4. That loads should be reduced 25 to 50 per cent during the period when frost is leaving the ground.
5. That this type of surface will accommodate 500 to 600 vehicles per day except in arid regions.
6 That bituminous or non-bituminous surface treatments will increase the traffic capacity, and eliminate dust.
7 The mileage of this type is increasing.

Observations on costs and service by the various builders of these roads are the best sources for further information. There are no extensive research investigations in progress

Suggestions for further investigations are

1. Cost of vehicle operation on this type compared with roads of equal cost and service

2 What is the cost to a community to be without road service?

3 What is the traffic limitation of this type in cost per vehicle miles or per ton mile?

4 What types of surface treatments are economical investments?

5 What is the salvage value, as sub-base for future high type pavements?

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SEMI-GRAVEL, TOP-SOIL, AND SAND-CLAY ROAD MATERIALS

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RÉSUMÉ OF PUBLISHED INVESTIGATION

Having limited this report to results with these road slabs obtained in Georgia, the body of the report will comprise in itself a résumé of the previously published work, most of which has emanated from the staff of the University of Georgia road laboratory

It will be sufficient to refer to appended bibliography at the end of the report and to state at this point the general nature of the problems involved in their successful use

Structural design as applied to these types of road slabs cannot be handled intelligently without considering their great variety in composition, the influence of methods of construction and of the subsequent maintenance operations involved Unlike concrete and bituminous types for which specific materials combined in a specific way result in a slab fixed in character and dimensions, road soil slabs, after placement, are subject to weather influences and traffic stresses which seriously modify the surface and require a kind of maintenance which from time to time shall restore the smoothness and crown of the road bed. They undergo larger losses of material under service and at times need the addition of new material at weaker points They are subject to traffic ruts, holes, ribbing or corrugations, loose layers of sand or mud according to the adequacy of the original material, to the nature of the subsoil, and to the duration of bad weather conditions Repairs are made with drags and road machines operating over the road slab and the earth shoulders, and by scarifying machines when undue roughness necessitates re-shaping or re-building the slab

Thus, the life history of such roads reflects the combined results of original slab composition, of depth, cross-section, and width used, of methods of mixing and consolidation followed, and of continuous attention, intelligent or otherwise, to constant maintenance by machinery.

Against this somewhat discouraging portrayal of the problem should be placed the facts of wide traffic experience, to wit:

If the road soils selected lie within certain recognized limits of composition and sustain a traffic burden of moderate intensity, the average quality and length of service are highly satisfactory, the maintenance operations are quickly, and easily performed, and the cost of both construction and maintenance is gratifyingly low.

FACTS, CONCLUSIONS, AND INDICATED SUGGESTIONS

The summary which follows draws its material from the range of experience and records covered by the bibliography listed, supported by the recent evidence acquired through a special cooperative study of some 29 federal aid projects widely distributed on the state highway system and embracing some 245 miles in length It can be succinctly presented under the headings which follows:

THE COMPOSITION AND CLASSIFICATION OF ROAD SOILS

In 1917, a special conference of State Highway Testing Engineers and Chemists called under the auspices of the Bureau of Public Roads adopted laboratory methods, classification limits, and specifications for these materials, which are still in use with only minor changes.

1. The proximate mechanical analysis as at present used seems a fairly adequate approach, and the definitions of coarse materials, sand, silt, and clay are in the main acceptable when stated as follows.

   Coarse material, hard gravelly material retained on a No. 10 mesh sieve, *i e*, more than 1 85 mm in diameter.

   Clay, material separated by subsidence through water, usually possessing plastic and adhesive properties and generally below 02 mm in diameter

   Silt, fine material other than clay which passes a No. 200 mesh sieve, generally from .07 to .02 mm. in diameter.

   Sand; hard material, usually siliceous, which passes a No. 10 mesh sieve and is retained on a No. 200 sieve, generally from 1.85 mm to 07 mm. in diameter.

   Soil mortar, a mixture of sand, silt, and clay; defined as above.

2. It is desirable to supplement the present mechanical analysis and other rough tests by a more detailed examination of the clay ingredients by determining the lower liquid and lower plastic limits (Atterberg method), amount of water, specific gravity of the solid substance, and other tests suggested by Dr. Terzaghi for the identification of clays, in his writings on Soil Mechanics (Engineering News-Record, 1925).

