LABORATORY INVESTIGATION OF SOIL-CEMENT MIXTURES FOR SUBGRADE TREATMENT IN KANSAS

By M D Catton

Cement can be added to soils for other purposes than the achievement of a hardened road surface for light traffic use. It may also be used to change the characteristics of unsatisfactory soils in subgrades under substantial load carrying pavements, such as concrete, so that these soils will function satisfactorily as subgrades.

The Kansas State Highway Commission has made extensive laboratory and field studies of very bad soils which produce distortion of concrete pavements at cracks and joints as a result of volume increases and moisture gradients in the soil which accompany infiltration of water As a result of these investigations a comprehensive field project was started in the fall of 1935 on a soil which would produce pavement distortion with a view to applying the laboratory and field studies in construction procedures in such a manner that the tendencies of very bad soils to produce pavement distortions would be overcome The work is in Douglas County and is identified as Project 10-13-PWS$_2$ Several methods of subgrade preparation and construction make up this project One section, (No 10) was to be treated with about 5.3 per cent cement by volume (45 lbs per sq yd) for a depth of 12 in

A typical sample of the soil was shipped to the Portland Cement Association in the winter of 1935–36 for analysis and suggestions for the treatment of the section with cement The following report covers the investigation of this soil mixed with various quantities of cement and covers data and analysis of data by the soil-cement Laboratory of the Development Department of the Portland Cement Association

Since the problem involved is one of reducing volume changes in the soil enough to overcome pavement distortion due to moisture changes or moisture gradients, two possible methods of treating the soil with cement were presented With one method, a soil-cement mixture would be used containing sufficient cement to give a cement hardened soil or subgrade when moisture content and compaction are properly controlled during construction This cement hardened soil would have very small volume changes and moisture gradients in comparison to the raw soil and would control pavement distortion very effectively

With the other method, a soil-cement mixture would be used containing enough cement to give a modified soil when hydration of the cement and manipulation of the mixture is properly controlled during construction This modified soil would have much lower volume change characteristics than the raw soil and would be similar in character to soils which do not produce pavement distortion In the case of this particular soil, the cement content required to change the character of the soil to that of one having small volume changes and moisture gradients is less than that required to give a permanently hardened soil. Therefore, in the course of time, weathering agencies would slowly granulate a hardened mixture to produce a modified soil similar to one obtained by pulverizing the same soil-cement mixture in the laboratory after the cement has hydrated In this case also, construction procedure similar to that used for the first method can be followed

CEMENT MODIFIED SOIL

Previous work in the soil-cement laboratory has indicated that the characteristics of soils are changed by the addition of cement, particularly volume changes accompanying moisture changes In this particular problem it is not necessary to strive for practically complete elimination of volume changes but only to change the soil characteristics to make the soils comparable with those which experience has shown do not cause pavement distortion

In order to determine the influence of cement on soil characteristics, cement was added in quantities of ½, 1, 2, 3, 4, 5 and 8 per cent of the volume of the mixture when compacted at optimum moisture by the Proctor procedure The soil-cement mixtures containing 5 and 8 per cent cement were permitted to hydrate for 43 days The soil-cement mixtures containing ½, 1, 2, 3, and 4 per cent cement by volume were permitted to hydrate for seven days in order to conserve time The soil-cement mixtures were dried, pulverized and the physical test constants determined at the ages indicated The results are given in Table 1, with the physical test constants of the raw soil The mechanical and hydrometer analysis of the grain size of the raw soil is shown in Figure 1 A few tests of physical constants on pulverized soil-cement mixtures one and two days old gave about the same physical test constants as those obtained on pulverized soil-cement mixtures seven days old and indicated very early influence of cement hydration on soil characteristics.

