticity of fines is for portion passing No. 40 sieve.

5 Fines shall be free draining.

6 Definition of quality ratings: E = excellent, G = good, F = fair, P = poor. If materials are predominantly sand (as SW = well graded sand), lower all the above ratings by one letter grade.

7 ISHC specifications for compacted aggregate surface specify No. 53 and No. 73 aggregates, both limited to 5-10% passing No. 200 sieve.

Table 1 shows the soil group classification requirements (percent gravel, sand, and fines; gradation and plasticity) for each one of the gravel groups. Table 1, in the two right-hand columns, also shows a rating system for each of the gravel groups, when the materials are used for wearing surfaces (roads with less than 100 vpd) or for bases (for high traffic roads).

When Table 1 is used, reading from right to left, it supplies general specifications for both wearing surfaces and bases. For example, inspection of the right-hand column shows an E, for excellent, for a wearing surface. Reading on the E line to the left one finds that specifications for an excellent gravel wearing surface are as follows: fines should be plastic; gradation—well-graded; percent of fines—6-12 percent; percent of sand—less than half the coarse grains; and percent of gravel—over half of the coarse grains (for a well-graded gravel the ratio of gravel to sand is about 2:1).

### ISHC Standard Specifications, 1974

ISHC specifications for bases and gravel wearing surfaces are in sections 303, of this publication "Compacted Aggregate, Base, Surface or Shoulders" and 903, "Aggregates." The specifications cover both construction details and materials requirements. Section 903.02, "Coarse Aggregate" and 903.02 (e), "Size of Coarse Aggregates" has gradation and plasticity information.

If one wishes to compare the gradation and plasticity of in-place materials with that of base materials for flexible pavements, one should refer to the gradation and plasticity requirements for either dense-graded bases, using No. 53B or No. 73B aggregate sizes, or open-graded aggregate sizes No. 4 or No. 5. The sieve sizes and limits of percentages passing as well as the plasticity of fines are shown in Appendix A.

## IV. WEARING SURFACE AND SUBGRADE QUALITY BY SOIL CLASSIFICATION

One may determine the quality of wearing surface materials and subgrade materials by sampling and testing for (1) percent of gravel, sand, and fines, (2) gradation, and (3) plasticity of fines. From these three items, one can determine a soil classification which in turn can be used to determine an approximate CBR value. The soil classification techniques are described in HERPIC Bulletin 13 and are only summarized here.

### Gradation and Percentages of Gravel, Sand and Fines

Gradation and the determination of percentages of gravel, sand, and fines is almost the same. However, gradation refers to a more detailed definition of particle size ranges. In the Unified Soil Classification System, the first step in soil identification and classification is the determination of percentages of gravel, sand, and fines. If a soil is predominantly coarse-grained (over 50 percent gravel and sand combined), the next step in identification is determining gradation, or the range of sizes of the gravel and sand particles. In

HERPIC Bulletin 13, visual and simple field tests are used to make the two determinations, (a) gradation and (b) percentages of gravel, sand, and fines. These field tests are summarized in the sections that follow.

*Visual Determinations*

Particle percentages and gradation can be done fairly accurately by visual examination when a representative sample is spread on a flat surface.

Simply note the percent of particle sizes: gravel, 3 in. to ¼ in.; sand ¼ in. to 3/1000 in.; silt and clay, smaller than 3/1000 in. (silt and clay particles fit into the finger prints—fine sand does not). Fine sand feels sharp and gritty. Silts and clays feel soft and smooth like flour. For gradation, note range of various sizes of the gravel and sand particles and the percent of fines. (HERPIC Bulletin 13, p. 17.)

*Simple Sieves and Visual Inspection*

These visual determinations might be enhanced by using two homemade sieves, one made from ¼ in. hardware cloth to retain gravel and one made from window screen mesh (about 32 wires per inch), to catch coarse and medium sand. Estimate the percentages of fine sand and fines passing the window screen visually and by feel. Gradation determination of the screened particles would be visual. (HERPIC Bulletin 13, p. 34.)

*Water Sedimentation Test of Sand and Fines*

For this test separate the gravel out of a representative sample by a ¼ in. screen or by hand (percentage estimated). Then place a large handful of the remaining sand and fines in a straight-sided jar (about one quart size) and shake vigorously. When the sand settles, with the fines on top, measure the height of each with an engineer's scale and compute the relative percentage of each. (HERPIC Bulletin 13, p. 35.)

*Standard Gradation Tests*

The standard ASTM and AASHTO laboratory test for gradation, called sieve analysis, is listed in Appendix B.

Precise gradation is determined by separating a representative sample of the aggregate into various size groups or fractions. This is done by shaking it through a series of sieves, the sieves with the largest openings, at the top. Usually most of the material passes through but some is retained on the top sieve. So, with each sieve, some material passes and some is retained. The last container in the nest of sieves, a pan, catches both the silt and clay size particles—if there are any.

Before sieving, the total weight of the entire sample is obtained (dried). Then the material retained on each sieve, and in the pan, is weighed separately. Using these weights, the percentages of the total weight can be determined for material retained in each sieve. For example, if 100 lb. of dry aggregate is shaken through the nest of sieves and 8 lb. is retained on the top sieve the percentage retained is 8 percent. Obviously, 92 percent went through or passed the top sieve, and so on for each sieve. However, instead of using the percent retained, engineers generally work with and speak of "percent passing," or "percent finer," than each of the sieve sizes.

*Gradation Curves*

The best way to see and understand the results of a sieve analysis is to plot the data on graph paper as shown in Fig. 3. The percent passing is plotted on the vertical arithmetic scale, and corresponding sieve size, or particle size, is plotted on a horizontal logarithmic scale.

A glance at such a particle-size-distribution curve quickly shows the general grading characteristics of an aggregate material. A well-graded aggregate, with several sizes ranging continuously from coarse to fine, is represented by a relatively smooth curve that extends across the logarithmic scale for several cycles. If all the particles of an aggregate are approximately the same size, the material is poorly (or uniformly) graded and is represented by a nearly vertical line on the grading plot. A gap-graded gravel may lie partly between the two lines and have a "bump" in it as shown in Fig. 3.

The specifications of the Unified system and the ISHC, have slightly different sieve sizes listed for the sieve analysis. When comparing the composition of in-place materials with a specific set of specifications, the sieves listed for those specifications should be used in the sieve analysis.

*Commercial Testing Services*

Where testing equipment and trained personnel are not available, county highway departments should consider using the services of commercial soil testing organizations, especially tests for gradation analyses (also called mechanical analyses or a sieve analyses). Several tests might possibly be satisfactory for the whole project especially when materials appear (by visual inspection) to be quite uniform throughout.

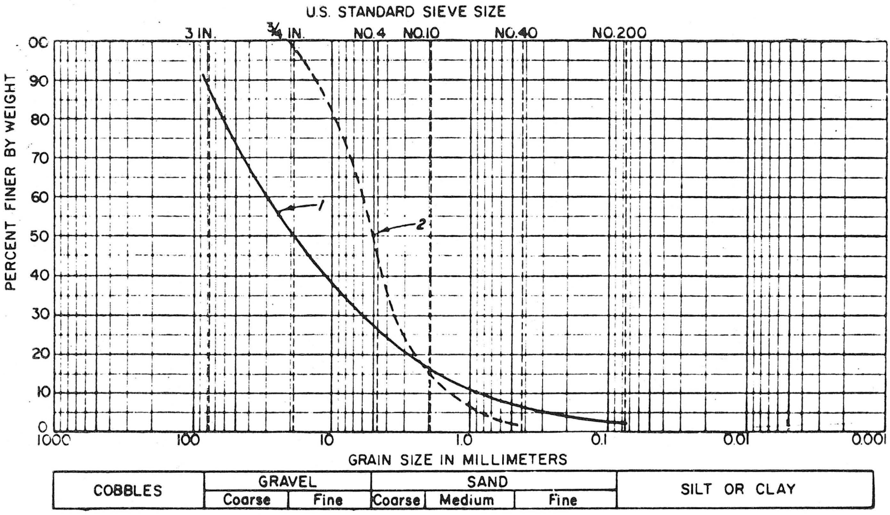
## Plasticity of Fines

As previously mentioned, fines are silt and clay particles. They pass a No. 200 sieve (200 wires per inch). However, to determine the plasticity of fines in an aggregate, all the material passing a No. 40 sieve (40 wires per inch) is tested, including not only silt and clay but also fine sand.

Plasticity tests include wet ribbons, dry strength, and thread-roll tests.

Specifications for base materials require nonplastic fines (for filler); whereas wearing surface materials require low-plastic fines (for binder and filler). (HERPIC Bulletin 13, p. 37.)

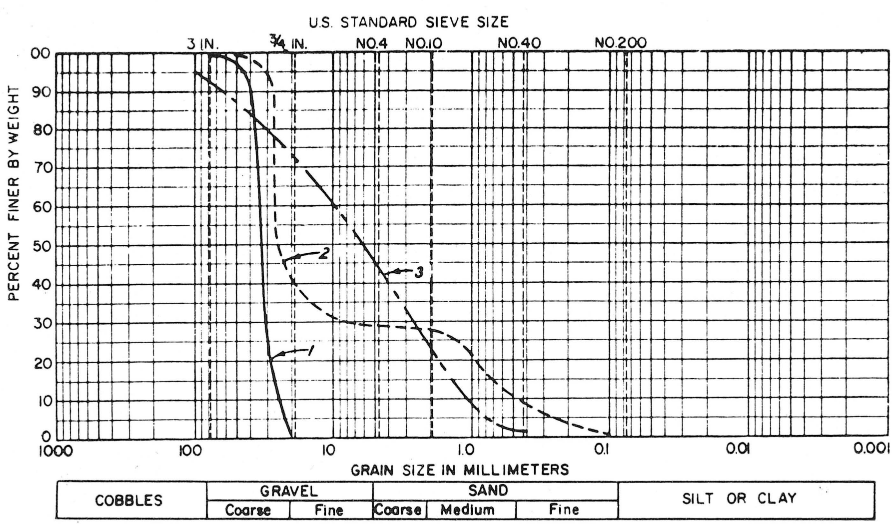
## GW GROUP




CURVE 1: Pit run gravel; nonplastic; well-graded; small percentage of fines

CURVE 2: Sandy gravel; nonplastic; no fines. Curve is about the steepest one that will meet the criteria for GW group.

## GP GROUP




CURVE 1: Uniform coarse gravel; nonplastic. Very uniform gradation.

CURVE 2: Gravel-sand mixture; nonplastic. Gravel is almost all of one size (3/4-to 1 inch), no fine gravel present. Poorly graded.

