# FIELD TESTS ON SHEARING RESISTANCE

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## SYNOPSIS

At the meeting of the Highway Research Board last year a field shear testing apparatus was described and some typical data obtained with it were presented (*Proceedings,* Highway Research Board, Vol. 18, Part II, pp. 249 and 426).

This report contains additional data on completed projects which have varying degrees of service and analyzes the results. An important quantitative confirmation is that the quality of the subgrade determines the behavior of calcium chloride stabilized roads. In order to get significant results it is necessary to test the various components which make up the road structure. It was also found that the stability strength obtained by this testing device on cohesive soils is related to the bearing capacity, the bearing capacity being approximately three times the stability strength. Data are also given that show the stabilities of the frictional type subgrades are greatly increased by the surcharge effect of the overlying layers, while the strength of the cohesive type subgrades are only slightly improved.

Attention is called to the additional information needed before a tentative design method can be formulated for stabilized road structures.

## DISCUSSION OF DATA

### *Tests Reveal That Quality of Subgrade Determines the Service Behavior of Stabilized Roads.*

The general plan for the field testing was to make stability tests on adjacent failed and unfailed areas by testing individually the various components which made up the road structure. That is, on a road made up of a stabilized mat on a clay subgrade, tests were made on each of the components. By making these tests on both failed and unfailed areas which were adjacent, a quantitative set of results was obtained which revealed the weakest component or the one causing the failure. Such a set of test results is shown graphically in Figure 1. This figure shows the influence of the quality of the subgrade on the service behavior of a calcium chloride stabilized road. Where the subgrade had a shear value of approximately 20 lb. per sq. in. at its yield point of 0.09 in., the 4½ in. of compacted stabilized gravel mat was in good condition. But on an adjacent area that had failed badly the subgrade showed a shear value of only 5.0 lb. per sq. in. at a deformation of 0.09 in. The quality of the stabilized mat was good as it had a shear strength of approximately 45 lb. per sq. in. The tests on the subgrade materials were made at the same depth (top 3 in. under stabilized mat) and within 12 ft. of each other.

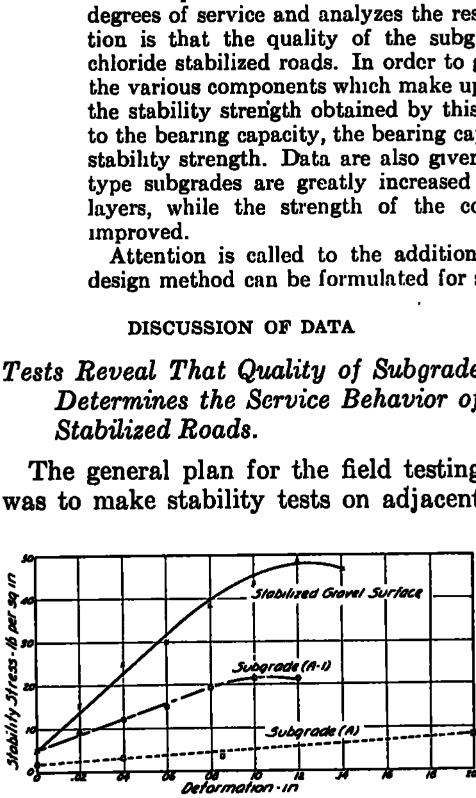


**Figure 1. Project I-2**

**Condition: (A) Badly failed, (A-1) Good**

The laboratory tests on these soil subgrades revealed some interesting results. Subgrade A, had a lower plastic limit of 19.5 and plasticity index of 16.3. The moisture content at the time the field shear tests were made was 21.4 per cent. Subgrade A-1, had a lower plastic limit of 20.7 and a plasticity index of 14.8. The moisture content at time of test was 18.3 per cent. Thus, for an increase of only 3.1 per cent in moisture content, over this critical range, the stability was decreased 75 per cent. Subgrade A, had a moisture content of 10 per cent above its lower plastic limit, and in subgrade A-1, the moisture content was about 12 per cent below its lower plastic limit. These results emphasize the importance of keeping the moisture content in cohesive type subgrades below their lower plastic limit and the effect of rather small changes in moisture content, in the vicinity of this value, on the soil stability.

Figure 2 also shows graphically the relationship between shear strength of the subgrade and the service behavior of a well graded and low plasticity crushed stone calcium chloride stabilized base, 6 in. thick, covered with a 2½-in. open type bituminous wearing course. These tests were made in August 1939, about one year after the wearing course was placed. Table 1 contains the physical tests on these subgrades and on the stabilized crushed stone base.