TABLE 1

TEST RESULTS ON RAW SOIL AND SOIL-CEMENT MIXTURES

	Raw Soil	Soil-Cement Mixtures (1) Containing						
		½% Cement (2)	1% Cement (2)	2% Cement (2)	3% Cement (2)	4% Cement (2)	5% Cement (3)	8% Cement (3)
Liquid Limit	54	51	48	46	45	45	45	41
Plastic Limit	24	24	24	25	27	28	34	33
Plasticity Index	30	27	24	21	18	17	11	8
Field Moisture Equivalent	31	31	31	33	32	31	37	34
$\frac{\text{Vol at S L}}{\text{Vol at F M E}} \times 100$	80 2	80 4	83 3	81 8	85 9	95 2	89 6	91 6
Shrinkage Limit	17	17	20	20	22	28	29	28
Shrinkage Ratio	1 8	1 8	1 8	1 7	1 6	1 5	1 5	1 5
$\frac{\text{Vol at S L}}{\text{Vol at L L}} \times 100$	60 5	62 5	65 8	69 0	73 2	79 2	80 1	83 6
U S B P R Soil Group	A-7	A-7	A-7	A-7	A-7-5	A-7-5	A-5-7	A-5-7

(1) Cement content based on volumes when compacted at optimum moisture by standard Proctor procedure

(2) Constants determined on pulverized soil-cement mixture by U S B P R standard procedure after cement has hydrated for seven days

(3) Constants determined on pulverized soil-cement mixture by U S B P R standard procedure after cement has hydrated for 43 days

The specimens remaining from the shrinkage limit determinations are shown in Figure 2

The following discussion is based on a

comparison of raw soil with various soil-cement mixtures in which the cement has hydrated and the mixture pulverized. Pulverization of the soil-cement mixtures permits determination of physical test constants in the same manner as they are determined for a raw soil.

By referring to the physical test constants of the raw soil and soil-cement mixtures in Table 1, it will be seen that adding cement to soil and allowing time for it to hydrate, changes most of the physical test constants.

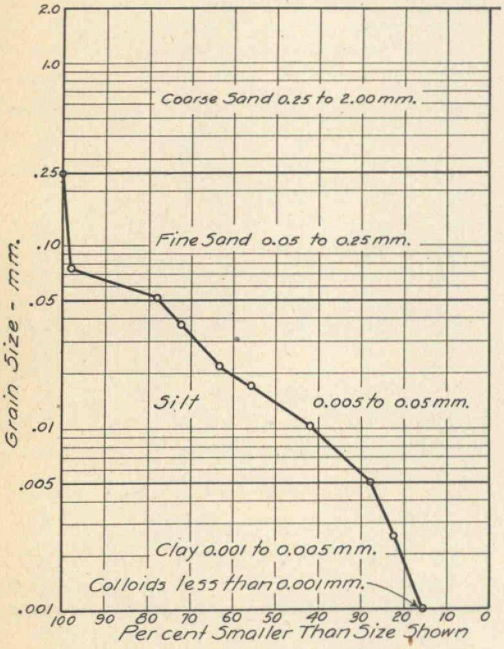

Figure 1. Mechanical and Hydrometer Analysis. Laboratory Soil Sample No. 1, Clay Loam Subsoil, Group A-7.

The liquid limit of the raw soil is 54, and, as increasing amounts of cement are added, it is lowered to 41 for the soil-cement mixture containing 8 per cent cement. In this particular soil it is probable that the cement exerts its greatest influence in reducing cohesion of the soil particles in the pulverized material.

The plastic limit of the raw soil is 24 and, with increasing amounts of cement, it is increased to a maximum of about 33 or 34 with 5 to 8 per cent cement. Moisture evaporates very much slower from soils when the moisture content is below the plastic limit than when it is above the plastic limit. Therefore, the raising of the plastic limit will be effective in reducing the rate of moisture change and the rate of volume change of the soil under similar drying conditions, which will be helpful in reducing pavement distortion.

The plasticity index of the raw soil is 30 and, with increasing amounts of cement, is reduced to a minimum of 8. This reduction in plasticity index is definite evidence that the cohesion of the soil particles in the pulverized mixture is materially reduced and approaches the values found in sandy, silty soils.

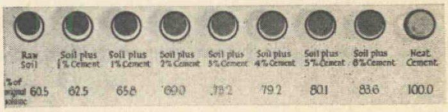

Figure 2. Relation of Shrinkage Limit Pats to Liquid Limit Volumes. Relative Shrinkage, Kansas Subgrade Soil Sample No. 1 showing effect of added cement. The cement treated soils were moist cured, then dried and pulverized for the test. The inside diameters of the circles show the original volumes of the pats molded at the liquid limit condition.

