USE OF CUTBACKS AND ROAD OILS IN SOIL STABILIZATION

By F V Reagel and R C Schappler

Missouri Highway Department

SYNOPSIS

The problem under consideration is the improvement of earth, crushed stone, and worn-out gravel roads of little thickness, to give dustless safe service at a reasonable annual cost The solution lies in working in the direction of waterproofed bases plus relatively thin renewable cover coats From the bituminous angle, the question arises as to whether enough oil can be added to a sufficient thickness to waterproof durably without causing a plastic condition and thereby losing the inherent stability of the soil, and whether, if this is not possible, the plasticity so produced can be overcome by addition of an economical amount of friction material Any treatment which keeps the moisture content of a soil system below the plastic limit, or which changes the character of the soil so as to raise the plastic limit, will in general improve the system Bituminous material tends to do these two things A certain amount of water, however, is necessary for a good oiling job, and the cohesive strength of the soil system is a function both of the water films and the oil films Laboratory experiments on soil-oil specimens have shown that water absorptions decrease with increasing bitumen content and that an optimum bitumen range demonstrated by stability measurements is roughly 6 to 10 per cent based on soil fines Two major construction projects were undertaken in Missouri, one utilizing the subsurface method of introducing the oil and afterwards, as a check, the mixing method These roads are now under observation, and although present indications are listed in this article, the subject is a current research and conclusions may not be final

During the past decade, large mileages of medium and high type road surfaces have been constructed upon which traffic can move from one population center to another without much inconvenience With this outlet to traffic available, the natural consequence is an increasing demand for feeder roads and for the local or so-called farm-to-market highways

Mileage of this type is extremely large as compared to that of the primary systems, whereas funds for construction become increasingly difficult to obtain as the direct needs of more and more of the population are met As a result, a limited amount of money must be diluted so as to spread over a very large area if traffic demands are to be met

This situation accounts, in a large measure, for the present wave of interest in low cost road construction and soil stabilization as a particular phase of that problem

During the early stages of most state road programs, the needs of light traffic were served by means of traffic bound stone and gravel surfaces These surfaces met the immediate needs with, however, attendant hazards of dust and loose material, until increasing traffic became educated to the possibilities of a bonded surface and demanded relief from the discomfort and accident toll of the granular type surface

Experimentation in several states then produced the oil mat type of surfacing A number of trial installations of this type on well established bases provided a sample of surfacing free from the objections of the floating type and the sale was complete and immediate

When a considerable mileage of this new type surfacing was placed on relatively stable gravel surfaces as a base, it was soon discovered that, while a gravel mat can carry traffic and remain stable as a surface if the underlying moisture is free to come up through the surface and evaporate, the same mat when blanketed with a moisture-tight surface was no longer uniformly stable We had been carrying traffic on a crust 1½ to 2 in thick which seems to be the natural equilibrium mixture of gravel and subgrade soil when the gravel is applied by the featheredge method

Along with most other states Missouri was faced with the problem of improving a large mileage of traffic bound surfaces and plain earth surfaces, which, in their existing conditions were not satisfactory as a support for a thin oil mat The answer seemed to be either to improve the base support or to spread the load over otherwise insufficient base support by adding additional layers of mat To provide the necessary base support seemed less expensive and it was therefore undertaken by making use of clay-gravel stabilization or other comparable methods

At the same time, thought was given to some form of chemical or bituminous stabilization for use in areas where additional gravel or other road metal was expensive

As has been stated elsewhere by the authors, any consideration of the low cost road problem brings us to the realization that soil or subgrade support is the basic factor with which we have to deal If, at the proper moisture content, the soil will support any practicable load, which is true in the majority of cases, then the simple stabilization of the moisture content will achieve the purpose to the extent that such stabilization can be made permanent It is a broad statement, but it follows that, if a practical, durable way to stabilize the moisture content of soil in the field can be found no other type of construction will be needed. Failing in this objective, the next step in design is to spread the load over sufficient area to meet the limited supporting power of the soil at the moisture conditions experienced, or else change the characteristics of the soil phase by adding friction material

Our conception of the difference between base and surface is that bases are simply additional thickness protected against reduction in thickness by traffic action, by means of surface layers designed to resist the abrasive action of traffic The protecting layers so far devised are in general more expensive than the bases, thickness for thickness

If the assumption is correct that a durable waterproofed thickness of soil is of just as much value (aside from failure to resist the abrasion of traffic) as an equivalent thickness of high type surface (again discounting beam strength) we are forced to just one conclusion—concentrate on the base and work in the direction of waterproofed bases plus relatively thin renewable cover coats as a solution to the low cost road problem This thin renewable surface can be maintained or improved but it costs heavily to work on the base after the top has once been placed.

