REPORT OF SUBCOMMITTEE ON DESIGN OF NATURAL SOIL MIXTURES AND EFFECT OF ADMIXTURES OF COMMERCIAL PRODUCTS SUCH AS CRUSHED STONE, GRAVEL AND SLAG

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The design and construction of stabilized road surface and base courses of natural soil mixtures with or without the addition of granular materials is an outgrowth of the experience obtained in building topsoil and sand clay roads, primarily in the Southeastern part of the United States.

Dr C. M Strahan (1)[1] summarized the requirements of suitable road soils (surface courses) as follows:

"(a) Enough clay present to cement the sand and silt in dry or low moisture condition, but not so much clay that its expansion by water will dislocate the seating and embedment bond of the granular particles, viz, the surface should maintain a constant volume

"(b) A liberal amount of coarse sand grains to furnish an adequate seating or bearing bond, not materially affected by water content

"(c) Only moderate amounts of silt and very fine sand A superabundance of silt, very fine sand, and especially of clay tend to reduce percolation after rains and to hold larger amounts of water in the surface whereby the liquid limits of the fine ingredients are more rapidly approached, and the stability of the surface more rapidly weakened

"When coarse material (retained on the No 10 sieve) is present or is added to a good soil mortar in appreciable amount (10 percent or more), the hardness and durability of the surface is increased until the full gravel type of surface is reached"

Simply stated, this means that in order to provide satisfactory service performance, a granular mixture must have a grading within a well defined band and, furthermore, the activity of binder must be limited.

The requirements for graded soil mixtures which are to be used as a surface course and those which are to be used as a base course under a flexible pavement are somewhat different. This is due to the fact that the conditions under which they function are not the same.

Both surface and base course materials must possess the inherent stability requisite to support the superimposed loads without detrimental deformation. Surface courses, in addition, must withstand the abrasive action of traffic, should shed a large portion of the rain which falls on the surface and should possess capillary properties sufficient to replace the moisture lost by surface evaporation. Base courses in contrast are protected by a wearing course which resists abrasion, sheds rain and, by preventing evaporation, maintains in the base course the desirable damp condition in which the particles are bound together by thin moisture films

It has been observed repeatedly that granular mixtures which served excellently as surface courses, failed when surface treated. Likewise, those mixtures which were too lean to give the best service as surfaces were excellent after the application of a thin bituminous wearing course.

The American Association of State Highway Officials has recognized these essential differences and has adopted separate specifications for both surface courses (M 61-38) and base courses (M 56-38).

There follows a summarization of published information pertaining to the design of graded soil mixtures.

FACTS ESTABLISHED

1. The location and utilization of available materials in base course construction will pay handsome dividends if reasonable care is exercised in the design and control procedures. Many State highway departments learned this when road funds were scarce. The accumulated experience is an

[1] Numbers in parentheses refer to list of references at end.

adequate guarantee that the practice is sound from both an engineering and economic standpoint (9)

2. Among the local materials which either meet the requirements for granular type base or surface courses, or can be made to meet them by the addition of relatively small amounts of soil or soil material, are the following: topsoil (as found in certain localities in southeastern United States), sand-clay, sand-clay gravel, sand gravel (from stream beds), crusher-run quarry products, blast furnace slag, limerock, caliche, chert, volcanic cinders, burnt shale and many others of purely local occurrence (9).

3. Control of grading is essential to insure satisfactory stability in granular mixtures containing soil binder (10, 11, 12, 13, 14).

4. Considerable latitude in grading requirements can be permitted when materials such as crusher-run limestone or slag are used for base courses. The natural cementing properties of these materials assist greatly in the formation of stable bases even when the grading is definitely coarser than would be allowed by the present A.A.S.H.O. specifications (12).

5. The soil-mortar gradation is the heart of the stabilized road and in all cases should be of the right composition (5).

6. Control of plasticity index is essential, particularly when the final mixture contains 40 percent or more of soil mortar. Although there may be many instances where carefully mixed and placed aggregates having relatively low mortar contents would give satisfactory service even though the plasticity index of the soil mortar might be in excess of 6, the possibility of segregation and collection of the fine aggregate into rich spots or layers must not be overlooked and makes the limit of 6 for the plasticity index a desirable, if not vitally necessary, requirement (11).

7. Because of its greater density and stability, a well graded sand-clay or sand-clay gravel is to be preferred to absolutely nonplastic material for base course construction (11, 12).

