# BEARING INDEX OF SOIL AS A CRITERION FOR THE MAXIMUM DENSITY REQUIREMENT

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## SYNOPSIS

In this paper a method is proposed for the use of strength as a criterion for the design of compacted soil and soil-aggregate mixtures to be used in constructing sub-bases and bases for flexible pavements The data presented in the paper show that at maximum density and optimum water content, as obtained by the standard A S T M method, the strength of soil mixtures varies widely and in general is quite low. It is also shown that, with a given soil mixture, the strength increases as the bulk density increases. Advantage is taken of this fact to devise a method whereby equal strengths may be developed in all soil mixtures

The method proposed is as follows: (1) Maximum Density and Optimum Moisture is determined on a given soil, or soil-aggregate, mixture by three compactive efforts whose energies are in the ratio of about one, two, and four The strength of the soil mixture at the three maximum densities and optimum moistures is then determined, and the strengths obtained are plotted against densities. From the resulting graphs the densities can be determined for the various mixtures under study which will give equal strength The strength of the mixture is taken as the load which is required to produce ½ in total deformation with a two in diameter bearing block on the surface of a soil mass compacted into a mold eight in. in diameter and four in. in height. This load is designated as the "Bearing Index."

The energy in foot-pounds per cu in of compacted material required to develop the desired strength may be determined by plotting energy against strength.

The authors believe that the use of strength as the criterion for maximum density requirements will result in more accurate pavement design and will give proper consideration to the inherent strength properties of soils.

### GENERAL

In the design of flexible pavements for load carrying capacity, the strength of the layers superimposed on the subgrades is of prime importance. Nevertheless at the present time the strengths of layers of compacted fine-grained soils and soil-aggregate mixtures are not controlled. Generally it is merely assumed that compaction to maximum density, or to some percentage of maximum density, at optimum moisture content by the standard A.S.T M. method (1)[1] develops adequate strength.

Laboratory investigations reveal that soils and soil aggregate mixtures possess a wide range of strengths when compacted to maximum density by the standard method. Load bearing tests made on test sections constructed in the field under rigid control, indicate that the strength imparting power of superimposed layers, per inch of thickness, varies with the different soils or mixtures, even though they are all compacted to standard maximum density. Compaction to maximum density by other methods such as that of the U. S. Engineers (2) which applies considerably more compactive effort than the A.S.T.M. method, also develops different strengths in different soils or soil-aggregate mixtures.

It is evident therefore that uniform strength cannot be developed by using any one compactive effort. However, uniform strength can be developed by using the proper compactive effort. In this paper we are proposing a method for doing so, but instead of using the compactive effort as the criterion for design we will use the dry bulk density produced by the effort. This is done because it is much easier to specify density in the letting of contracts, than it is the compactive effort

Briefly the procedure is as follows·

1. The maximum density and optimum moisture are determined on the sample by three different compactive efforts. 2. The strength is determined at each maximum density. 3 A graph is constructed by the

[1] Figures in parentheses refer to the list of references at the end of the paper

use of maximum density and strength. 4. The density which indicates the desired strength is then selected from the graph.

STRENGTH AND BEARING INDEX DEFINED

Before proceeding with the development of the method, it will be necessary to define the terms "Strength" and "Bearing Index" as used in this paper. The strength of a compacted soil mixture is measured by its resistance to consolidation or displacement. The load in pounds required to produce ¼ in. total deformation on the surface of the soil with a bearing block 2-in. in diameter is designated as the bearing index.

The strength test we propose to use is not new. It has been used by us since 1936, (3, 4) as a guide in the design of airport runways. Mr. O. J. Porter in 1942 (5) reported the use of a similar test by the California State Highway Department in connection with the determination of the bearing ratio of soils. Both tests measure the resistance of the soils to consolidation and displacement, or plastic flow.