The field moisture equivalent of the raw soil and the soil-cement mixtures are essentially the same. There is a tendency for the field moisture equivalent to be raised. However, in this problem, the significance of this moisture condition lies in the fact that it is the probable maximum volume and moisture content which will be found in the field without manipulation of the soil.

The relation of volumes at the shrinkage limit to volumes at the field moisture equivalent have been computed to show the maximum probable volume change which will occur in the field. As previously mentioned, the maximum probable moisture content will be near the field moisture equivalent and it can be presumed that a long period of hot, dry weather might reduce the moisture content of the subgrade to the shrinkage limit. Subsequent rains would tend to raise the moisture content of the subgrade at cracks, joints and edges, to the field moisture equivalent and, in case a steep moisture gradient is established in the subgrade soil, would produce pavement distortion

By referring to the ratios of the volumes at the shrinkage limit to the volumes at the field moisture equivalent it will be noted that the raw soil may undergo a 20 per cent volume change As the cement contents are increased, the possible volume change is decreased one-half or more to less than 10 per cent for the higher cement contents

The shrinkage limit of the raw soil is 17 and, with increasing amounts of cement, is raised to about 28 This is of particular interest in connection with soils having large volume changes producing pavement distortion for three particular reasons Since the shrinkage limit represents the moisture content at minimum volume

1 An increase in the shrinkage limit raises the permissible moisture content which will not produce volume changes In the raw soil, any increase in moisture content above 17 will produce corresponding volume increases In the modified soils containing 4, 5 and 8 per cent cement, the moisture content must exceed 28 per cent before corresponding volume increases occur

2 An increase in the shrinkage limit without a corresponding increase in the field moisture equivalent reduces the possible volume range between a dry condition (shrinkage limit) and a probable maximum field moisture content In the case of the raw soil the difference between the shrinkage limit and field moisture equivalent is 14 This difference is progressively reduced in the modified soils, as the cement content increases, to 10 for 3 per cent cement, 8 for 5 per cent cement and 6 for 8 per cent cement The probable maximum volume change due to a change from minimum volume (shrinkage limit) to probable maximum field volume (F M.E) is reduced very materially, one-half or more, in the mixtures of higher cement content.

3 An increase in the shrinkage limit when accompanied with less of an increase in the liquid limit will result in a decrease in the total maximum volume change which can occur between the driest (shrinkage limit) and wettest (liquid limit) conditions of soil in the field The raw soil has a difference of 37 for these conditions and, as the cement content increases, the difference is progressively reduced to about 17 for the higher cement contents.

The relation of soil volumes at the shrinkage limit to soil volumes at the liquid limit are given in detail in Table 1 It will be noted that the volume of raw soil at the shrinkage limit is 60 per cent of the volume at the liquid limit This volume change is successively reduced, as the cement content increases, to about 80 per cent for the mixtures containing 4, 5 and 8 per cent cement These soil-cement mixtures have only one-half the possible maximum volume change possessed by the raw soil These data and photographs of the shrinkage limit pats are given in Figure 2

The lower column of Table 1, shows the U S B P R soil group according to the physical test constants of the soil It will be noted that the characteristics of the raw soil, an A-7, are gradually changed by the addition of cement to give an A-5-7 soil

SUMMARY OF CEMENT MODIFIED SOIL RESULTS

The foregoing discussion brings out the appreciable decrease, in probable volume changes which will occur in the Kansas soil after 4 per cent cement or more, has been added and this mixture considered as a modified soil and not a cement hardened earth subgrade. It was also pointed out that the modified soil has some of the characteristics of sandy, silty soils.

