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H. W. WILEY, Chief of Bureau.

THE CEMENTING POWER OF ROAD MATERIALS.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Chemistry,
Washington, D. C., August 4, 1904.

Sir: I have the honor to transmit for your approval a manuscript containing the results of investigations made in the Division of Tests of this Bureau on the cementing power of road materials. Although the methods at present employed for the determination of this very important property of road materials can not be considered final, yet it is deemed advisable that those interested in the subject should be made acquainted with the progress of the work up to the present time. I recommend, therefore, that this report be published as Bulletin No. 85 of the Bureau of Chemistry.

Respectfully,

H. W. Wiley, *Chief.*

Hon. James Wilson,
Secretary of Agriculture.

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THE CEMENTING POWER OF ROAD MATERIALS.

INTRODUCTION.

For several years the road material laboratory, now included in the Division of Tests, has been desirous of impressing upon engineers and others interested in road building the importance of that property of road materials known as cementing power and its relation to the selection of the best materials. Everyone who has given careful attention to this subject is aware that different rocks vary widely in their binding power. While some broken stones will easily and rapidly consolidate under the roller or traffic, others will do so only slowly and with difficulty, while again some totally lack any binding power whatever. Furthermore, as pointed out in previous publications from this laboratory, the species of the rock is practically no guide as to its road-making quality, and a study of Table III (p. 17) clearly shows this to be true in regard to cementing value. This cementing power is caused by a hydrated condition of the particles, which is the result of certain secondary changes produced in the minerals composing the rock structure. Whether these changes take place depends upon circumstances, and not, broadly speaking, upon the rock species. This subject, however, will be more fully discussed later on.

The statement is frequently seen in road-building literature that so-called trap rocks invariably bind well and make the best road material. While this is perfectly true of the traps in certain localities, it is by no means true of those in others. In the same way a widespread impression prevails that sandstones are, as a rule, useless as road-building material. This again is by no means invariably true, and tests made in the laboratory, which were afterwards substantiated in practice, have shown that some sandstones are eminently suited for building good roads.

The question of the geographical distribution of road materials is one in which this laboratory is much interested. The accumulation of sufficient data from which to prepare and issue maps is only a question of time, and already the data obtained from the tests on about a thousand samples in this laboratory, while not sufficiently complete to warrant publication, point none the less to some very interesting facts.

It is the intention in this bulletin to give as concise a description as possible of the investigation and results of tests of the important property of road materials known as cementing power. In the course of many years' investigation of this and allied problems a vast amount of data has been accumulated, but the effort has been made at this time to select only such as are necessary for the presentation and discussion of the subject.

CEMENTATION TEST.[a]

The binding or cementing power of rock dust is such an important element in road building that much time has been spent in the endeavor