DEVELOPMENT OF METHOD

To demonstrate that the bearing index of different soils and soil-aggregate mixtures compacted by the same method varies widely, and to show that with any one soil the bearing index increases as the compactive effort increases, we are presenting data on six typical fine-grained soils and an equal number of soil-aggregate mixtures. Some characteristics of these soils and mixtures are given in Table 1

In Table 2 are given the maximum densities and optimum moistures of all the materials as determined by the A S T.M. method. The same information obtained by two other methods is also included. Method No. 2 is the same as the A S T M. except that a 10-lb. hammer is used. Method No 3 is that used

TABLE 1
CHARACTERISTICS OF SOIL MIXTURES

| Soil | | Gradation—Passing Sieve No | | | | | | Liquid Limit | Plasticity Index | Spec Gr |
|---|---|---|---|---|---|---|---|---|---|---|
| No | Source | 270 | 200 | 40 | 10 | 4 | ¾-in | | | |
| | | % | % | % | % | % | % | % | | |
| 1 | Omaha, Nebr | 84 0 | 88 0 | 100 0 | 100 0 | 100 0 | 100 0 | 29 5 | 5 0 | 2 69 |
| 2 | Omaha, Nebr | 98 0 | 100 0 | 100 0 | 100 0 | 100 0 | 100 0 | 34 5 | 10 5 | 2 70 |
| 6 | Kearney, Nebr | 85 0 | 97 5 | 100 0 | 100 0 | 100 0 | 100 0 | 38 0 | 19 0 | 2 68 |
| 9 | Grand Island, Nebr | 48 0 | 51 4 | 80 0 | 100 0 | 100 0 | 100 0 | 24 0 | 9 0 | 2 62 |
| 10 | Waterloo, Ia | | 34 6 | 67 6 | 94 4 | 100 0 | 100 0 | 24 2 | 7 7 | 2.65 |
| 13 | Scribner, Nebr | 96 8 | 98 6 | 99 8 | 100 0 | 100 0 | 100 0 | 41 7 | 21.1 | 2 60 |
| Soil-Aggregate | | | | | | | | | | |
| No. | Source | | | | | | | | | |
| 1 | Omaha, Nebr | | 20 0 | 30 0 | 60 0 | 88 0 | 100 0 | 26 5 | 7 5 | 2 63 |
| 2 | Omaha, Nebr | | 20 0 | 30 0 | 60 0 | 88 0 | 100 0 | 34 0 | 21 0 | 2 62 |
| 7 | Waterloo, Ia | | 7 2 | 24 7 | 42 5 | 47 3 | 100 0 | 15 2 | 2 8 | 2 63 |
| 8 | Sheridan, Wyo. | | 13 8 | 26 2 | 52 3 | 61.6 | 100 0 | 24 5 | 13.0 | 2 60 |
| 9 | Omaha, Nebr | | 11 4 | 26.3 | 47 3 | 71.9 | 100 0 | 20.1 | 4 8 | 2 61 |
| 11 | Waterloo, Ia | | 11 2 | 30.1 | 75 1 | 91 7 | 100 0 | 23 0 | 5.0 | 2 64 |

