THE PREPARATION OF SUBGRADES

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The method of preparing subgrades is widely varied in California, depending upon local conditions. Even though drainage, climatic conditions, and the type and amount of traffic receive careful attention in design our first consideration is maximum utilization of all low cost local materials.

In the mountainous and hilly sections of the State, disintegrated granite, soft sandstone and other suitable subgrade materials are often encountered in, and adjacent to roadway cuts. In the valleys, excellent material in the form of cemented sand and pit run gravel may be economically available from river beds or old stream channels. Intelligent selection and use of such materials in the subgrade effects maximum economy by permitting the construction of thin surface and pavement courses.

PRELIMINARY INVESTIGATIONS

Preliminary investigations are made before construction to obtain information for design regarding: (1) The character of the soils available from roadway excavation, and the possible need for special treatment to insure a stable subgrade. (2) The suitability and adequacy of local pits for base and subgrade reinforcement. (3) The probable sub-soil moisture conditions and the possible need for underdrains to effectively stabilize the roadbed.

Although the scope of investigation is usually dictated by the nature of the terrain and other project conditions, we usually first, study the geology of the region; second, make borings to expose and sample the typical materials; and, third, perform tests to determine the essential properties of the soil. A proper balance between these three methods of attacking a subgrade problem will usually produce adequate data at minimum cost.

The most common type of exploration used in this State consists of hand borings made with a soil sampler, similar in design to the larger power-operated sampler described by T. E. Stanton, in the Proceedings of the International Conference on Soil Mechanics, Vol. 1, June, 1936. This outfit, driven either by hand or by a light, portable gasoline hammer, is suitable for obtaining 1 in. cores from penetratable ground, to depths ranging up to 50 ft. Such borings, supplemented by tests on larger samples from relatively shallow hand auger holes, generally furnish sufficient information for preparing a soil profile through light grading work on valley projects.

More extensive explorations, however, are often required to disclose adequately the materials available in heavy cuts on larger grading projects and also to investigate any other local sources of material proposed for subgrade reinforcement. In such cases larger borings are made with a special combination drilling rig[1] (Fig. 1) designed and built by the department for (a) heavy duty churn drilling, (b) making rotary borings up to 36 in. in size through earth and soft sandstone and shale formations, and (c) operating the larger size of sampler outfit.

The churn drill is used to actuate a hammer for driving the sampler outfit and also for breaking through rock and boulders not readily penetrated with the sampler and rotary tools. The large diameter rotary borings are made to depths of 50 and 80 ft. to investigate ground water conditions and to examine the formations in place. Large undisturbed samples may also be obtained from the portion of

[1] "Drill Costs Cut by New Rig for Foundation Investigation." By O. J. Porter, *California Highways and Public Works*, September, 1937.

the ground explored with the rotary tools.

SOIL TESTS

The performance of a subgrade depends, in the main, on the character of the soil. A large number of soil tests have been devised to identify materials and to measure the basic properties influencing subgrade performance.

The tests normally performed at the laboratory of the Materials and Research Department of the California Division of Highways, can be segregated into two groups; first, those made in connection with research studies of subgrade soils, and major foundation investigations and, second, those regularly made to determine the suitability of routine samples of material proposed for use on the work.

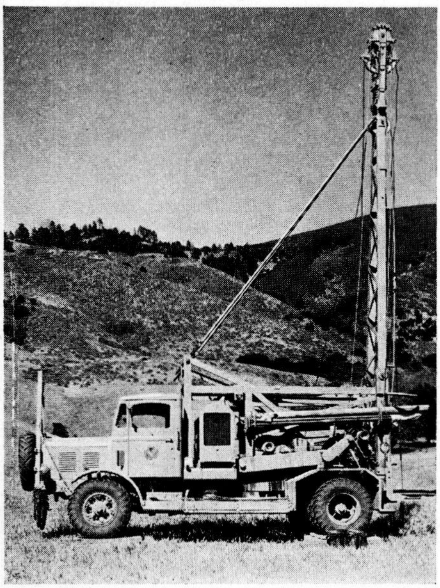

Figure 1. Combination Foundation Drilling Rig

Some of the more common soil tests included in the first group, are the determination of plastic limit, liquid limit, centrifuge moisture equivalent, shrinkage limit, shrinkage ratio, unit weight, void content, moisture content, grain size, consolidation, cohesive strength and angle of internal friction. Two of the simpler of these determinations; the plastic and liquid limits, are now being considered for adoption as additional routine tests.