   The writer accepts Dr Terzaghi's conclusion that the characteristic properties and variations of clay are explainable upon the basis of the flat scale shape and relative sizes of the clay particles in association with capillary pressure and other capillary moisture phenomena

   A road soil slab under wet conditions falls within the range of Dr Terzaghi's experiments which suggest many promising and pertinent answers to many mooted questions as to the separate ingredients and as to the combined actions of such road soils

3. Until a more accurate knowledge of the clay ingredient is available, the present limits of composition for Class A, Class B, and Class C soil mortars may be allowed to stand.

4 In judging these materials, full emphasis should be placed upon the soil mortar, i e, material below No. 10 sieve. Weak soil mortars even with large amounts of coarse material often do not give proper stability under traffic. Class C mortars are not usually to be recommended except for very light traffic or when the slab is to be covered with a 2-inch layer of gravel, semi-gravel or coarse screenings.

5 Coarse material above 10 per cent in amount distinctly increases the stability and durability of the slab, less with Class C, and progressively more with Class B and Class A mortars

6. Coarse material is most effective when present in graded sizes from one inch downwards Such material of micaceous, feldspathic, or slaty types is most commonly soft and soon becomes valueless in the slab.

7 Organic matter gives noticeable adhesive strength, but is soon oxidized or blown away

8 Of the total sand in a road soil mortar, that portion which lies above the No 60 sieve is a most important factor in hardness, supporting value, and durability of the slab, especially under wet conditions No soil mortar of this type will give satisfactory service unless it contains a liberal percentage of sand coarser than the No 60 sieve, except in the case of cherts

Mixing, Depositing, and Consolidation

The natural deposits of these materials, whether surface or underground, are rarely of uniform composition It is most important to secure fair uniformity before the road slab is consolidated.

1. Top-soil deposits are usually thin surface layers, 4 to 10 inches thick and of limited area They are loosened by plowing in one or more layers Preferably, the loosened material should be intimately mixed by harrowing before loading and depositing Care as to depth of plowing and limits of the good material are obvious precautions.
2. Sub-surface deposits excavated from pits should be well mixed by repeated harrowings after deposit on the road bed.
3. Intimate mixing is the most profitable, and at the same time the most frequently violated principle of construction with these types. It not only gives a uniform mix of the ingredients, but by physical subdivision of the clay, it both spreads the clay over the granular material and multiplies the opportunity for capillary action in creating adhesive and cohesive strength.

4 The loose material of these slabs should be spread in one layer to the full depth of the slab A 12-inch loose depth with an expected consolidated depth of 8 or more inches is advised.

Depositing in thin layers creates a weak stratified structure which breaks down piecemeal under traffic

5 Consolidation of the loose material from the bottom upwards is most effective At present, this is largely done by the wheels of construction teams and current traffic Slabs which while green are reduced by the rains to a soft mud state and are thoroughly puddled show markedly greater strength than those which are packed with less moisture.

Rolling with flat rollers is valueless A real need exists for a multiple rim type of roller for quicker and more uniform compaction of these slabs

6. The packing process is accompanied by repeated shaping of the surface with road machines until the finished cross-section is finally set up.

7 Lumpy consolidation in the early stages should be broken up by scarifying or plowing before final packing is permitted.

8. Current vehicle traffic need not be detoured. Its presence is an aid to consolidation But its passage over the loose slab should be guided and distributed

9 Clay subgrades should be preferably rolled and crowned before the slab material is deposited.

DEPTH AND WIDTH OF SLAB

The normal cross-section of these road slabs has been 18 ft. width, 8-inch average depth supported by 4-foot shoulders of local earth on each side, and with 2-foot shallow side ditches It is now suggested that·

1 The slab material should extend from ditch to ditch. For a 30-ft. road, the main slab should be 18 ft wide with an average depth of 8 inches and with a 6-inch depth covering the two 4-foot shoulders.

2 The crown should be approximately one-fourth inch per foot. Heavier crowns frequently show water made ribs adjacent to the side ditches The light crown is more easily smoothed and maintained by road machines and drags

STABILITY FACTORS DISCUSSED

The problem presented by these roads soils is a complex one in which a mass of loose soil aggregates composed mainly of material whose diameters range from 1 85 mm down to colloidal sizes is to be consolidated into a homogeneous slab of adequate strength to resist the wear and tear of traffic, to withstand the softening and weakening effects of water and weather, and thus to afford a traffic service acceptable in smoothness, reliability, and durability properly related to the cost involved Reliance for results is placed upon the properties and behavior of the several classes of ingredients (clay, silt, sand, coarse material) acting by virtue of mass and internal bond developed from interlooking grains and from the action of capillary moisture forces therein