TABLE 2
MAXIMUM DENSITIES AND OPTIMUM MOISTURES WITH DIFFERENT METHODS OF COMPACTION

| Soil No | Densities and Moistures | | | | | |
|---|---|---|---|---|---|---|
| | Method No 1 | | Method No 2 | | Method No. 3 | |
| | Density | Moisture | Density | Moisture | Density | Moisture |
| | *lb. per cu. ft.* | % | *lb per cu ft* | % | *lb. per cu. ft.* | % |
| 1 | 113 5 | 15 0 | | | | |
| 2 | 110 0 | 18 0 | 112 5 | 17 0 | 116 2 | 15 7 |
| 6 | 107.5 | 18 1 | | | | |
| 9 | 124 2 | 10 5 | | | | |
| 10 | 113 7 | 15 0 | 117.5 | 13 2 | 124 3 | 10 6 |
| 13 | 101 0 | 18 5 | 106 6 | 17 9 | 109.2 | 16 0 |
| Soil Aggregate No | | | | | | |
| 1 | 139 5 | 6 0 | | | | |
| 2 | 137 5 | 6 7 | | | | |
| 7 | 140 8 | 5 8 | 141 5 | 5.0 | 143 5 | 3 7 |
| 8 | 138.9 | 5 9 | 140.4 | 5 3 | 142 9 | 4 3 |
| 9 | 141 9 | 4 8 | 142 2 | 4.8 | 142 4 | 4 4 |
| 11 | 130 0 | 9.4 | 130 2 | 8 9 | 135 2 | 6.9 |

by the United States Engineer Dept The compactive effort per blow expressed in foot poundals is 177, 322, and 483 respectively, and the energy in foot poundals per cubic inch of material compacted is 235, 428 and 965 respectively.

The results in Table 2 indicate in a general way that the maximum density of all soils and mixtures increases and the optimum moisture content decreases, as the compactive effort increases The effects of increased compactive efforts are more pronounced with fine grained soils than with soil-aggregate mixtures. In fact one base mixture (9) shows hardly any increase

TABLE 3
BEARING INDEX OF SOILS AND SOIL-AGGREGATE MIXTURES AT STANDARD MAXIMUM DENSITY

| Soil No | Bearing Index | Soil Aggregate No | Bearing Index |
|---|---|---|---|
| | lb | | lb |
| 1 | 2,230 | 1 | 1,050 |
| 2 | 580 | 2 | 2,020 |
| 6 | 1,280 | 7 | 430 |
| 9 | 2,220 | 8 | 350 |
| 10 | 810 | 9 | 4,000 |
| 13 | 875 | 11 | 500 |

TABLE 4
BEARING INDEXES AT VARIOUS MAXIMUM DENSITIES

| Soil No. | Max Density | Bearing Index | Soil-Aggregate No | Max Density | Bearing Index |
|---|---|---|---|---|---|
| | lb per cu ft | lb | | lb per cu ft | lb |
| | 110 0 | 580 | | 140 8 | 430 |
| 2 | 112 5 | 1,180 | 7 | 141 5 | 2,620 |
| | 116 2 | 1,900 | | 143 5 | 7,600 |
| | 113 7 | 810 | | 138 9 | 350 |
| 10 | 117 5 | 1,110 | 8 | 140 4 | 1,225 |
| | 124 3 | 4,280 | | 142 9 | 1,800 |
| | 101 0 | 875 | | 141 9 | 4,000 |
| 13 | 106 6 | 1,575 | 9 | 142 2 | 4,450 |
| | 109 2 | 2,600 | | 142 4 | 6,200 |
| | | | | 130 0 | 500 |
| | | | 11 | 130 2 | 580 |
| | | | | 135 2 | 3,310 |

In Table 3 are shown the bearing indexes of all soils and mixtures after compaction to maximum density at optimum moisture by the standard method The results indicate very definitely that the bearing indexes vary widely when one compactive effort is used.

The bearing indexes obtained by compacting soils and mixtures by the three compactive efforts are given in Table 4. It will be noted that with all soils and mixtures, the bearing index increases as the density increases.

The data on the three fine grained soils in Table 4 are shown graphically in Figure 1 to illustrate how densities necessary to produce desired strengths can be determined.