This is the line of reasoning on which we are basing our plan of research attack on the low cost road problem

As previously indicated, the problem is the improvement of a large mileage of earth and worn out gravel and crushed stone roads of little thickness to give dustless, safe service to present and future traffic at a reasonable annual cost including maintenance expenditures

Considering only the bituminous angle, can enough oil be added to a sufficient thickness to water-proof durably without causing a plastic condition and thereby losing the inherent stability of the soil? If not, can the plasticity so produced be overcome by the addition of an economical amount of friction material?

The use of soil-bitumen mixtures is not by any means new We are told of earth-asphalt bricks constructed by the Assyrians thousands of years ago which are still withstanding the elements Oils have recently been used to stabilize adobe brick in the western states with surprising results Millions of gallons of oil are being applied annually to earth surfaces to provide, with proper renewal and maintenance, all weather roads with perhaps a greater return on the investment than for any other form of surface in use today

Assuming that the preceding discussion rather broadly outlines the situation, the factors affecting stability of soil and soil and aggregate mixtures may be further considered, somewhat more directly

Inherent stability may be defined as the property of a soil system to resist deformation under ordinary conditions of service subject to field variations of moisture content and temperature incident to such service, and is directly dependent, in degree, upon a combination of internal friction and cohesion For example, a plastic mass of material may have high cohesion but be very unstable in load supporting power Likewise, a mass of rough angular particles will have high frictional resistance but will have low supporting power if unconfined A combination of the two properties tends toward stability as illustrated by the introduction of granular material into plastic material Material normally stable when dry may become very unstable when lubricated with water

Cohesion in a water-soil system is due partially to linking of constituents by chains of oriented water molecules This action is particularly effective with plate shaped particles and small moisture content but is probably of negligible effect when spherical particles are considered The surface tension of the water itself has the greater effect in a partly saturated soil system

This part of cohesion is a function of the curvature of the water surface It is lost when the system is completely saturated with water, a condition very seldom reached in the field

During the formation of a soil-water system, the dry soil is wet with varying degrees of difficulty, assuming the water to be added in small increments In the absence of air films the soil particles are easily wetted In the presence of air films such as would surround dust particles, the difficulty of wetting varies directly with the amount of surface area In the case of clay this area will total at least an acre per cu cm whereas silts and sands have considerably less area of surface

With increasing quantities of water in a coherent soil-water system, the cohesion part of stability shows continual decrease, with noncoherent soil systems, such as dust, sand, dry lateritic soils, etc , the cohesion part of stability reaches the maximum at a water content near the plastic limit The stability curve for all soil drops rapidly at some point near the plastic limit, and with further increase in moisture, approaches zero at the liquid limit Any treatments, therefore, that we can give to these systems that keep the moisture content below the plastic limit, or which change the character of the soil so as to move the plastic limit to a higher point, will, in general, improve the system

The introduction of bituminous material to this system tends to do both

The results of replacing part of the water by bituminous material will depend upon whether the bituminous constituents tend to form lubricating or cementing films Especially to be considered is the formation of a thixotropic system in the bituminous phase from the constituents of the bitumen itself or as a result of a possible interaction of the bitumen with the mineral surfaces, for instance, soap formation.

Lubricating films are monomolecular layers and the cohesion of a soil-oil system containing them is a function of the Van der Waals forces between the lubricating film and the remainder of the bitumen. These forces are, in general, smaller than the same forces in the bulk of the bitumen.

Cementing films are polymolecular films induced by the character of the mineral surface and made possible by the shape and the chemical character of certain constituents of the bitumen. This type of film acts similarly to the chains of water molecules mentioned above and increases the cohesional resistance of the system. A film of this character may also be established by the catalytic effect of some mineral surfaces in oxidizing, polymerizing or condensing the active compounds in the bitumen.

In the case of either cementing or lubricating films, there is the additional effect of the interfacial tension between oil and air in the system. Due to the lower surface tension of the oil, this effect is less than in the case of water films.

