Practically all of this system occupies wholly new right of ways. That it has been possible to obtain so quickly the locations necessary is a demonstration that all of us who have been concerned with the securing of land necessary for public improvements must agree is a most convincing example of the power and determination of the national government of Germany.

France, through a history of at least a century and a half, has carried out major improvements through a central engineering control with all the personnel developed, or at least given final training in a single institution. In contrast, Germany almost over night upset the status of State control of planning and executing highway improvements and turned to a national plan rigidly controlled in conception and execution through the power of authoritarian government.

ROAD STABILIZATION WITH BITUMINOUS MATERIALS

F. V. Reagel,
Engineer of Materials, Missouri State Highway Department,
Jefferson City, Missouri

The increase in degree of completion of the various highway systems in this country has naturally tended to focus the attention of builders and designers on the need for development of intermediate and low-cost types of base construction.

Early in the history of road construction, intermediate types were dependent to a large degree upon the use of aggregates with or without the use of supplementary binders. There are, however, large areas where aggregates such as gravel and crushed stone are obtainable only at a high or prohibitive cost, and until recently no logical approach to the problem was available in such areas.

A new technique or approach has recently been placed in the hands of designing engineers by the splendid work of technologists of the Bureau of Public Roads and others, through the development of soil science as applied to road design.

Engineers are coming to the realization that the economic construction of road bases requires as extensive use as is possible of the soil material on location, and many recent researches have been directed toward this end.

CLASSIFICATION OF SOIL STABILIZATION

A technical definition of soil stabilization could be "the treatment of soils with admixtures which either, by themselves, introduce or increase a certain stability element (i.e. gravel and sand for friction and interlocking action) or change the soil as a result of physico-chemical or chemical reaction." The purpose of these admixtures is to provide a soil system which is stable under all climatic conditions and all traffic use occurring on the location. According to the function of the admixture, the methods can be put into three classes as follows:

(1) Mechanical stabilization
(2) Chemical stabilization
(3) Mechanical and chemical stabilization.

Mechanical stabilization involves the balancing of granular and cohesive material to obtain a soil aggregate system which is stable under all weather and traffic conditions. Chemical stabilization achieves this stability by chemical and physico-chemical reactions. The materials used for this purpose are of necessity restricted to low-priced commodities. At present such inorganic materials as portland cement, a combination of bi- and polyvalent cations, sodium silicate, and hydrated lime are being used or are of promise. Organic materials for this type of stabilization include asphaltic and tar bitumen, lignin waste liquor, and other resinous materials of natural or synthetic origins, etc. An example of mixed stabilization is the combined use of aggregate and bitumen.

The specific assignment for this discussion was intended to cover the design, construction, and utility of the latter two types.

One of the most simple and usable methods of chemical stabilization designed to meet the needs of motor traffic under certain conditions is the surface application of road oil (SC_2) at a rate of approximately one gallon per square yard, preferably in two or three increments to aggregate free earth surfaces.

This type has been more largely developed and used by practical road workers rather than by research engineers and consequently has not received the attention deserved in organized road building. There faces us, however, the fact that many millions of gallons of road oil are thus used annually to give satisfactory all-weather service between small centers of population and as temporary gap surfacing in discontinuous stretches of high-type pavement.

The essential technique, as described in *Public Roads*, Vol. 12, No. 3, in the report of a co-operative research with the Missouri State Highway Department, requires, among other things, satisfactory drainage, proper moisture conditions at time of application, comparative freedom from mutilative traffic, and annual retreatments in diminishing quantity.

The results obtained by plain earth oiling and also by the introduction of bitumen in soil-sand-gravel mixtures, combined with the data obtained in laboratory research on bitumen-soil systems, indicated the possibility of stable base construction without, or with only limited presence of, granular materials. The evidence was sufficiently impressive to serve as a basis for experimentation in the field and later for the extension of use in an active program.