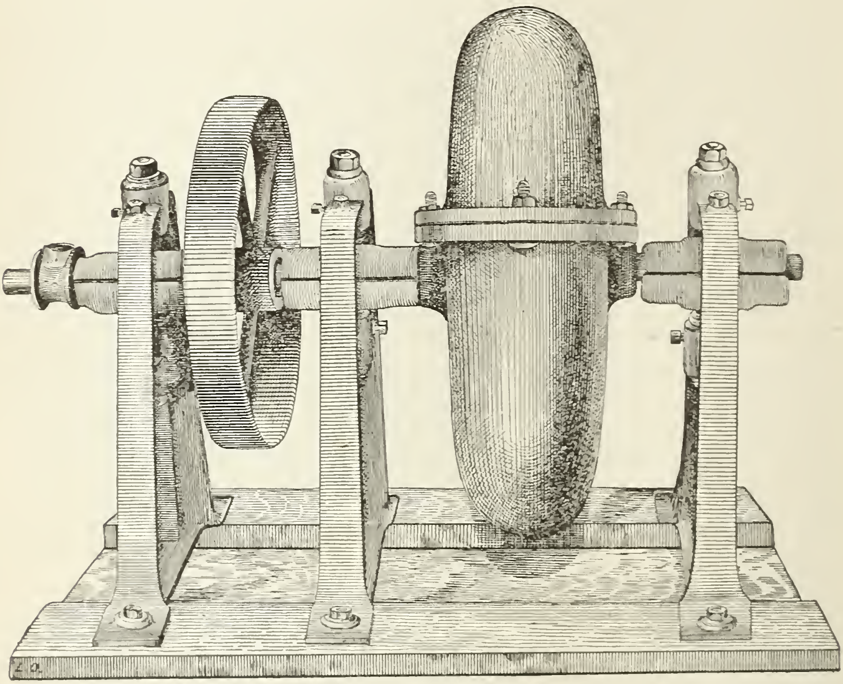

FIG. 1.—Ball mill.

to devise a suitable test for determining the degree to which the various rocks and gravels possess this property. Many tests have been tried, but as yet only an impact test, carried on in a uniform manner as described below, has given satisfactory results.

One kilogram of the rock to be tested is broken sufficiently small to pass a 6 mm. but not a 1 mm mesh screen. It is then placed in a ball mill and ground for two and a half hours. This ball mill (fig. 1) contains two chilled-steel balls, which weigh 25 pounds each, and is

[a] The description of this test and the machines used is partly abstracted from Bul. No. 79, Bureau of Chemistry.

revolved at the rate of 2,000 revolutions per hour. It was found by experiment that grinding rock thus prepared for two and a half hours is sufficient to reduce it to a powder which will pass through a 0.25 mm mesh. The dust thus obtained is mixed with water to about the consistency of a stiff dough, and is kept in a closed jar for twenty-four hours. About 25 grams of this dough is placed in a cylindrical metal die 25 mm in diameter, shown in figure 2. A closely fitting plug, supported by guide rods, is inserted over the material, which is subjected to a pressure of 100 kg per square centimeter.

It is most important that these briquettes should be compressed in a uniform manner, and for this purpose a special machine has been designed (fig. 3). The die is placed on an iron platform supported by a piston rod, which is connected directly with a hydraulic piston below. Water from a tank is admitted to the hydraulic cylinder through a small orifice in the pipe. As the piston rises, the platform and die are carried up with it, the plug of the latter coming in contact with a yoke attached to a properly weighted lever arm. When the lever arm is raised one-eighth of an inch it closes an electric circuit which trips a right-angle cock, shutting off the water and opening the exhaust. About one minute is required to compress a briquette, and the maximum load is applied only for an instant. By this device practically uniform conditions are obtained.

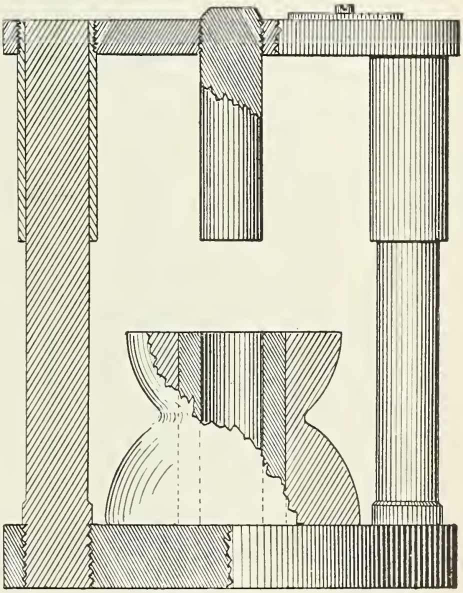

FIG. 2.—Briquette die.