8. Because it allows for economy in the use of maintenance equipment, saving in time, and more uniform composition of product, plant produced stabilized mixtures are favorably considered by highway engineers. Producers are likewise in favor of central plant-mixing because it often makes possible the utilization of accumulated aggregates and sand or clay wastes. The essential functions of the plant are thorough mixing and covering the aggregate particles with binder soil (3).

9. The blade grader is the most commonly used equipment for grading and spreading, and most road-mix operations can be performed with it (4).

10. Compaction should be as complete at the bottom of the base course as at the top, particularly with plastic materials, since even minor deficiencies in the compaction of plastic materials make them susceptible to softening and loss of stability when wet (10, 11).

STRONG INDICATIONS

1 The use of an excessive amount of fine mineral dust even though it may be relatively free of colloidal particles and, therefore, not productive of high plasticity, seems to retard or prevent effective compaction (10).

2. As the amount of soil mortar decreases below about 40 percent, the importance of the grading of the coarse material becomes relatively more important and the grading and plasticity index of the soil mortar becomes of relatively less vital importance (11).

3. It appears that there may be a specific maximum PI that should not be exceeded depending on the quality of clay binder soil used. For each ratio of binder soil to fine sand or soil fines there is an

optimum coarse sand content at which maximum density is obtained (2).

4. Laboratory tests indicate that there appears to be a definite relationship between the plasticity index and liquid limit and stability (8).

5. It is indicated that properties other than those revealed by the mechanical analysis and plasticity tests influence the behavior of crusher-run stone or slag base courses (12).

6. Early difficulties encountered in compacting materials having acceptable gradings and plasticity indexes need not be taken as an indication of poor quality since in the circular track tests (10, 11, 12) such materials, without exception, gave satisfactory service when compaction in conjunction with drying was continued until maximum practical density was obtained.

7 If the stabilized course is intended as a base for bituminous surface, the seasoning period should extend until a mosaic of aggregate appears at the surface, but if the material is retained as a surface, operations need be less exacting (4).

NEEDED RESEARCH

1. The influence of prevailing climatic and topographic conditions on specifications for stabilized mixtures

2 Investigation of local materials possessing properties peculiar to themselves in order to determine their suitability for use in base and surface course construction Such materials include shales, mine and quarry wastes and the like.

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DISCUSSION ON NATURAL SOIL MIXTURES

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LOGARITHMIC GRADING OF STABILIZED MIXES

Some years ago a French scientist, M. Feret, proposed that aggregates for concrete mixtures conform to a logarithmic particle size distribution. The general equation developed by A. N. Talbot[1] is as follows:

$$p=100(d/D)^n$$

Where

p = percentage of particles having a maximum diameter, d

D = maximum diameter of particles at p = 100 per cent

n = arithmetical slope of the logarithmic plat of the curve

Customarily, in soil stabilization, the percentage, p, is shown with respect to the logarithm of d. The resulting relation is an irregular curve. For gradings which conform to Feret's equation relations of p to d become straight lines when p also is plotted to logarithmic scale.

[1] Selection of Materials for Rolled-Fill Earth Dams, by Charles H Lee, Trans A.S.C.E, Vol. 103, 1938, see page 5.

The use of the log-log plat has three distinct advantages:

1 The average straight line relation having been determined for a given maximum size, D, the establishment of the tolerance band is quickly determined by drawing parallel lines through the values of p which represent the tolerance for any particular particle size, d
2. Excessive variations from either the average grading curve or grading band are quickly determined by inspection.
3. The optimum grading of any particular fraction with a maximum grain size, D, having been determined, parallel lines through other maximum values of D indicate the proportions of materials in any other fractions.

Figure 1 shows the grading of the best soil mortars, that is the fraction passing

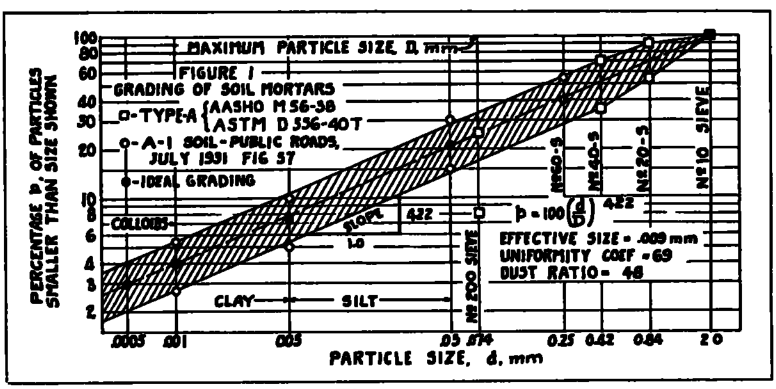

Figure 1.