CURVE 3: Sandy gravel; nonplastic. All sizes are present, but gradation does not meet curvature criterion for GW.

*Figure 3. Grain-size-distribution curves for well-graded (GW) and poorly graded gravels (GP).*

*Ribbon Formation Test*

A thoroughly moistened, worked and reworked wad of soil is shaped into a roll about the size of a pack of quarters. It is then forced and extruded between the thumb and the index finger into a ribbon shape about ½-in. wide and ⅛-in. thick. If no ribbon can be formed, the soil is nonplastic. Short ribbons indicate low and medium plastic soils (hanging vertically the ribbon breaks when less than 8 in. long). A ribbon over 8 in. long, hanging vertically and supporting its own weight, indicates a highly plastic soil. (HERPIC Bulletin No. 13, p. 15).

*Dry Strength Test*

A thoroughly dry lump of soil that breaks very easily in the fingers into essentially all individual grains is nonplastic. Dry lumps that break easily or with some slight difficulty into some individual particles and smaller lumps are low and medium plastic soils. Dry highly plastic soils are usually impossible, or nearly so, to even break into two pieces. (HERPIC Bulletin No. 13, p. 16).

*Thread-Roll Test*

Using a piece of ordinary window screen (instead of a No. 40 sieve), the tester thoroughly moistens separated fines in a container and forms them into a roll about the size of a pack of dimes. This roll is then rolled on a smooth, glass surface with the flat of the hand to further reduce its diameter. A roll breaking up before it reaches a ¼-in. diameter probably has a plasticity low enough for a base material. A roll reducing to between ¼-in. and ⅛-in. indicates a plasticity of fines suitable for a gravel wearing surface. A roll reducing to ⅛-in. or less indicates a plasticity too high for either a base or wearing surface. (HERPIC Bulletin 13, p. 37).

## Classification of Soils and Aggregates from Test Data

With: (1) percent gravel, sand and fines (2) gradation (if a coarse grained soil) and (3) plasticity of fines, a soil can be easily classified by applying the information to a flow chart. ("Soil Identification Procedure," HERPIC Bulletin 13, p. 32).

With the soil materials classified, the "Soil Use Chart," HERPIC Bulletin 13, p. 45, and the soil-CBR-correlation chart in this bulletin, Figure 4, provide considerable additional information, primarily on the quality of the soil as a base or wearing surface material and its approximate CBR value.

*Summary of USCS Soil Classifications Procedure*

The following is a summary of the use of the Soil Identification Procedue flow chart shown in HERPIC Bulletin 13, p. 32.

Note that the first step is to determine if the composition of the soil sample is over 50 percent coarse grains or over 50 percent fine grains.

*If over 50 percent fine grains* (silt and clay), determine if the fine grains are plastic or nonplastic. If plastic, the soil is basically a clay; if nonplastic, it is basically a silt. Note that there are three types of plastic clay: low plastic clay (CL), high plastic clay (CH) and organic clay (OH) (low or high plastic and with black organic material). There are also three types of nonplastic soils: silt (ML), micaeous silt (MH) (with numerous mica flakes), and organic silt (OL) (with black organic materials). The greater majority of Indiana's surface soils are low plastic clays, also called silty clays.

*If the sample is over 50 percent coarse grains (gravel and sand),* determine if the coarse grains are mostly (over half) gravel or mostly sand. If mostly gravel, the material is basically a gravel; if mostly sand, it is basically a sand. If either the basic gravel, or basic sand, has *less than five* percent fines and is well-graded, the material is a well-graded gravel (GW) or well-graded sand (SW). If poorly graded, it is poorly-graded gravel (GP) or poorly-graded sand (SP). For basic gravels or basic sands with *over 12 percent* fines, the plasticity of the fines (plastic or nonplastic) is the major quality factor, with gradation having little or no influence on quality. If the fines (over 12 percent) are plastic, the basic gravel is a clayey gravel (GC) and the basic sand, a clayey sand (SC). If the fines (over 12 percent) are nonplastic, the material is a silty gravel (GM) or silty sand (SM).

For basic gravel or sand, with fines between *6 and 12 percent,* both the gradation and the plasticity of the fines must be considered. (In this case, fines are all materials passing a No. 40 sieve, including silt and clay as well as fine sand). The fines must be analyzed and given one of the fine-grained symbols and this symbol added to one of gravel or sand symbols, such as GW-GC or SP-SM etc.

## Use of Soil-CBR Chart

Soil classification and the use of a soil-CBR chart is the least accurate of the equivalent CBR determination methods. However, once a soil is classified, its approximate CBR can be determined from a chart which correlates the range of CBR values with each of the various soil classification groups of the Unified Soil Classification System (see Fig. 4).

Accuracy of the equivalent CBR by this method will depend to some extent on the accuracy of soil classification. Levels of accuracy for soil classification, ranging from high to low, are as follows: (1) standard ASTM or AASHTO classification tests (see Appendix B), (2) visual inspection and simple field tests, and (3) use of agricultural or engineering soil maps.

## Soil Classification from Agricultural and Engineering Soil Maps

A new series of agricultural soil maps, started in 1965 by the Soil Conservation Service, USDA, in cooperatoin with Purdue University Agricultural Experiment Station, are being compiled and published for each Indiana

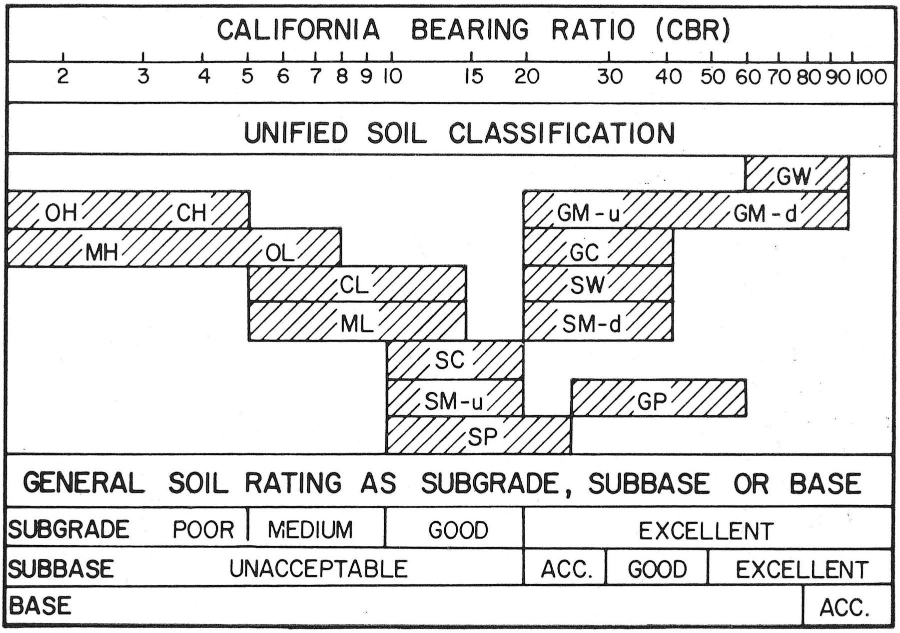



*Figure 4. A soil-CBR chart as modified from a chart in the Asphalt Institute Manual Series (MS-1), "Thickness Design-Asphalt Pavement Structures for Highways and Streets"; d=drained; u=undrained.*

county. The proper name of each county publication is "Soil Survey of X County." The status of county mapping is shown in Appendix C.

The agricultural soil maps show accurate locations of soils with specific pedological soil names. For each pedological soil name there is also a corresponding soil classification by both the USCS and AASHTO systems for each of the A, B, and C soil horizons. Considerable additional engineering soils data is in each of the county soil survey publications.

In addition, the Joint Highway Research Project (JHRP) is in the process of compiling engineering soil maps of each county, using air photo interpretation methods. These maps are compiled to a scale of one inch equals one mile, have general soils information and are used primarily for preliminary highway location studies as related to subgrade soils. The status of JHRP engineering soils mapping in Indiana is shown in Appendix D.

## Quality of Wearing Surface Materials

The following is typical field information, soil classification, and quality evaluation that will be frequently encountered in studying Indiana gravel road wearing surfaces:

| Field Info Logged | Info Applied to Soil Ident. Chart | Soil Classed by USCS |
|---|---|---|
| **Particle %** | | |
| Gravel = 55% | Over 50% coarse grains | |
| Sand = 25 | and over half is gravel; | |
| Fines = 25 | Over 12% fines | |
| **Gradation** | | |
| Poor | (When over 12% fines gradation is not considered) | GC (Clayey Gravel) |
| **Plasticity Fines** | | |
| Low plastic | Low plastic (versus high plas or nonplas) | |

After determining that this particular sample of gravel wearing-surface material is classified as clayey gravel (GC), obtain the following information from the Soil Use Chart, HERPIC Bulletin 13, p. 45: Permeability—Impervious; Load Carrying Ability—Good to *Fair;* Frost Susceptibility—Slight to *Medium*; Base Course—Good to *Poor*; Wearing Course—Excellent to *Good* (as the sample fines are 25 percent, and well over the 12 percent break point, all the lower qualitative conditions, in italics, should be anticipated). Using the Soil-CBR Chart, Figure 4, note that the average CBR value of GC material is 30—range 20-40.

### Quality of Subgrade Material

The following is an example of the classification and quality evaluation of a typical Indiana subgrade soil:

| Field Info Logged | Info Applied to Soil Ident. Chart | Soil Classed by USCS |
|---|---|---|
| **Particle %** | | |
| Gravel = 10% | Combined coarse grains | |
| Sand = 25 | less than 50%; | |
| Fines = 65 | Fine grains over 50% | |
| **Gradation** | | |
| None for fine grained soil | —— | (CL) Low Plastic Clay or Silty Clay |
| **Plasticity Fines** | | |
| Low plastic | Low plastic | |

The properties of a silty clay (CL), according to the Soil Use Chart, are: Permeability—Impervious; Load Carrying Ability—Fair; Frost Susceptibility—Medium to High; as Base Course and Wearing Course it is not rated as it is not usable for even a minimal traffic county road. The average CBR value of a silty clay (CL) according to the Soil-CBR Chart is 9—range 4-15.

## V. WEARING SURFACE AND SUBGRADE QUALITY BY PENETROMETER TESTS

Penetrometer tests provide another and more accurate method of determining an equivalent CBR value for wearing surface and subgrade materials. By driving specially designed cone penetrometers into in-place materials and measuring the drive force required (high-load penetrometer) or the distance penetrated (low-load penetrometer), an equivalent CBR of the in-place, undisturbed materials can be obtained.

