amount of settlement is considerable it may be possible to remove only a part of the pavement at each end of the settlement in order to be able to join the replaced slab properly to the surface adjacent to the settlement

It is unfortunate that the present methods of filling have been used for so short a time, as it is impossible for us to accurately estimate the amount of filling material necessary in Methods No 4 and No 5 Amounts will in each case be less than that obtained by using the curves derived from an investigation of fills which have been placed full width on the surfaec of the undisturbed peat It is hoped that in the near future, as soon as a sufficient number of these examples are available, to cross section and determine the amount necessary in using the new method We are confident that the methods proposed will to a great extent eliminate a great deal of the settlement formerly encountered, and will involve the use of smaller amounts of material in filling

SUBGRADE STUDIES OF THE U S BUREAU OF PUBLIC ROADS

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The purpose of this report is not to furnish information on how to build highways, but rather to secure assistance in the solution of a problem which has thus far vexed the research engineer, namely, that of designing the pavement to suit the subgrade condition

At present, very little information concerning the influence of subgrade on pavement behavior is assembled in such forms as to be utilized by the highway engineer Until recently, research of this character has been devoted in the main to laboratory tests and gratifying progress has been made Assuming that volumetric change and supporting value were the primary influencing characteristics of subgrade soils, practical field and laboratory tests were developed for measuring these properties In accordance with this assumption, current literature classed as poor subgrade those soils with high moisture equivalents and shrinkage values and as good subgrades those soils having comparatively low values in these tests However, as pointed out by Clifford Older[1] at last year's meeting of the Highway Research Board, our knowledge of pavement condition with respect to available subgrade information is meager

[1] Proceedings of the Fifth Annual Meeting of the Highway Research Board, Dec 3-4, 1925, Part I, pp. 129-130

Little is known about the relative life or condition of pavements laid on good and on questionable subgrades Do increased cracking, breakage, rutting, ravelling and unevenness accompany bad subgrades? How are maintenance and operating costs influenced by subgrade condition? What additional initial expenditure would be warranted by the difference in renewal, maintenance and operating costs? And shall this additional expenditure go into the subgrade, the pavement, or both?

Also, little interpretation has been made of soil test results Can less thickness or different type of pavement be used when the moisture equivalent is 15 instead of 30? And what test values bound the limits of good, intermediate and poor subgrades?

A scrutiny of current reports reveals but few references to soil test results translated into terms of road condition The most specific of these consists of A C Rose's statement[2] that when lineal shrinkage of a soil in the Pacific Northwest exceeded 5 per cent, the pavement showed degrees of deterioration corresponding to the amount by which the shrinkage exceeded this value and, conversely, that when the lineal shrinkage was less than 5 per cent, the pavements were found to be in relatively good condition Except for this statement, information on the subject seems to be scant

Without knowledge of any soil tests, the average highway engineer can, by inspection of a subgrade, select, with a fair degree of precision, the locations of questionable support Remedial measures, however, based upon the qualitative analysis of the subgrades are yet to be determined

The Highway Research Board has found that steel reinforcement in concrete slabs is one method of compensating for questionable subgrade conditions, but no correlation of the amount, type or design of the reinforcement with laboratory soil tests has been made Some engineers believe the remedy lies in the use of sub-bases, but definite information regarding the type and required thickness is lacking Furthermore, the relative economy of sub-bases or pavement precautions generally and for specific instances must be determined

Thus the aim of the proposed subgrade studies is to furnish the highway engineer with definite information on these questions Its objects as submitted to the Committee on Tests of the American Association of State Highway Officials at its meeting in Washington, D C, June 21-22, 1926, were to determine

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[2] Field Methods Used in Subgrade Surveys by A C Rose, *Public Roads*, Vol 6, No 5, July, 1925

I The practicability of varying the type or design of road surface to suit subgrade conditions

II The efficiency of various types of drainage, subgrade treatment and sub-bases

III The relative economy in subgrade reinforcement (treatment, drainage or sub-base) and change in pavement design (type, thickness or features) as compensation for varying subgrade conditions

The proposed method of attack was to correlate studies of roads in service with U S Bureau of Soils data, laboratory tests on subgrade soils and office cost records

The procedure required a classification of soils with regard to their physical properties But the current laboratory tests did not yield results which were adapted to a simple classification and consequently Doctor Terzaghi, of the Massachusetts Institute of Technology, was retained by the Bureau as Research Consultant to help solve these problems

His suggestion [3] was to make a preliminary grouping of soils based on region and simplified soil tests, and a final classification based on refined tests of representative samples of the preliminary groups

Also, he summed up the value of laboratory and field work as follows

Laboratory tests identify the raw materials of soils and are of value only for soil classification Tests on specially prepared specimens in the laboratory do not necessarily indicate the physical properties of cracked, crumbled or compacted soils in the field Nor can laboratory tests, alone, indicate the efficiency of a soil when used as subgrade

Only by field surveys can the influence of subgrade on pavements be determined Whether or not a certain type or design of pavement is adequate for a given subgrade condition can be determined only by a study of the specific pavement laid on the given subgrade

Thus can be seen the importance of studies of roads in service. But such studies are more or less a new departure in highway research and standardized methods of procedure do not exist A tentative working plan for making road surveys has been developed and has been tried on several roads to determine its workability.