In considering the causes of pavement distortion due to volume changes in the subgrade, the possible moisture gradients in the soil are of importance It was noted in working with the soil-cement mixtures that they were more mellow and granular than the raw soil which would tend to produce a subgrade condition of uniform moisture content While tests of permeability and capillarity were not made, the changes in the physical test constants indicate that pulverized soil-cement mixtures would tend to maintain more uniform moisture contents throughout than the raw soil as moisture contents increased or decreased

Test constants determined on soil-cement mixtures at one and two days were found to agree closely with those given in Table 1 and indicate a very early influence of cement hydration on soil characteristics

The discussion and analysis of data from Table 1 indicates that cement contents of 3, 4 and 5 per cent will change the soil characteristics about a maximum amount These cement contents, by volume, are approximately equal to 27, 36, and 45 pounds of cement per square yard of surface on a basis of a 12-in treated depth

The use of cement contents around 5 per cent would produce a cement hardened soil for a time which would slowly change from a hardened cake condition to a granular condition in proportion to the severity of weather conditions So long as the hardened condition predominates, the possible volume changes are very small. As the hardened condition changes to a granular condition, the characteristics of the granular soil-cement mixture would prevail

The analysis of data pertaining to such pulverized soil-cement mixtures shows that volume change characteristics are materially reduced by cement contents of 3 to 5 per cent. The volume change characteristics of these modified soils are similar to those of soils which should not produce pavement distortion

In view of the benefits to be derived from a construction procedure which will produce a cement hardened subgrade at no extra cost, it is worth while to take full advantage of these benefits as long as they prevail, after which the subgrade will function as a cement modified soil Since the primary objective of this field research project was the production of a subgrade which would not undergo such volume changes that pavement distortion is produced, it was unnecessary to produce a hardened subgrade since the cement modified soil will accomplish satisfactory results. The cement modified soil treatment therefore becomes the preferred method because of lower material costs At the same time, the beneficial influence of the hardened soil, so long as it prevails, can be obtained at no extra cost A cement content of 5 per cent by volume (42 3 lb per sq yd) for a depth of 12 in was suggested for this initial installation as a result of these tests

Construction methods similar to those used in building hardened soil-cement roads were used Due to last minute changes in construction plans in the field the subgrade treatment incorporated 10 6 per cent cement by volume (90 lb per sq yd) for a depth of 12 in instead of 5 3 per cent originally specified by the State Highway Commission This was followed with standard concrete surfacing

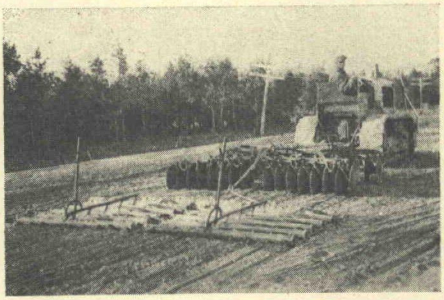

Figure 1. Disc and Spike-tooth Harrow Used for Pulverizing Clay, Wisconsin photo.

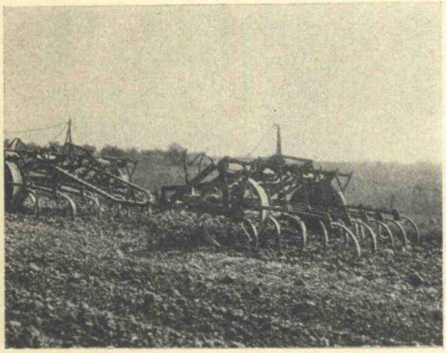

Figure 2. Quack grass diggers used in combination with disc cultivators in pulverizing scarified surfaces. Missouri photo.

Figure 3. Cement sacks were placed at a specified rate and emptied prior to spreading with a motor grader. Missouri photo.

Figure 4. Mixing cement with the soil. Illinois photo

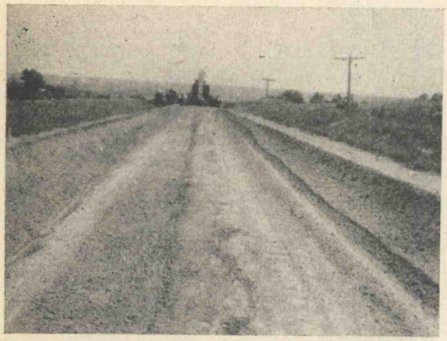

Figure 5. Traveling Mixing Plant in Missouri. Pulverized material is windrowed along each edge and a final depth measurement is taken. Note offset grade stakes along the shoulders. Windrows are joined along the centerline for the traveling plant. Missouri photo.