In practice, the amount of bitumen used is not sufficient to fill all pores. Further, the temperatures encountered are not sufficient to drive out the water which is adsorbed in thin films. The cohesive strength of such a system is therefore a function of both the water films and the oil films. The specific function of the oil film is to impede the entrance of water. Water entering the system will replace and expel air from the pores, resulting in a decrease of the surface tension part of the cohesion. In case the bond between the mineral surface and the bitumen is weak, water may enter between them, resulting in swelling and further weakening of the system.

In the resulting soil-water-oil system, we include the larger granular material in the term "soil." Water is included in this system for three reasons: first, all earthy materials under natural conditions possess water films; second, it has been shown that a certain amount of water is necessary for a good oiling job; and finally moisture is always present under service conditions.

The permanent stability of an oil-earth surface, or base, depends largely upon the relative affinity of the mineral surfaces for oil and water respectively. If the affinity of the mineral constituents for oil is greater than for water, then the oil will be preferentially adsorbed by the soil, preventing a detrimental reaction with water, whereas, if the opposite preference is shown, a system unstable toward moisture will be formed.

Several methods for measuring these relative affinities have been proposed and used. They are generally based on measurements of interfacial tension and preferential wetability. According to most of these tests, stable oil-earth systems should be impossible.

However, we have seen and constructed stable oil-earth roads. Apparently these tests neglect a very important factor, namely, the composite nature of the constituents of the soil-moisture and oil phases.

It has been shown that there are dissolved and suspended in the soil-water as well as in the oil, large amounts of various surface-active substances, some of which possess the same general character or exhibit the same behavior as soap molecules.

This behavior, that of orientation, is best illustrated by the following well known experiment. A drop of molten fatty acid is put on a water surface. After solidification and removal from the water, this drop is easily wetted by water, only on the surface first in contact with the water, whereas the portion which originally solidified in air is easily wetted by oil. Apparently, while in the liquid state, the fatty acid molecules have arranged themselves so as to bring their hydrophil heads into contact with the water, and moved the more inert organic portion toward the air.

Obviously, determinations of the surface tension of highly viscous or solid fatty acid systems toward water or oil will vary according to the time allowed for orientation of the molecules The same must be true of highly viscous asphaltic materials

Based on the foregoing discussion the following action as taking place in a successful bituminous soil treatment is pictured:

The substances dissolved and suspended in the oil, and which show greater affinity for water than do the oil molecules, but which are entirely soluble in water, will accumulate and be oriented at the oil water boundary Vice versa, the same action happens with the substances dissolved and suspended in the water phase or film The water film then gradually decreases in thickness by evaporation until the active oriented substances on the oil surface approach the soil particles closely enough to be adsorbed

This oriented adsorption brings about the greatest resistance for this type of system against further attack by water

The use of soap or similar compounds in connection with the construction of bituminous road surfaces and bases is primarily intended to increase the amount of readily available surface-active material which will be oriented to promote the establishment of a better oil-soil linkage

Based on the conception of the problem as stated above, attempts were made in the Missouri Laboratory to develop by means of laboratory manipulation optimum quantities and types of treating agents and conditions of treatment This work, in its early stages, failed to develop the desired information Interpretations were clouded by the vast differences in laboratory manipulations and in simple field treatments desired in practice It was found very difficult, if not impossible, to duplicate satisfactorily field conditions in the laboratory

Information was and is lacking in regard to field moisture conditions, and the extent and character of the curing of bitumen over periods of time are a matter of conjecture Both items may be presumed to influence stability values

Laboratory indications did, however, develop that water absorptions decrease with increasing bitumen content and that an optimum bitumen range is shown by stability measurements This range is roughly 6 to 10 per cent based on soil fines (passing 40 mesh sieve) However, the results are clouded by the influence of moisture content at time of test, the degree or extent of curing and the nature of the fines present The presence of clay in the system gives higher stability measurements and this is considered consistent with the conception of cohesion as previously stated

The laboratory studies referred to should not be confused with the work of Dr Winterkorn which has as its goal the chemical stabilization of soils by the use of chemical treatments, including bituminous materials The work of Dr Winterkorn in cooperation with the Bureau of Public Roads, the University of Missouri and the Missouri Highway Commission, is fundamental in nature, dealing with a number of phases of the subject, and is reported elsewhere

Following the preliminary laboratory work, development test sections were considered necessary and, during the season of 1935, two major projects were planned and constructed Early during the present year, these projects were covered with a light seal or armor coat and are now under observation as a service test The two methods used may be described as follows