The height of the briquette is measured, and if it is not exactly 25 mm the requisite amount of material is added or subtracted to make the next briquette the required height. Five briquettes are made from each test sample and allowed to dry twelve hours in air and twelve hours in a steam bath. After cooling in a desiccator they are tested by impact in a machine especially designed for the purpose (fig. 4). It consists of a 1 kg (2.2 pounds) hammer (*H*), which is guided by two vertical rods (*D*). The hammer (*H*), which ends in a small cone at the top (*L*), is caught on the lower side of the cone by two spring bolts (*S*), and is lifted by a crosshead (*I*) which is joined to a crank shaft above. A vertical rod (*P*), which is directly over the hammer cone, can be

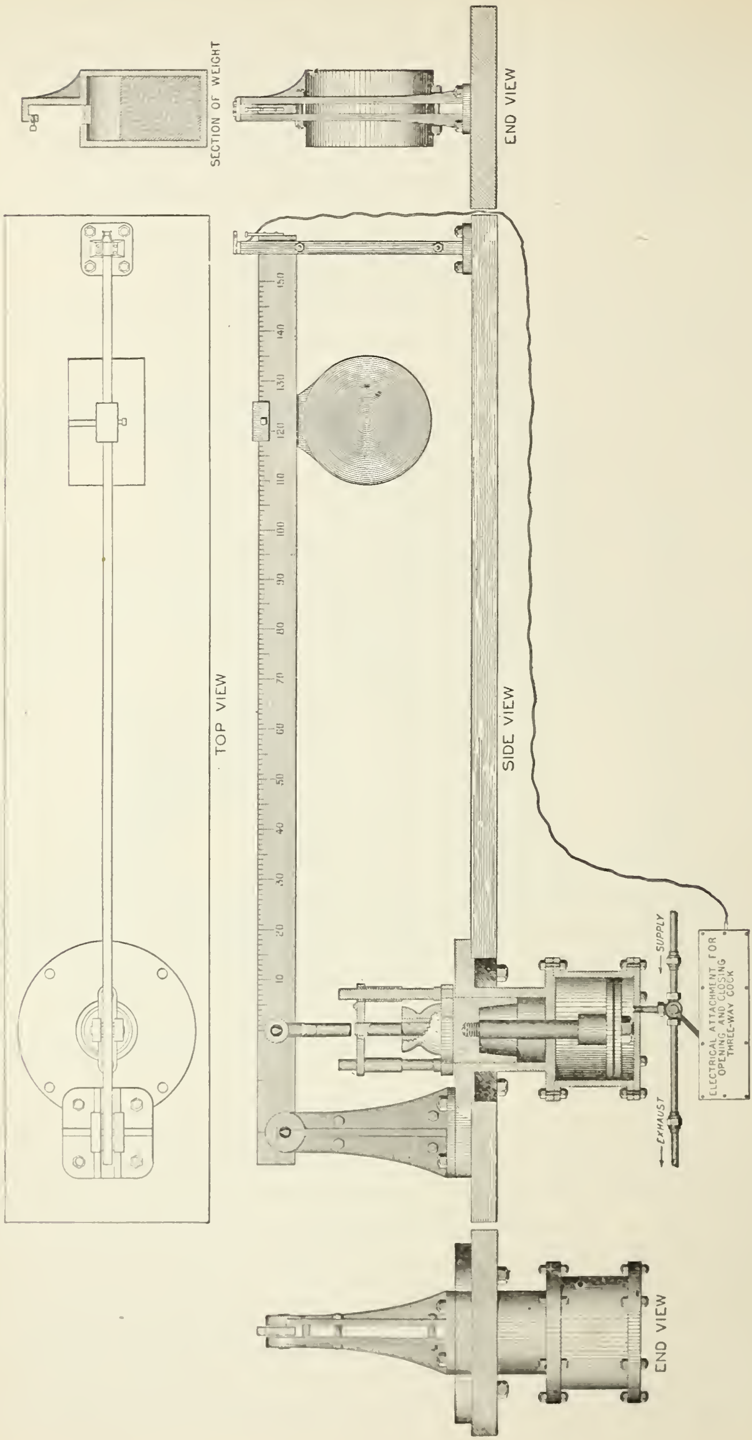

Fig. 3.—Briquette machine.

adjusted by thumbscrews to give a drop to the hammer varying from a fraction of a millimeter to 10 cm. This rod has a hollow cone at its