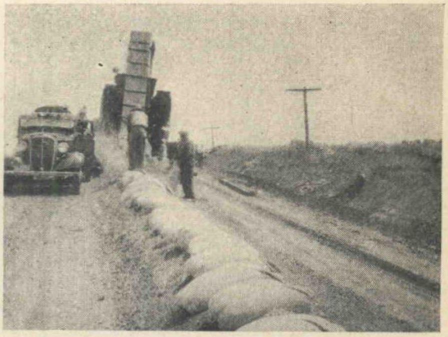

Figure 6. Sacks of cement are placed in the specified amount on top of windrow and are dumped over windrow just in advance of traveling mixing plant to prevent loss of cement by wind. Note some dusting at spiral feeders on machine. Supply truck is furnishing water for mix. Missouri photo.

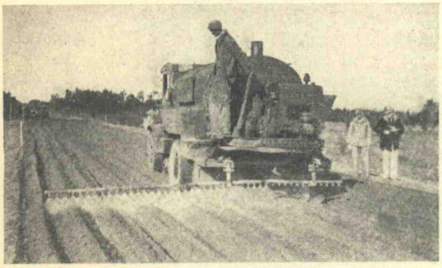

Figure 7. Oil distributor applying water. Wisconsin photo.

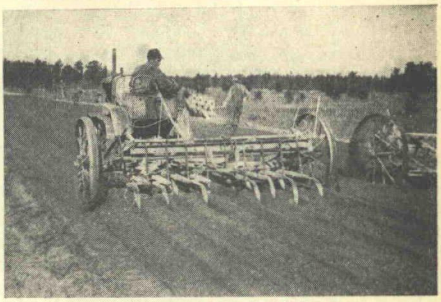

Figure 8. Quack grass digger used for all mixing operations. Wisconsin photo.

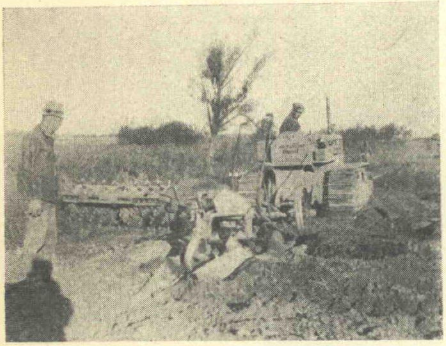

Figure 9. Fourteen-inch gang plow used in place of orchard cultivators during wet mixing. Note dry soil-cement mixture which is being turned up by the plow. Missouri photo.

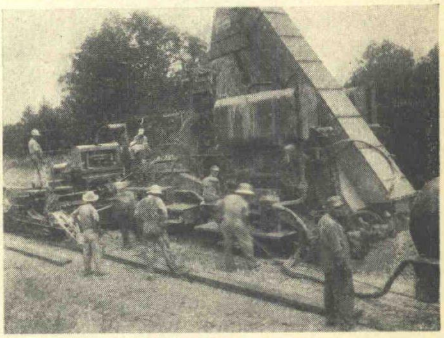

Figure 10. General view of traveling plant and finishing machine in operation. Missouri photo.