Observations made on roads constructed during the past three or four years indicate that roadbeds composed of mixtures of cohesive soil and gravel with the soil fraction (minus No. 40 sieve) ranging between forty and sixty per cent by weight of the total soil-aggregate mixture can be satisfactorily stabilized with approximately eight per cent of bitumen based on the dry weight of the fraction passing the No. 40 sieve.

PROCEDURES IN MISSOURI

Three general types of stabilized base construction have been used in the Missouri and other highway programs.

The procedures adopted in Missouri are best known to the writer and may be briefly described as follows:

1. Machine-Mix Method. The construction operations involved can be divided into three phases: First, scarifying, pulverizing, and windrowing the roadbed material (with or without added granular material); second, proportioning and

Fig. 1. Side view of Barber-Greene mixing machine and spreading unit.

mixing the bituminous material, water and/or other ingredients with the windrowed material, using the Barber-Greene traveling plant; and third, spreading, compacting, and finishing the mixed material.

The scarifying operation is best performed with a tractor-drawn heavy-type scarifier. The first operation should consist of loosening all material to the full width of the road bed and to a depth just sufficient to destroy the existing crust or mat. All material encountered, including any previous surfacing, should be broken down to approximately two inches in size and placed in a windrow. The roadbed should then be shaped to the planned cross-section, and all reclaimed material and any additional aggregate to be added should be uniformly spread over the width of the section. A second scarification should then loosen the roadbed to such a depth that the total thickness of loosened material, plus reclaimed and added material, will produce the compacted thickness planned. The subgrade soil and the granular material should then be pulverized and uniformly mixed by means of heavy disks until the soil-aggregate mixture will pass a two-inch circular screen.

The soil-aggregate mixture should then be windrowed and mixed to a uniform color with bituminous material and sufficient water to facilitate dispersion. The amount of water necessary under this method will approximate five per cent more than the optimum required for compaction.

All mixed material should be given a preliminary spreading within twelve hours after mixing. Finishing operations should begin within seventy-two hours after mixing. The spreading operation should be performed in such a manner as to leave a small windrow of material at the outer edge of the section to permit compaction to start at the outside edges and progress toward the center by overlapping trips of the roller. Compaction should be from the bottom of the mass upward, by means of sheepsfoot rollers or similar devices and should begin while the moisture content is slightly above the optimum (approximately two per cent) for compaction. Tamping should be continued while the moisture content is at the optimum until the tamper feet do not produce indentations exceeding one inch in depth. A motor grader is used during compacting operations to maintain a surface of uniform cross-section.

Sheepsfoot tamper rollers should, under working conditions, have a minimum weight of ninety pounds per inch width of roller and a minimum load on each tamper of two hundred pounds per square inch of cross-sectional area. If the width of the roller exceeds four feet, it should be constructed in two sections, so joined that each section may oscillate independently of the other.

Final compaction and smoothing is obtained by means of self-propelled, three-wheeled rollers weighing from five to seven tons and exerting a pressure on the road surface of two hundred to three hundred pounds per linear inch of width of rear wheel.

Tamper prints which are not eliminated by flat rolling should be removed by sprinkling the surface with water, blading it lightly and giving it additional rolling.

Sections which are consolidated with an excessive moisture content will crack into small checks and must be opened with the blade and reconditioned as to moisture content. Sections containing an excessive quantity of bitumen will roll and shove and must be reconditioned by addition of untreated material. Care should be taken to drain excess moisture from the subgrade to avoid waterlogging and softening of the underlying soil layer.

As soon as practicable, a suitable prime of bituminous material is applied, and the desired type of surfacing is placed over the constructed base.

It is the opinion of the author, based on field observations, that a flexible-type surfacing is essential for use on this type of base. The base is flexible, at least during its early life, and failures have been observed where bituminous mixes of a brittle nature have been used. Failures are also indicated where open-type surfacing is used. Remarkable service has been given by armor coats consisting of .35 to .5 gallon per square yard of MC or RC cutbacks covered with a suitable amount of stone chips or pea gravel.

The type of bituminous material to be used in treating the base under this and later-described methods may be selected by the engineer to suit economic conditions and soil types as discussed later, experimentation having shown satisfactory results to date with SC and MC cutbacks, emulsified oils and asphalts and tars.