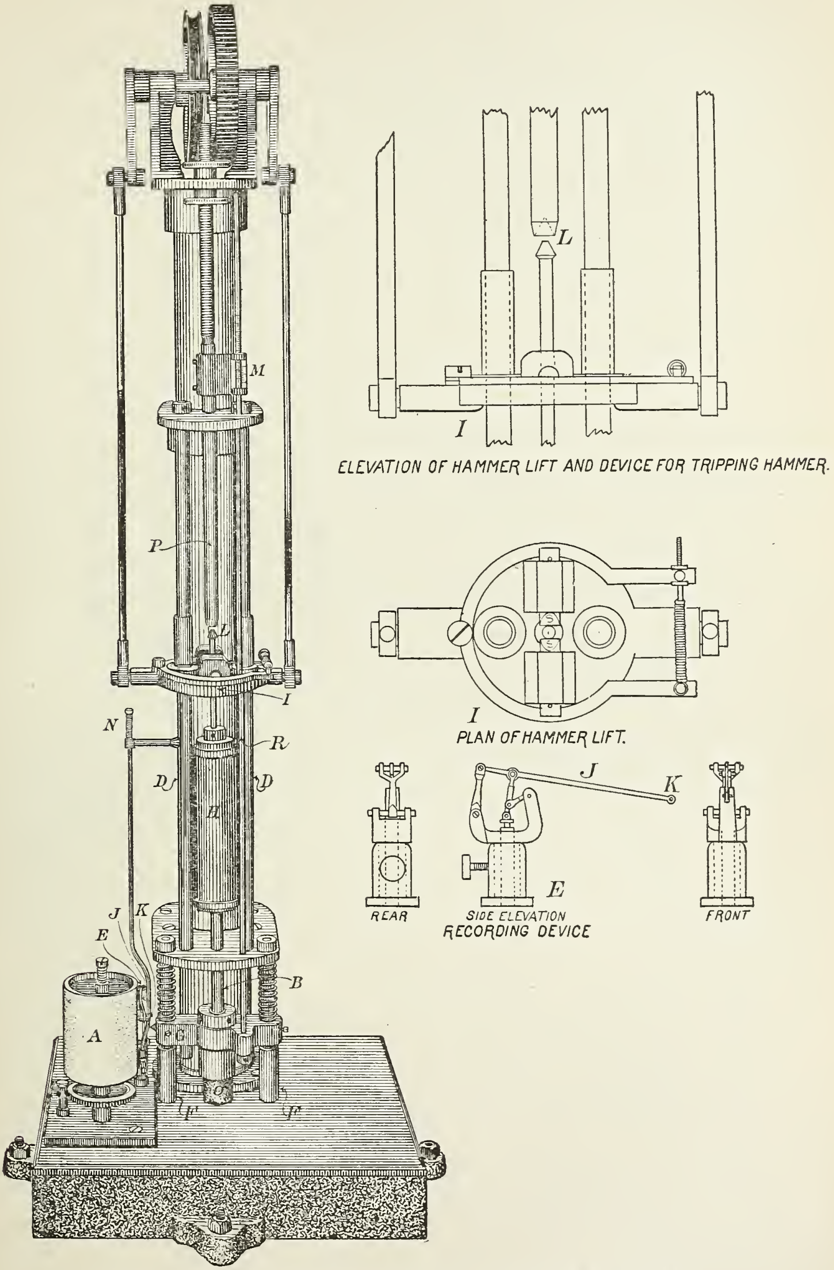

Fig. 4.—Impact machine to determine cementing value of rock.