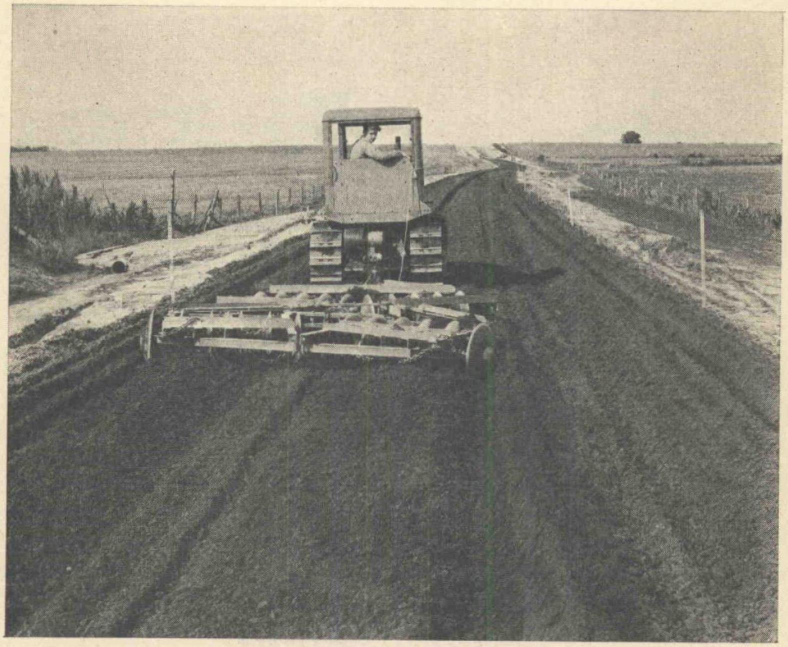

Figure 11. Surfacing material being loosened before being brought to line and grade and compacted. Illinois photo.

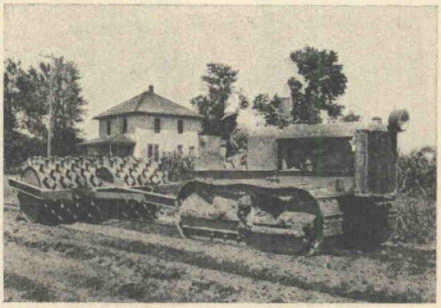

Figure 12. Beginning of sheepsfoot rolling. Iowa photo.

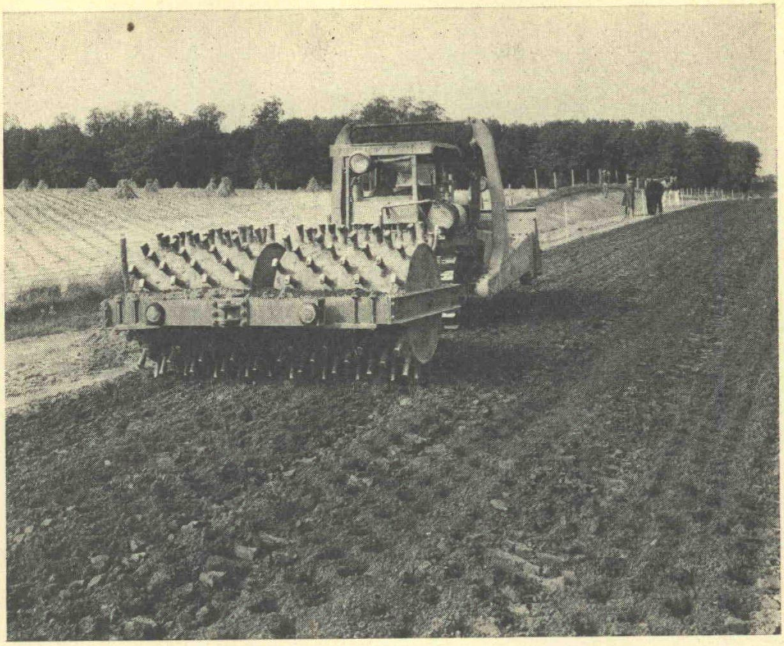

Figure 13. Compaction by sheepsfoot roller. Note drag bar placed in front of the roller to smooth and fill the roller marks made during the previous round. Illinois photo.

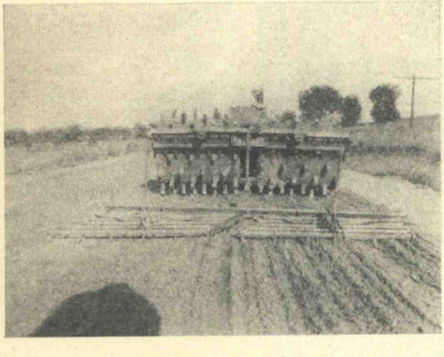

Figure 14. Final sheepsfoot rolling with small harrow attached to form a surface mulch for final smooth rolling. The surface was usually treated twice with this arrangement before smooth rolling. Missouri photo.