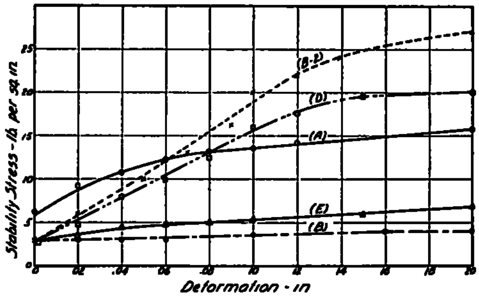


**Figure 2. Project I-1. Subgrades Condition: (B) badly failed, (E) badly failed, (A) slightly deformed, (D) good**

TABLE 1

SOIL TESTS ON SAMPLES FROM PROJECT I-1

| | Mechanical analysis | | | | | | | | Physical characteristics | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample | Passing ¾ in. Retained on ½ in. | Passing ½ in. Retained—No. 4 | Passing No. 4 Retained—No. 10 | Coarse sand No. 10—No. 40 | Fine sand 0.42—0.05 mm. | Silt 0.05—0.005 mm. | Clay 0.005—0.001 mm. | Colloids Below 0.001 mm. | Moisture content | Weight per cubic foot (dry) | Liquid limit | Plasticity index | Shrinkage limit | Field moisture equivalent | Volume change | Lineal shrinkage | Specific gravity | pH value | P. R. A. Classification |
| | | | | | | | | | % | lb. | | | | | | | | | |
| A | 7 | 5 | 2 | 1 | 41 | 21 | 12 | 11 | 16.3 | 106 | 29 | 11 | 16 | 26 | 19 | 6.0 | 2.60 | 6.2 | A-2-4 |
| B | 0 | 8 | 6 | 7 | 15 | 37 | 13 | 13 | 24.6 | 91.8 | 50 | 26 | 12 | 33 | 41 | 10.8 | 2.66 | 7.4 | A-7-6 |
| B-2 | 2 | 3 | 4 | 4 | 18 | 33 | 18 | 18 | 13.0 | 106 | 41 | 20 | 12 | 29 | 34 | 9.5 | 2.66 | 7.4 | A-7-6 |
| D | 3 | 29 | 14 | 16 | 15 | 14 | 6 | 3 | 13.0 | ..... | 22 | 5 | 14 | 22 | 17 | 5,1 | 2.60 | 7.2 | A-2 |
| E | 0 | 2 | 2 | 1 | 10 | 54 | 18 | 13 | 23.6 | 92.5 | 45 | 21 | 12 | 32 | 38 | 10.4 | 2.63 | 7.2 | A-7 |

Average gradation of calcium chloride stabilized base, passing 1 inch 98 per cent, passing ¾ inch 79 per cent, passing ½ inch 63 per cent, passing No. 4 sieve 48 per cent, passing No. 10 sieve 33 per cent, passing No. 40 sieve 22 per cent and passing No. 270 sieve 10 per cent. Plasticity index 3.0.

The tests shown in Curve B-2 were made on the soil in the shoulder adjacent to the location of tests given in Curve B and at a similar depth. The increased shear strength shown in Curve B-2 is due to the lower moisture content in the subsoil of the shoulder. From the results given in Table 1, the moisture content in sample B-2 was only 62 per cent of its lower plastic limit while the moisture content of sample B was 103 per cent of its lower plastic limit. The shear strength of the B-2 subgrade was approximately seven times greater than that of subgrade B. These tests were made within 6 ft. of each other and the physical tests and classification show that the materials are similar. Table 1 also shows a difference in dry weight per cubic foot of 14 lb. in favor of subgrade B-2.