the No. 10 sieve. The average line was obtained from data published in *Public Roads,* July 1931, Fig. 57. The slope, n, equals .422. The solid circles show the values obtained from this figure. To obtain the band, use was made also of the

standard specifications for stabilized base materials. The open circles show the values obtained from *Public Roads* The open squares show the values obtained from standard specification, type A, A.A S H.O M 56-38 and A.S T.M. D 556-40T. Only a glance is needed to with those given in the standard specifications and class A-1 soil for soil mortars Table 2 shows the logarithmic gradings of the soil binder and the soil fines fractions of ideal soil mortars.

In Figure 2 are shown the grading of soil-aggregate mixtures. The solid circles show the average values for type C FP-41 P.R A. (D = 1½ inches). Here, the slope n = .422 only applies to material which passes the No. 40 sieve. For larger sizes, the value n = 347. It is possible that if true instead of apparent sizes of particles were disclosed by the hydrometer analysis there would be no change in the slope, n, for the different fractions.

TABLE 1

GRADINGS OF SOIL MORTAR

Particles smaller than	Sand—Clay—Mortars					
	A-1 and Type A soil			Logarithmic grading, D = 2 0 mm		
	Maximum	Minimum	Average	Average	Maximum	Minimum
	Percent	Percent	Percent	Percent	Percent	Percent
No. 10 sieve	100	100	100	100 0	100 0	100 0
No. 20 sieve	90	55	72 5[1]	69 0	94 0	44 0
No. 40 sieve	70	35	52 5[1]	51 0	70 0	32 0
No 60 sieve	55	40	47 5[2]	41 0	56 0	26 0
No 200 sieve	25	8	16 5[1]	25 0	35 0	15 0
0 05 mm	30	15	22 5[2]	21 0	29 0	13 0
0 005 mm	10	5	7 5[2]	7 8	10 8	4 8
0 001 mm	5	3	4 0[2]	4 0	5 5	2 5

[1] Group A-1 Soil, Public Roads, July, 1931

[2] Type A Soil, AASHO and ASTM standard specifications for stabilized base course materials

TABLE 2

LOGARITHMIC GRADINGS OF SOIL MORTAR FRACTIONS

Particles smaller than	Soil binder—material passing No 40 sieve D = 0 42 mm			Soil fines—material passing No 200 sieve— D = 074 mm		
	Maximum	Minimum	Average	Maximum	Minimum	Average
No. 40 sieve	100 0	100 0	100 0	.	..	
No. 60 sieve	100 0	62 0	81 0			
No 200 sieve	65 0	33 0	49 0	100	100	100
0 05 mm	55 0	27 0	41 0	100	70	85
0 005 mm	21 0	10 0	15 5	43	21	32
0 001 mm	10 5	5 1	7 8	21	11	16

show that three of the points are inconsistent with the rest of the data. They are both minimum and maximum values of the material passing the No. 200 sieve of the Standard Specifications; and the minimum value of the material passing the No. 60 sieve of the Class A-1 soil, Public Roads Administration.

The data given in Table 1 shows the comparison of the logarithmic gradings

Comparison of standard specification

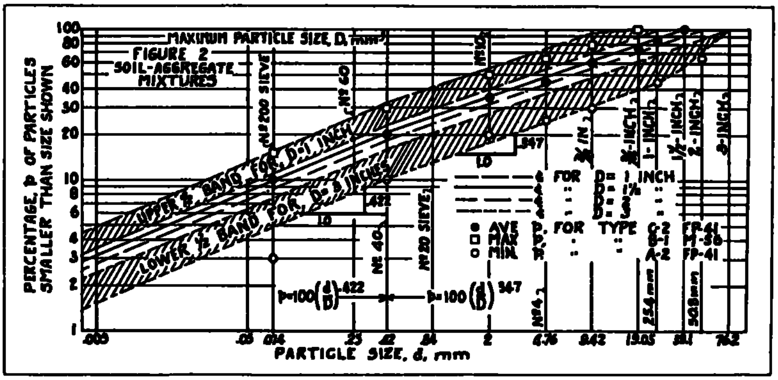

Figure 2.