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[3] Simplified Soil Tests for Subgrades and Their Physical Significance, by Dr Charles Terzaghi, *Public Roads*, Vol 7, No 8, October, 1926

The complete outline of subgrade studies of the Bureau, together with a description and discussion of the road survey procedure, is given as follows

PROCEDURE FOR SUBGRADE STUDIES

I. Studies of roads in service—experimental or otherwise
   A Field surveys
      1 Selection of pavements for condition surveys with regard to subgrade variables as follows
         a Variation in soil type (as shown by county maps of the U S Bureau of Soils) under the same road or under roads comparable as to age, traffic, climate and design
         b Special features (drainage, subgrade treatment or subbase) under only part of the same road or under different roads comparable as to age, traffic and design.
         c Same soil type or subgrade features under roads different in design or type but comparable as to age, traffic or climatic influences
      2 Detailed procedure for pavement and subgrade surveys to include procurement of
         a Record of pavement condition in detail (cracking, breakage, rutting, settlement, disintegration unevenness, replacements, etc)
         b Record of subgrade with regard to cut, fill, grade, excessive moisture, etc , and soil series, type and layer Soil inspection to be made by an experienced soil surveyor
         c Samples of subgrade soil for laboratory test.
         d Exact limits of special features (drainage, treatment, subbases) and of soil types
         e Samples of road surface and also original soils for sand-clay and similar roads
   B Analysis of pavement condition records—those now available and those to be secured
      1 Classification of pavements with regard to climatic conditions, age, traffic, type and design
      2 Classification of pavements with regard to type of soil according to the U S Bureau of Soils terminology

3 Grouping of pavements with regard to subgrade soil classification based on laboratory tests
4 Grouping of pavements with regard to absence and presence of artificial drainage, subgrade treatment and subbases
5 Tabulation of pavement characteristics on cut, grade and fill in regard to the foregoing classifications

II Subgrade laboratory procedure
A Routine tests
1 Determination of series, type and general characteristics of the soil by reference to maps and reports of the Bureau of Soils
2 Preliminary classification
a Color (optional)—Color determinations on both wet and dry pats for that fraction of the soil which passes the 0 5 mm screen
b Sedimentation—Settlement of soil after being thoroughly mixed with water in a 50 cc graduate To be used only for the purpose of selecting from a group of samples those for routine testing In the same soil type, routine tests to be made only on representatives of groups having approximately the same color and sedimentation characteristics
c Revised mechanical analysis Determination of fractions of soils passing the 0 5, 2, and 5 mm screens Coarse material classified as rounded, angular, etc
d Lower liquid limit for 0 5 mm fraction [4]
e Lower plastic limit for 0 5 mm fraction
f Shrinkage limit for 0 5 and 2 mm fractions
g Shrinkage rate for 0 5 and 2 mm fractions
h Slaking value for 0 5 mm fraction [5]
i Moisture equivalent for 2mm fractions
k Volumetric change computed at moisture equivalent percentage from shrinkage limit and ratio on 2 mm fraction

[4] Adaptation of Atterberg Plasticity Tests for Subgrade Soils, by A M Wintermeyer, *Public Roads*, Vol 7, No 6, August, 1926

[5] The Slaking Test, by Prof F H Eno, page 142, these Proceedings

3 Final classification Terzaghi swelling tests and bearing power determinations on representative soil samples only
   a Modulus of compression
   b Modulus of expansion
   c Coefficient of permeability
   d Compressive strength of oven dried specimens
   e Compressive strength of specimens compacted from lower liquid limit to pressure of 3 kg per sq cm
4 Additional tests
   a Current or special tests as desired or requested

B Research in soil tests Additional work as follows
1 Lower liquid limit
   a Determination of air content of representative samples at lower liquid limit
   b Comparison of results from standard lower liquid limit test with those obtained from samples on which a vacuum was produced
   c Development of an automatic device for making the lower liquid limit test
2 Lower plastic limit
   a Influence of final thread diameter on results
   b Comparison of results when threads are rolled on paper (different kinds) and glass
3 Slaking value test
   a Influence of temperature
   b Influence of size and form of specimen
   c Development of standard test
4 Volumetric change test
   a Study of errors of observation connected with the mercury and paraffin method for determining the volume of soils
   b Development of a method for determining the volume of soils in an undisturbed condition
5 Specific gravity determinations
   a Influence on result when cold water, boiling water and different organic liquids are used
6 Preparation of test specimen
   a Development of a method for preparing soil powder and water without air

7 Swelling tests
  a Influence of air content in soil samples
8 Bearing power tests
  a Influence of size of sample
  b Influence of size of bearing block
  c Revision of apparatus to allow release as well as application of load

C Soil classification
1 Preliminary classification (all routine soil samples)
  a Grouping of soils by regions with regard to geological and climatic conditions
  b Classification of each regional group with regard to *lower liquid limit* as follows

Class	Lower Liquid Limit
0	10 0 to 14.2
I	14 2 to 20 0
II	20 0 to 28 4
III.	28 4 to 40 0
IV	40 0 to 56 8
V	56 8 to 80 0
VI	80 0 to 113 6

  c Subdivision of each lower liquid limit class with regard to plasticity index as follows

