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COMMITTEE ON FLEXIBLE PAVEMENT DESIGN

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REPORT OF SUBCOMMITTEE ON METHODS OF SUBGRADE, SUBBASE, AND BASE PREPARATION FOR STRENGTH

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SYNOPSIS

Strength as used in this report is the resistance of compacted soil mixtures to plastic flow or consolidation and their ability to distribute load The report reviews methods for selecting, proportioning and mixing, control of water, compacting, making field control tests and preparing subgrade

The reviews led to the following conclusions and recommendations.

1. More soil surveys and their use to better advantage are needed
2 Mechanical mixing is recommended.
3 Equipment for compaction in one pass and for direct compaction of sandy soil is needed.
4 Drainage should receive more attention
5. Greater subgrade density and thickness should be required
6 In specifying density more attention should be given to strength of mixture
7 Laboratory tests for correlation with field tests of density are needed
8 Contracting and inspecting personnel should know more about basic principles of soil compaction
9. Attention should be given to possibility of frost damage.

The assignment of the subcommittee is: "Examination of all the present methods of construction procedure by means of which the inherent values of soils of any type may be developed to the greatest degree, with the view of making some recommendations in regard thereto and also indicating need of new types of equipment if any"

It is recognized that soil mixtures can be rendered more or less stable by a process of densification. The degree of stability can be measured by the resistance of the compacted mixtures to. (1) volume changes when submitted to drying and freezing, and (2) absorption of water by capillarity, gravity, condensation and frost action. The resistance to these natural destructive agencies is governed not only by the degree of compaction but also by the gradation of particles, plasticity and other factors not as yet completely understood.

The strength of a soil or soil mixture is governed by its dry bulk density which in turn limits the water content. There are mixtures which, at a given density, have the same strength at all water contents, but in the majority of cases the strength, at a given density, varies with the water content. In general it can be stated that in order to be able to pre-determine the minimum strength of any compacted soil or soil mixture its maximum water capacity must be known. Not enough data are available from which to draw definite conclusions but indications are that soil mixtures can be designed which will not take up any more water by any of the natural processes than is indicated by the optimum point on the moisture-density relation curve. This optimum can be varied by varying the compactive effort

The term "strength" as used in this report is intended to express the resistance of the compacted soil mixture to plastic flow or consolidation under load as well as the ability to distribute load.

It is evident from the foregoing considerations that the design of soil mixtures is of primary importance, since only by proper design can the inherent properties of soil mixtures be developed. However, as far as our subcommittee is concerned we will confine ourselves to a study of field construction methods now being used to develop the properties specified. We will also make some suggestions regarding future design and construction methods

In reviewing the methods now in use to impart durability and strength to soil mixtures we will consider: (1) selection, proportioning and mixing of soils and soil-aggregate mixtures, (2) water control, (3) compaction methods, (4) field control tests, (5) preparation of subgrade, (6) compacted soil pavements. It is not our intention to make a minute study of each item but rather to point out major trends.

SELECTION, PROPORTIONING, MIXING

Soil surveys are being made on most large projects to depths of from 2 to 10 ft. The data obtained are used to identify and classify soils, eliminate undesirable soils and to furnish information on the moisture conditions The liquid and plastic limit tests together with the mechanical gradation are generally used for classification purposes. The moisture-density relation test is made on typical soils During construction the data obtained from the soil survey are used to select soils and to control the degree of compaction Borrow pits are located and classified in connection with the soil survey.

Usually, enough suitable soils are available but occasionally it is found necessary to mix very heavy clays with sands or silts to produce suitable mixtures As a rule the mixing is done by blading and discing which results in a heterogeneous mixture of sand or silt and mud balls These final mixtures are very undesirable and often worse than any of the materials composing them If such mixtures are to be used successfully they will have to be prepared by mechanical processes which will produce thorough disintegration of the clay component and intimate mixing of the clay and sandy materials.