The subgrade shown in Curve E had a moisture content equivalent to 98 per cent of its lower plastic limit and the

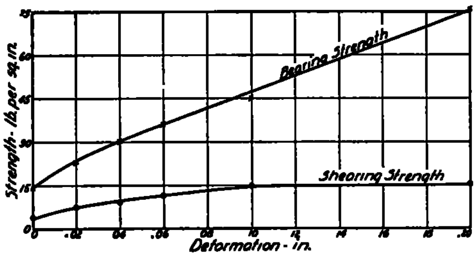


**Figure 3. Relation of shearing to bearing strength Project MJ-1**

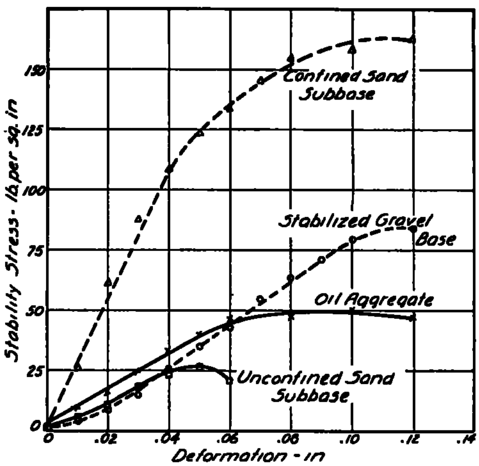


**Figure 4. Project M-2**

road structure was badly failed. Curve A represents a subgrade with a moisture content 91 per cent of its lower plastic limit and there was slight deformation noted in the road surface. The subgrade shown in Curve D had a moisture content equivalent to only 76 per cent of its lower plastic limit and the road surface was excellent. The shear strength of this subgrade would probably have been higher if it had been tested in a confined condition as the results given in Table 1 show it to possess a low plasticity index and a large quantity of fine internal friction type of material.

The failures in this road were due to a combination of unusual environmental conditions that permitted water to become entrapped in the high cohesive type subgrade, with the detrimental results shown quantitatively in Figure 2.

These two figures show that when the shear strength of a cohesive type subgrade is reduced to a certain value the service behavior of the road will suffer, regardless of how well the other components in the road structure are designed.

*Relationship of Shearing to Bearing Strength of Cohesive Subgrades.*

Figure 3 shows graphically the relationship of the shearing strength obtained by this machine to the bearing strength of cohesive type soils. The same size and shape plate was used in making these tests. The plate was parabolic in shape and had an area of approximately 14 sq. in.

The results of this test and others show that the unit bearing capacity of cohesive soils is approximately three times that of the unit shear strength obtained by this machine, when the tests are made with plates having the same shape and area. The relationship is based on the strength in shear at its yield point. The effect of different size and shape plates has not been studied.

*Interrelationship of Stresses and Deformations in a Three Component Road Structure, When Each Component Is Tested Individually.*

Figure 4 shows graphically the stress and strain results of the individual elements in a three component road structure.

The SC-4 oil aggregate wearing surface was $2\frac{3}{8}$ in. thick and was 5 months old at the time of test. The temperature of the oil mat at the time of test was 62° F. at a depth ¾ in. below the surface.

The rounded gravel stabilized base was 5½ in. thick and had a weight per cubic foot of 150.4 lb. The moisture content at time of test was 3 per cent.

The sub-base was a sand lift 9 in. thick over a heavy clay subgrade. The sand lift material had a gradation quite similar to that of a fine concrete sand and the moisture content at time of test was 5 per cent.

The most interesting stress and strain relationship in this figure is that shown between the oil aggregate wearing surface and the stabilized gravel base. The yield point of the oil aggregate surface is approximately 0.06 in. and the shear strength at this point is 45 lb. per sq. in., which indicates a very good quality. The yield point of the stabilized gravel base is 0.1 in. and it possesses a shear strength of 80 lb. per sq. in. at this point. But this value of 80 lb. per sq. in. cannot be utilized for design purposes, as it is attained at a deformation of 0.1 in. which is greater than the yield point (0.06 in.) of the oil aggregate mat. That means for basic design purposes the shear strength of the stabilized gravel base at or slightly below the yield point of the oil aggregate surface, should be used. In the present case the strength of the base at this point (0.06 in.) is approximately 45 lb. per sq. in., which can be classed as good. A similar analysis of the relationship between the stabilized base and the confined sub-base can be made.

The characteristics revealed by these two curves indicate that it is possible to have a surface failure and not a base failure due to loading. A wheel load of such intensity as to cause an 0.08-in. movement in the base would not cause it to fail as this movement is less than its yield point, but this deformation is greater than the yield point of the oil aggregate surface, and small cracks would be expected to appear. In general, this figure shows that by knowing the characteristics of the individual components, their interrelationship can be determined and the service behavior of the entire road structure can be predicted.

