THE PREPARATION OF NATURAL SOIL FOUNDATIONS AND SOIL SUBSTRUCTURES

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When highway construction was started on a large scale in this country, the engineer endeavored to design and build pavements of sufficient strength and durability to overcome the defects in underlying soils. It appears now that the attention, to a great extent, is focused on stabilizing the "subgrade"—the soil directly beneath the pavement.[1] This is necessary but not final. All the underlying soil, even to the natural soil-foundation upon which fills are placed must be made relatively stable, or the movements therein must be controlled to such an extent that they will not produce objectionable pavement surface irregularities. Different methods must be employed for stabilizing different parts of the roadway structure. The most practical methods for making the natural soil-foundation stable may not be best for the soils of high embankments, and the most practical methods for stabilizing the soils of fills may not be the most practical for riding surfaces or for bases and subbases.

In order that the different parts of the roadway referred to in the following discussions may be definite, the roadway is divided vertically into three major parts with definitions as follows:

1. *Natural soil-foundation:* The undisturbed soil upon which the "soil-substructure," the subbase, the base, or the wearing surface placed directly thereon, depends for its support.
2. *Soil-substructure:* The man-made part of the roadway lying between the top of the natural soil-foundation and the bottom of the "superstructure," where the soil types therein are predetermined and the structure is designed in accordance with the mechanics and chemistry of the soils.
   (*Fill and embankment* are terms used where the soils are not predetermined and the structure is not designed in accordance with present knowledge of soil mechanics and chemistry, as described under "soil-substructure.")
3. *Superstructure:* (1) The subbase, base and wearing surface, or (2) the base and wearing surface, or (3) the wearing surface only, where no subbase or base are used. (When the superstructure is built by stages, the first wearing surface eventually may become the subbase or the base of the completed superstructure.)

The word *subgrade* is used herein to mean only the prepared surface of the natural soil-foundation and of the soil-substructure for the receiving of the superstructure.

With modern equipment and supervision, the laying of smooth surfaced pavement is a problem of the past. The engineer now is confronted with the matter of laying pavements which will retain their smooth riding surfaces. Usually, objectionable movements in the roadway superstructure are caused by movements in the underlying fills or in the natural soil-foundations. Properly designed and constructed superstructures are necessary, but no matter matter how skillfully they are built,

[1] This statement might also be made relative to compacting soils to their maximum densities.

they will not render the desired service until they are placed on stable natural soil-foundations and on properly designed and constructed soil-substructures. Comparatively little engineering design and supervision have been applied to the latter. Known laws of nature and soil mechanics, generally have been neglected in natural soil-foundations and in the design and construction of soil-substructures. This paper deals principally with the preparation of the natural soil-foundation and the soil-substructure, the investigation for which should begin during the preliminary survey for the locating of the highway.

SUBSEQUENT NONUNIFORM VERTICAL MOVEMENTS

Longitudinal: No doubt the type of the underlying soil is now the major cause of the development of pavement surface irregularities. As illustrated hereafter, subsequent movements have occurred to a great extent in pavements laid on expansive and plastic clay soil, while comparatively little movement has been found in pavements laid on non-expansive soils, such as sand. Many old pavements, however, laid directly on highly expansive and plastic soil have retained comfortably smooth riding-surfaces. It is possible, therefore, and perhaps practicable, in most instances, to lay pavements on highly expansive and plastic soil which will not move appreciably after the laying of the pavement.

On a 16-mile paving project built in 1929–30, the design, materials, methods of construction, and supervision of laying the pavement were the same throughout the entire project. A few months after completion, high joints or longitudinal warping of the pavement developed on the west half of the project, as shown in Profiles 3 and 4, Figure 1, while the east half retained its comfortably smooth riding-surface, as shown in Profiles 1 and 2, Figure 1. Investigations of these phenomena revealed highly expansive soil to depths of approximately 10 feet under the warped pavement, and non-expansive sand to depths of 8 feet under the smooth pavement.

A pavement laid in 1915 gave such excellent service under heavy traffic and adverse weather conditions that investigations were made in 1935 to determine the reason. Figure 2 shows the condition of this section of pavement in 1935.

At the time this picture was made in 1935, sections of the pavement and the underlying soil were investigated. The maximum thickness of the slabs investigated was 5 in. The minimum thickness was 2½ in. The only reinforcing found was fencing wire and it appeared that the wire had been laid on the subgrade and the concrete placed on top of it. The underlying soil was clean beach sand to a depth of more than 4 ft. The water table was 40 in. below bottom of pavement, practically the same elevation as the water in the nearby bay.

Some old pavements laid directly on highly expansive soil have retained their smooth surfaces. Where investigations have been made, however, usually it was found that the soil was uniform in type and the soil moisture content fluctuations were uniform to such an extent throughout the entire length of these pavements that the seasonal movements in the pavements were sufficiently uniform that they were not objectionable to traffic.

Subsequent ill effects on pavements of abrupt longitudinal changes in the type and in the density of the soil at the time of laying the pavement are shown by the following data on two projects which, for convenience, will be referred to hereafter as Project "A" and Project "B":

During the spring of 1931, on Project "A" a rigid type pavement was laid directly on a soil fill of highly expansive black waxy clay. The north end of the project was laid during and after a long period of slowly falling rains. At the time this pavement was laid, the fill and natural soil-foundation perhaps were saturated with water and expanded to the maximum.