Class	Plasticity Index
a	Less than 1
b	1 to 7
c	7 to 14
d	14 to 21
e	21 to 28
f	28 to 35
g	35 to 42
h	42 to 49

  d Further subdivision, should some other simple test, as dye adsorption, etc , be found to identify soil characteristics other than those disclosed by the Atterberg plasticity tests
  e Identification of each soil type according to the U S Bureau of Soils terminology Thus, test results and other soil data published by the Bureau of Soils can be utilized

2 Final classification with regard to the Terzaghi Swelling Tests (representative samples of each of the preliminary groups only).
   a Modulus of compression
   b Modulus of expansion
   c Coefficient of permeability

III Additional investigations

A Determination of basis of correction for influence of coarse materials in subgrade Since laboratory tests are confined to that fraction of soil passing the 0 5 mm screen, the characteristics of the entire subgrade soil sample can not be learned until a basis for this correction has been established for all tests with both round and angular grains

B Determination of relative efficiency of various types and designs of pavements with different loads and subgrade supports Soil pressure cells will be installed under the desired pavements at the time of construction From each location subgrade soil samples will be obtained and sent to the laboratory for identification and classification At subsequent periods observations will be made as follows

1 Concrete pavements—Subgrade support (pressure cells) and fibre deformation (graphic strain gage) for wheel loads of different magnitudes.

2 Macadam and bituminous pavements.
   a Subgrade support and pavement deflection (local) for wheel loads of different magnitude.
   b Supplemental investigations (at Arlington) to determine the magnitude of repeated deflections which macadam and bituminous pavements can safely withstand

C Evaporation, freezing and other tests relating to the physics of the subgrade

D Detailed investigation of specific road failures for determining the conditions which cause these failures and the locations where these conditions are liable to occur

E Experimental sections Whenever opportunity occurs, sections comprising the current and proposed corrective measures for overcoming questionable subgrade conditions will be included in roads to be constructed Future observations will be made on these sections to determine their efficiency

IV Digest of preceding investigations

V Correlation of road studies (condition surveys) with soil classification (laboratory studies)

- A Influence of type of soil on pavement behavior
- B Influence of soil characteristics on pavement behavior
- C Determination of type and design of pavement for given subgrade condition
- D Determination of efficiency of various types of drainage, subgrade treatments and subbases

VI Correlation of road studies and subgrade investigations with office records

- A Influence of road condition on maintenance costs
- B Influence of type of soil on maintenance costs and life of pavement
- C Influence of soil characteristics on maintenance costs and life of pavement
- D Relative cost of compensating for variation in subgrade condition with
  - 1 Change in type or design of pavement
  - 2 Drainage, subgrade treatment or subbases
  - 3 Change in both surface and subgrade

All proposed investigations can not be started immediately If they had pertinent bearing on the subject, they were listed so that a definite working plan for evaluating subgrade variables could be presented Every effort, however, is being made so that the road condition surveys can be started as soon as possible

PROPOSED SUBGRADE CONDITION SURVEYS

The idea of deriving pertinent information on the relative influence of the various factors affecting pavement behavior is not new Extensive surveys covering the entire State highway system have been carried on as a part of the routine work in Pennsylvania, North Carolina and Washington, while an especially large scale survey has been made in California[6] This method for obtaining information was also utilized by the Highway Research Board[7] in its study of the economic value of steel reinforcement in concrete road surfaces

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[6] Report of a Study of the California Highway System by the U S Bureau of Public Roads, 1920

[7] Report of Investigation of the Economic Value of Reinforcement in Concrete Roads, by C A Hogentogler; Part 1, Proceedings of the Fifth Annual Meeting of the Highway Research Board, Dec 3-4, 1925

The use of condition surveys in connection with subgrade studies has been advocated by the Bureau of Public Roads[8] and by others interested in highway research As part of the discussion on structural design of pavements at the last meeting of the Highway Research Board, Clifford Older[9] directed attention to the need of a more comprehensive study when he suggested "a condition survey with the view of correlating soil classification and pavement condition "

Recognizing its importance, the State of Michigan is now engaged in an investigation of this kind [10]

SELECTION OF ROADS FOR STUDY

The selection of representative surfaces for study is of the utmost importance To make a survey at this time of the many thousands of miles of roads now in existence or to analyze the data secured from a survey of such magnitude would be a stupendous task It is necessary, therefore, to make selections which will furnish the maximum amount of information with the smallest mileage of inspections

While primarily the effect of subgrade is to be studied, it is appreciated that the ensuing data will yield information on the influence of every variable affecting pavement behavior Before the influence of subgrade can be determined, the effect of other variables must be understood and, except for variations in the concrete itself, this can be accomplished by confining observations to roads in which all but one variable are eliminated As to variations in the concrete, it is expected that valuable information will be derived from such experiments as the Virginia Demonstration Road,[11] in which the influence of climatic, construction and curing variables on various designs are being determined

If the resulting information is to be conclusive, it is essential that the projects inspected shall have acquired sufficient age or shall have been subjected to enough traffic to have developed defects, and it will also be necessary to pay particular attention to the modern type of construction, devoting to the obsolete types only a limited amount of study It seems advisable also to select only those roads with a recorded history of design and construction, for it is recognized that

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[8] Practical Field Tests for Subgrade Soils, by A C Rose, *Public Roads*, Vol 5, No 6, August, 1924

[9] Proceedings of the Fifth Annual Meeting of the Highway Research Board, Dec 3-4, 1925, Part I, pp 129-130