lower end, into which the cone of the hammer head is thrust when the hammer is lifted by the crosshead (*I*). When the cone of the hammer head is brought into the cone of the adjusting rod the hammer is exactly centered and brought free of the guide rods (*D*). As the cross head (*I*) continues to rise, the bolts supporting the hammer, which are tapered at an angle of about 45°, are thrust open by the sloping head of the adjusting cone rod (*P*), releasing the hammer, which falls on a flat-end plunger (*B*) of 1 kg weight, which is pressed upon the briquette (*O*) by two light spiral springs surrounding the guide rods (*F*). This plunger (*B*) is bolted to a crosshead (*G*). A small lever (*J*), holding a brass pencil (*K*) at its free end, is connected with the side of the crosshead by a link motion arranged so that it gives a vertical movement to the pencil five times as great as the movement of the crosshead. The pencil is pressed against a drum (*A*), and its movement is recorded on a slip of silicated paper fastened thereon. The drum is moved automatically through a small angle at each stroke of the hammer. In this way a record is obtained of the movement of the crosshead during and after each blow of the hammer. To the crosshead (*G*) is fastened a steel rod (*R*), which passes up through the crosshead (*I*) and through a piece of metal securely attached to the cone rod (*P*). At this junction a vernier scale is graduated, by means of which the height of blow of the hammer can be accurately

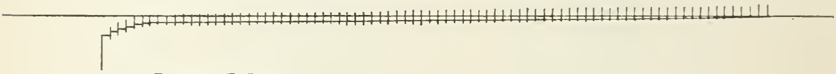

FIG. 5.—Diagram showing point of failure in cementation test.

set to 0.1 mm, and by lowering the cone rod until it rests on the hammer cone (*L*) the height of the briquette can also be measured to 0.1 mm.

The standard fall of the hammer for a test is 1 cm (0.39 inch) and this blow is repeated until the bond of cementation of the material is destroyed. The blow producing failure is easily ascertained, for when the hammer falls on the plunger, if the material beneath it can withstand the blow it recovers; if not, the plunger stays at the point to which it is driven, and in either case the behavior of the test piece is recorded on the drum. The automatic record thus obtained from each briquette is filed for future reference. A copy of one of these records is shown in figure 5. The number of blows required to destroy the bond of cementation or resilience, as described above, is noted, and the average obtained upon five briquettes is given as the cementing value.

The problem of holding the test piece rigidly under the intervening plunger so that it would not be subjected to lateral movements and transverse strains is one which has given much difficulty. Until recently, a small brass plate with a beveled hole slightly larger than the diameter of the briquette was used, but it was found that the test piece was often seriously abraded by the side thrust developed. Later attempts to secure the briquette by various clamping devices were not satisfactory. Finally the method was adopted of placing a drop of thick shellac on the bottom of the test piece, which causes it to adhere firmly to the bedplate. Careful attention to such details as these is necessary in order to get satisfactory results from this test.

The original method for molding the briquettes was worked out in the laboratory of the Massachusetts Highway Commission and differs somewhat from the method described above. In the earlier practice the requisite amount of rock dust to make a briquette was weighed out while dry, mixed with 3 to 4 cc of water, and the briquette immediately molded from the wet dust. It is well known to practical road builders that the binding power of many rocks increases under the combined influence of water and traffic as time goes on. This question has received a great deal of attention and investigation in this laboratory and will be fully discussed later on.

CEMENTATION AND RECEMENTATION.

In the earlier practice of the laboratory it was the custom to make a recementation test. The fragments of the briquettes from the cementation test were ground, again mixed with a definite quantity of water and immediately remolded into briquettes. This was done on the theory that the rock dust on a road surface is continually being cemented, broken up, and recemented under traffic. A very large number of tests showed that the recementing values in by far the larger number of cases were smaller than the corresponding cementing values. There were, however, a number of cases in which the reverse took place. This is shown in the following table, in which the cementing and recementing values of a number of rock species are compared:

TABLE I.—*Comparison of cementing and recementing values.*

Serial No.	Name.	Cementing value.	Recementing value.
335	Diabase (trap)	110	89
336	Ferruginous limestone	158	72
337	Dolomitic limestone	59	42
338	Novaculite (chert)	24	18
340	Limestone	95	29
343	Dolomite	32	23
344	Sandstone	54	23
349	Diabase (trap)	49	44
346	Limestone	8	13
351	Gravel	11	13
383	Limestone	22	34
403	.....do	110	126
492	Dolomitic limestone	22	30
497	Hornblende schist	7	9