Due to the large number of soil samples to be tested, routine methods must be as simple and economical as possible and still furnish sufficient information to properly evaluate subgrade and base materials in relation to their probable roadway performance.

Prior to 1929, the selection of soil was based upon results of field moisture equivalent, lineal shrinkage and alkali determinations. With an increasing amount of heavy truck traffic and the demand for smoother roads, it became apparent that this procedure was not sufficient. Extensive investigations were undertaken to devise improved methods of selecting materials and treating subgrades to maintain the integrity of the roadway at nominal cost.

The study resulted in the adoption of the bearing value and expansion (swell) tests in 1930, and subsequently the more extensive use of low cost local materials for subgrade reinforcement. These tests are for the purpose of determining the two most important subgrade properties affecting pavement service, namely, the resistance to displacement under moist to wet conditions and the volume increase and uplift resulting from absorption of moisture subsequent to construction. The favorable correlation between test data and field service is one of the principal reasons for the continued use of these tests in lieu of the current eastern identification practice which is based largely on analyses of minus 40 mesh particles. We prefer methods that tend to measure directly the basic physical properties of the combined material as used in the work.

Our bearing value and expansion tests are suitable for testing both base and subgrade materials, including all the coarse sand and rock particles up to 1 in. in size.

With portable equipment, (Fig. 2) the test can be made locally in the field or in district laboratories.

Tests are made by wetting the material to optimum moisture content and then consolidating the sample in a 6-in. cylindrical mold under a load of 2000 lb. per sq. in. The sample contained in the mold is then tested for bearing value (Fig. 3) by penetrating the center of the compacted specimen at the rate of 0.05 in. per minute with a piston, 3 sq. in. in area. A

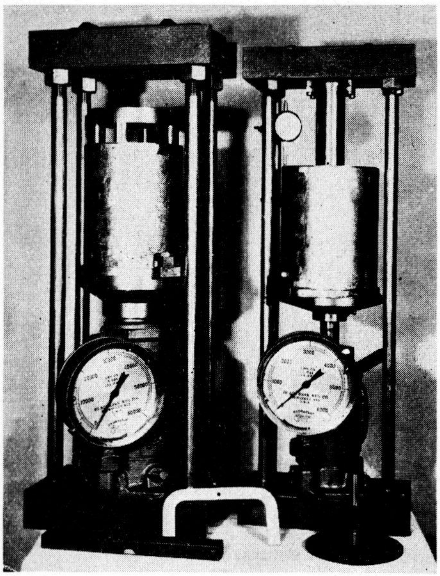

Figure 2. Field Bearing Value and Swell Testing Equipment. Hydraulic Jacks Compression Testing Assemblies (A) for Consolidating Soil Sample, (B) for Bearing Test.

dial fastened to the apparatus accurately measures the penetration of the piston. The loads for each increment of 0.1 in. penetration, to a total of 0.5 in. are recorded. Following this operation the specimen is loosened, reconsolidated, and then placed in a tank of water, after first noting the height. During the soaking period the sample (Fig. 4) is confined within the mold by a porous disc and a 10 lb. weight which represents the surcharge effect upon the subgrade of a 4 to 5 in. thickness of pavement. After the specimen has soaked for four days the swell is recorded and the bearing value