[10] Survey of Soils and Pavement Condition in Progress in Michigan by V R Burton, *Public Roads*, Vol 7, No 4, June, 1926

[11] Virginia Building Demonstration Road, *Public Roads*, Vol 7, No 6, August 1926

the analysis of any condition survey is a complex problem even when all of the historical data are available

In order to simplify and expedite the work, the field surveys will be divided into three separate classes

Class I surveys will concern roads which have failed only in part of their lengths And an effort will be made to determine if the failures were caused by change in soil type, soil layer or some other subgrade agency which could be foreseen and located in future road construction These studies will be very much in detail and will be made from the view point of the geologist, the soil scientist and the highway engineer

Class II surveys will concern roads, in parts of which various corrective measures have been used for offsetting undesirable subgrade conditions These corrective measures may be change in type or design of pavement, subgrade treatment, subbases, or special artificial drainage The object of these surveys will be to determine the relative efficiency of the various corrective measures now in use

Class I and Class II surveys will be carried on by separate parties and will be started immediately

Class III surveys will concern roads laid on different soil types The object of these surveys is to determine the relative occurrence of trouble in the different kinds of soil

For information as to the effect of soil types, roads will be listed first with regard to age, type, design, traffic and climate The U S Bureau of Soils maps will then be consulted and the final list for field study will embrace those roads which include the greatest number of soil variables For information with regard to maintenance costs as influenced by the subgrade, various projects will be compared, each of the same age, type, and design and, as nearly as possible, subject to the same traffic and climate, but with different subgrade soils Owing to the difficulty of securing cost data, this phase of the problem will be more difficult than those concerned with the condition of the surfacing only

INFORMATION TO BE OBTAINED IN THE CONDITION SURVEYS

Information obtained from the condition surveys should show all pavement defects For concrete roads there should be included all controlled and uncontrolled cracking, corner breaks, general breakage and surface checking, scaling and raveling The width of the cracks and the degree of raveling, if any, are also important A certain slab may be cracked badly and yet present a smooth, uniform riding surface, while another, cracked to the same extent, may be so uneven as to make early replacement necessary The difference is an important distinction necessary in the survey report Some corner breaks mean little with respect to the life or riding qualities of the pavement Others exist in such a state as to demand early attention Information as to the difference in condition is as important as the record of the break All concrete pavements show surface defects, it is, therefore, the magnitude and degree of these phenomena which merit attention in the survey

The condition of the shoulders and ditches and the elevation of the shoulders of the roadway in relation to the pavement are points of particular interest both as to the condition of the surfacing and the subgrade Information is of value also upon the general topography of the land adjoining the road and upon the nature and extent of the vegetation in the adjacent areas Cross-roads, bridges, and culverts are responsible in many cases for localized cracks and failures, and information as to their location is important

The subgrade survey carried on in connection with the condition survey involves the inspection of the soil at points sufficiently close to identify the soil type Samples of the soil for laboratory analysis are secured at the time of the inspection from both the subgrade and soil layers The condition of the soil with respect to compaction and degree of saturation is also noted as well as any changes in gradation, color, and character It is important to record data relative to water seepage in cuts and free water where its presence is indicated Where surveys have not been made by the Bureau of Soils and where any difficulty in determining the soil type is encountered, it is proposed to have a special soil survey made by a soil scientist

Figure 1 illustrates the symbols used and manner of recording the slab condition with respect to joints, cracks, corner breaks, general failures, raveling, and width of cracks and joints Conventional symbols for indicating the classification of the corner breaks, general failures, and culverts, bridges and cross-roads are also shown The elevation of the side banks or height of the pavement above the adjacent terrain is shown continuously by a profile system Base lines represent the elevation of the pavement The points of inspection and sampling of the subgrade are numbered and indicated as shown Faulted sections are distinguished by an arrow and a dimension for depth of the settlement Scaling of the surface is indicated by enclosing with a broken line the areas affected and marking them with the letter *S* A variation in the degree of scaling may be suggested by the numerals *1, 2,* and *3,* thus signifying slight, moderate and bad scaling, respectively Checking of the surface is indicated similarly by enclosing the affected areas with broken lines and marking them with the letters *CK*, the numerals *1*, *2*, and *3* indicating the degree as in recording the scaling