The functions of the several ingredients in relation to binding strength and resistance to traffic and weather are conceived as follows:

1. All the ingredients present contribute to a certain total of seating and embedment stability, and furnish mass and weight resistance to traffic impacts and pressures
2 The very fine ingredients, notably the clay, within the range of their combined lower liquid and lower plastic limits and below the latter, supply an additional adhesive and cohesive bond variable in amount with the per cent of water and the capillary structure of the mass
3 The coarser sizes of sand and the coarse material furnish the main hardness and supporting strength, especially in wet weather They also give the chief seating bond which the finer sand and silt and clay supplement by an embedment bond
4 In a rough sense, the integrity of the slab, during dry weather and with low moisture conditions, is largely maintained by the adhesive influence of the clay in preventing surface and internal displacement of the granular materials
5 This adhesive and cohesive action of the clay continues through a wide range of internal moisture, diminishing with the increase of the moisture It becomes negligible if the slab is fully saturated; or, more accurately, when the clay reaches its lower liquid limit Possibly the silt plays a similar but less important part
6 As the above condition is approached, the stability of the slab depends more and more on the mechanical bond of the sand, and especially of the coarser sizes

7. Free absorption of water by clay is accompanied by notable expansion From the foregoing suggestions, the desirable composition of a suitable and effective road soil is derived 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
   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. The fine sand, always present in these road soils, has some value in adding an embedment support to the coarser sand, and silt has a similar action under low moisture.
   d. But a superabundance of silt, of very fine sand, and especially of clay tend, when it rains, to reduce percolation and to hold larger amounts of water in the slab whereby the lower liquid limits of the fine ingredients are more rapidly approached, and the stability of the slab more rapidly weakened

   A Class A road soil mortar fulfills the desired conditions very effectively As now specified, it calls for clay, 12-18 per cent, silt, 5-15 per cent; total sand, 65-80 per cent, and sand above No 60 sieve, 45-60 per cent

   Experience fully supports the superior stability of road soils thus composed.
8. When coarse material is present or is added to a good soil mortar in appreciable amount, 10 per cent or more, the hardness and durability of the slab is increased, and continues to increase until the full gravel type of slab is reached
9. Maintenance of a smooth surface and crown on these slabs for prompt removal of surface water is obvious. But regardless of this, rain water disappears with considerable rapidity from holes or depression showing active percolation through the slab and rapid evaporation The porosity of these slabs when most densely packed is not less than 20 per cent. Thus permeability must be considered both as to rate of gravity drainage and as to the attendant capillary retention in the clay and silt Class A samples taken after long periods of rain always show large

strength and no serious internal softening. On the road, the phenomenon shown in wet weather is commonly a thin coat of sandy mud, non-slippery, one-fourth to one-half inch deep underlaid by a firm supporting surface.

10 The conclusion to be reached and its explanation are:

For Class A Soils When rain begins, the clay in the surface layers expands and tends to close the surface pores and make the slab less pervious If a smooth crown exists, rain water is largely discharged into the side ditches The expansion of the clay into the sensible pores prevents dislocation of the coarser sand grains Abrasion by the traffic creates a thin, loose layer of non-slippery mud, which rebinds to the slab on drying out In a depression, water collects, and either percolates through the slab or evaporates from the surface. Here some weakening occurs, but owing to the sensible size of the pores and small amount of clay, it is not serious

For Soils High in Clay In wet weather the expansion of the clay loosens the mechanical bond of the sand grains. Absorbed water is retained by the clay in large amount Layer by layer the fine materials approach their lower liquid limit, and under the wheels of the traffic the slab is rapidly cut into deep mud.

11. Paragraph 10 explains, also, why it is desirable for the selected road soil material to extend from ditch to ditch, and why clay subgrades should be rolled and crowned Both requirements provide better opportunity for prompt removal of percolating water.

12. Soil mortars are analyzed in percentage of the material which passes a No 10 sieve The percentage of coarse material relates to the whole unseparated sample. It is found that when 15 per cent or more of coarse material is present, the allowable amount of clay in the mortar may be somewhat increased, limited by a maximum clay content of 25 per cent of the unseparated soil sample which includes the coarse material.

LOSS OF SLAB MATERIAL UNDER SERVICE

Loss of material from soil slabs is affected by several variable factors. The most important are machining, dragging, and scarifying the slab, when concurrent with high winds or washing rains.