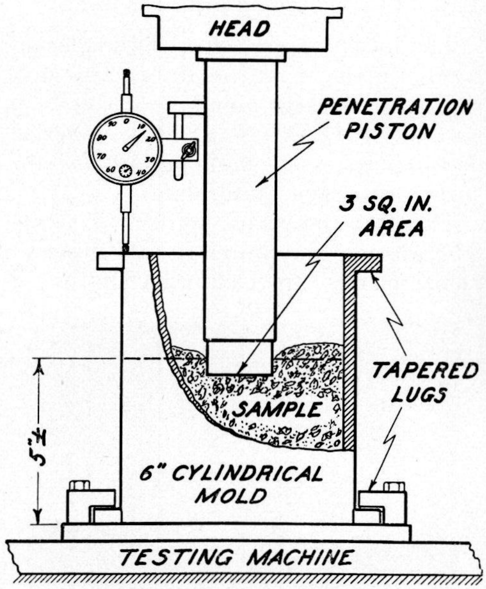

Figure 3. Bearing Value Test

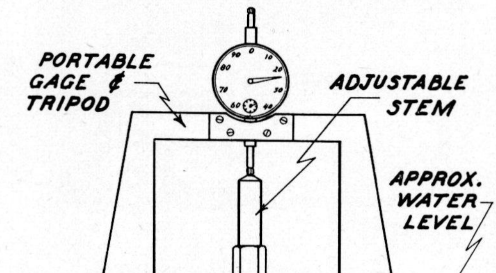

Figure 4. Expansion Test. For Determining Swell of Bearing Value Specimens

again determined for the compacted and soaked condition.

The bearing value results, for both con-

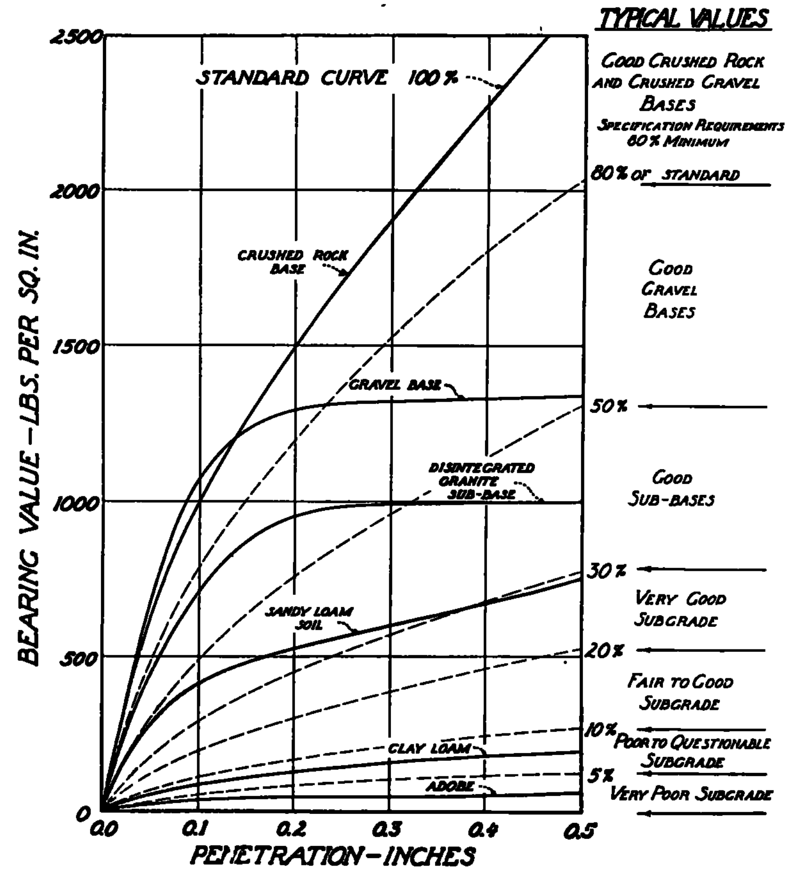

Figure 5. Bearing Value Tests. Compacted and Soaked Specimens

TABLE 1

Typical Test Results Bearing Value and Swell Tests

Type of Material	Minimum Bearing Value, Percent	Expansion (Swell), Percent
Untreated surfacing—all crushed	90 to 150	0 to 1
Good crusher run bases—50% or more crushed	80 to 120	0 to 2
Good gravel bases—uncrushed	40 to 80	0 to 2
Good disintegrated granite	30 to 60	0 to 2
Pit run gravel—poorly graded	10 to 40	0 to 3
Sandy-clay mixtures—well graded	15 to 40	0 to 3
Clay—sandy	5 to 15	3 to 6
Heavy clay and adobe	1 to 5	6 to 20

ditions of the specimen, are reported in pounds per square inch and also in percentages of the loads required to obtain like penetrations of a standard sample of crushed rock surfacing material similarly tested. The expansion of the specimen during the test is recorded in percent of the volume of the compacted sample before soaking.