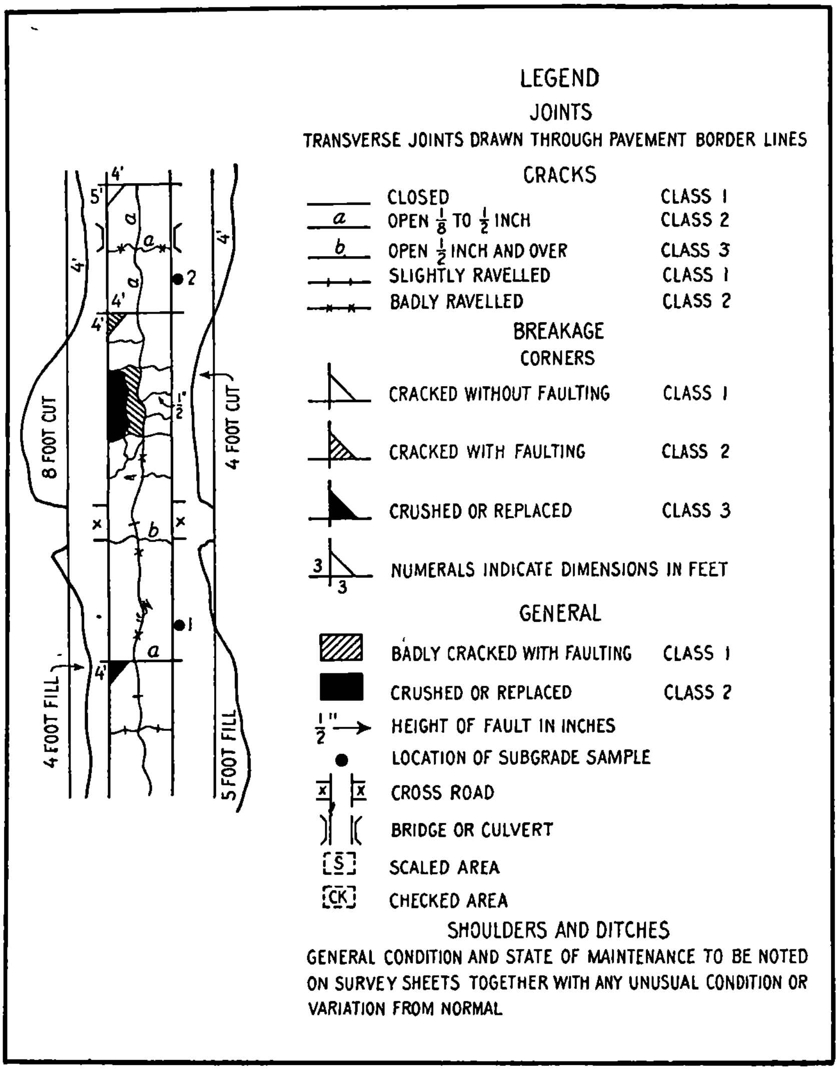

Figure 1—Symbols and manner of recording slab condition

THE SURVEY PARTY

The pavement condition party should consist of four members, a chief, experienced in road construction, and three assistants Two assistants measure off and mark the stations on the road, while the engineer walks along the pavement, and by means of a log board and specially prepared form sheets sketches pavement defects and other features previously mentioned The other member of the party inspects the subgrade and collects the soil samples

The specially prepared form sheet which has been used in the surveys to date and which contains space for plotting 1,200 feet of pavement survey is shown in Figure 2 The form sheet is fastened

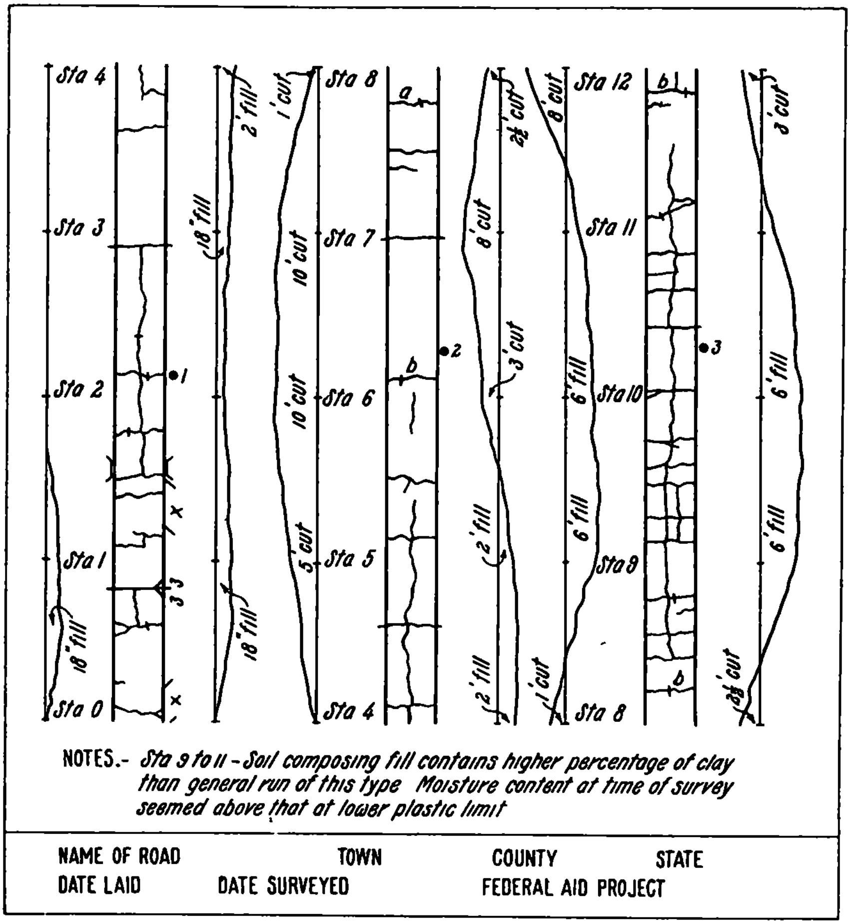

Figure 2—Form sheet used in condition surveys

upright on an ordinary log board and plotting is begun at the left lower hand corner

In this instance, considerable surface checking had occurred during construction, and one of the purposes of the survey was to determine the influence of the soil type upon this phenomenon Therefore, the intensity of the checking was divided into four classes, as follows

1 Slightly checked—5 checks per lineal foot of pavement
2 Moderate checked—15 checks per lineal foot of pavement
3 Badly checked—30 checks per lineal foot of pavement
4 Very badly checked—45 checks per lineal foot of pavement