Later in 1931, after considerable dry weather, another section of pavement, Project "B" 1½ miles in length, was laid adjoining the north end of Project "A". The fill of project "B" was of the same type of highly expansive black waxy clay as that on "A" but immediately prior to laying this pavement, the top 8 in. of the soil fill were treated with sand by admixing. No water was applied to this soil before pavement was laid, consequently the soil was much drier and less expanded at the time the pavement was

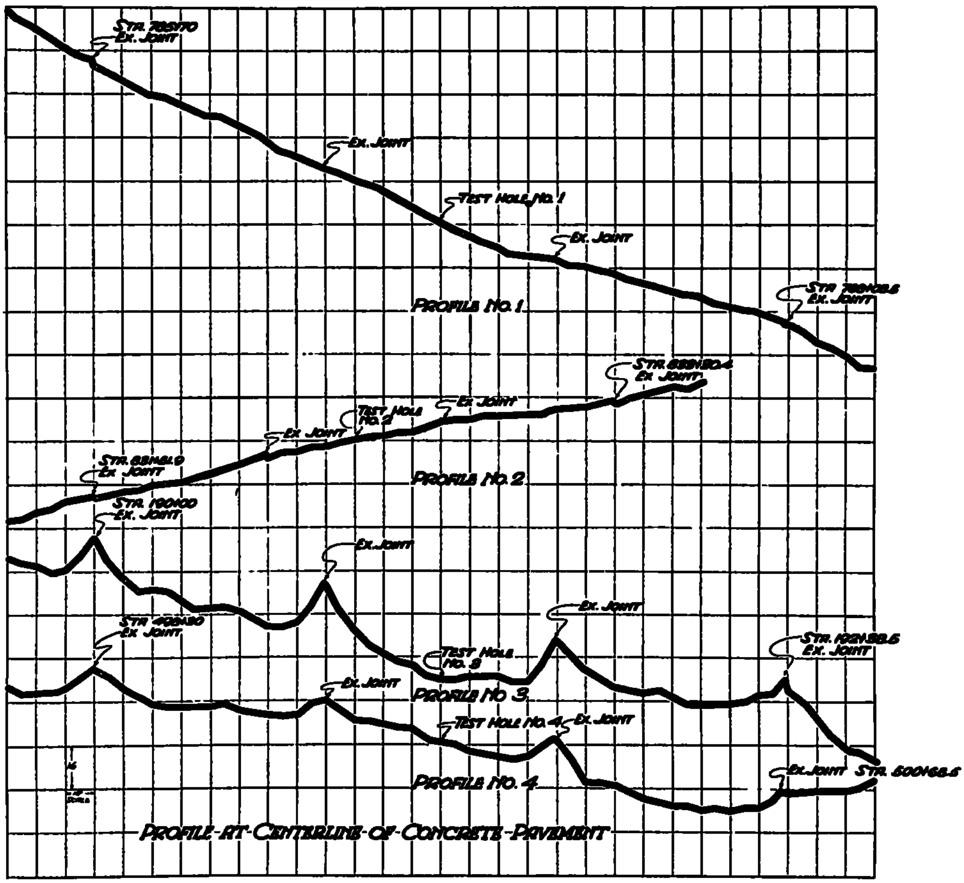

Figure 1. Profile at Centerline of Concrete Pavement

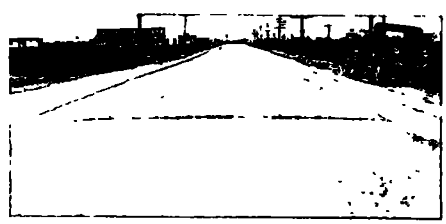

Figure 2. Twenty-year-old Pavement That Carries Heavy Port Traffic and Which Stood under Water for Several Days after a Tidal Wave in 1919.

laid than was the soil on Project "A." Figure 3 shows the expansion joint between the two projects. There are no dowel bars in this joint.

During an unusually long period of dry weather in the summer of 1934, the pavement on Project "A" subsided as much as $2\frac{1}{2}$ in. more than did the pavement on Project "B."

Figure 3. Expansion Joint between the North End of Project A, Shown in the Foreground, and the South End of Project B, in the Background.

The uneven joint between the two sections was built up with bituminous material to prevent a traffic hazard. After the following winter rains it was noted that these slab-ends were gradually returning to equal elevations. By the end of the spring rains there was practically no difference in the elevations of the pavement on each side of the expansion joint.

Natural soil-foundations in hill cuts often have been composed of different types of soil. Where the pavement was laid directly on the natural soil and where the grade line intersected strata of different type soils, subsequent moisture content fluctuations therein have caused different amounts of movement in different parts of the pavement. When investigations first were started about 1928 on the causes of warping in pavements, it was found that more irregularities developed on hills, in hill cuts, and on fills adjoining hill cuts than on the embankments across creek and river bottoms. The development of irregularities on one part of the fill and not on the other created a great deal of confusion and discussion.

At the time of the grading of these early-day roads, no attention was paid to the types nor to the placing of the soils in the fills. The most convenient method for the contractor usually was employed. Although contrary to the specifications, often fills and embankments were built up to grade line as the work progressed by spilling the soil from wheelers and fresnos over the embankment ends, which resulted in embankments formed of more or less vertical sections of soil of different types. An exaggerated illustration is shown in Figure 4.

This embankment, therefore, was as longitudinally nonuniform as the natural soil-foundation in the hill cut.

After the hill cut material was disposed of in the adjoining fill, usually the remainder of the fill across the creek bottom was built of soil taken from borrow pits and placed in more or less longitudinally uniform layers as the soil came from the pits.

To overcome this mechanical defect, the types of soils in the hill cut should be predetermined and the soils therefrom spread in longitudinally uniform layers, as illustrated in Figure 5.[2] The most

[2] This is an exaggeration used for illustration. Generally, there are not more than two or three strata of appreciably different materials.

highly expansive and plastic soils generally should be placed at the bottom of the soil-substructure where they will be afforded the most protection from subsequent alternate wetting and drying effects of the different seasons, and the most pervious and nonexpansive soil placed at the top. The nonuniform structure in the hill cut should be excavated below grade and backfilled with suitable uniform material.

Transverse: Where the embankment is of highly expansive clay, even though it be of uniform type, nonuniform cross-sectional movements often occur due to a variation of the moisture content of the soil under the center line and under the edges of the pavement. Data taken on Project "A" illustrate these movements, as shown in Figure 6.