RESULTS ON TYPICAL MATERIAL

Test results (Fig. 5 and Table 1) indicate that clay, adobes and other adverse soils usually have a good supporting value when in a thoroughly compacted and relatively dry state. This ideal condition, however, does not maintain over a period of years. Such material usually absorbs sufficient moisture from rainfall, ground water or by capillarity, to cause expansion and, as a consequence of the increase in water content, the soil often reaches a state of compaction and wetness comparable with the soaked specimen in our bearing value test.

SPECIFICATION REQUIREMENTS

A net bearing value requirement of "not less than 80 per cent" of standard for untreated crushed rock surfacing and crusher run base is included in the California Standard Specifications. Special provision requirements for pit run gravel base, imported selected subgrade material and imported borrow are varied considerably to fit project conditions and to obtain the best material economically available. For different projects, however, the minimum net bearing value may be set within the following ranges:

Pit run gravel bases and sub-base	40 to 60%
Imported selected subgrade material	20 to 60%
Imported borrow	10 to 30%

Standard practice calls for rejection of unsuitable soils having low bearing value and high swell characteristics in the top layer of roadway embankments and subgrade. Where the natural soils are unsatisfactory protective measures are applied.

SUBGRADE REINFORCEMENTS

A protective measure, to be effective, should eliminate moisture from the subgrade, as far as possible, or at least control it and in addition provide base reinforcement sufficient in thickness to dissipate traffic loads to a degree where the stresses do not exceed the supporting strength of an adverse soil. Experience indicates that safe roadway design should be based upon the compacted and subsequently saturated subgrade conditions, rather than upon the ideal state of the soil which may exist when the pavement is placed.

The standard practice for many years in California, has been to reinforce weak subgrades by mixing sand and clay in the proper amounts to raise the bearing value of the natural soil or by blanketing adverse materials with 4 to 18 in. of selected subgrade material. More recently, stabilization has been accomplished on some projects with bituminous emulsion or with portland cement. Detailed studies, including laboratory tests and the costs of the local materials and treatment processes are necessary, however, on each project to determine the most economical method of insuring adequate subgrade support.

In the event untreated selected material is used for subgrade reinforcement, the thickness is varied according to the bearing value of the underlying soil with due consideration being given to the climatic conditions and the anticipated amount of heavy truck traffic.

Extensive investigation of non-rigid pavements has indicated that with good drainage and adequate consolidation, failures usually do not occur when the total thickness of the pavement surface, base and subgrade reinforcement is approximately equal to the amounts given in Table 2 for the various classes of soil.

In the case of bituminous pavements, most of the subgrade failures have occurred when the thickness was 20 to 30 per cent less than the amounts indicated in the table. Although lesser thicknesses of reinforcement are often constructed, particularly on light traffic roads, these values warn against the construction of high cost pavements over inadequate subgrades. On light traffic roads, California design usually provides for stage construction, consisting of selected subgrade material and a 2 or 3 in. bituminous treated surface, which is subsequently resurfaced with an additional wearing course or pavement, when the traffic conditions justify the added expense.

SOIL EXPANSION

Expansion values indicate the tendency of a subgrade to expand subsequent to construction. The uplift of the subgrade not only roughens, cracks and distorts non-rigid bituminous surfaces of the drier types but also may cause serious distortion or warping of concrete pavement slabs if the moisture content is increased by leakage of water through cracks or transverse joints, or by capillarity from below.

TABLE 2

Subgrade Bearing Value		Total Thickness of Subgrade Reinforcement and Pavement Surface, Inches
Lb. per Sq. In. for Penetration of 0.1 in.	Per Cent	
800	80	3
500	50	4
300	30	5
200	20	6
100	10	9
60	6	12
50	5	15
30	3	18