2. Suboiling Method. This method involves the use of a suboiling machine which may be described as a four-wheeled, tractor-drawn A-frame, seven and one-third feet wide, on

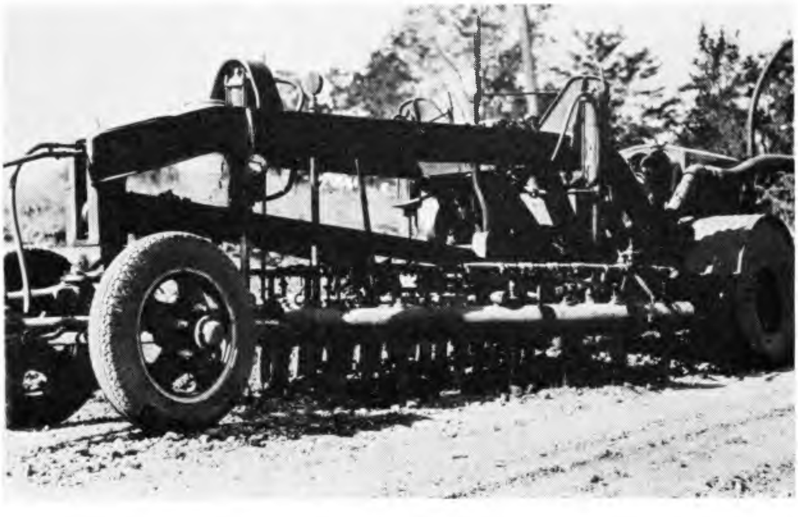

Fig. 2. View of suboiler used in application of bitumen below the surface.

which are mounted thirty-one scarifier teeth. An oil tube extends almost to the bottom of the heel behind each tooth. These tubes are all connected to a main supply pipe through which the oil passes when drawn by a pump mounted on the frame. Oil-supply tanks are attached behind the machine, and their motive power is furnished by the tractor that pulls the suboiler. The teeth and steering are hydraulically controlled in order that adjustments may be made to any depth or in any direction. The treating material is pumped through the oil tubes for depositing at the desired depth.

The theory of this method is based on the following premises:

(a) It is practically impossible, by practical mechanical means, to subdivide aggregated soil particles into their primary units. Therefore, mechanical mixing cannot give more than a meagre distribution of a liquid throughout a soil system if this liquid does not possess pronounced affinity for the surface of the soil particles.

(b) Water, because of its great affinity for soil, wets more energetically than bitumen. Water, furthermore, can widen the fine soil pores while inducing the soil system to swell.

(c) The affinity of soil for water may produce an upward suction of water from a reservoir below if the water in contact with the upper soil layer is lost by evaporation. This upward movement is able to carry along a contacting liquid such as bituminous oil if the adhesion of the two liquids is greater than the frictional resistance of the moving column. If given sufficient time, the natural forces may be able to secure a good distribution of the bitumen through the soil. If a uniform job is desired in a limited space of time, mechanical manipulation is required to supplement the forces of nature. If tars, road oils, and cutback asphalts are applied with the suboiler, their more active constitutents are liable to be absorbed in the lower layers while the lighter fractions have a greater tendency to move upward. This fractionation can be eliminated by the use of slow-breaking emulsions, the bituminous droplets of which move more integrally through the soil mass.

The suboiling practice may be described as follows: If any granular material is to be added, it is spread uniformly over the roadway, and the width to be stabilized is scarified to the desired depth. The scarified layer is pulverized to such a size that all material will pass freely between the suboiler teeth. The bituminous treating agent is introduced at one or more depths, as is also a predetermined quantity of water (except in the case of emulsions).

The surface is smoothed to approximate cross-section by blading after the introduction of the treating agent. If emulsions are used, no mixing manipulation is required before compaction; but with other treating agents the entire depth of treated material is disked thoroughly with heavy twenty- to twenty-four-inch disks loaded to a weight sufficient to cause penetration to the bottom of the soil reservoir. Compaction is obtained by means of sheepsfoot rollers operated through the range of optimum moisture content, and by a final rolling with a heavy, flat-wheeled roller.