The preparation of soil-aggregate mixtures which are used as sub-bases or bases requires even greater attention since they are expected to be stronger and more stable. In addition to thorough mixing the gradation and plasticity must be closely controlled. At the present time mixing is being accomplished by one of two general methods The oldest and most widely used method is by mixing in place by means of blades, discs and harrows In recent years travelling and stationary mechanical mixers have been used to some extent In connection with the blading and travelling mixer methods proportioning is done by the windrow method In stationary set-ups proportioning is done either by volume or weight In the blading method the water is added usually in two or more increments but in the mixer methods all the water, including a small excess, is added at one time

Judging from results and performance the stationary mixer method gives the best results, with the travelling mixer and blading methods following in order.

WATER CONTROL

Water is added either on the subgrade or in borrow pits in the preparation of the subgrade Either method can produce good results Experience shows that more uniform moisture contents and density are obtained if the water content is slightly in excess of optimum when compaction is started By so doing the feet of the roller will penetrate the entire new lift and will pack from the bottom up Spots which are wetter than the average will be the last to pack but will have the desired density On the other hand having the moisture content on the dry side of the optimum may result in very rapid but so called "false packing" accompanied by low density Adding a slight excess of water is equally important in the compaction of soil-aggregate mixtures.

Excess water in soil mixtures is always removed by a process of natural evaporation, sometimes hastened by discing Driers have been talked of but none have been extensively used to our knowledge

Water lost by evaporation during compaction is replaced by sprinkler trucks

COMPACTION METHODS

The compaction of soil is accomplished principally by sheepsfoot and pneumatic-tired rollers Plastic fine grained soils and soil-aggregate mixtures must be densified by the former whereas slightly plastic soil-aggregate mixtures may be compacted with either one No equipment is available for compacting sands satisfactorily More will be said about the compaction of sands under "The preparation of subgrades" Sound crushed rock may be densified by heavy flat rollers while crushed rock containing appreciable amounts of soft fragments may be densified by the sheepsfoot roller which produces binder material during the compaction process

Engineers generally specify a degree of compaction equal to 95 per cent of the maximum density determined by the A S T M or A A S H O test methods[1] for subgrade and 100 per cent for sub-bases and bases. Recently the United States Engineer Department, U S Army, has modified the methods to increase the compactive effort several hundred per cent In the field both the Army and Civil Aeronautics Administration require a density of from 95 to 100 per cent of these standards.

Field results indicate that with present equipment fine-grained plastic soils can be compacted to 95 per cent of standard density quite easily and to 100 per cent with some difficulty Soil-aggregate mixtures with low plasticity indexes can be compacted to 100 per cent with moderate care. On the other hand it has proven very difficult and sometimes impossible to compact plastic soils to 95 per cent of the U S Engineer Dept. density. With soil-aggregate mixtures 100 per cent of the U. S E. D. density is obtainable with moderate care.

It is evident that if the U S E D. standard is to be used as a basis of field compaction for plastic soils, either more effective equipment will have to be developed or new ways of using the present equipment will have to be devised.

In connection with methods of compaction it should be pointed out that it is generally assumed that the density produced by the standard laboratory method provides adequate strength. This assumption is erroneous since the strengths of soils compacted to standard maximum density vary widely and in most cases are very low It appears, therefore, that strength, rather than one compactive effort, should be used as a criterion for design

The so called "curing of compacted soils" is very beneficial The expression refers to the expulsion of small amounts of water after densification is practically complete It has been found in practice that nearly all the densification required can be obtained with a slight excess of water and sheepsfoot rollers moderately loaded. After this stage has been reached the mixture is allowed to lose water by evaporation while undergoing rolling with pneumatic equipment Very high densities can be developed in this manner If plenty of time is available this combined method of densifying soils is probably the most economical

When sheepsfoot rollers are used for compaction it has been found expedient to finish

[1] "Tentative Method of Test for Moisture-Density Relations of Soils", A S T M D698-42T

Standard Laboratory Method of Test for Compaction and Density of Soil, A A S.H O T-99-38 the upper inch or so of a layer with pneumatic-tired rollers in order to develop density in the extreme upper part of the layer. Following fine grading flat rollers are used to re-compact loosened material.

FIELD CONTROL TESTS

Field control tests are generally limited to the determination of plasticity index, gradation, moisture content and density. All operators follow practically the same methods in making these tests with the exception of the density test. There are two general methods for determining the volume of the sample. One measures the volume of the space formerly occupied by the sample and the other measures the volume of the sample itself.