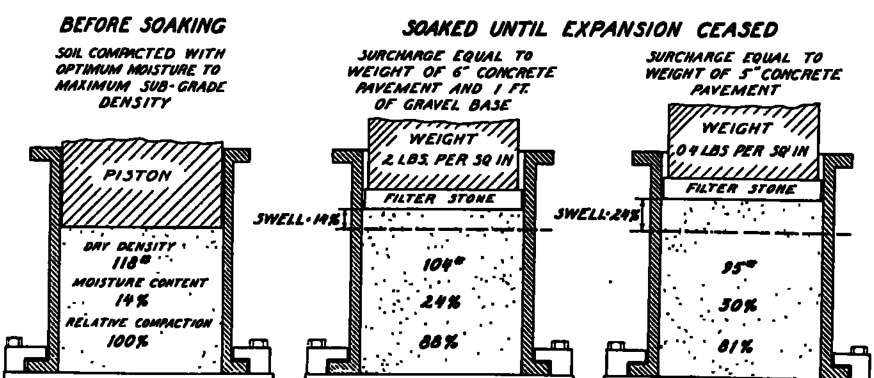

Figure 6. Expansion of Adobe Soil When Surcharged with Two Pavement and Subbase Loads

Subgrades which have proven entirely satisfactory usually show an expansion during the soaking period of less than 3 to 5 per cent. Many of the poorer clay and adobe soils often show an expansion value ranging between 7 and 20 per cent. Our early studies of soil expansion indicated that each material has a state of equilibrium regarding density and moisture content for each condition of confinement and that the moisture capacity of a soil varies inversely with the superimposed load. As an example, tests on one sample of adobe (Fig. 6) indicate that the material will take up 24 per cent of water when confined by 2 lb. per sq. in., the approximate weight of a 6-in. concrete pavement and 1 ft. of blanket material, and about 30 per cent of moisture when confined by 0.4 lb. per sq. in., the weight of a 5-in. thickness of surfacing.

In order to reduce the roughening of concrete pavements to a minimum, we use, where economical, a subgrade material having a bearing value of 10 per cent or more, at a penetration of 0.1 in., and an expansion value of 3 per cent or less. Natural subgrades, having bearing values of more than 5 per cent and expansion values ranging between 3 and 5 per cent are considered fairly satisfactory, provided ideal moisture and compaction conditions are maintained. With such materials great care is exercised, during construction, to moisten the subgrade properly before placing the pavement. Shoulders and joints are also well sealed to prevent infiltration of surface water and evaporation of sub-soil moisture.

One of the following protective methods is usually employed when portland cement concrete pavements are placed over heavy clay and adobe soils:

1. Application of an impervious membrane on top of the adverse soil to prevent infiltration of surface water and evaporation of sub-soil moisture. The membrane usually consists of from $\frac{1}{2}$ to $\frac{3}{4}$ gal. per sq. yd. of heavy road oil or E grade asphalt.

2. Saturation of the soil to a favorable moisture content prior to construction of the pavement. In this case tests are made to determine the moisture capacity of the soil for the weight of pavement and blanket contemplated.

Blanket material is used in both cases. In the first case, to prevent construction operations from disrupting the membrane and in the second, to reinforce a weakened subgrade resulting from expansion and saturation.

CORRELATION BETWEEN TEST VALUES AND SUBGRADE PERFORMANCE

Many projects constructed throughout the State during the last eight years, since adoption of these test methods have been under close observation. Numerous investigations indicate a good correlation between test values and the performance of subgrade materials. It is fully realized, however, that the bearing values are not a direct measure of the supporting value of materials, particularly for loads over larger areas. Furthermore, while the four day soaking period for the expansion test is often not sufficient to obtain equilibrium throughout the specimens, the results on poor soils are sufficiently high to indicate their adverse character.

Investigations made on two projects, on which adequate protection against adverse soil was not provided, will illustrate results in connection with two types of pavement failure.

On the first project, near Williams, Colusa County, concrete pavement was placed in the fall of 1931, on a sub-base consisting of approximately 13 in. of pit run gravel over an adobe soil. This sub-base had been previously constructed in 1930, as the first stage of the improvement and had been under traffic for over a year with only a light oil seal.

During the first two winters following pavement construction the slabs warped enough (Fig. 7) to result in a harmonic throw to vehicles traveling at certain speeds. An investigation was made in March, 1933, on four sections of the road, to determine the relation between the

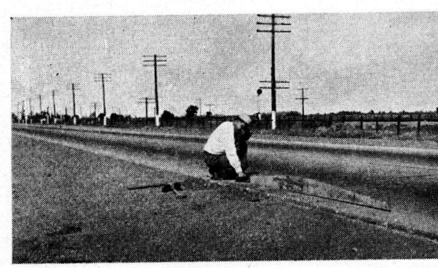

Figure 7. Distortion of Concrete Pavement Resulting from Expansion of an Adobe Sub-soil. The straight edge is over an expansion joint.

pavement distortion and the moisture content of the adobe sub-soil. Results, typical of those obtained on all four sections, are shown in Figure 8. It will be noted that the maximum moisture content of the sub-soil beneath the joints is approximately 24 per cent, which closely agrees with the amount of water absorbed by this adobe soil in the laboratory, (Fig. 6) when surcharged with a load equal to the weight of the pavement and gravel blanket (2 lb. per sq. in.).