These anomalous results called for a thorough investigation of the whole question. As it is well known in clay working that the soaking and kneading of a clay for protracted periods increases not only the plasticity, but the binding power, it was suspected that the prolonged action of water on fine rock dust might well increase the binding power at least up to some maximum value. Investigations were at once begun to see if the underlying cause of the cementing power could be discovered. Some of the results of this research have already been published[a] from this laboratory. It is sufficient to say here that the conclusion was reached that the rock powders which have binding power contain a certain proportion of particles which are colloid in their nature. Under the action of water the particles to some extent soften and become adherent. On drying out, this adherent bond locks the particles together. In the case of clays this bond is usually very strong, while with rock dust it is extremely variable, ranging from those which yield briquettes that break on the first blow to those which will sustain hundreds without failure.

After the observations had been made which led to the conclusions outlined above it became evident that a modification was necessary in the manner of making the briquettes for the cementation test. Since the bond is developed under the prolonged action of water, it is manifestly unfair to wet the rock dust and immediately mold the test pieces. Moreover, as the action of water begins at once, and according to the laws of physical chemistry is more rapid at first, slowing down gradually as the point of completion of the reaction is approached, it is apparent that considerable errors in the results may be occasioned by small variations in time after the wetting of the dust takes place until the briquette is molded. It will also be shown that with nearly all materials the amount of working or kneading which is done upon the wet mass will effect the softening of the particles, and hence the strength of the bond. These variations were sufficiently large in some cases to account for the anomalous results in the cementation and recementation tests; hence the recementation tests were immediately given up as being of no value, and methods were devised by which the cementation test was improved.

The finely ground and sifted rock dusts were mixed with a sufficient quantity of water, and were worked and kneaded until an even consistency of stiff dough was obtained. From these doughs series of briquettes were made at intervals and tested. The effects produced by age on doughs of three typical specimens, including samples of good, medium, and poor cementing values, are given in the curves shown in figure 6. A study of these curves shows that there is invariably a rapid rise in binding power in the newly made doughs, and that after the lapse of twenty-four hours the value has, for the purpose of the test, become practically constant. This effect is, of course, more apparent in materials of high cementing value than in lower ones. Numerous experiments have shown that with powders, such as fine sand, which

[a] J. Amer. Chem. Soc., 25: 5.

have no particles of a colloid nature, and therefore no binding power, soaking or kneading will not develop the slightest increase. In carrying out the cementation test the doughs are now invariably aged for at least twenty-four hours, and the workman is trained to knead the dough always in the same manner for about the same length of time. Careful attention to these details has resulted in a great improvement in the value of the test, both in a lessened percentage of variation in different test pieces of the same series, and also in the agreement of the tests with the results of service. The percentage of error from variation is about the same as in cement testing if carried out with the same care.

Several criticisms have been made upon the cementation test, the opinion offered being to the effect that the results are too uncertain to be of value. The persons making these criticisms had not, however,

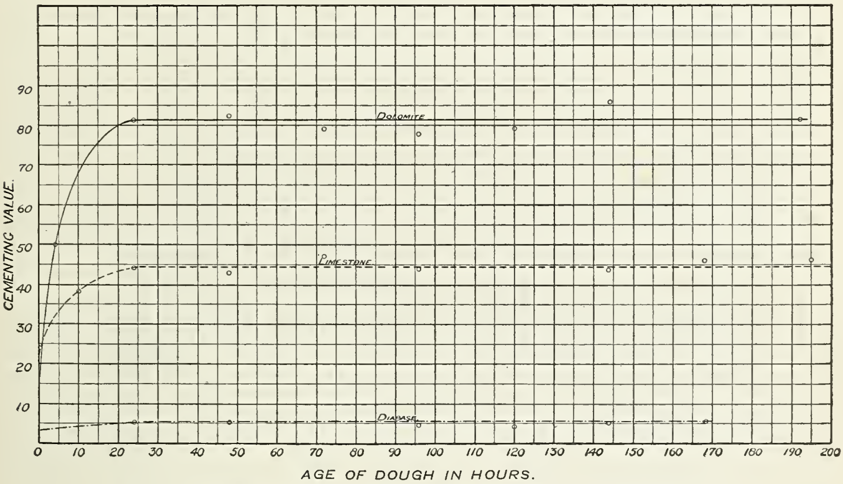

FIG. 6.—Diagram showing prolonged effect of water on cementing value.