Figures 1 and 2 show pictures of the two penetrometers. The Boeing Corporation developed the hydraulic equipment to measure an equivalent CBR of granular bases for airport pavements. The official name is the Boeing High-Load Penetrometer—hereafter called simply, high-load penetrometer.* The smaller, hand-operated penetrometer was developed in South Africa based upon concepts first developed in Australia. It is known as the Dynamic Cone Penetrometer, hereafter referred to as the low-load penetrometer.†

The heavy-duty, high-load penetrometer is hydraulically operated and jacked against the frame of a large dump truck, loaded with sand or gravel for ballast. This sturdy penetrometer can penetrate compacted dense gravel, crushed stone, and/or sand and obtain equivalent CBR readings in the range of about 50 to 100. The lighter, low-load penetrometer, driven by a small, sliding, hand-operated drop-hammer, is used for fine-grained soils and fine and medium sands, usually subgrade materials. It can obtain equivalent CBR readings in the range of zero to about 50.

Low-load and high-load penetrometers have various advantages and disadvantages. Advantages are: (1) they are accurate; (2) they are light and easily portable; (3) they can be used and operated by unskilled personnel; (4) their operation is fast and simple; and (5) they are relatively inexpensive, especially the smaller penetrometer.

Their disadvantages or limitations are as follows: They should only be used in the field when the roadway materials are in their wettest and weakest

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* This penetrometer manufactured by: J. D. Ott Co., 115 S. Lucile St., Seattle, Washington, 98108. Phone (206) 762-7722. Price: $1067 F.O.B. Seattle (two @ $943 each) as of November 1976. Price good for 60 days, delivery in 90 days.

† This small penetrometer can be manufactured in a local machine shop, using the dimensions shown in Figure 6. There is no patent on the equipment.

condition; they probably are best used after spring thaws followed by periods of heavy rain. This incurs a time-of-year limitation and a generally short-time period for field testing. (It would be feasible, however, to methodically pre-soak the selected test sites before testing). The high-load penetrometer is designed to test granular soils a minimum of six inches thick. When less than six inches, the equivalent CBR reading is that of a combination of wearing surface material and subgrade.

### Equivalent CBR of Fine Grained Soils by Low-Load Penetrometer

Figure 5 shows a low-load penetrometer in use. It is a light, portable tool used for the rapid determination of the equivalent CBR of in-place, fine-grained soils. When the cone is driven into the soil by the drop hammer, an equivalent CBR of each soil layer encountered can be determined—including fine and medium sands. For sands the cone point is removed and the slightly rounded tip attached. The small penetrometer can measure equivalent CBR values up to 50 percent.

#### *Description of Equipment*

Figure 6 shows a sketch of the penetrometer with the dimensions of the various components. The equipment is not patented and can easily be constructed locally in a machine shop.

The main part is a long rod with a cone point. On the cone-pointed rod are two fixed anvils or stops placed so that the bottom of the drive weight can free fall 460 mm. The lower anvil takes the force of the blows produced by the sliding drop hammer. The top anvil merely marks the height to which the hammer is raised previous to a drop. At the top of the rod is an engraved scale slightly over 1 ft. long (13.22 in. or 33.58 cm on a Purdue constructed penetrometer), and the smallest unit on the scale is a centimeter (10 mm or $\frac{1}{2.54}$ in.).

The other main part of the apparatus is the pointer attached to the vertical rod on the tripod. The pionter can be raised or lowered by means of a set screw.

#### *Equipment Operations and Equivalent CBR Determinations*

Field operation of the equipment and the determination of subgrade CBR is described below. The equipment should be used only on fine-grained soils, fine sands, and medium sands.

Equipment operation, step-by-step, is as follows:

1. After clearing away gravel surfacing material to subgrade, an area at least 1 ft. in diameter, operator No. 1 places the cone of the drive rod on the subgrade near the side of the cleared area. With the drive-rod

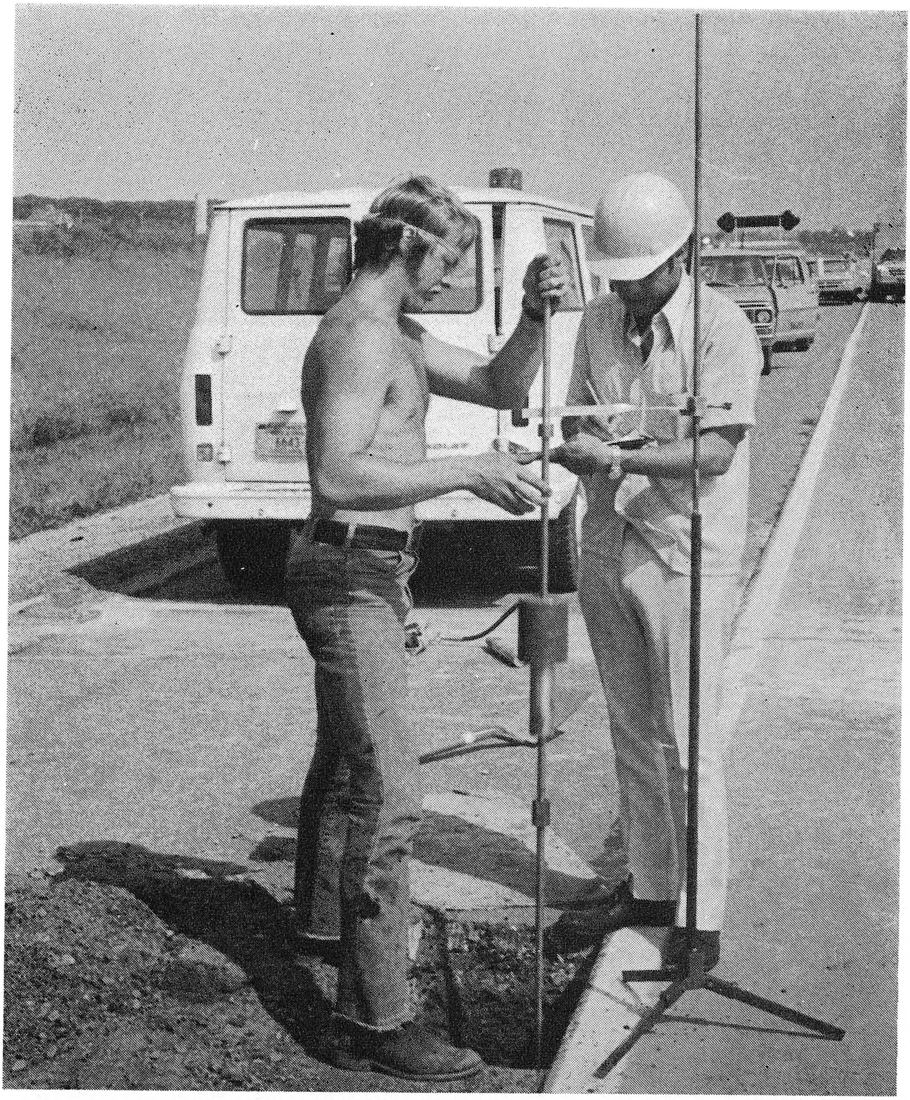


*Figure 5. A low-load penetrometer is being used to test the subgrade of an interstate highway. The drop hammer is in the midst of its free fall. The note taker records an initial and final scale reading at the pointer and, by subtraction, determines the millimeters of penetration of the cone point.*

vertical, the tripod pointer assembly is placed so that the tip of the pointer nearly touches the scale on the drive rod.

2. Operator No. 2 records the initial scale reading indicated by the pointer with the weight of the drop hammer on the lower anvil. The weight of the rod and drop hammer will be enough to force the cone through

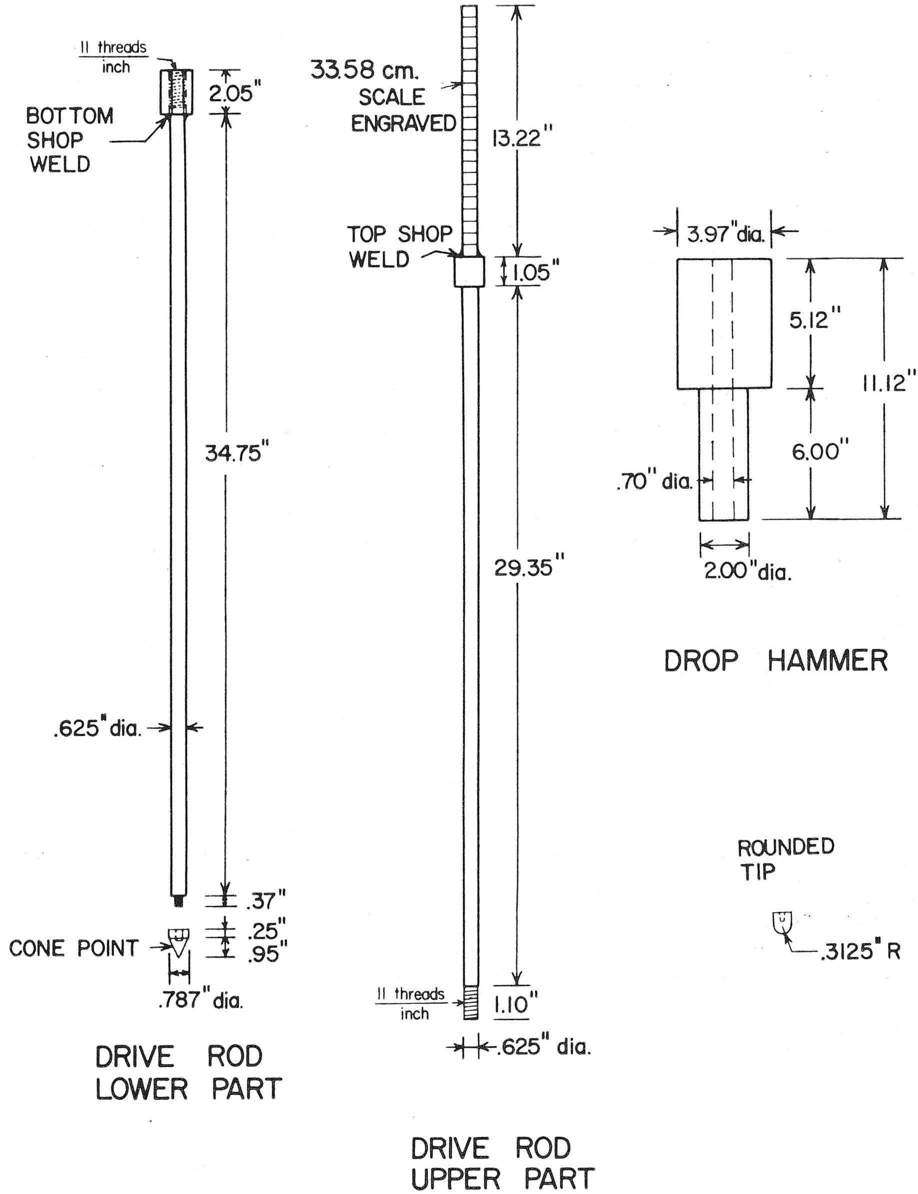



*Figure 6. This sketch shows the dimensions of the disassembled low-load penetrometer. The drive rod is 5/8 in. standard rod. It is important that the cone point be the exact size shown, the drop hammer weigh 10 Kg and have a free fall distance of 460 mm, and the scale on the rod be in millimeters—as the penetration-CBR chart is millimeters. (However, both could be converted to inches if desired). The rounded tip shown is used in sandy soils.*

essentially all loose and disturbed soil. A form for recording scale readings and computing millimeters of penetration per blow is shown on the back side of the field log, page 40.