1—The Ingalls or subterranean method is a method for the deposition of a quantity of liquid bituminous material or other treating agent, at the bottom of a scarified layer of earth, or earth covered with granular surfacing, followed by compaction to permit the oil to permeate upward and diffuse through the mass Later manipulation may or may not be necessary

This method in principle was, in so far as we know, first conceived by Mr Ingalls in connection with the hauling of heavy equipment in the western oil fields Its first trial in Missouri was by Mr Alex F Sachs, County Engineer of Jackson County, on short stretches of earth, and earth covered with crushed stone surfacing After promising indications were observed on these sections, which were constructed during the summer of 1935, ten miles of experimental sections were constructed on the Missouri State Highway system in Platte County

The method as now developed consists essentially of scarifying the existing roadway to a depth of four or five inches, followed by the introduction of the bituminous material with or without prior or subsequent application of a small mount of water or soap solution After the application, the roadway is kept smooth under traffic and rolled as necessary to obtain the desired compaction

The equipment for application consists of a heavy frame supporting hollow curved teeth which project down to the desired depth and through which the bituminous material is forced from an accompanying distributor by means of a pump mounted on the rear of the applicator

The bituminous material tried included SC oils, MC oils, MC oils emulsified, and commercial emulsions Specifications of these materials are given in Table 1 The quantities vary from approximately 5 to 15 per cent of oil by weight of the layer treated, based on percentage of the material passing the 40 mesh sieve and the percentage of 100 penetration residue in the treating oil These quantities attempt to bracket the optimum quantity or in other words to obtain some sections too lean and some too rich in order to obtain maximum information

To a number of sections varying quantities of aggregate were added prior to scarification in order to test the efficiency of additional friction material in case too great a degree of plasticity was induced and also to check the relative efficiency from an economical viewpoint The range of percentages of the material passing the 40 mesh sieve on the completed sections approximated 20 to 30, 50 to 60 and 100

It seems to take about two to three weeks for the oil to permeate the mass, the final stage of diffusion seeming often to follow a rain

It is apparent in our opinion that the final result is a base and not a surface but it is hoped that the base obtained will require only a light armor-coat as a surface The resulting combination, if successful, will be obtained at considerably lower cost than other types of low cost construction in Missouri, in areas where aggregates are not readily available

The project was constructed in the late fall during a rainy season and under conditions which were considered as distinctly unfavorable Some sections, particularly those having little or no granular material present, did not have a complete drying action such as would be necessary for the best results

The lateness of the season prevented application of trial sections of surface and consequently the base was exposed to traffic during the following winter without surface protection

While exposed, the base carried traffic throughout its entire length

The soil type is predominantly a silt with a few stretches of clay at low points in the grade line

2 —Since the success of this method was not certain, as a check, a second method was tried in Lewis County in which we scarified the surface, windrowed

the material and mixed it with the desired percentage of bituminous material and water by means of a traveling plant (Barber Greene Type) This method is referred to as the mixing method

The variations tried with the first method, including addition of granular material, were approximated under this process but at an increased cost The advantages hoped for in the second method were greater uniformity, better mixing and better control Only about

TABLE 1

Typical Bituminous Material

Cutbacks	SC-2	SC-3	
Percent Water	Trace	Trace	
Specific Gravity (60°F/60°F)	1 0286	1 0691	
Furol Viscosity, Secs at 122°F	159		
" " " at 140°F		201	
Percent Residue of 90 Pen	60 0		
" " " 90 "		78 2	
Ductility of Residue at 77°F	145	130	
Flash Point, (Cleveland open cup)	340°F	255°F	
Percent Loss on Heating (50 gm 5 hrs 325°F)	5 84	8 07	
Percent Soluble in carbon tetrachloride	99 89	99 89	
Cutbacks	**MC-3**	**MC-4**	
Specific Gravity (60°F/60°F)	0 9647	9747	
Flash Point (Cleveland open cup)	170°F	190°F	
Furol Viscosity, secs at 140°F	385	721	
Distillation by volume			
Initial Boiling Point	450°F	452°F	
Percent off at 437°F	0 0	0 0	
Percent off at 500°F	5 0	3 0	
Percent off at 600°F	15 5	11 5	
Percent off at 680°F	19 5	15 5	
Tests on Residue			
Pen (77°F , 100 gm 5 sec)	136	141	
Ductility at 77°F	108	150+	
Ductility at 39 2°F	9	10	
Percent soluble in CCl_4	99 80	99 85	
Heterogeneity Test	No spot	No spot	
Emulsions	**No 1**	**No 2**	**No 3**
Percent Demulsibility (35 cc of 02 N $CaCl_2$)	1 8	0 0	94 9
Percent Demulsibility (50 cc of 0 1 N $CaCl_2$)	0 7	93 5	95 5
Distillation			
Percent Water	44 0	48 5	46 0
Percent Asphalt Residue	55 8	48 0	49 0
Percent Oils and Loss	0 2	3 5	5 0
Tests on Residue			
Specific Gravity (25°/25°C)	1 0443	1 0041	9848
Penetration (25°C 100 gr 5 sec)	129	300+	300+
Ductility at 25°C	43	21	43
Total Bitumen (Sol in CS_2)	98 41	99 72	98 90
Percent Ash	0 56	0 02	0 18
Float Test at 50°C		*	167