availed themselves of these later improvements in the manner of making the test pieces. On the other hand, it can not be too strongly urged that the object of the test is to gain information which will be of use to road builders and not merely to accumulate data of abstract interest. Rocks are far from being homogeneous materials, and in addition the cementing power itself is such a variable quantity that it may be said that the test has served its purpose if it does no more than distinguish high binding material from that which is only fair, and this in turn from that which has little or no binding power at all.

We come now to the bearing of the test upon the results of actual service. There have been few instances in the experience of the laboratory where the results actually attained upon the road have not agreed with the results obtained in the laboratory; the few exceptions to this rule occurred before the investigations were completed, the results of which are given in Table II. In many of the Southern and

Southwestern States, notably Alabama, occur large deposits of chert and cherty gravels which bind well and make excellent roads. In the laboratory these materials gave low cementing values by the older method of procedure: when, however, the chert dust was soaked and kneaded the binding power rose to the values which would be expected. It is well known in practical road building that some materials which do not consolidate readily do improve with age upon the road, and wet rolling, where possible, is the invariable remedy for the difficulty. The results obtained by the old and new methods are given in Table II.

TABLE II.—*Cementing values of samples of chert by the old and new methods.*

Serial No.	Locality.	Cementing values.	
		Old method.	New method.
338	Graytown, Tenn	24	240
342	Near Columbia, Tenn	148	1,083
389	Birmingham, Ala	10	84
391	.....do	35	127
392	.....do	26	113
393	.....do	6	58
394	.....do	26	102
388	.....do	8	31
443	.....do	118	390
414	Walker County, Ga	2	12
418	.....do	9	35
438	Hot Springs, Ark	2	10
538	San Jose, Cal	9	13
360	Blue Springs, Nebr	17	102
584	Elco, Ill	4	15
437	.....do	12	72

An investigation recently taken up and at present in progress further illustrates the importance of the wet rolling of roads and may ultimately be shown to have a direct bearing on the cementation test. It consists in grinding the material with water in the ball mill and immediately molding it into briquettes. Up to the present time all rocks, even quartzite, show a cementing value, and in almost all cases results are higher than by the dry method. At this writing, however, the number of results is too small to be correlated, and no general conclusions can be drawn. This investigation will be continued and the results reserved for a future publication.

CAUSES OF CEMENTING POWER.

As was outlined in the introduction, the whole question of the binding power of rock dust was early recognized as being closely associated with the same property in clays. In fact, considered from the standpoint of road materials, it is difficult to determine where the classification as clay should stop; that is to say, clays pass imperceptibly into gravels. Some gravels which contain a certain proportion of clay base will be found to bind, while a clean quartz gravel absolutely lacks this property. While this is easily understood, it does not, on first examination, seem to have any bearing upon the great difference in binding power which is exhibited by clean, deepquarried rock. It will be found, however, that the considerations are identical. Clays themselves are the product of rock decay under the action of water and watery solutions. The essential clay base is supposed to be a hydrated silicate of aluminum, known as kaolin, which is the result of the action of water on the double silicates of aluminum and the alkali metals. The most typical of the double silicates are the feldspars, a class of minerals very widely distributed in nature and occurring as a crystalline ingredient of a great number of different rock species. The microscopical analysis of rocks shows that a great many of the minerals which make up the aggregate structure have undergone secondary changes similar to, if not identical with, kaolinization of feldspar. Now, kaolin, as found in nature, although not lacking in binding power, does not, as a rule, excel in this quality. The ball clays are usually added by potters to the purer kaolins and china clays to increase both the plasticity and the binding power. It is very evident that binding power is not due to the presence of a particular mineral such as kaolinite; on the contrary, the higher binding clays show a preponderance of amorphous rather than of crystalline particles.