Cross sections No. 1 show the relative elevations of top of pavement directly after it was finished in May, 1931. At that time there was an 0.08 ft. crown in the pavement. Sections No. 2 show the relative cross-sectional elevations of the pavement in August, 1931, after the dry summer. The crown in the pavement at that time was 0.34 ft. Sections No. 3 show the relative elevations in May, 1932, after the wet winter and spring season. The crown in the pavement at that time was 0.1 ft.; only 0.02 ft. different from the amount of crown which existed at the time the pavement was finished.

At the same time as the unequal settlement between Projects A and B the exposed shoulder soil near the expansion joint between the two projects had shrunk until it was approximately 5 inches lower than top of edge of pavement. Where these shoulders were built up with the same type of native clay soil, after winter rains the soil had expanded until it was approximately 5 inches higher than the edge of pavement.

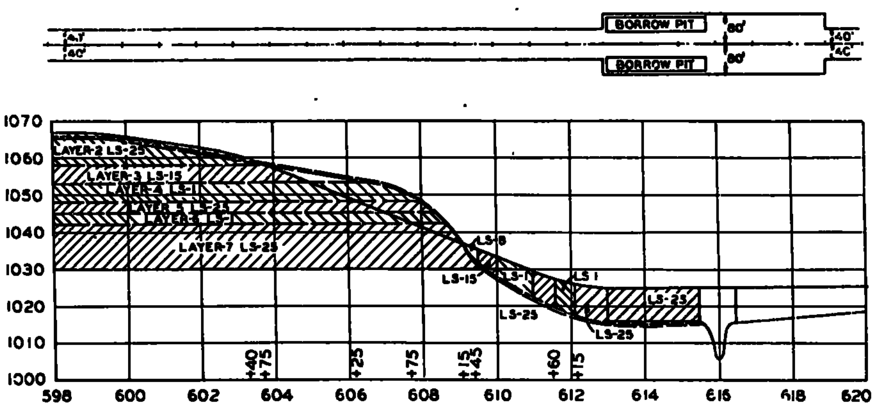

Figure 4

During the extended dry weather, large cracks developed in the shoulder soil of this section of pavement. A fishing pole could be extended to depths of from 8 to 10 ft. in some of the cracks. In many instances the cracks extended under the pavement and probably to the opposite side. In the vicinity of these transverse cracks, the soil had subsided to as much as 2 in. below the bottom of the pavement, leaving it to carry the traffic loads by its beam strength.

When subsequent rains came, these cracks filled with water which eventually permeated the entire soil fill and also the

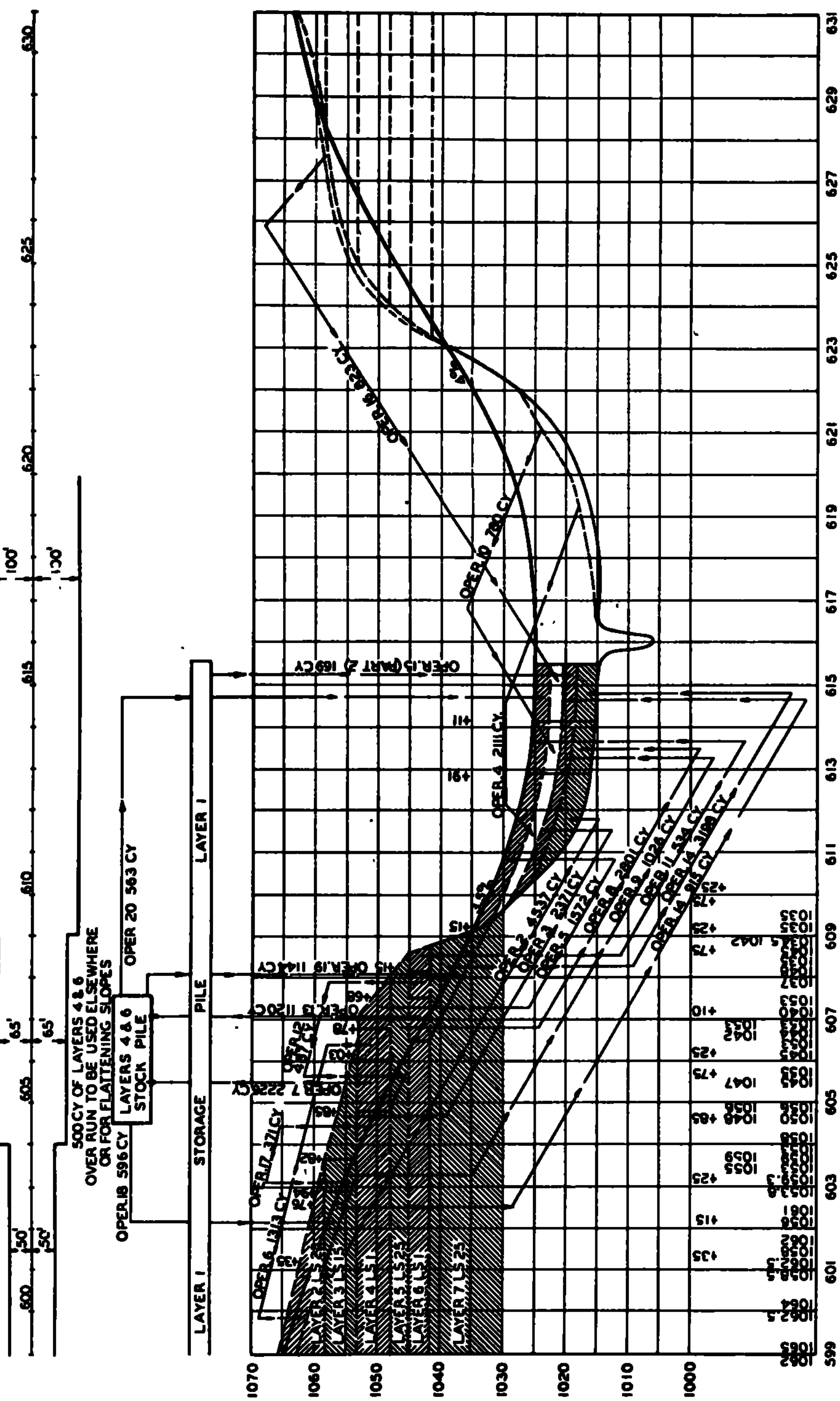
LAYER I
STORAGE
PILE
LAYER I
LAYERS 4 & 6 STOCK PILE
OPER 20 563 CY
OPER.18 596 CY
500 CY OF LAYERS 4 & 6
OVER RUN TO BE USED ELSEWHERE
OR FOR FLATTENING SLOPES
OPER 7 2226 CY
OPER.19 1144 CY
OPER.13 1120 CY
OPER.4 2111 CY
OPER.10 780 CY