The final surfacing, following this method of base construction, is the same as was described under the machine-mix method.

3. **Road-Mix Method.** This method is the most recent of development, having been avoided for some time because of a fear that ordinary blade-mixing methods could not overcome the possible cohesion of the treated mass. A very usable technique has, however, been developed during the past two years.

In general, the procedure is the same as is described under the machine-mix method up to the time of application of bituminous material except that no windrow is formed.

After the roadbed is shaped to planned width and cross-section, following scarification and pulverization, the bituminous treating agent is applied in increments of one-half gallon per square yard (for a five- or six-inch base thickness). Each application is incorporated with the soil aggregate mixture, together with a suitable amount of water, by means of disks and gang plows. This operation consists of thoroughly cutting in the bituminous material and water by means of the disks and then turning the mixture over by means of the plows as often as is necessary to avoid concentration of the treating agent. Mixing operations are continued after all bituminous material is added until the mixture is uniform.

Compaction methods are as described under the machine-mix method except that, if the specified compacted thickness is in excess of four inches, the mixture is compacted in two layers of approximately equal thickness.

As is indicated under the machine-mix method, subgrade drainage should be provided by lateral ditches through the shoulders or by other satisfactory methods to eliminate surface water.

Remarks regarding types of treating agents and surfaces made in the description of the machine-mix method are also applicable to this method.

TESTING

Preparation and testing of specimens should precede and parallel every project of base stabilization. Unfortunately, the test methods are not yet standardized, and the practical value of test data still depends to a great extent upon the qualifications of the interpreting engineer. In general, the tests are concerned with the following features:

6—55306

(a) Determination of the granulometric composition of the soil material to be treated.
(b) Determination by the original or modified Proctor Test of the moisture content inducive to best compaction of the soil material.
(c) The testing for water affinity of soil mixtures which have been treated with varying amounts of the admixtures contemplated for use.

For bituminous stabilization, then, the natural soil is treated with varying amounts of bituminous material (the quantity being based on the minus-forty mesh material or other empirical dividing line) and water. Duplicate specimens are prepared in either two- or four-inch diameter cylinders and compacted under a standard pressure. The specimens are then dried in air at room temperature to constant weight, after which one is immersed in water and the time-water intake is measured. The immersed and the non-immersed specimens are then both tested for stability by means of an extrusion apparatus.

Such tests may be sufficient for the determination of the immediate behavior of the treated base; but in our opinion further experience will show some natural tendencies toward loss of density after one or more years of service, and repeated freezing and thawing and wetting and drying tests similar to those employed in connection with portland cement stabilization testing may prove to be desirable or necessary.

The first two methods described have been used experimentally and under construction conditions in Missouri for approximately four years and, with an armor coat as a surfacing course, are giving a good account of themselves under a varying traffic, which might be described as light and medium. Failures occurring are, as a rule, localized and generally may be explained by drainage and subsoil conditions coupled with insufficient thickness.

One of the outstanding observations made in connection with this type of construction has been the length of service rendered by the light surfacing applied. Original installations with minor maintenance are still intact and giving promise of longer life, whereas the original intent was to provide a temporary surfacing to permit development of failures without loss of expensive surfacing. It is possible that future developments will continue to show that bases that are waterproofed throughout and consequently primed for their full thickness may require only a thin renewable cover-coat rather than a thicker, more expensive surfacing.

Developments as of this date indicate that the type of base described has a real place in road design, with suitable modifications to fit additional information as developed. The specific range of use as regards type and volume of traffic, etc., is, however, not developed and must be ascertained by development research in various localities and under differing conditions. As suggested before, however, the general type should prove an entering wedge or logical approach toward the solution of a problem existent in areas where aggregate materials are not available or are very costly.