When the volume of space method is used, volume is determined by one of three methods, viz: (1) by filling it with standardized sand (2) by filling it with lubricating oil and (3) by filling it with water contained in a thin rubber balloon.

When the volume of sample method is used, volume is determined by the liquid it displaces. By one method the sample is coated with molten paraffin wax before immersion and by another the sample is saturated in kerosene before immersion.

All the methods for determining volume are basically sound and will give correct results if used properly. In general, however, the standardized sand method for measuring volume of space is the most practical for all all mixtures. The saturated kerosene displacement method for measuring volume of sample is used extensively also for plastic mixtures. These two methods are used more widely than the others.

It should be pointed out that, in determining the volume of the sample by the displacement method, only cohesive masses can be used and for that reason loosely bound mixtures or layers should not be tested in this manner. Very porous masses should not be tested by the oil method.

The testing of compacted mixtures containing aggregate larger than the opening of a No. 4 sieve is causing some confusion and controversies in the field. This situation arises from the fact that the standard moisture-density relation test requires that all the material used must pass a No. 4 sieve. In the field, however, the amount retained on the No. 4 sieve may be as high as 60 per cent and the maximum size may be 1½ in. or larger. To set up standards for the entire mixture some calculate the density of the final mixture by using the maximum density of the minus No. 4 material and the percentage and the specific gravity of the 'plus' No. 4 material. Others determine the moisture-density relations on the minus ¾ in. material and then calculate the maximum density of the entire mixture. In making field density tests some use the entire sample and others discard the 'plus' No. 4 or ¾-in. material as the case may be and thus determine the density of the fine portion of the sample only.

It is known that the theoretical density of a mixture of minus No. 4 or minus ¾ in. and plus No. 4 or plus ¾ in. is higher than that actually obtained. It is also known that the theoretical optimum moisture is lower than the actual for the same mixtures. This means that the density requirements in the field are actually higher than they should be and that the optimum moisture is lower than it should be. Consequently, the field densities are always lower than anticipated even with good control and compactive effort. Naturally the good inspector insists on getting what he considers the proper density but the contractor complains that some one is wrong in the design department. As a remedy either the moisture-density relation should be determined on the entire sample or proper corrections should be applied if the test is made on only a portion of the mixture.

SUBGRADE

Natural subgrades may be classified roughly as strong or weak. Strong subgrades may be further subdivided into two classes, cohesive and non-cohesive. Strong cohesive subgrades normally consist of fairly dry plastic soils. During construction, very little is done to them before superimposing other layers except that occasionally the upper few inches is scarified, brought to the desired moisture content and densified. These subgrades are strong because of their low water content which is the result of naturally good drainage. Unless good drainage is provided as part of construction they may become very weak.

Non-cohesive or sandy subgrades are not strong in the sense that they will not resist abrasion, but are very strong in load supporting value, if properly densified and confined. They are usually compacted indirectly. Two methods are proving satisfactory and are based on the confining effect of plastic mats. By one process plastic material is incorporated into the upper few inches of the sand and densification is accomplished, with pneumatic-tired equipment. By the other process a few inches of plastic material are placed above the sand and densification accomplished with sheepsfoot rollers. With either method the higher the compactive effort the greater and deeper will be the effect on the sand.

Weak subgrades are generally composed of wet plastic, or semi-plastic mixtures In constructing above them three procedures are followed: (1) If the condition is spotty, the wet material is removed and replaced with dry material compacted to the same density as the adjoining normal soil; (2) If drainage will remedy the condition the water is removed, (3) If construction must be done on the subgrade as found, one of two methods or a combination of the two is used. Either suitable soil is compacted above the subgrade or a layer of granular material is added to the subgrade followed by compacted soil To insure good compaction in the superimposed layers the upper portion of the subgrade is allowed to dry whenever possible before the addition of new material The thicknesses of superimposed soils or granular materials depend on the subgrade support required.

With any type of subgrade, drainage is beneficial as it preserves the strength of the untreated portions of the subgrade soils and prevents possible softening of the superimposed layers. Engineers in general recognize this principle but are slow to apply it in detail.