Figure 5

natural soil foundation to great depths. Table 1 shows relative moisture contents of this soil at different times of the year. It is noted that between March and November, 1934, the moisture content at the 12 ft. depth fluctuated 14 percent. The soil fill was approximately 2 ft. deep. At the 2 ft. depth the soil moisture fluctuation was 25 percent.

These phenomena have been substantiated by other observations and data. Figure 7 shows a picture taken in 1937 during an unusually dry period of weather on a project in a different part of the State, near the Gulf coast. The underlying soil on this project subsided a maximum of 0.4 ft. below the bottom of edge of pavement. A 2½ in. square rod could be pushed under this pavement in some places for a distance of 5 or 6 ft. This pavement was laid in 1931 and retained its smooth surface until the unusually dry period of weather in 1937.

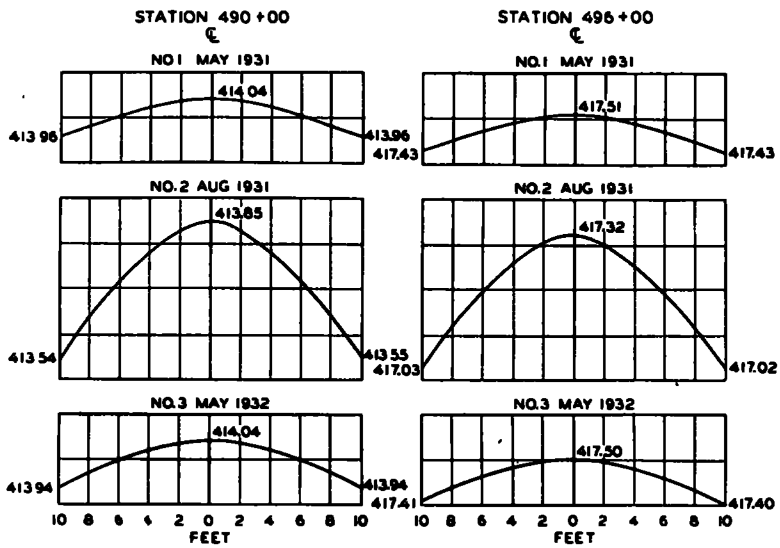

Figure 6. Cross-sections

TABLE 1

SOIL FILL AND NATURAL SOIL-FOUNDATION MOISTURE CONTENT FLUCTUATIONS WITH WET AND DRY SEASONS

Depth of Sample Below Surface of Ground, Ft.	Soil Moisture Contents on Dates as Shown	
	March, 1934	November, 1934
0	33	15
2	45	20
4	39	21
6	46	22
8	39	22
10	35	22
12	38	24
14	35	27
16	34	27
18	33	29

TABLE 2

SHOWING THE CONSTANTS AND CLASSIFICATIONS OF THE SOILS AT DIFFERENT DEPTHS, THE MOISTURE CONTENT FLUCTUATIONS IN WHICH ARE SHOWN IN TABLE 1

Depth Below Surface of Ground, Ft.	Soil Constants							
	LL	PL	PI	SL	LS	FME	CME	Class
0	84	25	59	9	27	41	56	A-7
4	79	26	53	10	25	45	74	A-7
12	83	28	55	10	26	47	67	A-7
16	97	28	69	11	28	48	82	A-7
18	100	26	74	9	29	44	87	A-7

During the time the soil was in this shrunken condition, a movement of loaded army trucks over the north side of this pavement caused longitudinal cracks to form in many of the slabs. Usually these cracks developed parallel to the center line and approximately half way between the center line and edge of the pavement.

Where one slab broke and followed the soil down and the adjoining slab did not, differences of as much as 3 in. in elevations of the adjoining slab-ends developed at the pavement edge at the expansion joint.

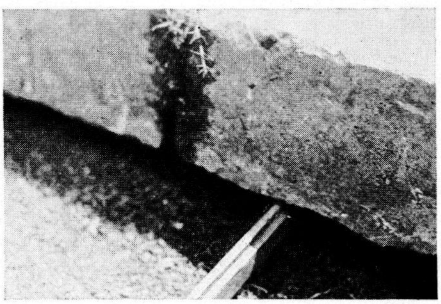

Figure 7. A $2\frac{1}{2}$-in. Rod Extending 5 ft. under the Pavement

In order to overcome this mechanical defect, the roadway shoulders should be constructed so as to maintain, as nearly as practicable the moisture content and volume that existed in the natural soil foundation and soil substructure at the time of the laying of the pavement as will be discussed hereafter.

ADEQUATE DRAINAGE

Proper drainage has been considered the major problem in railway and highway construction and maintenance, but for a long time it was thought of as surface or external drainage. In order to maintain the soil substructure at as nearly a uniform moisture content and volume as is practicable, internal drainage must be given proper attention. When gravity water is impounded in the soil substructure where clay is present, the clay is apt to be overly wetted and expanded during the wet seasons. The placing of coarse grained material on clay soil and the flanking of the coarse grained material with tight clay soil probably has caused more pavement failures than any other one item. When pavement is placed on soil that is overly wetted by water impounded in the soil structure, eventually the soil will lose its large moisture content and volume and cause a large range of movement in the overlying pavement.