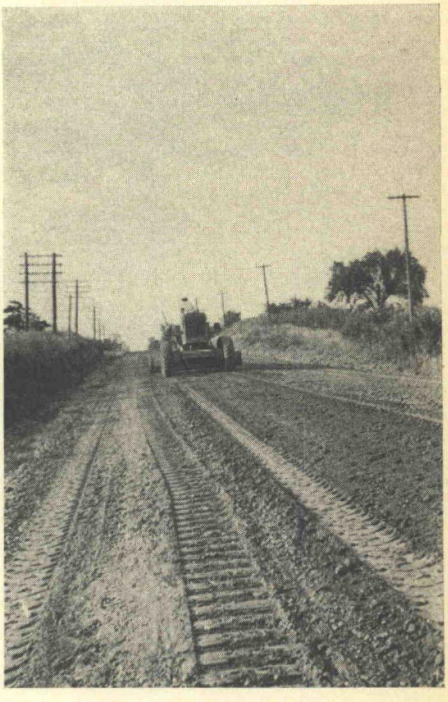

Figure 15. Preliminary shaping. Iowa photo.

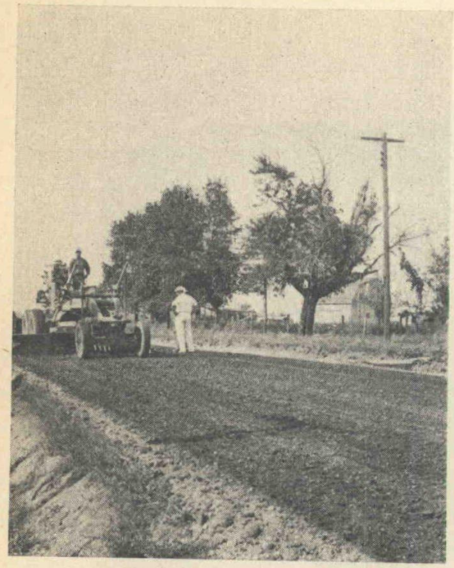

Figure 16. Final shaping with Auto Patrols. Iowa photo.

Figure 17. Pneumatic Roller. Iowa photo.

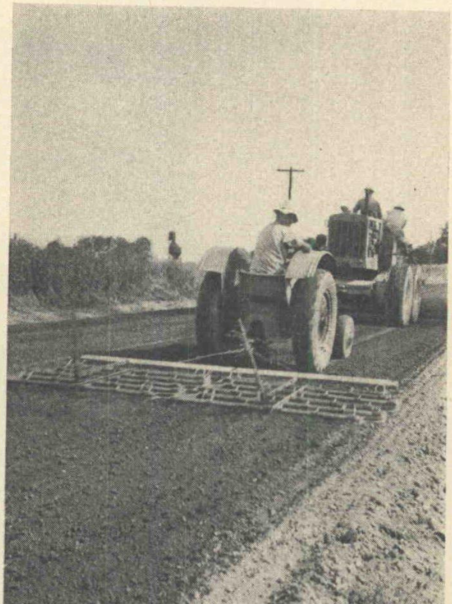

Figure 18. Removing compaction planes and preparing mulch for final packing. Iowa photo.

Figure 19. Final compaction with an 8-ton three wheel roller. Illinois photo.