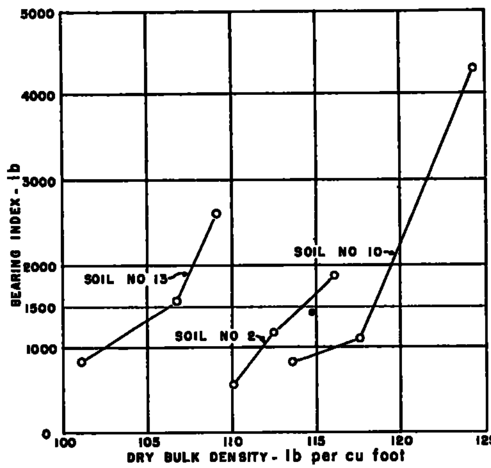


**Figure 1. Density—Bearing Index Relations. Data taken from Table 4.**

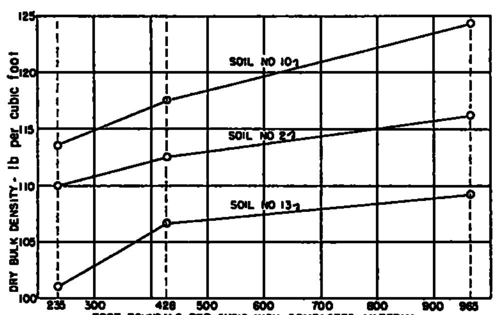


**Figure 2. Density—Energy Relationship**

For instance, if it is desired to obtain a bearing index of 1500 lb with each of the three soils, soil No. 2 will have to be compacted to a density of about 114 lb , soil No. 10 to about 118 lb., and soil No. 13 to about 108 lb

If the energy necessary to produce a required density is also desired, it can be determined by plotting density against energy, expressed in foot-poundals per cubic inch of compacted material, as shown in Figure 2.

By plotting the bearing index against energy the work required to develop equal strength with all soils can be calculated In Figure 3 it will be observed that to develop a bearing index of 1500 lb, soils 13, 10 and 2 require 410, 490, and 665 foot-poundals respectively. Optimum moistures corresponding to selected densities may be determined by plotting optimum moistures against densities

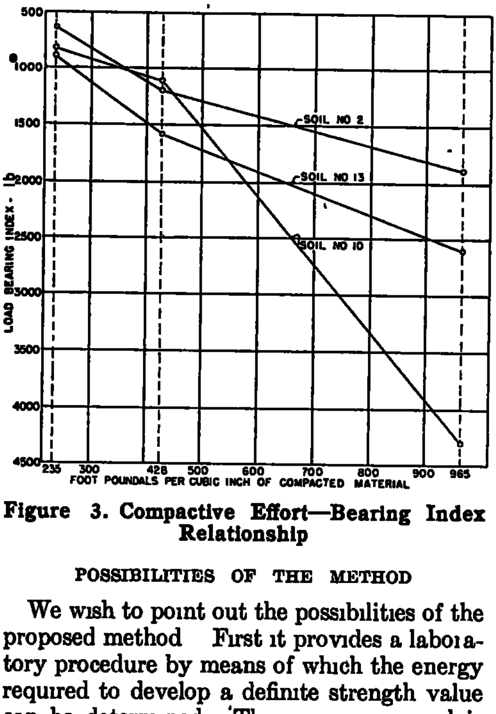


**Figure 3. Compactive Effort—Bearing Index Relationship**

POSSIBILITIES OF THE METHOD

We wish to point out the possibilities of the proposed method First it provides a laboratory procedure by means of which the energy required to develop a definite strength value can be determined. The energy required is correlated with the density developed. The density is later used as a control in construction Secondly it provides a means of determining the least amount of energy required to develop the desired strength in any soil or soil-aggregate mixture This should lead to economy of construction Lastly it provides another tool by means of which flexible pavements can be designed for load carrying capacity more accurately

In conclusion we are not unmindfull of the fact, that compacted soil masses when used as superimposed layers in flexible pavements must be able to distribute loads as well as to support them We do not believe that the bearing index measures the ability to distribute loads However, there is no doubt but that the distributive ability does increase as the bearing index increases For the present it appears that the distributive value of a given mixture at a given bearing index must be determined in the field in terms of strength imparting power (6).