On Test Section No. 37 of the Guadalupe County Research Project, a 12-in. depth of sand was placed in a 20-ft. width trench cut in the top of the clay soil. The pavement was placed on the sand, and the roadway shoulders were built up with the native clay soil. After a long period of slow rains, a hole was dug in the clay shoulder soil at the edge of pavement, and down to slightly below the bottom of pavement. Immediately water began to flow from the sand under the pavement into the hole. In one hour's time $3\frac{1}{2}$ in. of water had accumulated in the hole.

At the time this hole was dug, water was seeping up through contraction joints and trickling down the surface of the pavement on Section No. 37.

Test Section No. 36, adjoining Section No. 37, was built in the same manner except that the top of the clay soil was made to slope continuously from the center line to intersections with the roadway side-slopes and the 12 in. depth of sand was placed entirely across the crown, to intersections with the roadway side-slopes. At the same time the hole in Section 37 was made, a similar hole was dug on Section 36, but no water accumulated in this hole. At the time, however, it could be seen that water had been draining from the sand blanket to the roadway side-slopes.

Some of the effects of impounded water

on highly expansive and plastic soil are illustrated as follows:

Figure 8 shows the cross-section plans of a section of highway which called for coarse grained base material (crushed gravel conglomerate) to be placed in a trench cut in the top of impervious, highly expansive, and plastic clay soil.

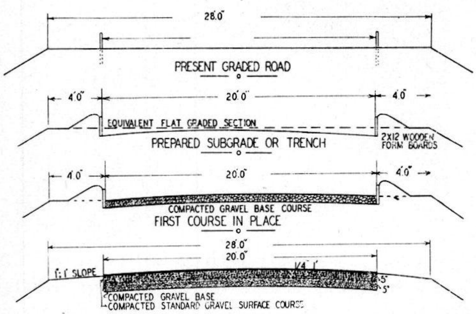

Figure 8. Typical Cross-section of Plan Specifying Coarse-grained Material Placed in a Trench Cut in a Crown of Clay Soil.

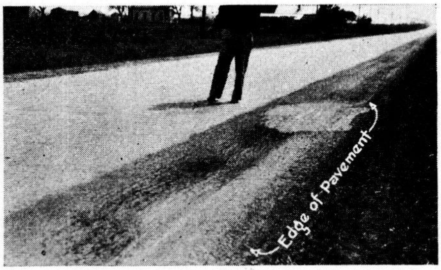

Figure 9. Showing Failures and Patching along the Edges of a Pavement Where the Crushed Conglomerate Base Material Was Placed in a Trench Cut in the Tight Clay Soil.

Figure 9 is a typical view of this highway taken in 1935, approximately five years after its completion, and gives an idea of the large number of failures that developed in the riding surface. Figure 10 shows impounded rain water along the edges of the base material. The line of least resistance to the flow of this water is into the large voids in the base material. The water is impounded on the underlying clay soil until it eventually penetrates it enough to cause it to become plastic and move appreciably under traffic loads.

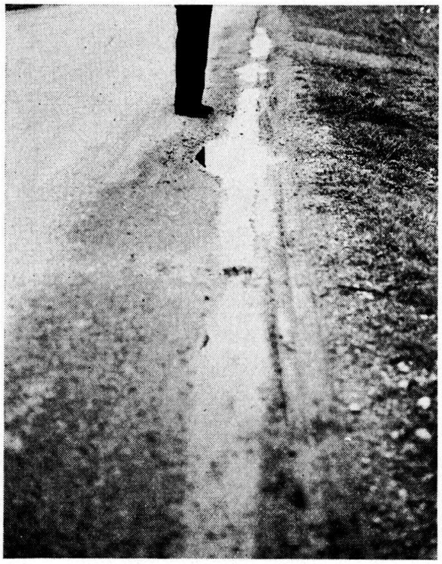

Figure 10. Showing Rain Water Accumulated in a Rut in the Shoulder Soil at Edge of Pavement. When this water first accumulated, the line of least resistance to its movement was into the large voids of the base material.

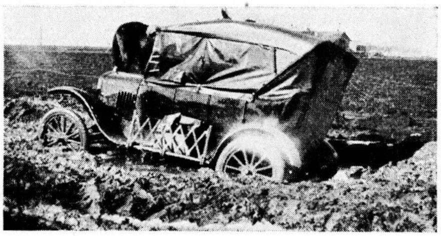

Figure 11. Exaggerated Subsequent Ill Effects of Placing Coarse-grained Material in a Trench Cut in Tight Highly Plastic Clay Soil.

Figure 11 shows the subsequent ill effects of gravel surfacing material placed in a trench cut in tight clay soil (without appreciable maintenance). Water was impounded in the gravel in the trench until it finally penetrated the underlying highly expansive and plastic clay soil.

Traffic pushed the gravel down into the soft clay and the clay came to the surface. At the time this picture was taken (1923) no gravel could be found at the surface of the roadway.

On the other hand, Figure 12 shows the cross-section plans of another pavement project built in 1932, where the soil-substructure was of the same type of black waxy clay as that on the projects shown in Figures 8 to 11. Figure 13 shows the condition of this wearing surface in 1938. The difference in the behavior of pavements on these projects is mainly because water was impounded in the base of the first two and drained freely from the base of the latter to the roadway side-slopes and ditches.

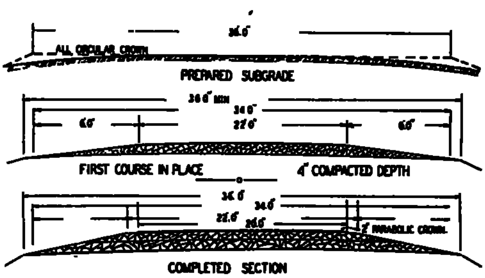

Figure 12. Typical Cross-section of Crowned Clay Soil with Coarse-grained Material Placed as a Blanket Entirely Across the Crown.

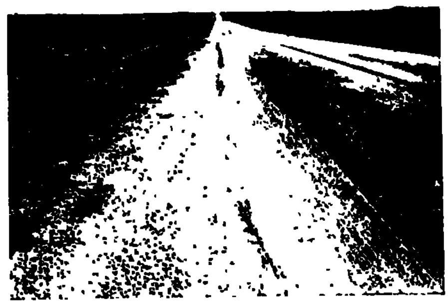

Figure 13. Smooth Riding Surface after Six Years of Heavy Traffic Where Rain or Gravity Water Moved Freely from the Base Material to the Roadway Side Ditches.