1. The loss of slab depth is progressive, but not at a uniform annual rate
2. Such loss is not consistently related to the traffic count Some slabs with very light traffic show high losses, while others of similar composition and much heavier traffic show much less loss. The influence of grade under washing rains and heavy winds causes much of the loss independent of traffic density Also, the moisture conditions at the time of machining and shortly subsequent thereto will have much to do with the loss
3. Slabs with 15 per cent or more of coarse material resist depth losses much better than slabs with little or no coarse material
4. An approximate general figure from the observed data may be indicated, lying between ½ inch and 1 inch per year under a traffic count of 400 to 600 vehicles per day.
5. When slabs reach a thinness of 2 inches or less, their behavior is directly influenced by the nature of the subsoil Apparently, thin slabs on highly clayed subsoils will cut through more easily in wet weather than those on sandy loam subsoil, but not much comparative difference is noted between thin slabs on clay and those on very fine sand subsoil The slab integrity in both cases is rapidly destroyed with the production of wet weather mud on clay subsoil, and loose sand pockets and wheelruts in dry weather for the fine, sandy subsoil.
6. In general, when these slabs are worn to less than 3 inches, it is wise to scarify and rebuild them to an 8-inch compacted depth

LIMITS OF ACCEPTABILITY

This type of road slab is best adapted to light or moderate traffic densities which recent data place at 400 to 600 vehicles per day, according to composition of the slab, and to the provision for constant patrol maintenance Adequate equipment for and intelligent execution of maintenance work have much to do with both the quality of service rendered and the efficient life of such roads. Recent records have established a satisfactory quality of service for an average life of more than six years for the projects studied to July, 1927, and a probable residual life of from one to two years still available.

CONSIDERED AS SUBGRADES FOR PAVED ROADS

These slabs form the logical first stage of substantial betterment on important heavy traffic roads, following at once upon relocation and grading and giving service until hard paving can be constructed.

They bridge over the period of settlements in newly built roadbeds, and have shown their value as highly stable subgrades for the subsequent heavy pavements. In proof may be cited the count of cracks appearing in concrete slabs laid on old road-soil slabs in this state and those of equal age laid on unselected natural subgrades In all such cases the cracks shown in the former concrete slabs are fewer by a large ratio than in the latter projects

As subgrades under pavements, these road-soil slabs have the following merits:

1. A well-established initial supporting value quite uniform under the paving slab
2 A capillary structure not easily softened by water, nor conducive to capillary lift of moisture from the subsoil below.
3 Not liable to expansion under frost Observation has frequently noted a sound road-soil slab in winter flanked by clay shoulders, on which hoar frost stood several inches in height

ATTAINMENT OF BETTER RESULTS

Despite the many variables involved, knowledge and methods now available enable the engineer to secure very substantial road service from these road-soil slabs at a remarkably low cost There remains, however, a large margin of improvement in their use yet to be made Better results in service and durability can be reached mainly along the following lines:

1. Greater care by the contractor and by the resident engineer in all the details which affect uniformity of composition and intimate mixing before consolidation
2. Improved types of machines for quickly and more uniformly packing the loose material from the bottom upwards
3. The abundant use of water during the consolidation stage, either by taking advantage of rains and scarifying or puddling the new bed before its final pack is permitted, or by the most liberal use of sprinkling carts which circumstance and finances permit.
4. A more intelligent appreciation and specific knowledge on the part of both engineers and contractors of the possibilities attainable

UNPUBLISHED RESEARCHES

Since 1922 there has been in progress a comprehensive research covering 29 Federal Aid Projects in Georgia under the auspices of the Bureau of Public Roads and the Georgia State Highway Department.

The writer has been in charge and has completed the manuscript of a final report for submission to the authorities concerned.

This research is addressed, in one phase, to a quantitative answer regarding financial costs, traffic efficiency, and life periods obtainable, and on the other side to a study of the observed effects relating to loss of material, influence of weather, of traffic, of maintenance operations and of subgrade conditions upon the composition of the slab and upon the progressive behavior shown

The projects are widely distributed on the state highway system embracing some 245 miles in total length and located to include typical conditions of topography, available material, climatic influences, and subsoil variations

SUGGESTIONS FOR FURTHER RESEARCH

A pre-requisite for substantial improvement in results with road-soils is a more definite knowledge of the quality of the clay ingredients As a result of the Terzaghi experiments, the way has been opened to attain such knowledge. It will require patience, special apparatus and specially trained men.

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