* Could not be obtained due to skin forming on surface of specimen

six miles of the contemplated ten miles of test sections were completed before winter weather caused a shutdown, but sufficient sections were constructed to give an interesting comparison after the effects of traffic and weather during the winter season were observed

The previous remarks regarding weather conditions also apply to this project Due to use of a pug mixer, it was necessary to add about 35 gal of water per cu yd of mixed material in order to obtain a dischargeable mix This water does not immediately leave the mix, and since a number of sections were not sufficiently dried to permit traffic prior to freezing, they were not spread until the following spring

Sections which had a longer drying time carried traffic with little or no signs of distress There was evidence, however, of a sponginess or rubbery action indicating that future additional consolidation should take place

The field test sections constructed during 1935 were rather short due to the numerous variations of conditions tried These sections gave a promising indication and permitted the elimination of a number of sets of conditions For example, the optimum range of bitumen content was confirmed and narrowed The advisability of thickening the edge of the surface was suggested

The costs of construction were higher because of numerous changes and delays, and in order to further develop the possibilities, a number of contracts were let during the 1936 construction season to try out the two methods under actual contract conditions These projects have been largely completed as to base but will not be covered with armor coat until the spring of 1937 In the meantime observations will be continued

The work during this season was constructed in general under the methods followed on the shorter sections and the treating materials were essentially the same except that, in addition to the use of SC and MC materials, some bituminous fluxes were emulsified and one car of TC No 2 tar was used in connection with the suboiling method

All the work discussed in this paper is considered as current research and therefore care should be taken to avoid final conclusions

There are however certain indications which may be stated for the benefit of those who might desire to include similar projects in their programs They are as follows:

1 There is a fairly definite range in amount of bituminous material optimum for use with the types of soils tried and the material used (6 to 10 per cent based on soil fines passing 40 mesh sieve) Definite failures occur consistently due to plasticity induced by excessive amounts of treating agent

2 With the soil types encountered, emulsions diffuse more completely, uniformly and rapidly in the case of the suboiling method than do the other materials thus far observed

3 Emulsification is not necessary in the case of the mixing method, complete diffusion being obtained in all cases by the pug mill mixer used The presence of fines in the mix promotes the formation of a clay emulsion as indicated by the appearance and action of the material discharged by the pug mixer

4 Treating agents such as cutbacks, having abrupt gaps in distillation range, tend to fractionate during the diffusion period when used with the suboiling method It is believed that such fractionation tends to cause a slower and much less uniform diffusion

5 No fractionation has been noted in the case of the use of emulsions

6 Rescarification and blade mixing can be economically used to improve nonuniform and insufficient diffusion in the case of the suboiling method and

may prove essential to the success of this method suboiled lower layer and the prime and armor coats This condition is not