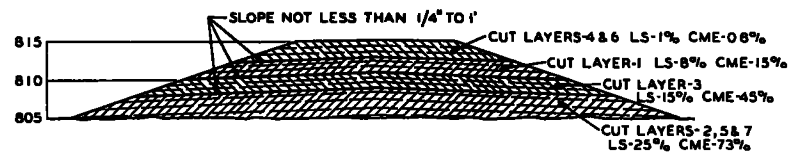

Figure 14. Cross-section Showing Method of Properly Placing Materials in the Soil Substructure. Soil to be placed in layers not more than 10 in. in depth. Each layer to be thoroughly bladed and rolled where specified.

These data show the incorrect and correct methods of placing granular material on clay soil under the pavement and on the roadway shoulders to facilitate proper drainage. Several years ago the A.A.S.H.O. condemned the practice of placing pervious large-grained base material in trenches and pockets in impervious fine grained soils, but in many instances the practice has not been discontinued. This mechanical defect at lower depths in the soil fill also causes failures in pavements, and in general, should be guarded against throughout the entire roadway construction, as illustrated in Figures 14 and 15.

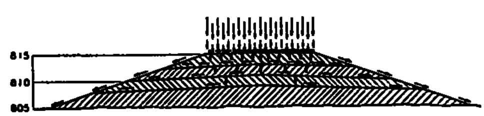

Figure 15. Cross-section of Fill Showing Drainage Gained by Properly Placed Soils. Arrows indicate direction of movement and amount of gravity water on and in the layers of different type soil in fills.

As the different types of soils shown in Figure 14 are placed in thin layers in the substructure, the center should be carried higher than the edges of crown by at least ¼ in. to 1 ft., measured transversely. In particular, when all the soil of one type is finally in place, its surface should slope continuously from the center line to intersections with the roadway side-slopes in order that there will be no cups or depressions to impound gravity water. With this arrangement, rain water that eventually permeates a pervious layer of soil will drain toward the side-slopes, along the top of the underlying more impervious soil in the structure.

SOIL MOISTURE CONTENT AND DENSITY

The foregoing data show that in order to build highways with pavements which will not develop appreciable riding surface irregularities, one of two major conditions must prevail.

(1) The natural soil-foundation and the soil-substructure must be of materials that will not move appreciably with moisture content fluctuations, or

(2) The moisture content fluctuations in expansive and plastic soils must be controlled to such a degree that subsequent movements in the soil will not be objectionable.

It is economically necessary in many instances to place pavement over soils of appreciable volumetric change and plasticity, but it is practicable to design this type of soil-substructure with sufficient protection from moisture content fluctuations to eliminate or greatly retard non-uniform movements in the pavement. One of the foremost problems in this regard is the bringing of clay soil to its average subsequent moisture content, density, and volume, immediately prior to the laying of pavement.

In the same county where projects "A" and "B" were built with natural soil-foundation and soil-fill of the same type, another pavement was constructed in 1930, as is illustrated in Figures 16 and 17. Figure 16 shows the profile of one section of this pavement at the time it was completed in August, 1930, in comparison with its profile one year later. The season at the time pavement was laid was very dry. The top of the soil was supposed to have been wetted to a

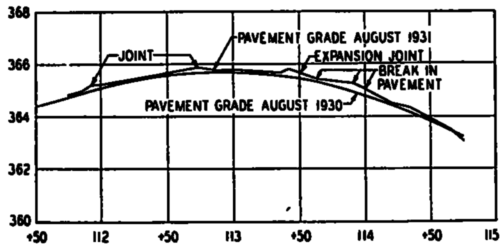

Figure 16. Sketch Showing Changes in Pavement Grade. This section of pavement, poured during the dry summer of 1930 is located at the crest of a small hill. The pavement was placed on a comparatively dry subgrade with the surface wet approximately 10 to 12 in. There was a large amount of rain during the following fall and winter, at which time surface irregularities developed.

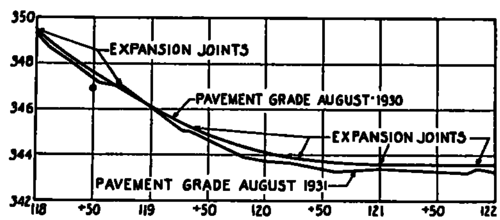

Figure 17. Sketch Showing Change in Pavement Grade. This pavement was constructed on subgrade that was ponded and jetted about 3 weeks prior to paving.

depth of 10 to 12 in. During the following winter there was a great deal of rain and the pavement rose throughout its entire length, more so at the expansion joints than elsewhere. The soil did not contain so much moisture when the pavement was laid as it attained eventually.

On another part of this same project the pavement was laid in August, 1930, on an embankment of the same type of highly expansive clay soil as that of Figure 16. The embankment on this section was jetted and ponded with water three weeks prior to laying pavement. In one year's time enough of the excess moisture was lost from the soil to cause it to shrink in volume and lower appreciably the elevation of the pavement, as shown by the two profiles in Figure 17. It is noted that the pavement

Figure 18. Ponded Water on a Soil Substructure Directly after Completion of the Grading Work.

Figure 19. Irregularities in Pavement Surface Caused by the Subsidence of the Embankment When Water Was Ponded on It.

did not subside so much at the expansion joints where the moisture perhaps was replenished by leakage of rain water from time to time, as elsewhere. In this instance the soil was wetted and expanded prior to laying pavement to a higher degree than it would hold under normal weather.

If the laying of pavement on a dry clay soil causes excessive subsequent movement of the pavement in one direction and the laying of pavement on saturated clay soil causes excessive movement in the opposite direction, then the bringing of the soil to its average subsequent moisture content and volume immediately before pavement is laid should reduce these movements.