REFERENCES

1 American Society For Testing Materials Method D698-42 T
2 T A. Middlebrooks and G E Bertram, "Soil Tests for Design of Runway Pavements" *Proceedings*, Highway Research Board, Vol. 22, 1942
3 W. H Campen, "Omaha Airport Runways," *Roads and Streets*, May, 1940
4 W H Campen and J R Smith, "Some Physical Properties of Densified Soils," *Proceedings*, Highway Research Board, Vol 22, 1942
5. O J. Porter, "Foundations for Flexible Pavements," *Proceedings*, Highway Research Board, Vol 22, 1942
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# DISCUSSION

MR. H G. NEVITT, *White Eagle Division, Socony-Vacuum Oil Company:* This paper is probably only one of a number of contributions which will be made in exploring the field of the effect of densification on the strength of soils and bituminous mixtures, both of which are extremely important in highway designs It has become quite obvious in recent years that densification is an essential step in the construction of highway pavements It is a logical corollary that control of this densification is an essential point in design and that it must, therefore, be predetermined for this reason and controlled in the actual construction. This paper outlines an approach involving soils and makes some suggestions in connection with the design. Other work, such as has been done or is underway in our own laboratories involves the effects of densification on bituminous aggregate mixtures Eventually the whole field must be explored and from it will come improved control designs and techniques

The paper discussed attacks the problem

rather broadly and by implication reaches some rather basic conclusions. Without attempting to take a position regarding them, it seems desirable to point out some of the factors in the situation.

The data shown are rather interesting While they represent a fair amount of work, it has been our experience that the variability in soils or mixtures in this field, the inaccuracies in testing them, and similar factors all require that more data on any one soil be determined previous to drawing sweeping conclusions. For example, we suspect that five or six points are necessary to get a really reliable densification versus energy curve, and that in general a considerable amount of work must be done before final design techniques can be really worked out. Later comment amplifies this point

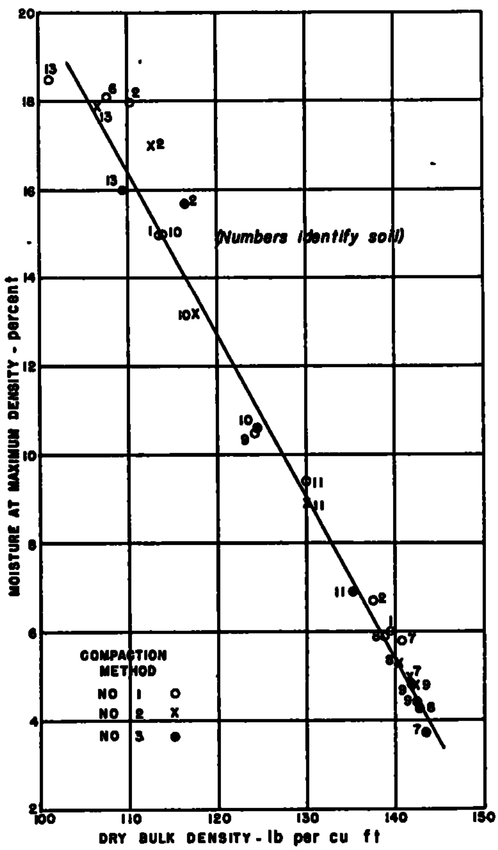


**Figure A. Per cent Moisture of Maximum Density vs. Dry Bulk Density.**

The densification-energy approach is an interesting one, but in our opinion some care is required in its application It remains to be demonstrated that the densification resulting from a given amount of energy applied to the compaction system is independent of the way in which the total energy involved is put in More simply stated, it is not certain that reaching the amount of energy in question by more blows gives the same densification as by obtaining this energy with the same number of more intensive impacts