3. Operator No. 1 then lifts the sliding drop hammer until it just touches the top anvil. The hammer is then dropped to free fall on the lower anvil.
4. Operator No. 2 records the new scale reading at the pointer after the cone point has been driven into the soil (measured in millimeters by estimating a centimeter to the nearest tenth) by the single hammer blow. The number of millimeters driven is determined by subtracting the last scale reading from the previous one. (If it appears that the cone is hitting a relatively large rock and not penetrating, try a new spot a few inches away).
5. Steps 3 and 4 are repeated until the cone and rod have penetrated 1 ft. into the subgrade.
6. From Table 2 determine an equivalent CBR corresponding to each cone penetration (mm) and record the CBR value in the appropriate space on the log. The log will then show a CBR value for each hammer drop.

**TABLE 2. Low-Load Penetrometer Correlation**
**Penetration per Blow (in millimeters)**
**- vs -**
**Equivalent CBR of Soil Material Tested**

| Cone Penetration mm/blow | CBR pct | Cone Penetration mm/blow | CBR pct |
|---|---|---|---|
| 4 | 50+ | 16 | 13 |
| 5 | 50 | 18 | 12 |
| 6 | 40 | 19 | 11 |
| 7 | 33 | 20 | 10 |
| 8 | 29 | 23 | 9 |
| 9 | 25 | 25 | 8 |
| 10 | 22 | 28 | 7 |
| 11 | 20 | 33 | 6 |
| 12 | 19 | 38 | 5 |
| 13 | 17 | 45 | 4 |
| 14 | 16 | 60–70 | 3 |
| 15 | 14 | 80–90 | 2 |
| | | 100 | 1 |

7. Compute the average CBR value for the 1 ft. of subgrade soil immediately below the gravel wearing surface as follows: total all the CBR values obtained for the 1 ft. of subgrade (right hand column of the log) and divide this total by the number of CBR readings obtained or used.
8. Repeat all steps, 1 through 7, two more times and obtain a total of three average CBR values for the top foot of subgrade over an area about 1 ft. in diameter. The average CBR of the soil, in this particular roadway cross-section, is found by adding the three CBR tests values and dividing by three. Computation space is provided on the log.
9. The subgrade CBR value for the project length is found as follows: take all the average CBR values in each cross-section in the project length and write them down in order of magnitude, highest value at the top of the list to the lowest at the bottom. It is recommended that the CBR value at the 75th percentile be used for the pavement design CBR. The 75th percentile of the CBR listings is the one three-quarters (75 percent) of the way down the listing from the top of the list or one-quarter of the listings up from the bottom.

## Equivalent CBR of Wearing Surfaces By High-Load Penetrometer

Figure 7 shows a high-load penetrometer in use. It is a relatively light and portable cone penetrometer used for the rapid determination of equivalent CBR values of in-place gravels and sands. It is also relatively accurate, can be used by unskilled personnel, and can measure equivalent CBR values up to 100 percent.

### *Description of Equipment*

Figure 2 shows a picture of the penetrometer with names of various components.

The primary parts are the hydraulic pump and jack. The ramrod part of the jack has a blunt, 2-in. diameter, hard steel, cone point—the cone penetrometer. The jack ramrod has a throw of 9 in.—that is, the cone point can be jacked through a gravel and/or sand layer 9 in. thick.

The hydraulic jack is connected to the hydraulic hand pump by a short, high-pressure hose. The hand pump is fitted with a hydraulic pressure gauge that reads in pounds per square inch (psi)—the pressure being applied to the cone point.

When jacking the cone penetrometer through a hard granular surface, a heavy load is required to jack against. Usually a good-size truck, loaded with sand or gravel, is sufficient. To jack against the truck frame it may be necessary to make a simple, adjustable, but heavy I-beam-frame adapter, as shown in Figure 8, to transmit the reactive force from the jack to the truck.

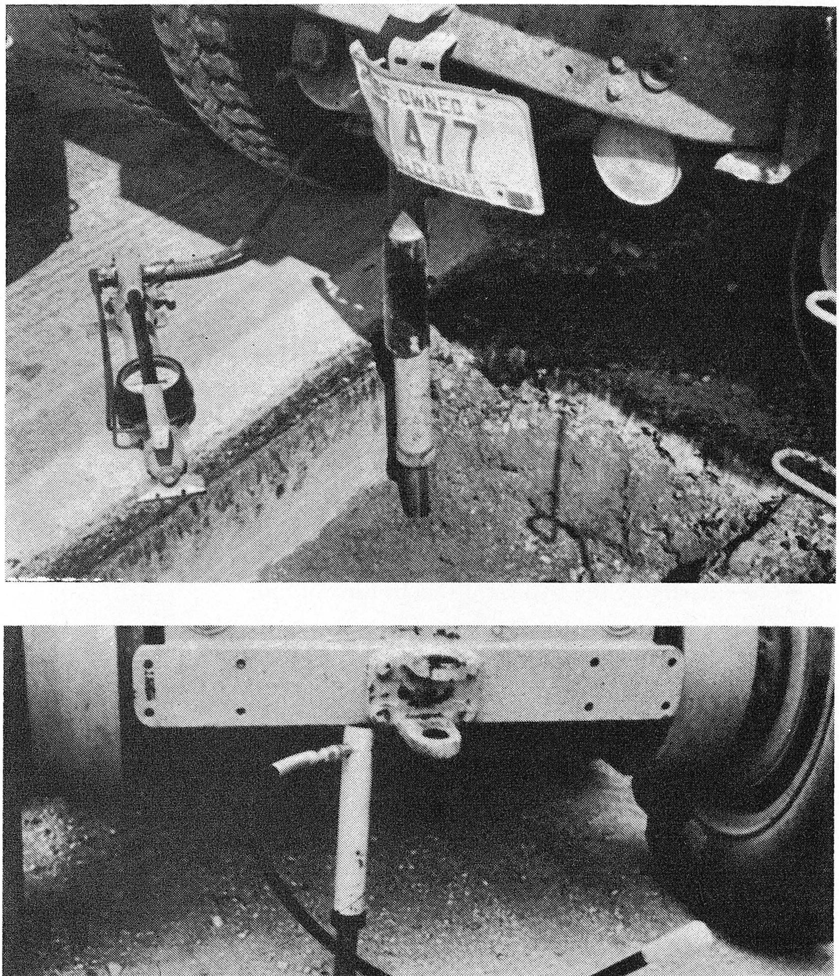



*Figure 7. Top—checking the CBR of an existing base. Bottom—the CBR of a gravel road wearing surface is determined before paving. Also note the heavy reactive forces required for the hydraulic jack, a loaded dump truck (top) and a scraper (bottom). The high body frame of the truck also requires an extension adapter (Figure 8) for the short hydraulic jack.*

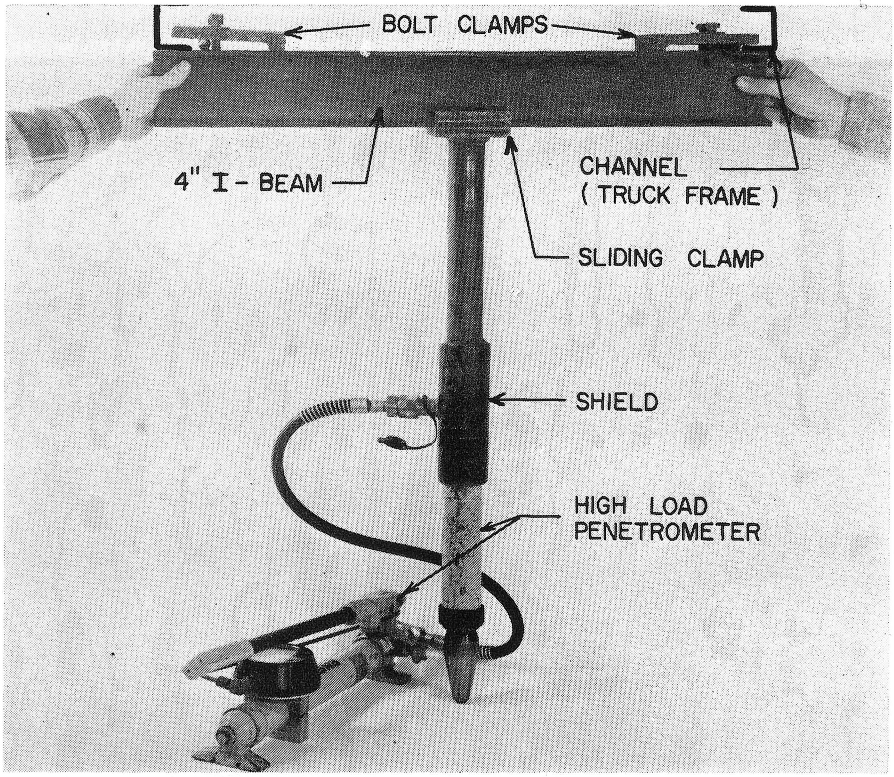



*Figure 8. This photo shows a custom made adapter for using the hydraulic jack under a large dump truck. The clamps, on each end of the I-beam, lock onto the truck's channel-body-frame. The vertical extension piece, on the adapter, can slide left or right on the lower flange of the I-beam. The vertical extension has a small shield piece to prevent slippage at its contact with the jack.*

The maximum load required for the cone point to penetrate a CBR 100 surface is about 10,000 pounds. Therefore, a total vehicle weight of over 25,000 pounds must be used on this material.