If it were practicable to prevent moisture content fluctuations in the natural soil-foundation and in the soil-substructure, subsequent to the laying of pavement, perhaps it would be best to compact all the soils to their maximum densities during the building of the soil-substructure. In the first place it is not practicable at present to prevent all water from reaching the soil, and in the second place it is questionable as to whether it is possible to compact all the different types of soils in the substructure to their to their maximum densities by rolling alone. It should be borne in mind that uniformity is one of the essential objectives to be attained in roadway construction.

In view of the fact that moisture content governs the volume of some soils under pavement, it appears that in many instances water can be used to advantage in bringing the natural soil-foundation and soil-substructure to the average volume that will prevail after pavement is laid thereon. This water should be applied, not only immediately before laying pavement, but also directly after completion of grading operations. Figure 18 shows water ponded on the crown of a soil-substructure directly after all the soil was in place. Generally, the water should be replenished as it soaks into the soil until no more will be absorbed. The soil then should be allowed to dry naturally.

Often sand is damp and bulked when placed in the soil-substructure. Eventually this sand becomes saturated with water and settles or shrinks in volume and causes a cavity which works its way to the top of the embankment and causes a depression to develop in the pavement, as shown in Figure 19.

Figure 19 shows irregularities in pavement surface caused by the subsiding of the embankment when water was ponded on it.

This settlement occurred when water was ponded on the soil in preparing to widen the old 10-ft. width half-section of pavement to the 20-ft. width 9 years after completion of the grading and 7 years after the half-width pavement was laid. If the soil embankment had been given a thorough wetting immediately after the completion of the grading work, these settlements would have occurred then and been built up with soil.

Because one cycle of wetting and natural drying is not sufficient to bring all the soil-substructure to its average subsequent density, the graded roadway should be allowed to weather as long as practicable before final pavement is laid. The black waxy clay soil-substructure of the highway shown in Figure 13 weathered under traffic for 3 years before the pavement was placed. During these 3 years the top of the soil-substructure was kept true to line and grade by intensive maintenance. When the time arrived for placing pavement, very little reshaping and disturbing of the weathered soil was necessary. It so happened that at the time of year this pavement was laid, the moisture content and volume of the soil-substructure was perhaps near its subsequent average. These physical conditions of the soil-substructure are considered some of the reasons the pavement has given excellent service with comparatively little maintenance expenditures.

"Water subgrade treatment," immediately before laying of pavement, has been used by some of the States for many years, but generally it appears that it has not been done on a very scientific basis. In 1934 and 1935 experiments were performed on five pavement projects in an effort to bring the soil to its average subsequent moisture and volume as nearly as practicable immediately prior to laying pavement. From compiled data on soil moistures at different depths under old pavements in the State, estimates were made of the amounts of moisture that should be placed in the completed fills and embankments of these five experimental projects. The first problem encountered was the bringing of all the soil to the estimated moisture contents, to specific depths, by similated natural methods. Because there was no appreciable ground water on these projects, the natural method of wetting was permeation of water applied to the top of the soil. In order to wet the soil to a certain depth, a sufficient amount of water had to be ponded on the soil to wet all the soil to its field carrying capacity to that depth. This was done, and the amount of water required was determined from the difference between the existing natural moisture in the soil and its field moisture equivalent. Figures 20 to 22

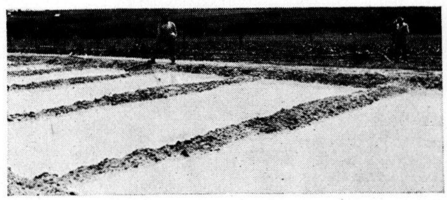

Figure 20. Showing Sufficient Water Ponded on the Soil to Wet It to Its Field Carrying Capacity Down to the Arbitrary Depth of 3 Ft.

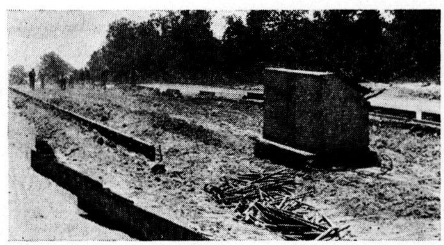

Figure 21. Effect of Setting Side Forms for Pavement so That the Wetted Excess Soil between the Side Forms Could Be Excavated to the Proper Subgrade Elevation without Appreciably Disturbing the Underlying Soil.

show progressive pictures of some of these operations.

After the ponded water had disappeared, all traffic was kept off the prepared soil. No walking other than was necessary for construction purposes was allowed on the wetted soil. On some of the projects a "subgrade planer" was used that did not disturb any of the soil except that which was cut off and carried out on a belt.

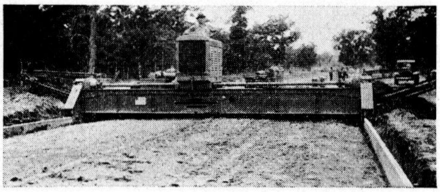

Figure 22. Removal of Excess Soil down to Subgrade without Disturbing the Soil below the Subgrade Elevation.

PROTECTION OF MOISTURE CONTENT AND VOLUME

Bringing the soil-substructure to its average moisture content and volume is not a cure-all by any means. It is only one of many things which should be done in properly preparing the natural soil-foundation and soil-substructure. All that is economically practicable should be done to maintain this prepared moisture content and volume subsequent to pavement laying. Because of the excessive shoulder soil-cracking during dry weather on Projects "A" and "B" as heretofore described, the bringing of that soil to its average moisture content and density alone would not have stopped the movements in that pavement. It would, however, have reduced or probably eliminated the difference in amounts of movements of the pavements on the two adjoining projects.

Had the shoulder cracks been kept covered, the loss of moisture from the soil beneath the pavement would have been reduced appreciably. This statement is substantiated by the agricultural theory of continuous plowing of crops during droughts to preserve the subsoil moisture, and by data taken on the Guadalupe County Research Project as follows:

Figure 23 shows large cracks that formed during dry weather in a corn field that had not been plowed for several weeks. Figure 24 shows mulched topsoil in an adjoining cotton field only

Figure 23. Large Cracks in a Corn Field Which Allow Dry Winds and Sun to Rob the Subsoil of Its Moisture.

five steps from the place where the picture was taken in the corn field. Holes were dug at both places and soil moisture content samples taken at different depths below the ground surface and tested. A comparison of the moistures at the same depths in the two places is shown in Table 3.