TABLE 3
Gradings of Soil—Aggregate Mixtures

Particles smaller than	Type A-2, PRA—FP-41			Logarithmic grading—D = 3-in		
	Maximum	Minimum	Average	Average	Maximum	Minimum
	Percent	Percent	Percent	Percent	Percent	Percent
3 -in. sieve	100	100	100 0	100	100 0	100 0
2 -in. sieve	100	65	82 5	87 0	100 0	74 0
1½-in sieve				78 0	100 0	56 0
1 -in sieve	75	45	60 0	68 0	92 0	44 0
¾-in sieve				61 0	83 0	39 0
⅜-in sieve	60	30	45 0	48 0	65 0	31 0
No. 4 sieve	50	25	37 5	37 0	50 0	24 0
No 10 sieve	40	20	30 0	28 0	38 0	18 0
No 20 sieve				20 0	27 0	13 0
No. 40 sieve	25	10	17 5	16 0	22 0	10 0
No. 60 sieve				13 0	18 0	8 0
No 200 sieve	10	3	6 5	7 6	10 4	4 8
0 05 mm				6 4	8 8	4 0
0 005 mm				2 4	3 3	1 5
0 001 mm				1 2	1 6	0 8

Particles smaller than	Type B-2, FP-41 PRA M-56-38, AASHO D 556-40T, ASTM			Logarithmic Grading—D = 2-in.		
	Maximum	Minimum	Average	Average	Maximum	Minimum
2 -in sieve	100	100	100	100 0	100 0	100 0
1½-in. sieve	100	70	85	91 0	100 0	82.0
1 -in sieve	85	55	70	78 0	100 0	56 0
¾-in sieve	80	50	65	71 0	95 0	47 0
⅜-in sieve	70	40	55	55 0	74 0	36 0
No. 4 sieve	60	30	45	43 0	59 0	27 0
No 10 sieve	50	20	35	32 0	44 0	20 0
No 20 sieve				23 0	30 0	15 0
No 40 sieve	30	10	20	18 0	25 0	11 0
No. 60 sieve				15 0	21 0	9 0
No 200 sieve	15	5	10	9 8	14 2	5 4
0 05 mm				7 4	10 2	4 6
0 005 mm				2 8	3 9	1 7
0 001 mm				1 4	1 9	0 9

TABLE 3—CONTINUED

Particles smaller than	Type C-2, FP-41			Logarithmic grading—D = 1½-in		
	Maximum	Minimum	Average	Average	Maximum	Minimum
1½-in sieve	100	100	100	100 0	100 0	100 0
1 -in sieve	100	70	85	87 0	100 0	74 0
¾-in. sieve	90	60	75	78 0	100 0	56 0
⅜-in sieve	75	45	60	62 0	85 0	39 0
No. 4 sieve	60	30	45	48 0	65 0	31 0
No 10 sieve	50	20	35	36 0	49 0	23 0
No 20 sieve				26 0	35 0	17 0
No. 40 sieve	30	10	20	21 0	29 0	13 0
No. 60 sieve				16 0	22 0	10 0
No 200 sieve	15	5	10	9 8	13 4	6 2
0 05 mm				8 3	11 3	5 3
0 005 mm				3 1	4 2	2 0
0 001 mm				1 6	2 2	1 0

Particles smaller than	Type B-1, M 56-38 AASHO D 556-40T, ASTM			Logarithmic grading—D = 1 in		
	Maximum	Minimum	Average	Average	Maximum	Minimum
1 -in. sieve	100	100	100 0	100 0	100 0	100 0
¾-in sieve	100	70	85 0	90 0	100 0	80 0
⅜-in sieve	80	50	65 0	71 0	95 0	47 0
No. 4 sieve	65	35	50 0	56 0	76 0	36 0
No. 10 sieve	50	25	37 5	42 0	58 0	26 0
No 20 sieve				31 0	43 0	19 0
No. 40 sieve	30	15	22 5	24 0	33 0	15 0
No. 60 sieve				19 0	25 0	12 0
No 200 sieve	15	5	10 0	11 0	15 0	7 0
0 05 mm				9 6	13 2	6 0
0 005 mm				3 6	4 7	2 5
0 001 mm				1 8	2 4	1 2

limits for soil-aggregate mixtures with the logarithmic grading limits can be made from the data given in Table 3. All materials which have particle size distribution curves more or less parallel to those given in Figure 2, and which fall within the limits of the diagram as shown should be suitable for use in base courses.

The above material is not new or original but is given at this time simply as a guide in the consideration of future specifications. The logarithmic relation was suggested several years ago by R. W. Miller of the Columbia Alkali Corporation.