*Equipment Operation and Equivalent CBR Determinations*

1. Select the site point to be tested and move the loaded dump truck, with the jack adapter directly over the point of test. The truck should be as level as possible. (Four tests are suggested for each roadway cross-section —see Figure 13.)

2. Place the jack (penetrometer) as vertically as possible under the adapter—Figure 8.

3. Work the pump handle at a moderate rate (about one second up and

one second down) to apply hydraulic pressure and start movement of the cone point into the gravel surface.

4. As the cone penetrates, gravel road surface material will push up around the cone as shown in Figure 9. Using a rule, carefully determine when the reference-point on the cone is 4 in. below the original surface (top of cone will be 2 in. below original surface—Figure 9). At this 4-in. depth, "boiling up" of the gravel will stop and a gauge reading on the pump will indicate an equivalent CBR of the surface material, provided the surface material is homogeneous to a depth beyond the cone point. The pressure gauge is read when the cone point has stopped moving (without additional pumping) and a condition of equilibrium is reached between the hydraulic pressure and the surfacing material pressure. If the load is applied for a prolonged length of time, the pressure will be slowly relieved by the gravel,

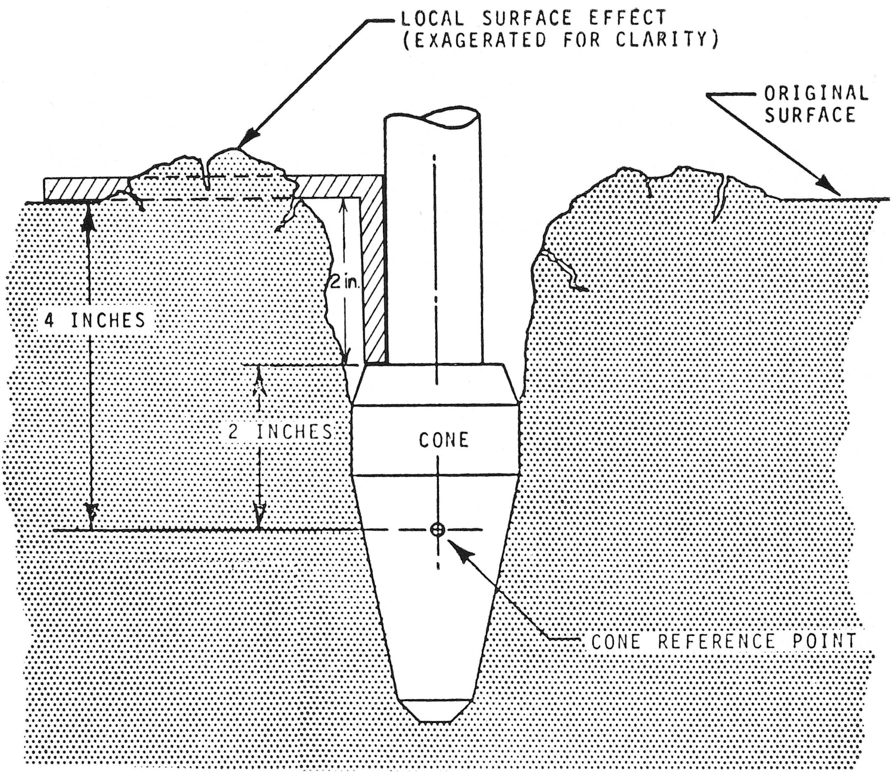



*Figure 9. This sketch shows results of the high-load cone being forced into a compacted gravel. Note the bulging up of material around the area of penetration. The cone reference point shown must penetrate 4 in. before a pressure gauge reading is taken. A custom-made feeler gauge can be made to measure 2 in. from the original ground surface to the top of the cone (reference point at 4 in.).*

but the calibration curve is based on the initial stabilization which occurs in about 30 seconds—when visible motion has ceased. When the cone point encounters a large stone, a sudden increase in pressure will be evident and the cone point will stop penetrating the gravel surface. This reading is disregarded and the test is rerun a few feet away. The number of individual tests increases the accuracy of any evaluation.

Since the reference point of the cone must be 4 in. below the surface for a reading, the gravel surfacing must be at least 6 in. thick before the CBR determined can be considered the CBR of the gravel surfacing. When less than 6 in., the subgrade soil is influencing the CBR reading taken on the gravel surface.

5. The location of the test and the gauge pressure (psi) should be recorded in the appropriate space (upper box) of the log shown on page 39.

6. The CBR is determined from the curve shown in Figure 10. Read the CBR for the determined psi gauge reading. The CBR values for each of four tests suggested in the cross-section and the average of the four should be recorded in the appropriate spaces at the top and bottom of the log form, page 39.

7. When the test is completed, the valve on the pump (see Figure 2) is opened and the pressue on the hydraulic jack relieved. The jack and cone

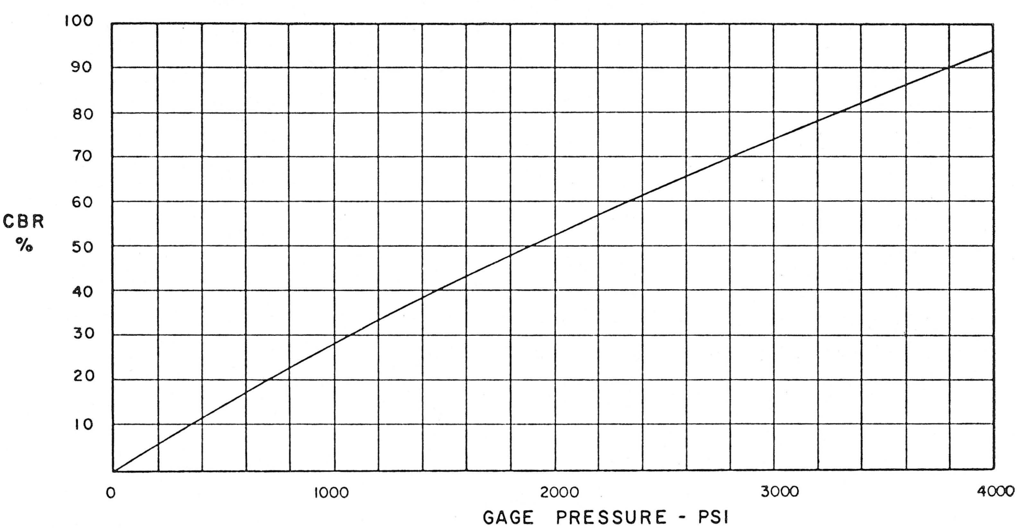



*Figure 10. A pressure (psi)-CBR chart. Enter a penetrometer pressure reading on the horizontal scale, read upward to the diagonal curve and left, horizontally, to the vertical scale, and determine the CBR for the field psi reading. (Calibration was done by making penetrometer tests in various soils and also running conventional CBR tests on the soils. From Boeing Aircraft Co.)*

point are carefully moved to and fro to release the cone from the base or wearing surface before being withdrawn.

8. The CBR of the gravel wearing surface (or base), for the project length, is the 75th percentile of all the individual high-load penetrometer CBR readings. The 75th percentile is obtained by writing down all the CBR values, not the averaged values, in order of magnitude, with the largest number at the top of the list and the smallest at the bottom of the list. The 75th percentile is then the CBR reading located three-quarters (75 percent) of the way down the list from the top. For example, if there are 40 CBR readings, the 75th percentile is the 30th CBR value in the list from the top —tenth from the bottom.

### Moisture Content Samples and Determinations

Penetrometer tests to determine an equivalent CBR of the wearing surface and subgrade should be done in wet seasons. Ideally, they would be best early in the spring just after complete ground thawing and preferably after several heavy rains. To verify the wet condition, it is advisable to take moisture content samples at the time of making penetrometer tests. However moisture content samples are not absolutely necessary.

For a gravelly or sandy wearing surface, with top size material 1½ in. or less, quickly fill a quart can with material as soon as it is excavated from a test hole. Quickly apply the lid and seal it air tight with either melted paraffin or cellophane tape, whichever is feasible. Do the same for fine-grained subgrade soils, though only a half pint is needed. If the subgrade is coarse-grained use a quart-can sample.

Carefully label containers with the station number, location left or right of center line, sample number and approximate soil texture classification. Also place container sample numbers on the cross-section log form.

Weigh sample containers with the paraffin or cellophane tape seal removed but with lid still on. After weighing and recording this weight on the log form (page 40), heat the sample in a warm oven over night and compute the percent moisture content as indicated on the log form, page 40.

## VI. FIELD SAMPLING, TESTING, AND APPLICATION OF RESULTS

This chapter provides information on the field sampling and testing of (a) in-place wearing surface materials to determine their quantity and quality and of (b) subgrade materials to determine their quality only.

It provides information on sampling and testing equipment, its operation, and information to be obtained and logged in the field. A suggested field log form is provided, as well as a sketch showing a suggested plan for location and spacing of various sampling and testing sites in the roadway cross section and along the project length.

The first part of this chapter provides information on how to determine the thickness and width of wearing surface materials with either power tools or hand tools. The second part of this chapter recommends a schedule for sampling and testing wearing surface materials and subgrade materials for quality, mainly gradation, plasticity of fines and equivalent CBR determinations by penetrometer tests.

## Wearing Surface Thickness and Width Measurements

Measuring the thickness or depth of in-place wearing surface or base materials requires the cutting or digging of small holes in the cross-section of the roadway. About 90 of these excavation-probings per mile are suggested. Because of the relatively high number of small excavations, the fastest and most efficient tools and techniques should be used to do the job.

When obtaining a depth measurement of the surfacing material, the inspector should be aware of possible material changes or a layering of different materials. This layering could be due to subgrade intrusion or to the application of two or more different types of wearing surface materials. The thickness and classification of each layer should be recorded. Changes in subgrade materials should also be noted and recorded. Use the "Notes" section of the log to record additional information.

One excavation in each roadway cross-section investigated will also be used for taking classification samples and moisture content samples of both the wearing surface and subgrade. This same excavation can also be used for making cone penetrometer tests into the subgrade. Carefully open a hole to the subgrade (without disturbing the subgrade) at least 1 ft. in diameter.

Depending on the equipment, manpower, time, and money available, the county supervisor or engineer should select one of the suggested excavation techniques listed below. There are hand-tool techniques, power-tool techniques and combinations of these. Perhaps a preliminary survey by the engineer or supervisor, using one or two laborers with picks and shovels, to determine the approximate thickness and toughness of the materials would be advisable. Most likely, power augers would be the most efficient equipment for the overall investigation.

*Tools, Equipment and Techniques*

Here is a listing of several various combinations of tools and equipment that could be used to determine wearing surface depths and obtain samples for classification tests.