PERMANENT SURVEY RECORDS

The permanent records of the survey are made on 24 by 36-inch sheets, on which are shown in detail the condition of the slab, the results of the soil analysis, and other pertinent information secured from the construction plans of the road This latter information includes the actual depth and length of the cuts and fills made prior to the construction of the pavement, the beginning and end of relocations from the old road, and the grade and alignment changes The better procedure in correlating this information is first to locate the station numbers in the survey layout by means of appropriate ties and to transfer the other data to this plat The ease of correlation of the survey layout with the condition survey depends upon the accuracy of the measurements between ties on the condition survey Too much emphasis can not be laid on this phase of the field work

The permanent detailed record serves a number of purposes In addition to being a record to be used as a base for future surveys, it is of immediate value as the basis from which may be compiled the summary record All computations are made directly from the permanent record charts Figure 3 gives the details of a portion of such a chart, a single sheet of which is sufficient to record the data for 6,400 feet of pavement

SUMMARY RECORD OF THE CONDITION SURVEY

The summary record is the analytical digest of the entire survey It consists of condensed information from which deductions may be drawn as to the variables in one road as compared with similar variables in another project The form and extent of the summary record is shown in Table I

The information is obtained directly from the permanent record charts by scaling and totaling the respective length of the individual cuts, fills, and grade sections in each soil type The original ground line is used in these computations

The record shows in detail the slab condition corresponding to

1 Cut, fill, and grade sections in each soil type
2 Each soil type, including the cut, fill and grade sections
3 Cut, fill, and grade sections in all soil types combined

TABLE I

TYPICAL SUMMARY RECORD OF CONDITION SURVEY

Soil type	Section (cut, fill or grade)	Number of each	Length of pavement	No of transverse cracks and joints	Slab length	Total length of longitudinal cracks	Longitudinal cracks	Number of corner breaks			General breakage		Surface checking in relation to the length of the section, per cent — Number of linear feet of pavement						Soil tests (average values), per cent				Climatic conditions
								Class			Class		Slight, 5	Moderate, 15	Bad, 30	Very bad, 45	None	No per ft of section	Moisture equivalent	Volume change	Lower plastic limit	Lower liquid limit	
								1	2	3	1	2											
			Feet		*Feet*	*Feet*	%				*Sq ft*	*Sq ft*											
Conowingo loam	Cut	8	1,400	39	36	750	52	1					10.0	6.0			84.0	1.5	22	11	26	29	
	Fill	8	3,500	108	32	2,520	72	4	3				15.0	14.0	5.0	0.6	65.0	5.0	24	16	26	28	
	Grade	3	1,000	26	39	510	51	3					17.0	14.0	12.0		57.0	7.0	25	17	23	27	
	Total		5,900	173	34	3,780	64	8	3				14.0	12.0	5.0	0.3	69.0	4.0	24	15	26	28	
Manor loam	Cut	14	4,275	86	50	1,370	32	2					39.0	27.0	7.0	2.0	35.0	10.0	20	5	28	29	
	Fill	12	4,675	70	67	3,000	64		1				26.0	22.0	10.0	2.0	40.0	10.0	21	5	29	29	
	Grade	4	1,900	50	38	950	48						24.0	6.0	3.0		67.0	3.2	19	10	23	23	
	Total		10,850	206	53	5,320	49	2	1				31.0	21.0	7.0	2.0	49.0	8.5	21	6	25	26	
Chester loam	Cut	9	2,000	32	62	1,100	55	2	1				47.0	11.0	6.0	6.0	30.0	9.0	22	12	26	27	
	Fill	8	3,625	58	63	2,430	67						20.0	17.0	8.0	2.0	53.0	7.7	21	9	27	27	
	Grade	4	1,125	17	66	780	69						15.0	23.0	29.0	6.0	27.0	15.0	29	23	27	27	
	Total		6,750	107	63	4,440	66	2	1				27.0	16.0	11.0	4.0	42.0	9.5	22	12	27	27	
Louisa loam	Cut	2	500	6	83	330	67						30.0				70.0	1.5	19	7	27	27	
	Fill	2	1,000	14	71	680	68						17.0				83.0	0.8	25	10	32	32	
	Grade		200	4	57	200	100						82.0				18.0	4.0					
	Total		1,700	24	72	1,210	71	0					29.0				71.0	1.4	23	9	30	30	
Iredell loam	Cut	2	1,150	23	50	720	65						50.0	11.0	7.0		32.0	7.5	28	27	27	34	
	Fill	4	2,150	40	54	2,020	94	1	3				40.0	17.0	9.0		34.0	7.8	23	18	22	26	
	Grade																						
	Total		3,300	63	53	2,740	83	1	3				44.0	15.0	8.0		33.0	7.5	25	20	24	29	
Granville loam	Cut	1	350	10	37	310	91	1					31.0	31.0	4.0		34.0	8.4	18	10	17	22	
	Fill	1	450	4	112	450	100								4.5		55.0	1.5	22	12	22	26	
	Grade	1	200	3	66	200	100						15.0	5.0			80.0	1.5	21	10	23	28	
	Total		1,000	17	60	960	96	1					14.0	12.0	3.5		61.0	4.0	20	11	21	25	
All types	Cut	36	9,675	196	49	4,580	48	6	1				36.0	18.0	5.2	2.0	37.8	7.5					
	Fill	35	15,400	294	52	11,100	72	5	7				23.0	16.0	7.5	1.3	52.0	7.0					
	Grade	13	4,425	100	44	2,640	60	3					23.0	12.0	11.0	1.5	52.5	7.5					
Grand totals	Total		29,500	590	50	18,320	62	14	8				27.5	16.0	7.3	1.6	47.5	7.4					