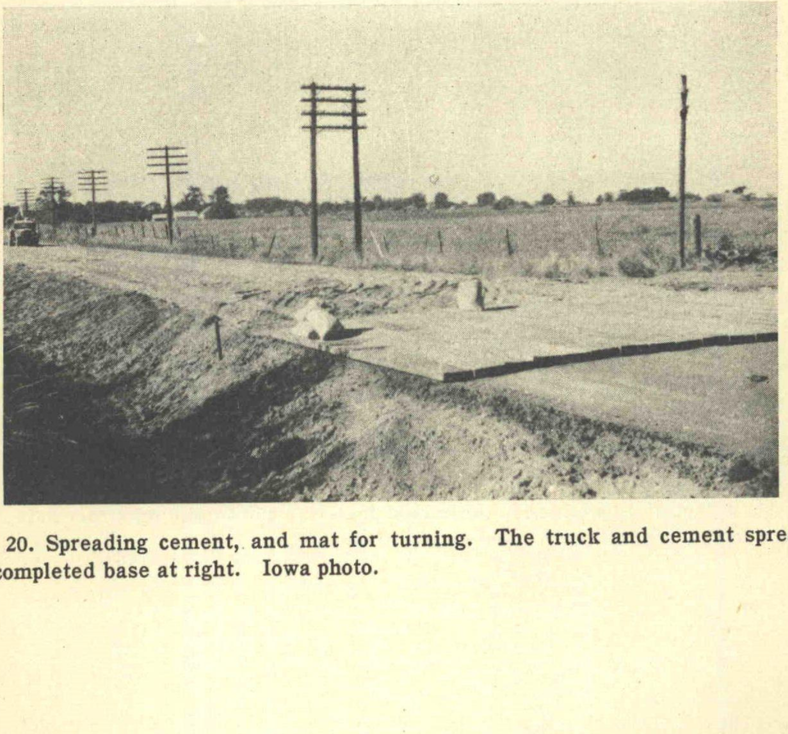

Figure 20. Spreading cement, and mat for turning. The truck and cement spreader is at the left; completed base at right. Iowa photo.

Figure 21. View showing straw placed on finished surface and covered with approximately six inches of dirt for turn-around for mixing equipment. Missouri photo.

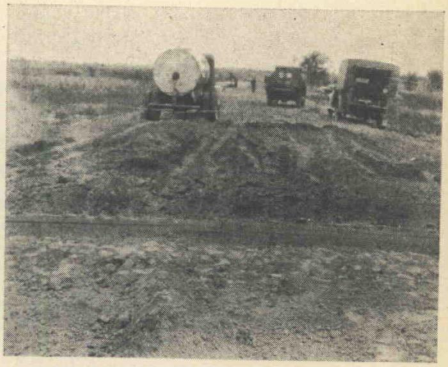

Figure 22. General view of turn-around and temporary wooden joint to be removed, after which the wet-mixed materials are pushed back into place. The length of the turn-around is about 30 ft. Missouri photo.

Figure 23. A typical turn-around, the mixed material windrowed on either side of the next increment, and the cement ready to be placed. Illinois photo.

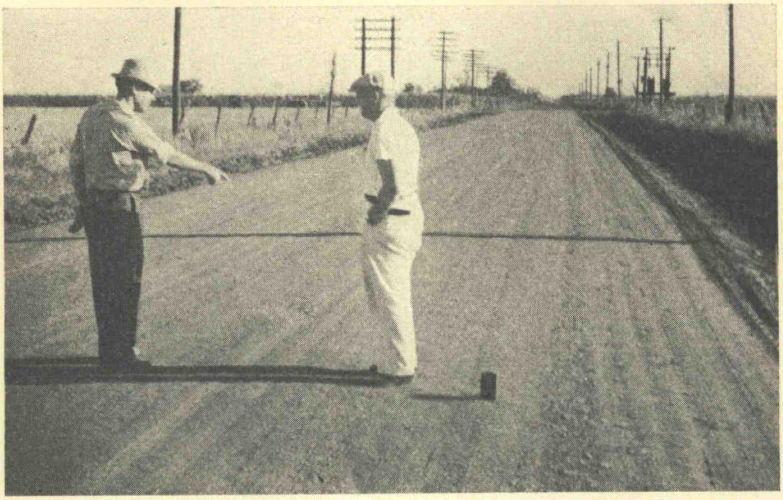

Figure 24. Completed base. Early morning inspection of previous day's run before application of prime. Iowa photo.

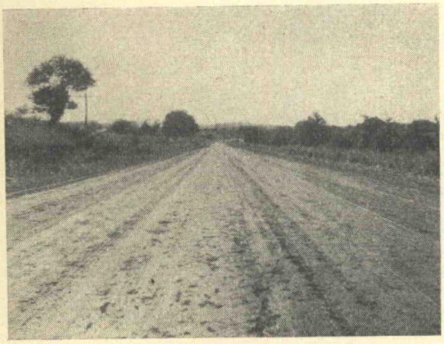

Figure 25. General surface appearance of 8 per cent cement soil-cement mixed-in-place base. Surface was primed with TC-2. Note some slight traffic pickup. Missouri photo.

Figure 26. General view of surface on 8 per cent soil-cement machine mix base. Ravelling occurred after priming but the prime coat kept it from becoming excessive. Several weeks later the left half was primed with TC-2 and the right half with MC-1. Missouri photo.