*Strength of Overlying Components Greatly Increase the Stability of Frictional Type Subgrades.*

In Figure 4 is shown graphically the stress and strain results of the sand sub-base tested in an unconfined and a confined condition. The unconfined tests were made on the sand sub-base after removing the oil aggregate surface and stabilized gravel base. The confined tests were made by testing the sand sub-base with the overlying components in place and acting as a surcharge.

The results show that the unconfined sand sub-base had a shear strength of 25 lb. per sq. in. at a deformation of 0.04 in. For a similar deformation the confined tests revealed a shear strength of 110 lb. per sq. in. In other words the confining action of the overlying stabilized gravel base and the oil aggregate surface increased the shearing strength of the sand sub-base approximately five fold. The effect of this surcharge appears to be a function of the inherent strength of the overlying layers rather than of their weight.

A sand lift should be so constructed that it extends across the full width of the road grade and should never be placed in an undrained trench.

In general this figure shows that the use of sand lifts over heavy soils is probably the most effective means of obtaining high supportability and at the same time cutting off the detrimental capillary action of cohesive type subgrades.

*Strength of Overlying Components Only Slightly Increase the Stability of Cohesive Type Subgrades.*

Figure 5 shows graphically the stress and strain results of an unconfined and a confined clay loam subgrade along with that of the overlying calcium chloride crushed stone stabilized wearing course. The results show that the shear strength of the confined cohesive subgrade is only about 10 lb. per sq. in. stronger than the unconfined subgrade. In other words, the confining action of the 50 lb. per sq. in. stabilized crushed stone wearing course

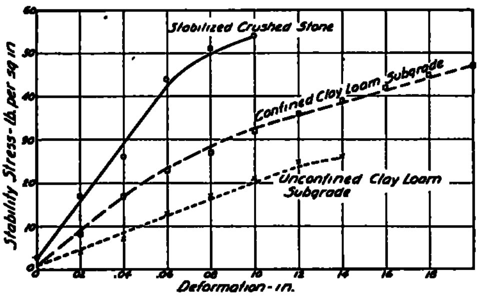


**Figure 5. Project W-1**

only slightly affects the shear strength of the cohesive type subgrade.

It is possible that as the cohesive type subgrades decrease in shear strength, such as under certain conditions in the spring, that the overlying layers will have no beneficial effect. Such a condition would be one in which the yield point of the subgrade would be greater than that of the overlying layers and the applied load would have a tendency to compact rather than displace the subgrade vertically.

*A Set of Tests Revealing an Ideal Stress and Strain Relationship Between the Base and Wearing Course.*

Figure 6 shows graphically an ideal relationship between the stress and strain characteristics of a calcium chloride stabilized gravel base and an oil aggregate surface. This figure shows that the stress and strain relationship of these two components are almost identical up to the abnormally high shear strength of 115 lb. per sq. in.

The oil aggregate surface contains an SC-8 oil and was 5 months old at time of test. The total thickness was 2½ in. and the temperature of the mat was 60° F. at time of test. The calcium chloride stabilized gravel was 5½ in. thick and contained 38 per cent of crushed material.

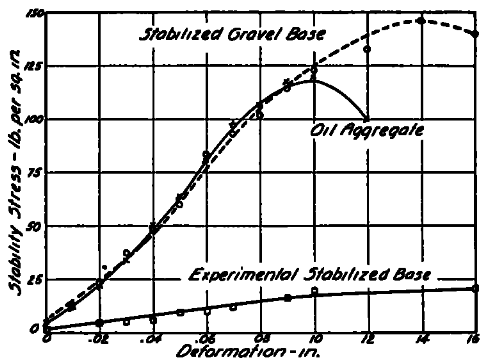


**Figure 6. Project M-3**

The moisture content at time of test was 4 per cent.

The shear strength of 120 lb. per sq. in. for the oil aggregate surface is the highest strength ever obtained for this type of mat, and the 145 lb. per sq. in. is the highest value obtained to date on a calcium chloride stabilized road surface or base.

In general this figure shows what can be attained in the way of both high quality and similarity in structural properties between the components in a road structure of this type. The lower curve in this figure contains the results obtained on a short experimental section in which a light bituminous material was mixed in with the regular stabilized material. The oil aggregate surface placed over this base failed badly. The results given in Figure 6 show the lack of sufficient stability. This stability was probably less in the summer due to the higher temperature (absorbed heat), as it was at this period that the surface failures occurred.