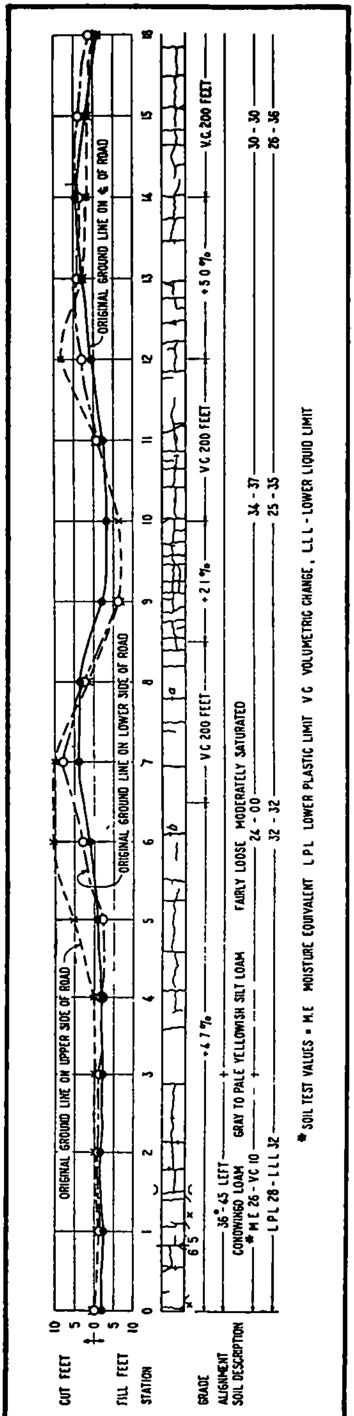

Figure 3—Typical condition survey record chart

4 The entire length of road represented by the survey

5 There should be shown also on the record the geological character of the soil residual (kind of rock derived from), transported (by ice, water or wind), or organic (peat, muck)

The surface conditions are also shown with respect to the checking for each combination of sections and soil types enumerated above

In many surveys, information concerning the effect of the soil type and of cuts and fills upon slab or surface condition would include a relative showing in the summary record of

1 The width of cracks and joints

2 The raveling of cracks and joints

3 The faulting of slabs

4 The scaling of the surface

In other surveys, the relative showing of the slab condition for different grades and degrees of alignment might be necessary for the proper interpretation of the results The effect of depth of cut or height of fill may also be shown on the summary record

Finally, the data contained in the summary record permit relationships to be established between the slab or surface condition and the results of the soil tests [12] These relationships may be shown con-

[12] Routine soil test procedure given on page 117 was adopted after this survey was made

veniently in diagrammatic form For example, slab condition as compared with the moisture equivalent, percentage of longitudinal cracking against moisture equivalent, number of corner breaks and areas of general failure versus the moisture equivalent and the other test values such as the shrinkage of the soil

The entire survey will be carried on in cooperation with the several State highway departments The procedure as herein set forth is more or less tentative pending suggestions from the Committee on Tests of the American Association of State Highway Officials, from the Committee on Structural Design of Roads of the Highway Research Board and from all engineers interested in the highway problem It is only by criticism and suggestion from those most interested that the final program of the investigation can be so framed that the results obtained will have the utmost value

In addition to criticisms and suggestions, information on the following will be very much appreciated

1 Locations of roads, under parts of which were used special drainage, subgrade treatments or subbases
2 Locations of roads whose subgrades are comprised of radically different soils
3 Existence of maintenance costs for roads which are similar in all respects except in regard to subgrade
4 Existence of all pavement condition survey data without regard to scope or purpose for which they were obtained A study of previously acquired information of this character will be made before new survey data are secured

PRESENT SUBGRADE PRACTICE

A scrutiny of current practice in regard to subgrades seems pertinent at this point Many States give it little or no consideration, using the same pavement designs for all conditions of support Other States consider subgrade influence and compensate for it in varying degrees and manner From information furnished by the District Engineers of the Bureau, specific practice in subgrade compensation are given as follows

Arizona—Design of pavements dependent on subgrade, rainfall and temperatures Type and thickness of pavement varied Silty sand subgrade stabilized by adding mixture of gravel, caliche and clay Very fine dust subgrade (high cementing value) surfaced with clean coarse gravel Adobe soils surfaced with volcanic cinders, gravel or similar available material In some cases, this treatment is used as "stage" construction for surfacing

California—Subgrade soil tests are part of routine on new construction jobs Soils of low shrinkage and low moisture equivalent values are given preference for embankments When moisture equivalent exceeds 30 per cent and the lineal shrinkage exceeds 5 per cent, subgrades are stabilized by the addition of sand, decomposed granite or similar material

Oregon—Inspections by division engineers generally determine subgrade conditions but in some cases laboratory tests are employed In some cases of questionable subgrades, sand subbases (thickness dependent on soil shrinkage values) are used, while in others (soft places or "dobe") slab design is changed by adding reinforcement and reducing joint spacing