RATIONALIZATION

At this point, a rationalization of bituminous base stabilization might be in order. The primary point of interest concerns the mechanisms of the bitumen effect in soil mixtures. If bitumen is to be used as a binder in higher-type pavements, its function can be more or less definitely specified in advance. In the case of bituminous soil stabilization, neither the engineer nor the physical chemist can presage clearly enough the specific functions of the bitumen.

Soil, generally speaking, possesses a number of properties highly undesirable for road-base material. Foremost among these is its great affinity for water, resulting in easy slaking and in an adjustment of its moisture content to the amount of water available. This change in moisture content is accompanied by changes in consistency and in resistance to deformation. Even at constant moisture content the stability of a soil is liable to change as a result of changes in its structure. On the other hand, soil possesses some very desirable attributes, such as its self-healing power, its great cohesion in dry or slightly moist condition, and its impermeability to water when swollen. The test for bituminous (as for any other) soil stabilization might then be expressed, though very loosely, as enhancement of the desirable, and control of the undesirable, properties of the soil. Consequently, under normal conditions, soil stabilization could not have as its goal the construction of a sheet asphalt pavement with soil material as a filler but rather the establishment of a new type of system.

In such a system the bituminous admixture should prevent excessive swelling and softening of the soil, but the soil particles should retain sufficient activity to add to the cohesive strength of the system by means of their absorbed water films. Also, a certain, though perhaps controlled, amount of the swelling and self-healing power of the soil should be preserved. Such ends can best be served by introducing the treating agent throughout the mass in the form of a fine lattice work rather than by attempting the absolute coating of each particle. The latter result is practically impossible and would probably result in the entire loss of the desirable characteristics of the soil and of stability.

The physical properties of soils are functionally connected with their granulometric composition and the chemical character of their fine constitutents. Accordingly, the specific function of the bitumen may change with each new soil type to which it is applied. For soils possessing small cohesive power, either as a result of their granulometric composition (sandy soils) or their chemical character (lateritic and desert soils), the primary function of the bitumen is to induce a better cohesion by cementing together the soil particles. Cohesive soils, on the other hand, require only a reduction of their water affinity and swelling capacity while their cohesive properties are interfered with as little as possible. It is logical, therefore, to choose the type of bitumen in accordance with its prospective function; that is, a material giving a bituminous residue of well-defined consistency and cementing power for noncohesive soils and a water-proofing road oil for cohesive soils. Bituminous materials ideally suited to stabilize the noncohesive desert soils of California are liable to be "over-designed" and uneconomical for use on heavy midwestern soils.

If the machine-mix (pugmill) method is used, the applied liquid bitumen undergoes emulsification in the pugmill, with the clay acting as an emulsifying agent. Consequently, the use of emulsified asphalt in connection with this method serves no essential purpose. Therefore, a prepared emulsion has no advantage in itself; it can be justified economically only if the superiority of the use of an emulsified bituminous cement for a certain job can be demonstrated by experiment and test.

From time to time changes in design, especially concerning the depth of stabilized bases, have been introduced. Thickness of the bases, produced by the three methods described, has varied from three to six inches in depth in the Missouri program, with the trend toward the greater thickness due to a tendency toward edge failures at points of poor subgrade support. Thickening of the edges of the sections has been practiced on some projects where the first two methods were used, since they lend themselves easily to such a procedure. Such changes in design reflect the condition that, while the aforementioned methods were being evolved, there existed no reliable theory of design by which to determine the necessary depth of a stabilized base. Nor was there any very definite concept of the specific function of a base except that it should reduce the impacts and stresses received on the road surface to an allowable minimum before they reached the subgrade. This minimum was understood to be controlled by two factors, i.e., the stress which just failed to achieve permanent deformation of the subgrade, and the stress which just failed to change the soil structure sufficiently to weaken the subgrade. Reliable data on this allowable stress are, to say the least, difficult to obtain.

A realization of the many unsolved problems involved in the theory of base stability explains why the desirable thickness of bases still must be determined empirically. Savings of millions of dollars still wait on the solution which will permit the thickness of base to be varied accurately in accordance with the supporting power of the underlying soil.