1. Two-man crew with pick, mattock, spud, and flat spade. Possibly the wheels of an accompanying truck could be used for recompacting backfilled holes.

2. Same as (1) but also with an air compressor, jack hammer, and small spade attachment for thick, tough wearing surfaces.
3. Use of power augers, for digging post holes, would undoubtedly be the most efficient means of quickly cutting a large number of holes. Shallow holes can be cut quickly. These small portable augers are owned by many county highway departments. Some of the augers attach to the back of tractors or trucks and operate from a power takeoff.

   An auger bit should be sized to cut a hole large enough to permit easy examination of the wall of the hole or excavation. Measure the depth of the wearing surface and any layering in the wearing surface and note the top foot of the subgrade.

   Various types of auger cutting bits are shown in Figure 11. Capabilities of the various bits are provided in the figure caption. If an auger is used to open a hole to subgrade for subgrade testing, the bit should be at least 1 ft. in diameter.
4. Use of small trenching machines or backhoes. The small backhoes could be fitted with a small custom-made digging shovel. The trenching machine might be used to make a small trench across the entire road width. A precise picture could then be obtained of base depth, width and feathering at the edges.

## Location and Spacing of Tests Along Roadway

The wearing surface and subgrade materials in most unpaved county roads are subject to variations, (1) in the depth and quality of base and (2) in the quality and character of the native subgrade soils. Therefore, a sufficient number of field samples and tests must be made to develop a picture of the range of variations that exist in a given section of roadway. In this way, the road design may be increased to compensate for low-quality in-place materials or reduced to take advantage (reduced cost) of the high-quality, in-place materials.

The complete cross-section of the roadway must be sampled and tested at periodic intervals along the length of the road project. Figures 12 and 13 suggest a spacing of test sites longitudinally and laterally along a mile of roadway. The number of tests suggested may be adjusted to the length and importance of the project. Basically, about 10 cross-sections per mile should be sampled and tested. This frequency will set the interval spacing or the cross-sections at 528 feet, or a spacing of 500 feet may be used if more convenient.

If several miles of roadway are to be studied, the county engineer or supervisor may find it more efficient to increase the spacing of the cross-sections sampled and tested to, let us say, 1000 feet. He may also wish to reduce the number of tests per cross-section. The spacings and number of

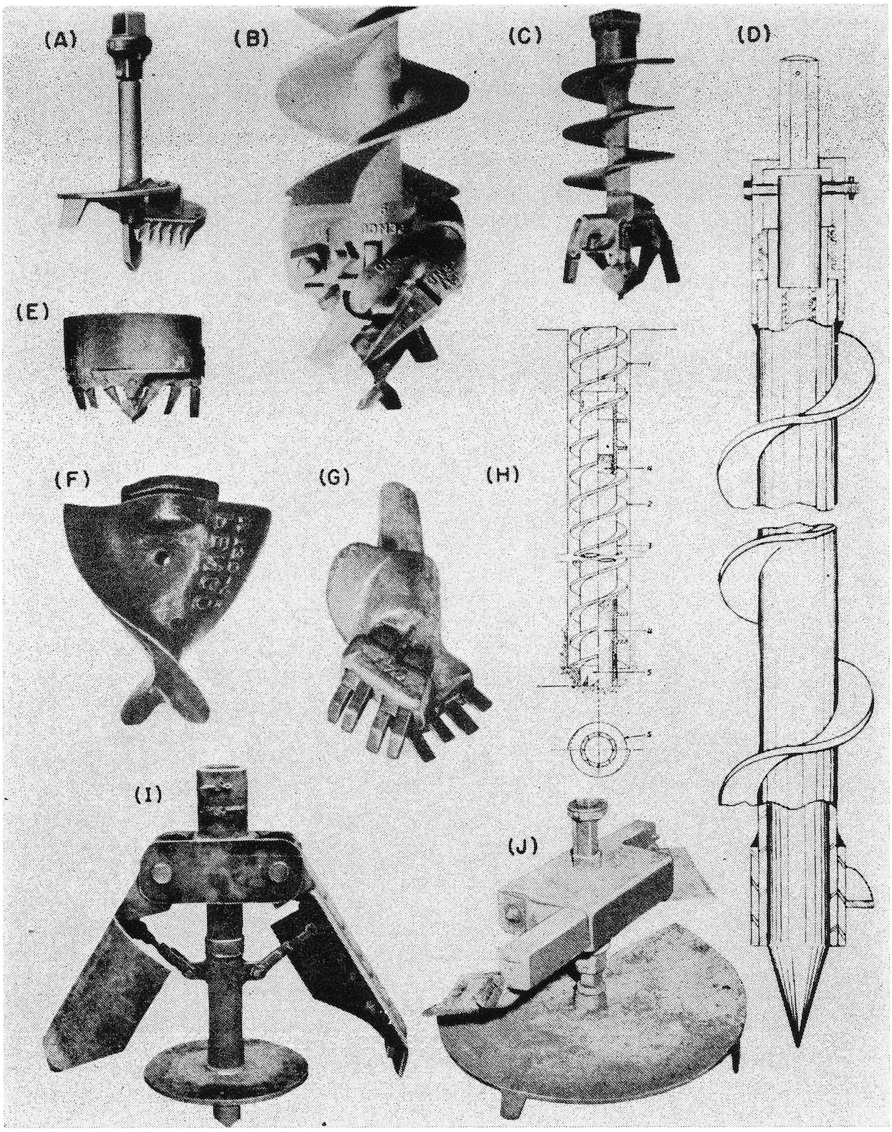



*Figure 11. Soil sampling and drilling tools for power augers. For taking shallow bites, and retaining a sample on the auger, single flight bits (A), (E) and the lower half of (J) could be used. For fast drilling, bits (B) (C) and (G) could be used, but materials will be mixed and layer thicknesses will have to be measured in the side-wall of the augered hole.*

tests will depend upon the length and importance of the project and the uniformity of the findings.

Figure 13 also provides a recommended plan of sampling and testing in the cross-section of a roadway. For each cross-section, nine measurements of the wearing surface depth are suggested, or 90 per mile. The number of depth measurements per cross-section and their distance from the center-line of roadway may have to be adjusted to the existing width of the wearing surface material. In any event, depth measurements should be made at the edge of the nominal width of the wearing surface material. Four high-load penetrometer tests (CBR data) per cross-section are suggested—a total of 40 per mile. Three low-load penetrometer tests (CBR data) on the subgrade are suggested—30 per mile. Other tests to be taken at the rate of one per cross-section, (ten per mile), include wearing surface classification tests, wearing surface moisture content sample, subgrade classification test, and subgrade moisture content sample.

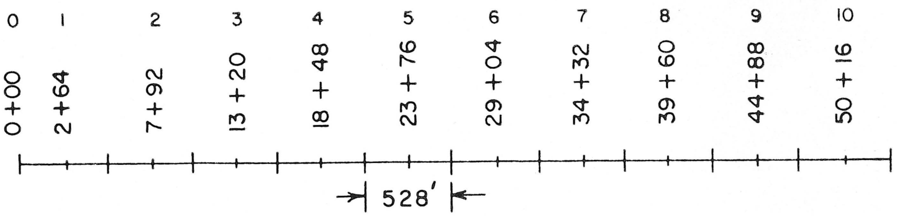
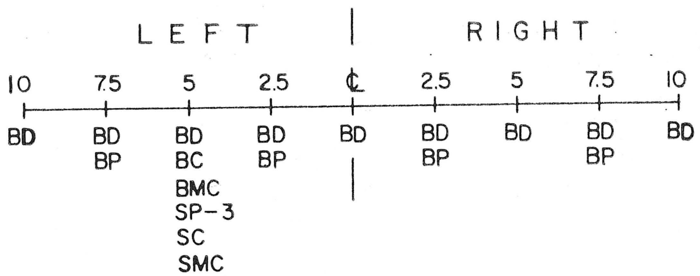



*Figure 12. Recommended cross-section investigations along the length of roadway. This diagram shows a mile of roadway divided into ten 528-ft. sections. The station numbers at the center of each 528-ft. section are indicated. Cross-section investigations may also be spaced at 500-ft. intervals if more convenient.*

## Use and Application of Field Test Results

The ultimate use of the recommended field tests is for the design of road project improvements that provide better, safer roads to serve the local communities traffic needs. To accomplish this end, the county road official should refer to Appendix E which lists four outstanding and authoritative guide manuals on flexible pavement design using CBR criteria. The first two manuals listed, published by the National Crushed Stone Association and the Asphalt Institute, respectively, are especially suited to the needs of county road officials. However, all four manual publications outline methods and procedures to determine the thickness of pavement and base required for subgrade soils ranging from excellent to poor as measured by CBR values.




| Code | Tests | Number Per X-Section | Number Per Mile |
|---|---|---|---|
| *BD* | *Base depth* | *9* | *90* |
| *BP* | *Base penetrometer* | *4* | *40* |
| *BC* | *Base classification* | *1* | *10* |
| *BMC* | *Base moist. content* | *1* | *10* |
| *SP* | *Subgd. penetrometer* | *3* | *30* |
| *SC* | *Subgd. classification* | *1* | *10* |
| *SMC* | *Subgd. moist. content* | *1* | *10* |

*Figure 13. Recommended sampling and testing in cross-section of roadway. This diagram shows the type of field tests and their suggested location in each roadway cross section investigated. The larger grouping of tests should be alternated from 5 ft. left of centerline to 5 ft. right of centerline, etc., along the roadway.*

Aside from the ultimate design use of the field test results, there are a number of other related items of information that county road officials need to know in planning road improvement projects. With the completion of the field tests, the results should next be plotted or recorded in linear graph form, showing the significant variations of the test results throughout the mile or length of the road project investigated. Such a record of test results will quickly reveal some important items to be considered in planning the road improvement.

*Subgrade Soil Test Results*

When used with design criteria, the CBR values and their variation throughout the length of the project will indicate the total depth of pavement required. For example, using the NCSA design criteria, a light traffic road (no trucks) would require total pavement thicknesses from 5 in. (subgrade CBR = 15+) to 11 in. (subgrade CBR less than six). Therefore, with the subgrade CBR values in hand for the length of the project, an estimate of pavement thickness and costs can be made. With an approximate cost estimate, the availability of funds and financial planning can be brought into play. If available funds are insufficient for the total completed project, perhaps a stage-construction approach can be developed.

*Wearing Surface Test Results*

The CBR test values for the wearing surface material, with the depth and width measurements, will immediately indicate how the existing wearing surface (or base) materials can be used effectively in the proposed road design improvement.