Washington—Subgrades are inspected by Mr Hoffman, Construction Engineer, and the District Engineer Questionable subgrade compensation consists of increasing the thickness of paving, increasing or adding reinforcement, reducing the slab lengths or by adding gravel subbases Soft spots are dug out and back filled with gravel Tile drains are used in wet and spongy places

Colorado—Subgrades sampled and tested before pavement construction Subgrades having lineal shrinkage in excess of 5 per cent receive sand treatments (2 to 10 inches) varying in depth in accordance with the extent the moisture equivalent exceeds 20 per cent

Minnesota—Clay subgrades are stabilized by additions of sand and gravel and sand subgrades by the admixture of clay In swampy sections, fills are made with coarse-grained upland material while deep wide ditches and a generous amount of tile are used to accommodate free water Frost boil failures are treated with admixtures of gravel Special reinforcement is added to concrete pavements when soil seems especially unstable In some cases subgrades are oiled

Kansas—In isolated cases, a sand subbase is used on gumbo soil

Massachusetts—Subgrade condition determined by visual inspection during spring breakup, test pits along the proposed project and by inspection during construction Concrete pavements are not varied, but foundations (stone and gravel) and drainage are Side drains are effectively used

Rhode Island—Subgrade conditions are determined by inspections made in the spring when frost is leaving the ground and the subsoil is well saturated with water When road follows new location samples of subgrade are secured for test Subbases of gravel are used under penetration macadam or concrete roads as questionable subgrade compensation

Connecticut —Double reinforcement in the slab and either sand, gravel or stone subbases connected to underground drains, are used in locations where heaving is expected

Maine, New Hampshire, New Jersey and New York also compensate for questionable subgrade This compensation includes gravel and stone subbases, bituminous treatments on the subgrade and steel reinforcement in the slab

Where extreme conditions of lack of support are found, rather elaborate precautions have been taken In North Carolina one road consisting of heavily reinforced slabs has been laid on four rows of piling In the flat land of Southeast Missouri, drainage by tiling into wells which are carried down to a sand or gravel stratum has been used And in Louisiana, conditions were improved by dredging out the original muck and back filling with lake bottom soil

ECONOMIC POSSIBILITIES IN SUBGRADE STUDIES

Before undertaking an investigation of this kind, it is pertinent to inquire as to the value of the results Or in other words, how much money could be saved if the engineer had definite answers to all the questions asked in the beginning of the paper A definite estimate of the saving which would result from utilizing available subgrade support will not be attempted But that difference in subgrade has money value is indicated in a number of instances

In one of the older Maryland roads (Beacon Hill-Elkton), one section shows about 30 per cent breakage, while an adjoining section is intact—variation in subgrade being responsible for the difference

In the Gansevoort Road in New York one section shows no defects while an adjoining section is a total failure—the difference again being due to change in subgrade

Mr W. F Purrington points out that in New Hampshire a section of gravelly soil road treated with bituminous materials has now accommodated traffic through two winters, while wheels sank to their hubs where the road was not treated That additional support afforded by this simple treatment would warrant reduction in thickness of gravel, macadam or bituminous surface is plainly indicated

The State of Delaware has found 5-7-5 concrete surfaces more satisfactory in some locations than 6-8-6 thickness in others That means that the difference in support in the several locations has a money value of about $3,000 00 per mile

In the survey of 1,277 miles of California roads (1920) it was found that no failure occurred on sand subgrade, 24 per cent of the failures occurred on loams and 76 per cent of the failures occurred on adobe and clay subgrades

These few examples seem sufficient to indicate that the possibility of suiting pavement design to subgrade condition presents attractive economic aspects

A COMPARISON OF ROAD CONDITIONS WITH ATTERBERG'S LIMITS AND THE OTHER STANDARD SOIL TESTS

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It is desirable, as soon as sufficient data have been collected, to correlate them with the actual conditions upon the highways and determine whether limits may be set upon the various tests indicating where the line shall be drawn between good and unsafe soils

It is also desirable to compare the various soil tests made, for the purpose of selecting those tests which will classify the soil in the safest and most definite manner

In August, 1926, the Co-operative Soil Laboratory at Columbus, Ohio, began testing soils by the Atterberg method, with a view to substituting this method of testing soils for the standards previously used by the soil laboratory of the U S Bureau of Public Roads, which standards were also used by the Ohio laboratory, providing, of course, that the Atterberg tests proved better Therefore the present comparisons have been made

Appended at the end of this report is a brief statement regarding the condition of the pavement at a number of the stations where these soils were taken

In Table I the test data for sixty soils are grouped according to the lower plastic limit and the other test data are given for comparison Opposite and *before* the number of the soil from those stations at which the pavements have shown the most trouble is placed an x Most of the soils whose analyses are shown in this table were selected because they were considered to be bad soils The fact that no x appears before the number does not mean the soil is a good one, but simply that nothing is known about road conditions at that point, or, that the road has not shown failure up to the present This may be due to the road being new, or to light traffic, or to the fact that the road is only an earth road

It will be noted that the roads known to be in bad condition are rather evenly scattered throughout the list with perhaps a slightly greater number near the middle of the list

Comparing the lower plastic limit with the other tests there are a few soils in every one of the test series that do not fall in the same