The mulching of clay shoulder soil, however, is not advocated for preserving moisture in roadways. There are other methods more efficient, permanent, and economical. Shoulders of nonexpansive materials, such as sand, caliche, gravel, and crushed stone, have given satisfactory service. The natural soil-foundation and soil-substructure of the project shown in Figure 12 is highly expansive and plastic black waxy clay. Figure 25 shows the largest shoulder crack that has ever been found on this project.

Figure 24. Showing Mulched Top Soil That Covered the Ground Cracks and Retarded the Loss of Subsoil Moisture to Dry Winds.

TABLE 3

SUBSOIL MOISTURE CONTENTS AT DIFFERENT DEPTHS IN THE CORN FIELD IN COMPARISON WITH THE MOISTURE CONTENTS AT THE SAME DEPTHS IN THE COTTON FIELD

Samples taken July 10, 1933

Depth Below Surface of Ground, Inch	Soil Moisture Contents in Corn Field, Percent	Soil Moisture Contents in Cotton Field, Percent
2	6.5	18.0
6	14.9	17.7
12	17.4	18.6
24	19.8	21.5
36	21.2	28.8

Average soil moisture where cracks were exposed.............................. 16%
Average soil moisture where cracks were covered.............................. 21%

In this case because the top of the clay soil-substructure was made to slope from the centerline and the pervious crushed stone was placed entirely across the crown to intersections with the roadway sideslopes, no large amounts of rain water have been impounded on the clay eventually to penetrate and appreciably expand it during wet seasons. This, of course, materially decreases the tendency for the soil to shrink and crack during dry weather.

Figure 25. The Largest Shoulder Crack That Has Ever Been Found Where the Roadway Shoulders Are of Crushed Stone on Highly Expansive Clay Soil.

Where nonexpansive coarse grained material is not economically available, other methods of maintaining a uniform moisture content in the subsoil have been used. On Section 32 of the Guadalupe County Research Project, a bituminous mat (3 gal. of asphalt per sq. yd.) was placed entirely across the prepared sloping crown of the soil-substructure. The pavement was placed directly on the asphalt mat, and the roadway shoulders were built up to top of edge of pavement with native clay soil placed on the asphalt mat. After 5 years, this is one of the smoothest riding sections of pavement on the research project. During hot weather some of the asphalt has risen into the expansion joints and cracks and has kept them sealed.

SUMMARY

1. Subsurface investigations should be made during the preliminary and location surveys, and the soil profile drawn.

2. Provisions, such as drainage and the intercepting of ground water, should be made where necessary to insure the permanent stability (as nearly as is practical) of natural soil-foundations upon which soil-substructures are to be built, and upon which superstructures are to be laid directly.

3. Where the natural formations below grade line in hill-cuts are of nonuniform types of soil, the nonuniform formations should be excavated below grade line and backfilled with selected material of uniform type.

4. From the soil profile data the soil-substructure should be so designed that there will be no longitudinal or cross-sectional mechanical defects such as abrupt longitudinal changes in types of soil in a layer, and the placing of coarse grained permeable material on and flanked by soil that is less permeable.

5. Where all the different type soils from hill-cuts, side-ditches, and borrow pits are to be placed in the soil-substructures should be shown on the construction plans.

6. Because it is impracticable at present to draw soil profiles that are correct in every detail during preliminary survey, a competent soils engineer should be on the construction of the project at all times, when soils are being moved. He should check the soils as excavated with the data shown on the soil profile, and where discrepancies are found, he should direct the contractor as to where and how to place the material.

7. The plans should show proper methods of internally draining the soil-substructures and of intercepting ground water where necessary to insure stability.

8. The soils engineer should see that all soil is properly treated (such as densifying) as it is placed in the soil-substructure.

9. It is difficult to compact by rolling during construction all the different types of soils to their average subsequent densities. Immediately after the completion of grading operations, water, therefore, should be ponded on the crown of some type soils until no more water will be absorbed by slow permeation. This thorough wetting will cause overly compacted soils to expand and underly compacted soils to shrink and settle.

10. Because one cycle of artificial wetting and natural drying is not sufficient to bring all the soil to its average subsequent density, the graded roadway should be allowed to weather under traffic as long as is practicable before final pavement is placed.

11. During the weathering period the graded roadway should be maintained true to line and grade, in order that no pools of rain water will stand and nonuniformly wet the soil-substructure; and so that the top of the soil-substructure will not have to be disturbed in reshaping when the subbase, base, or wearing surface is placed on it.

12. Where the top of the natural soil-foundation and the soil-substructure is relatively dry clay and a crust has been formed by traffic, enough water should be ponded on the crown to bring the soil to the average moisture content that will prevail after pavement is laid, as nearly as is practicable.

13. After the required amount of

ponded water has disappeared into the soil, the soil should not be disturbed No traffic should be allowed on the wetted soil and no more walking thereon than is necessary during the laying of pavement

14 Where the top of the soil-substructure is damp sand that bulks when disturbed, or where a sand blanket is placed on clay soil-substructure immediately before the laying of pavement, care should be exercised that the sand is not in a bulked condition when the pavement is laid Thorough saturation of the sand with water is perhaps the most practical method of eliminating bulking

15 Where large grained permeable material, such as sand, is placed on more impermeable material, the top of the impermeable material first should be made to slope continuously from the centerline to intersections with the roadway side-slopes Adequate drainage being one of the paramount items, care should be taken that coarse grained material is never placed in a pocket in fine grained impermeable soil

16 After the soil-substructure is brought to its average subsequent moisture content and volume immediately prior to placing pavement, all that is practicable should be done to prevent subsequent appreciable change in that moisture and volume