Wearing surface (or base) materials that have a reasonably uniform in-place CBR value and a reasonably uniform width and depth can usually be incorporated directly into the new pavement design. However, under these conditions, additional depth and/or width of base material may be necessary to upgrade the base to meet the new pavement design.

By contrast, however, if the wearing surface (or base) materials are highly variable as to depth, width, and quality it may be inadvisable to attempt to salvage any benefit from the existing in-place wearing surface materials. In that case the average in-place depth would be scarified, pulverized, mixed and spread to a uniform width and depth for compaction as subgrade material.

To the extent possible it is highly desirable to effectively use existing in-place wearing surface (and base) materials. However, the degree to which these in-place materials can be salvaged for an economic advantage depends mainly on the quantity and quality of the in-place material and also on the care with which these materials are to be manipulated during construction. Judgment and experience are needed here to work out a practical plan.

If there is ample quantity of wearing surface (base) materials but of variable quality, then give some consideration to upgrading those sections having low CBR values, with select aggregates to provide a base having a uniform quality. Here again, an additional lift or lifts of base material may have to be added to meet the new pavement design.

LOG OF FIELD TESTS IN ROADWAY CROSS SECTION
FOR WEARING SURFACE AND SUBGRADE MATERIALS

Road Name________________ General Location____________________ Date________

Sta.No. X-Sec.___________;X-Sec. in____ft. cut;________ft. fill;Crew__________

Other

I. WEARING SURFACE FIELD TESTS

NOTES

| | Left | | | | | Right | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Wearing Surface | 10' | 7½' | 5' | 2½' | ℄ | 2½' | 5' | 7½' | 10' | Avg. |
| Depth (in.) | | | | | | | | | | |
| Penetrom (psi) | | | | | | | | | | |
| Equiv. CBR(%) | | | | | | | | | | |

Moist. Sample No. and Computations Log Backside

II. CLASSIFICATION OF WEARING SURFACE MATERIAL(Sample #__)

Material (check) gravel__; crush gravel__; crush stone_
Gravel___%; Sand___%; Fines___%
Plasticity fines (check) plastic__; nonplas__.
Gradation (check) well__; poorly__; uniformly__.
Avg. top size ___in. and/or avg. predom size ___in.
Classif. (G=gravel, S=sand, M=silt, C=clay, W=well graded, P=poorly graded

| | 0-5% Fines | 6-12% Fines | | 13-49% Fines | |
|---|---|---|---|---|---|
| | | Plastic Fines | Nonplas Fines | Plas | Nonplas |
| circle | GW, GP | GW-GC, GP-GC | GW-GM, GP-GM | GC | GM |
| one | SW, SP | SW-SC, SP-SC | SW-SM, SP-SM | SC | SM |

III. CLASSIFICATION OF SUBGRADE SOIL (Sample #__)

NOTES

Gravel___%; Sand___%; Fines___%;

(a) If less than 50% gravel &/or sand:
Ribbon Length of fines (check)
over 8 in.__;under 8in.__;none formed__.
Dry Strength -- lumps break (check) very easy__;
easy to difficult__;difficult to impossible__.
Dry Powdering (check) none__;incomplete__;complete__.
Classification(circle one): CL CH OH ML MH OL

(b) If more than 50% gravel &/or sand:
Plasticity fines (check) plastic__;nonplas__.
Gradation(check) well__;poorly__;uniformly__.
Avg. top size ___in. and/or avg. predom size ___in.
Classif. (G=gravel, S=sand, M=silt, C=clay, W=well graded, P=poorly graded

| | 0-5% Fines | 6-12% Fines | | 13-49% Fines | |
|---|---|---|---|---|---|
| | | Plastic Fines | Nonplas Fines | Plas | Nonplas |
| circle | GW, GP | GW-GC, GP-GC | GW-GM, GP-GM | GC | GM |
| one | SW, SP | SW-SC, SP-SC | SW-SM, SP-SM | SC | SM |

IV. SUMMARY OF WEARING SURFACE AND SUBGRADE DATA

| | Soils Classif. | CBR-Soils Chart | CBR - Penetr. | %Moist Content | Avg(in.) Depth |
|---|---|---|---|---|---|
| Wear Surface (or base) | | | | | |
| Subgrade | | | | | |

## LOG FOR SUBGRADE CBR AND MOISTURE CONTENT OF SUBGRADE AND SURFACING OR BASE AGGREGATE MATERIALS

AVERAGE CBR'S FOR 1 FT. OF SUBGRADE* -- 3 tests

| TEST 1 | | | |
|---|---|---|---|
| Blow No. | Scale Read (mm) | mm per blow | CBR % |
| Start | | X | X |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| 11 | | | |
| 12 | | | |
| 13 | | | |
| 14 | | | |
| 15 | | | |
| 16 | | | |
| 17 | | | |
| 18 | | | |
| 19 | | | |
| 20 | | | |
| | | TOTAL = | |
| Avg CBR*= | ——— = | | % |

| TEST 2 | | | |
|---|---|---|---|
| Blow No. | Scale Read (mm) | mm per blow | CBR % |
| Start | | X | X |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| 11 | | | |
| 12 | | | |
| 13 | | | |
| 14 | | | |
| 15 | | | |
| 16 | | | |
| 17 | | | |
| 18 | | | |
| 19 | | | |
| 20 | | | |
| | | TOTAL = | |
| Avg CBR*= | ——— = | | % |

| TEST 3 | | | |
|---|---|---|---|
| Blow No. | Scale Read (mm) | mm per blow | CBR % |
| Start | | X | X |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| 11 | | | |
| 12 | | | |
| 13 | | | |
| 14 | | | |
| 15 | | | |
| 16 | | | |
| 17 | | | |
| 18 | | | |
| 19 | | | |
| 20 | | | |
| | | TOTAL = | |
| Avg CBR*= | ——— = | | % |

$$\text{*Avg CBR* (of 1 ft of subgrade)} = \frac{\text{Total of CBR'S per ft}}{\text{No. of blows per ft (last blow No.)}}$$

AVERAGE CBR OF X-SEC --- average of three above CBR averages

Avg CBR per ft -- test No. 1 =
ditto 2 =
ditto 3 = ______
Avg CBR of X-sec =( Total) ÷ 3 = [ % ] (record bottom front page)

MOISTURE CONTENTS -- SUBGRADE AND SURFACE OR BASE MATERIALS

$$\%\text{Moisture Content } (F_{\%}) = \frac{\text{Wt. of water in material (C)}}{\text{Wt. of dry material (E)}} \times 100$$

| | Subgrade | Surface or Base |
|---|---|---|
| Container No. | | |
| A. Wet wt. + container | | |
| B. Dry wt. + container | | |
| C. Wt. of water | | |
| D. Wt. of container | | |
| E. Dry wt. of material | | |
| F. Water content (%) | | |

Subgrade F= $\frac{C(\quad)}{E(\quad)}$ X 100= [ % ]

Base F = $\frac{C(\quad)}{E(\quad)}$ X 100= [ % ]

(record bottom front page)

COMPUTATIONS

| Subgrade | Base |
|---|---|
| **C= A-B** | |
| A= | A= |
| B=(-) | B=(-) |
| C= | C= |
| **E= B-D** | |
| B= | B= |
| D=(-) | D=(-) |
| E= | E= |

# APPENDIX A

## ISHC Gradation Specifications for Pavement Bases and Gravel Road Wearing Surfaces

| Aggregate Size | Total Percent Passing Sieves Having Square Openings | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Number | 1½ in. | 1 in. | ¾ in. | ½ in. | ⅜ in. | No. 4 | No. 8 | No. 30 | No. 200[2] | Uses[3] |
| 4 | 100 | 70–90 | 45–65 | 10–30 | 0–15 | 0–5 | ----- | ----- | 0–2 | OGB |
| 5 | 100 | 85–98 | 60–85 | 30–60 | 10–35 | 0–10 | 0–5 | ----- | 0–1 | OGB |
| 53[1] | 100 | 80–100 | 70–90 | 55–80 | ----- | 35–60 | 25–50 | 12–30 | 5–10 | DGWS |
| 53B | 100 | 80–100 | 70–90 | 55–80 | ----- | 35–60 | 25–50 | 12–30 | 0–5 | DGB |
| 73[1] | --- | 100 | 90–100 | 60–90 | ----- | 35–60 | ----- | 12–30 | 5–10 | DGWS |
| 73B | --- | 100 | 90–100 | 60–90 | ----- | 35–60 | ----- | 12–30 | 0–5 | DGB |

[1] The fraction passing the No. 200 sieve shall not exceed ⅔ the fraction passing the No. 30 sieve. The liquid limit of the fraction passing the No. 40 sieve shall not exceed 25 except if slag is used. Then it shall not exceed 35 and the plasticity index shall not exceed 5. The liquid limit shall be determined as set out in AASHO T 89 and the plasticity index as set out in AASHO T 90. Unless otherwise specified, when these materials are not to be surfaced or sealed under the contract, the amount passing the No. 200 sieve shall be 5% to 12% and the plasticity index shall not exceed 7.

[2] For all sizes from No. 1 through No. 33, inclusive, the amount passing the No. 200 sieve shall be determined by AASHO T 11 (decantation) only.

[3] Possible uses of commercially manufactured aggregates for Indiana county highways: OGB = open graded base; DGB = Dense graded base; DGWS = Dense graded wearing surface.

## APPENDIX B

### Listing of Standard ASTM and Equivalent AASHTO Tests for Sampling and Testing Gravel Road Wearing Surface Materials and Subgrade Materials in Order to Obtain Soil Classifications and Soil CBR Values.

| Characteristic | Method of Test ASTM | Method of Test AASHTO |
|---|---|---|
| Investigating and Sampling Soils and Rock for Engineering Purposes | D420 | T86 |
| Sieve Analysis | C136 | T27 |
| Amount of Material Finer than No. 200 Sieve | C117 | T11 |
| Liquid Limit | D423 | T89 |
| Plastic Limit | D424 | T90 |
| Bearing Ratio CBR (4 days soaked) | D1883 | T193 |
| Moisture-Density Relations of Soils | D698 | T99 |

## APPENDIX C

### Status of SCS Soil Survey Mapping of Indiana Counties as of June 1, 1976. Completion of State-wide Mapping Project Planned for 1984.

Recent county, agricultural soil maps and reports (since 1964) contain engineering soils data on each agricultural soil series in the county as follows: (1) highly accurate soil locations, (2) engineering soil classifications (Unified and AASHO), (3) engineering properties, and (4) interpretations of engineering properties (uses).

County soil survey reports issued 1958-1964 did not include engineering soils data; such data may be obtained from reports of nearby counties issued after 1964 and having the same soil series.