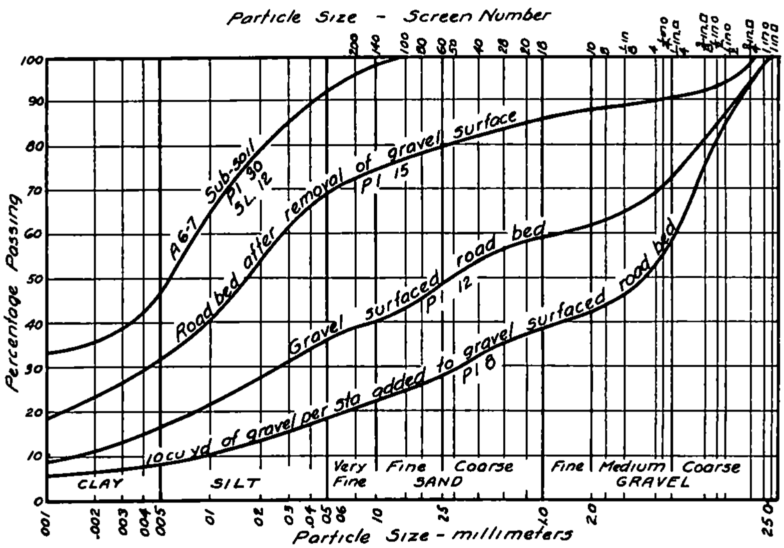

Figure 1. Grain Size Accumulation Curve, Bituminous Stabilization, Gravel Road on Clay Subgrade

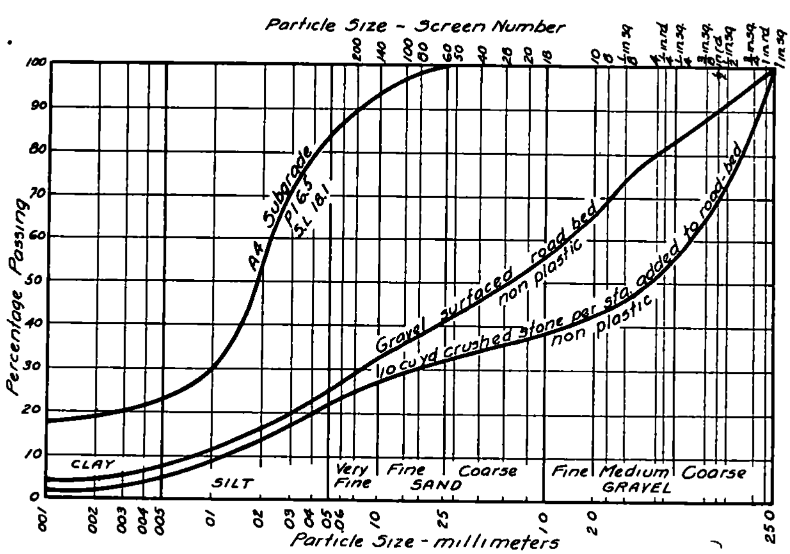

Figure 2. Grain Size Accumulation Curve, Bituminous Stabilization, Gravel Road on Silt Subgrade

7 Some sections are under observation which have a considerable layer of untreated soil sandwiched between the considered desirable but there are indications that such sections may prove serviceable

8 Thickening of the edges of these bases is advisable and desirable In the mixing method the subbase is immediately available for shaping to provide for tapering to a thickened edge With present suboiling equipment, the maintaining of a uniform bitumen content in the treated material requires a uniform depth of treatment for the application of oil to the edges

9 More accurate means of control of the bituminous material applied by the suboiling method is desirable To obtain suitable accuracy at present it is necessary to add the treating agent in more than one increment

10 Under the conditions used and at the present stage of development of both methods, the mixing method gives a more complete and uniform diffusion of the treating agent although at a higher cost of manipulation

11 The presence of proper amounts of moisture is necessary or highly beneficial, both as an aid to proper coating of the particles and to insure a high degree of compaction The addition of excessive moisture at the start of treatment does not appear to be detrimental assuming that compaction is continued through the drying range However, where conditions are such that an excessive amount of water is trapped in the subbase, serious trouble may be experienced for sometime due to subsoil weakness caused by abnormally high moisture content

12 Mixtures containing as low as 50 per cent of aggregate retained on the 40 mesh are entirely stable and indications are that this percentage may be considerably reduced with further study Sections containing no aggregate have been under service since 1935, and wherever proper amounts of treating agent were used, no serious failures have been observed

13 Percentages of aggregate may be varied to obtain economy dependent upon the relative costs of aggregate and bituminous material, since the addition of plus 40 mesh material permits a proportional decrease in oil

14 Preliminary compaction must proceed from the bottom upwards Multiple wheel rollers equipped with automobile or truck tires, and sheepsfoot rollers seem to give satisfactory results when supplemented by use of the ordinary flat wheel roller for final compaction

Table 1 gives typical test results on the various bituminous materials used in treatments on experimental projects and Figures 1 and 2 show the approximate gradations and characters of the materials treated