Some attention is being given to the possible effects of frost action on subgrades and added layers. Some engineers demand a layer of sand between the subgrade and the superimposed layers Others attempt to get well selected and densified soils to a depth down to the frost line. Still others treat a portion of the subgrade and added layers with a chemical, such as calcium chloride, to prevent freezing

COMPACTED SOIL PAVEMENTS

While compacted soils and soil aggregate mixtures can be made fairly resistant to the destructive forces of nature, best results can be obtained by restricting their uses to subgrades, sub-bases, and bases. Wearing surfaces of other materials must be used above them not only to resist abrasion but to protect the soils from surface moisture. Research and experience have shown that properly designed and densified soil mixtures will resist absorption by capillarity but will disintegrate from the surface downward by the combined actions of water and traffic

The thickness of the wearing surface depends on the strength of the soil layered system, the type of wearing surface and the imposed load. The soil layered system can be made so strong that only a thin bituminous coarse will be required to handle extremely large wheel loads.

CONCLUSIONS OF THE SUBCOMMITTEE

As a result of our study we make some recommendations which in our opinion will benefit the design and construction of flexible pavements.

1. More and better soil surveys should be made. The information obtained should be used to better advantage.

2. Soils and soil-aggregate mixtures should be mixed in mechanical devices capable of producing intimate mixtures.

3. The compaction equipment now available is capable of producing satisfactory densification. However, a type of equipment which would compact mixtures in one pass would not only produce more uniform results but would save much time and perhaps money. In addition, some type of equipment which will compact sandy soils directly is needed.

4. Lack of adequate drainage has contributed to failures. This item deserves more attention than it has had in the past.

5 In preparation of subgrade more density should be required and greater thicknesses should be used since load carrying capacity can be attained most economically in this manner

6. In specifying degree of density more attention needs to be given to the strength of the compacted mixture At present the maximum density produced by the A S.T.M. or A.A.S.H O. test methods is more or less accepted as being sufficient to produce adequate strength. Actually the strength, at this density and corresponding optimum moisture varies greatly among soils of different types. Eventually, we should use some strength index test as the criterion for design. Another factoı that needs attention in connection with moisture density relationships is the percentage of air-voids at maximum density and optimum moisture. Laboratory tests indicate that unless the air-voids are low at optimum conditions the compacted sample will take up water Therefore, in addition to designing for strength we should also design for permanence by restricting the water capacity of the compacted mixtures

7. Methods need to be developed for the determination of density in the laboratory so that field tests can be correctly correlated with them

8 Both the contractors and the field inspection personnel need to know more about the basic principles of soil compaction

9 The possibility of damage by frost action should be given more attention. However, it should be pointed out that a great many compacted soil mixtures will withstand frost action even under very adverse water conditions.

FLEXIBLE PAVEMENT TEST SECTION FOR 300,000-LB. AIRPLANES, STOCKTON, CALIFORNIA

By Ralph A. Freeman, *Senior Engineer* and O J. Porter,[1] *Consulting Engineer Pacific Division, Corps of Engineers*

SYNOPSIS

A special test section has been constructed at Stockton Army Airfield by the Corps of Engineers to obtain data for the establishment of flexible pavement design criteria for 300,000-lb airplanes, using the California Bearing Ratio method

The test section proper is a paved area 70 ft wide and 650 ft long which is divided into 23 different items Each item is of a different design having total thicknesses varying from 40 to 66 in over a weak clay subgrade (CBR 8 per cent ±), from 22 to 37 in over a medium strength clay loam subgrade (CBR 24 per cent ±) and from 7 to 22 in over a strong sand subgrade (CBR 50 per cent ±). A high quality asphaltic concrete pavement varying from 2 to 16 in. in thickness and a crushed rock base (CBR 100 per cent +) varying from 0 to 19 in in thickness, are being tested

Data are being obtained on the relative behavior of these subgrades when protected by different thicknesses of pavement, or by combinations of various thicknesses of pavement and foundation materials, and subjected to the accelerated traffic of a heavily loaded 110-in. diameter airplane tire.

Accelerated traffic of this huge tire mounted in a mammoth testing rig of unique design and loaded to 150,000 lb has been uniformly distributed over a 20-ft. wide traffic lane in each item Because of the trend towards heavier airplane loads the wheel load will be increased to 200,000 lb or more, if feasible, and traffic continued over all items until failure, or until 2,000 coverages (repetitions of load) have been completed

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