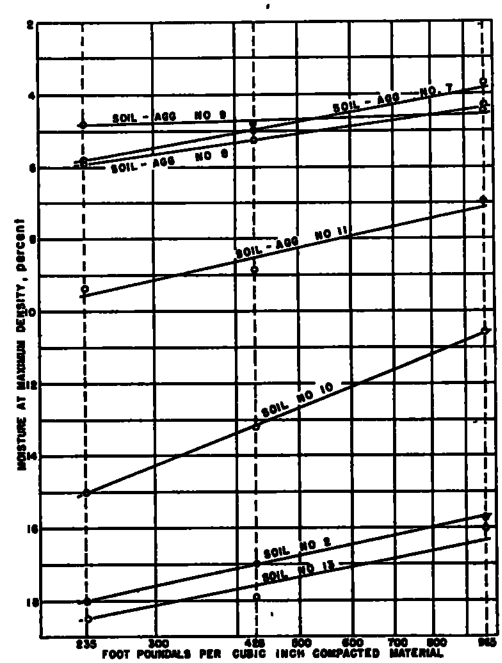


**Figure B. Per cent Moisture at Maximum Density vs. Compactive Effort.**

Furthermore, in comparing different systems of densification, we must deal with the energy received into the soil mass, which may be something quite different from that applied to the equipment system.

Some further analysis of the data supplied in the paper is of interest, particularly the plot of variation of optimum moisture resulting from variation in density due to changing the compactive effort. The curves in Figures A and B speak for themselves. The indicated situation that the densification increase is proportional to the per cent compaction increase is not unreasonable, and Figure B, according to this theory, shows that the data are not always too exact.

Apparently in these finely divided soils the lubricating action of moisture is more important than its weakening effect in shear, and hence for any desired density the optimum water content is roughly that which fills the voids less the amount of entrained air necessarily left. This minimum entrained air corresponding to the optimum moisture is somewhat dependent upon the particular soil, and probably varies with the individual sample, but it tends to lie between 1 per cent and 5 per cent, with some indication that it decreases as the compaction effort increases, all of which seems reasonable enough. An exactly similar situation may not exist in bituminous aggregate mixes.

While the proposal that densification be carried on to an arbitrarily predetermined figure has theoretical merit, it seems a questionable method of design; the economic factors must also be considered, with the cost of densification balanced against thicker bearing courses.

In general, it seems obvious that in addition to the properties of the actual soil or aggregate encountered we must consider not merely the amount of liquid (either moisture or bitumen) present, but likewise the degree of compaction to which the mixture will have been subjected and the consequent density existing at the time of the occurrence of the stress conditions designed for. This paper is a very commendable effort to bring out some of these effects, discloses the importance of the problem, and is therefore an excellent contribution to this field.

# DESIGN AND CAPACITY OF GUTTER INLETS

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IN ABSTRACT[1]

The design and installation of gutter inlets to carry water from city streets to the sewer systems has long been a troublesome problem. The capacities of existing designs are known only in a general way, and new types of construction give no assurance of improvement in capacity.

Several years ago, in Raleigh, North Carolina, the replacement of several types of old street surfaces with smooth concrete base pavement and gutters so increased the rate of run-off that the existing drainage facilities had to be revamped to take care of the additional water. In many instances the sizes of culverts were adequate, but the number, size and design of many of the inlets and catch basins had to be changed to meet the new conditions. A standard design of inlet was adopted for use in the newly-paved streets, which consisted of an opening in the side of the curb 6 in. by 24 in. and a 24 in by 24 in castiron grate in the gutter. Before the paving program had been completed, trouble began to develop because of flooding conditions

In order to secure information on the performance of inlets, the City of Raleigh and the North Carolina State College Engineering Experiment station undertook a joint research project The purpose of the investigation was twofold: first, to determine the capacities of the several types of inlets in use when installed on various grades, and second, to study the hydraulic principles involved whereby improvement in inlet design could be effected, especially on steep grades.

[1]For a complete report of the tests see "Design and Capacity of Gutter Inlets" by N. W. Conner, Bulletin No. 30, Engineering Experiment Station, North Carolina State College, Raleigh, North Carolina.