In view of the fact that a section of the warped pavement was straightened when water was introduced into the subgrade beneath the center of the slab, the study definitely established that the roughening was due to expansion of the adobe soil underlying the pit run gravel base, following leakage of surface water through the joints.

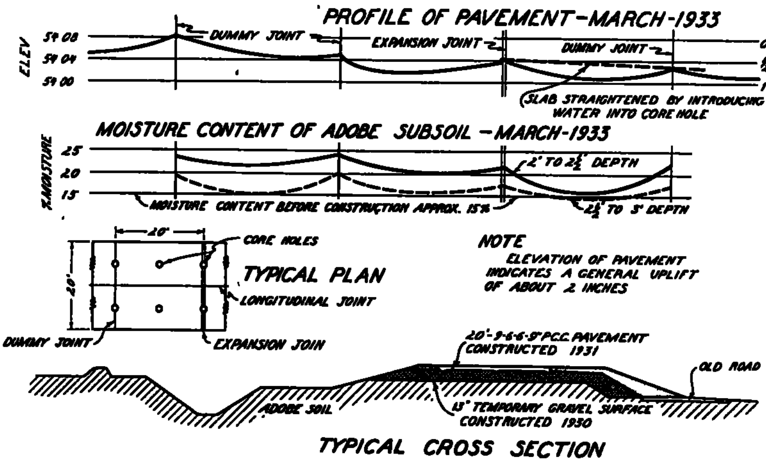

Figure 8. Relation between Pavement Distortion and Subsoil Moisture Content

On the second project, an asphaltic concrete pavement, 7 to 9 in. thick had been constructed in 1931, on natural soils, varying from good cemented gravel to heavy clay. Although this project was in the Imperial Valley where the rainfall usually does not exceed 1 or 2 in. per year, the pavement cracked and roughened over a portion of the project, after three or four years of service. A survey was made during July, 1935, on 20 sections of the road, each 200 ft. in length, to determine the pavement roughness, extent of cracking, moisture content of the subgrade, expansion of the soil, and the bearing value of the subgrade (Fig. 9).

It will be noted that low bearing and high expansion values were consistently obtained on the subgrade from the rough sections. Considering the climate and lack of irrigation near the project it is rather startling to note that the adverse soils beneath the very rough sections of the road carried moisture contents comparable to that normally found under much wetter climatic conditions. The fact that the natural soil adjacent to the roadway was dry to a depth of 5 feet or more, indicates the impervious pavement had shut off evaporation, permitting capillary moisture to accumulate in the subgrade.

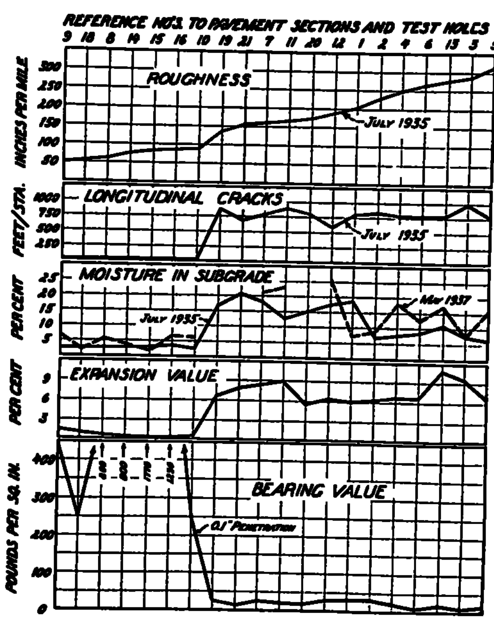

Figure 9. Comparison between Pavement Condition and Subgrade Characteristics. 20-ft., 9-in. by 7-in. by 7-in. by 9-in. Asphalt Pavement.