CONCLUSIONS

The results obtained by this machine show:

1. That to fully evaluate the significance of the stability factor of each component, it is necessary to obtain the stress and deformation data along with the moisture content and density of the structure at the time of test. These tests should be supplemented by the gradation and regular soil constant tests, as there is some indication that a soil factor may be derived from a combination of these tests which is related to the stability factor.
2. That the relationship between the stability of confined and unconfined subgrades of the frictional and cohesive types is widely different, the confining action affecting the strength of the cohesive types tested only slightly, but greatly increasing the strength of the frictional type.
3. That the stability strength obtained by this machine on cohesive soils is related to the bearing capacity. The bearing capacity being approximately three times the stability strength.
4. That based on the service behavior of stabilized mats of normal thickness, the cohesive type subgrades may be classed as follows:

| Shear strength (lb. per sq in ) | Service behavior |
|---|---|
| Over 30 | Excellent |
| Over 20 | Good |
| Between 20 and 15 | Good to fair |
| Between 15 and 10 | Fair to poor |
| Below 10 | Very poor |

For the frictional type subgrades the confined tests gave the better indication of their true worth and the surcharge effect of the overlying layers appears to be a function of their inherent strength instead of their weight.

5. That a thorough study of the stress and deformation relationships of the different components that make up a non-rigid type road structure offers a very promising field for the development of a design method, as from the characteristics of the individual components and their interrelationships, we may be able to predict the performance of the road structure as a whole. The results indicate that only the stress developed in the stabilized base and subgrade at or slightly below the yield point of the wearing surface should be used for designing purposes.

The machine provides a means of eliminating incorrect deductions for failures.

It also is a means of obtaining quantitative data which when interpreted will lead to the elimination of the present unsatisfactory qualitative term—stabilization.

Field testing offers the quickest and most practical means of getting information from which some type of a design method may be formulated, as here you have the actual evidence of the behavior of the road structure under the forces of traffic and weather.

ADDITIONAL INFORMATION NEEDED

Before a tentative design method can be formulated for stabilized road structures, it will be necessary to:

A. Acquire more data similar to that included in this report, which correlates the structural qualities of each component to the service behavior of the road during varying climatic conditions.

B. Correlate the shear test results of the base and wearing course to their ability to distribute the imposed wheel loads over larger areas of the subgrade. This also includes the factor of thickness of these layers. The present work on load distribution being carried on by Iowa State College and the National Crushed Stone Association will undoubtedly produce valuable information.

C. Determine quantitatively the values of layers of different thicknesses of frictional material, such as sand lifts, on heavy soils for increasing supportability of stabilized mats and for breaking the detrimental capillary action of the cohesive soils. The Calcium Chloride Association through a Research Fellowship at Michigan State College expects to study this problem during the present year by a series of circular track tests.

Information is also needed on the correlation of the results obtained by this machine with those determined by the laboratory tri-axial loading method. In such a case the quantitative effect of such variables as, moisture content, density, "seasoning," and other structural variables could be controlled and determined. It is possible that the field testing apparatus may be utilized as a laboratory machine for testing stabilized soil slabs, in which the above mentioned variables could also be controlled.

Based on experience obtained during the inspection of several hundred miles of flexible type roads in "spring breakup" periods, there appears to be a need for more information on why the light (less than $\frac{3}{4}$ in.) bituminous surface treatments are more susceptible to surface failure than are the heavier (over $1\frac{1}{2}$ in.) types on similar stabilized bases.

On the roads which are covered with the lighter bituminous mats, the upper inch or so of the stabilized base directly under the bituminous mat softens and this causes the thin surface mat to deform, crack and sometimes peel off. This is not the case with the heavier bituminous mats.

The following factors in the problem apparently need to be studied:

A. Are the thin bituminous mats pervious and do they permit water to enter either during the fall rains or during the spring thaws? Or is this an accumulation of surface and capillary moisture? Are the thicker mats impervious to moisture?

B. Are the thin bituminous mats insufficient insulating layers and do they so regulate the rate of freezing as to cause a concentration of fine ice crystals in the upper layer of the stabilized base? What are the insulating properties of the thicker bituminous mats?

C. Do the thin bituminous mats absorb the heat of the sun to such an extent as to cause rapid thawing of the upper layer of the stabilized base and does this plus the vibratory action of traffic cause the semi-plastic condition? What is this effect on the thicker mats?

D. Does the structural strength plus the increased thickness of the thicker mats distribute the loads over a larger area of the base and thus produce more favorable results?