County soil survey reports are free to Indiana residents at each county office of USDA-Soil Conservation Service. If unavailable from SCS, contact the Agronomy Department, Purdue University, West Lafayette, Indiana 47907.

**Soil Survey Progress—6/1/76**

| 29 Counties with Published Soil Surveys | | | | |
|---|---|---|---|---|
| Allen | Delaware | Hendricks | Owen | Spencer |
| Boone | Elkhart | Howard | Parke | Sullivan |
| Carroll | Fayette | Jennings | Perry | Tippecanoe |
| Clark | Floyd | Lake | Pulaski | Union |
| Crawford | Fountain | Madison | Scott | Vigo |
| Daviess | Harrison | Newton | Shelby | |

## APPENDIX C (continued)

### 10 Counties with Field Mapping Complete, But Not Published

| | | | | |
|---|---|---|---|---|
| Bartholomew | Hancock | Marion | St. Joseph | Vermillion |
| Hamilton | Johnson | Noble | Vanderburgh | Warrick |

### 25 Counties With Soil Survey Underway with Estimated Completion Date

| County | Completion | County | Completion | County | Completion |
|---|---|---|---|---|---|
| Miami | Dec. 1976 | LaGrange | Dec. 1977 | Clay | June 1979 |
| Dearborn* | June 1977 | LaPorte* | Dec. 1977 | DeKalb* | June 1979 |
| Marshall* | June 1977 | Monroe* | Dec. 1977 | Starke* | June 1979 |
| Ohio | June 1977 | Steuben | Dec. 1977 | Decatur* | Sept. 1979 |
| Posey | June 1977 | Morgan* | June 1978 | Jefferson* | Dec. 1979 |
| Porter** | July 1977 | Putnam** | June 1978 | Kosciusko | Dec. 1979 |
| Clinton* | Dec. 1977 | White* | June 1978 | Wabash* | Dec. 1979 |
| Dubois** | Dec. 1977 | Cass* | Dec. 1978 | Orange* | June 1980 |
| | | Knox* | Dec. 1978 | | |

* Denotes State Employed Soil Scientist.

### Soil Survey Priority of Needs (Ranking of Counties By Total Need Factors*)

| County | Factor* | County | Factor* | County | Factor* |
|---|---|---|---|---|---|
| Henry | 26 | Ripley | 20 | Adams | 15 |
| Jackson | 26 | Washington | 20 | Benton | 15 |
| Jasper | 26 | Whitley | 20 | Jay | 15 |
| Brown | 24 | Lawrence | 19 | Martin | 15 |
| Grant | 24 | Wells | 19 | Pike | 15 |
| Huntington | 23 | Gibson | 18 | Rush | 15 |
| Montgomery | 22 | Greene | 18 | Blackford | 14 |
| Wayne | 22 | Franklin | 17 | Fulton | 13 |
| | | Warren | 17 | Switzerland | 13 |
| | | | | Tipton | 13 |
| | | | | Randolph | 12 |

* This ranking is based on population, erosion, and sediment hazard, complexity of soil pattern, projects and major activities influencing land use decisions, and quality and quantity of existing soil survey information as of August 1973.

## APPENDIX D

See map on page 45

### Status of Engineering Soils Mapping of Indiana Counties, by Joint Highway Research Project, Purdue University, as of October 1976.

Maps show location of land-form, soil types classified according to the ISHC soil classification system (modified BPR Soil Classification). Maps are on a scale of one inch = one mile and are primarily for preliminary highway location studies.

For copies of maps, write for "Engineering Soils Map of ———— County" (see status map for county maps completed). Write to: JHRP, School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907.

## APPENDIX E

### A Select List of Guide Manual Publications on Flexible Pavement Design Procedures using CBR Criteria; publications by: NCSA, AASHTO, AI, USCE.

1. "Design Guide for Low Volume Rural Roads," National Crushed Stone Association, February 1973.

   Write: NCSA, 1415 Elliot Place, N.W., Washington D.C. 20007

2. "Thickness Design—Full-Depth Asphalt Pavement Structures for Highways and Streets," Asphalt Institute, Manual Series No. 1 (MS-1), Revised Eighth Edition, August 1970.

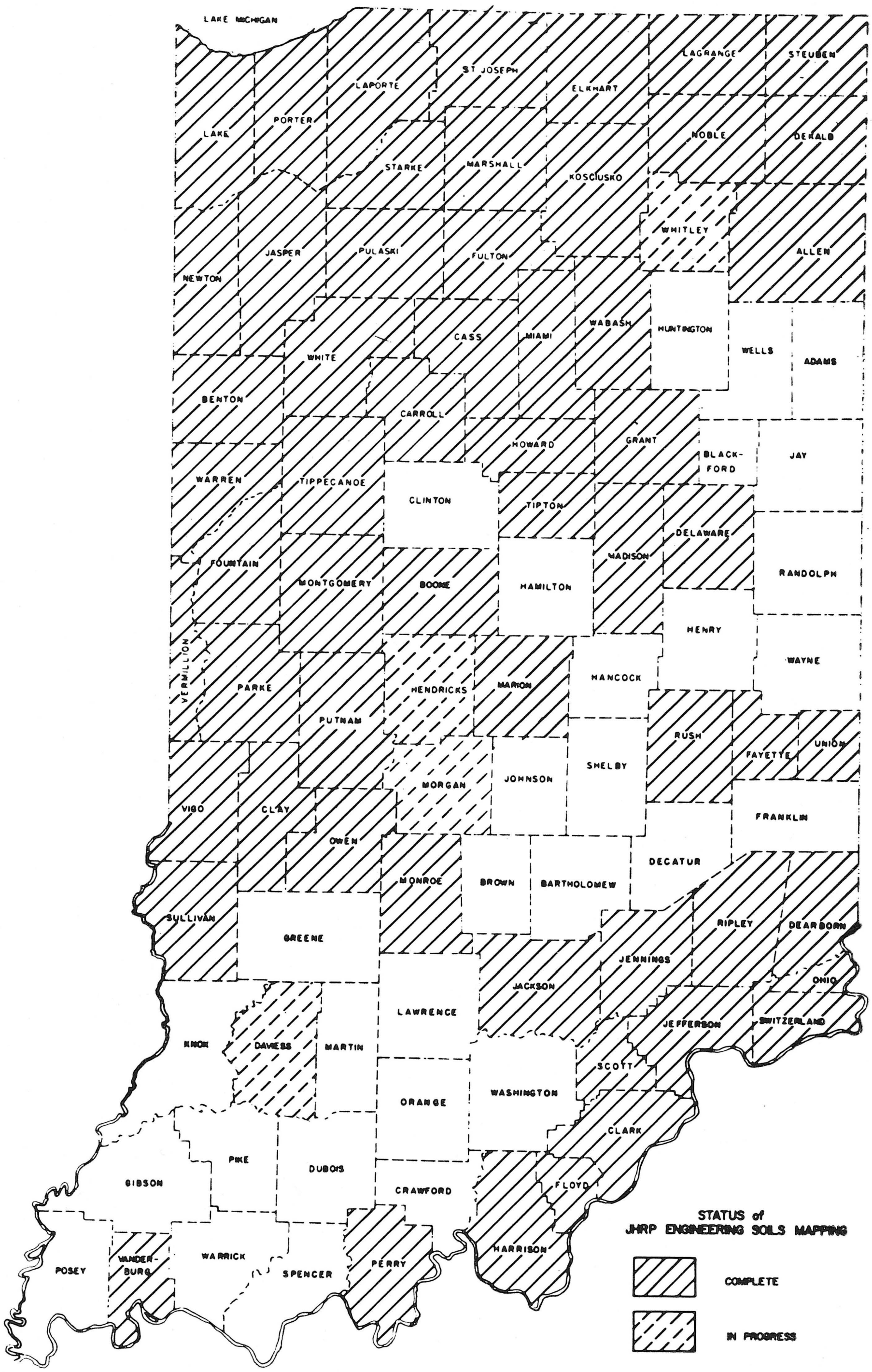
   Write: Asphalt Institute, Asphalt Institute Bldg., College Park, Maryland 20740

3. "AASHO Interim Guide for Design of Pavement Structures 1972," American Association of State Highway Officials.

   Write: AASHO, 341 National Press Building, Washington, D.C. 20004

4. "Revised Method of Thickness Design for Flexible Highway Pavements at Military Installations," Technical Report No. 3-582, August 1961, U.S. Army Engineer Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi 39180

   Write: same address as above


LAKE MICHIGAN
LAKE
PORTER
LAPORTE
ST JOSEPH
ELKHART
LAGRANGE
STEUBEN
NOBLE
DEKALB
STARKE
MARSHALL
KOSCIUSKO
WHITLEY
ALLEN
NEWTON
JASPER
PULASKI
FULTON
WHITE
CASS
MIAMI
WABASH
HUNTINGTON
WELLS
ADAMS
BENTON
CARROLL
HOWARD
GRANT
BLACK-FORD
JAY
WARREN
TIPPECANOE
CLINTON
TIPTON
DELAWARE
FOUNTAIN
MONTGOMERY
BOONE
HAMILTON
MADISON
RANDOLPH
VERMILLION
PARKE
HENDRICKS
MARION
HANCOCK
HENRY
WAYNE
PUTNAM
RUSH
FAYETTE
UNION
VIGO
CLAY
MORGAN
JOHNSON
SHELBY
FRANKLIN
OWEN
MONROE
BROWN
BARTHOLOMEW
DECATUR
SULLIVAN
GREENE
RIPLEY
DEARBORN
JENNINGS
JACKSON
OHIO
LAWRENCE
JEFFERSON
SWITZERLAND
KNOX
DAVIESS
MARTIN
SCOTT
ORANGE
WASHINGTON
CLARK
PIKE
DUBOIS
GIBSON
CRAWFORD
FLOYD
POSEY
VANDER-BURG
WARRICK
SPENCER
PERRY
HARRISON
STATUS of
JHRP ENGINEERING SOILS MAPPING
COMPLETE
IN PROGRESS

## THE SCHOOLS OF ENGINEERING AT PURDUE UNIVERSITY

Graduate degrees are offered in the fields of aeronautics and astronautics, and agricultural, chemical, civil, electrical, industrial, materials, mechanical, and nuclear engineering.

The research activities in these fields are conducted as a part of the program of graduate instruction with students participating under the direction of their professors. As the engineering profession faces increasing responsibilities for dealing with problems whose solutions lie at the frontiers of knowledge, the programs of graduate research and education in the engineering schools are increasingly concerned with the fundamentals of the physical sciences and mathematics.