The evidence obtained in this laboratory points to the following conclusions: Many minerals under the action of water or of watery solutions are decomposed. The secondary products, which are usually highly hydrated, may or may not lead to binding power, as they are capable of existing in allotrophic modifications which differ in this respect. Alumina and many other substances can be easily prepared by wet reactions in the laboratory, either as gummy colloids or as finely crystalline precipitates, by slightly varying the conditions. In nature the conditions are of every possible variety, and thus we find a physical property like cementing power varying through wide limits in those rock species which exhibit it. In a word, those rock dusts which contain a certain proportion of particles which on soaking with water soften to the extent that they become, to ever so slight a degree, glue-like (colloid), and thus adhere, are those which are useful to the road builder. Many of the traps, limestones and sandstones, fall under this head. Those rocks, on the other hand, which are of an entirely unaltered crystalline structure, or those which, through metamorphic changes—heat and pressure—have had the active hydrated particles destroyed—such as slates and quartzites—should be avoided on the surface portion of the road.

These conclusions are borne out in service where the problem has to be solved of building roads of material which, while hard enough to bear traffic, is without binding power. A good example is furnished by the excellent sand-clay roads in the Southern States, described in the Yearbook of the Department of Agriculture for 1903. A somewhat similar case is that of burnt-clay roads, which have been advocated by this laboratory for several years and upon which experiments are now being made. Clay itself, as every one knows, is generally too soft and plastic to bear traffic in wet weather, although its binding power is high. By burning and clinkering a portion of the clay to be used on the road its hardness is increased and its binding power destroyed. By proper constructive methods and mixing we approach the conditions obtained with rock dust and with sand-clay mixtures.

It may be objected that at least one exception to the general rule is furnished by certain furnace slags which certainly have not undergone secondary changes, and yet have been successfully used on roads in some localities. This subject has been especially investigated, and it has been found that siliceous slags are in no case suitable for a binder surface. Certain basic slags, which have an excess of lime in their composition, and which have been quickly cooled at the furnace, make an excellent material for light-traffic roads, as the slag dust takes on an actual mild set similar to that of Portland cement. Doughs made of such slag dust set hard before they can be aged twenty-four hours preparatory to molding the test pieces. It is apparent that this special case of slags has no general bearing upon the conclusions reached.

It happens that certain ferruginous limestones and gravels bind exceedingly well, and this has led to an erroneous impression, which prevails even among engineers of long experience, that "iron" is the cause of the bond of cementation. Broadly speaking this is not true, for many of the highly ferruginous red sandstones do not bind. A series of experiments was made in the laboratory to determine whether iron ores, such as hematite and the hydrated oxid, limonite, possessed cementing power, and it was found that exceedingly pure limonite had a low value and hematite none at all. If, however, there were siliceous or clayey impurities present, the values would be much higher. It has been frequently observed that when metallic iron filings—as, for instance, in the neighborhood of a machine shop—are thrown upon a footpath, the path consolidates into a hard impervious shell under the light impact of human feet. This bond may be due to the mere rusting together of the iron particles, or it is possible that hydroxid of iron, which is formed under the influence of water and oxygen, is colloid in its nature, and thus acts as an ordinary binder. If hydroxid of iron is precipitated by the wet method in the laboratory and the resulting colloid precipitate after partial drying out is mixed with inert material like fine sand or ground glass, the hydroxid on drying will bind the particles together. In the same way it is possible to prepare in the laboratory colloid preparations of alumina, silica, and various silicates, such as those of aluminum, calcium, iron, and magnesium. All these substances appear in rock structures, gravels, clays, and soils, and all of them were found to act to a greater or less degree as binders when tested in the laboratory.

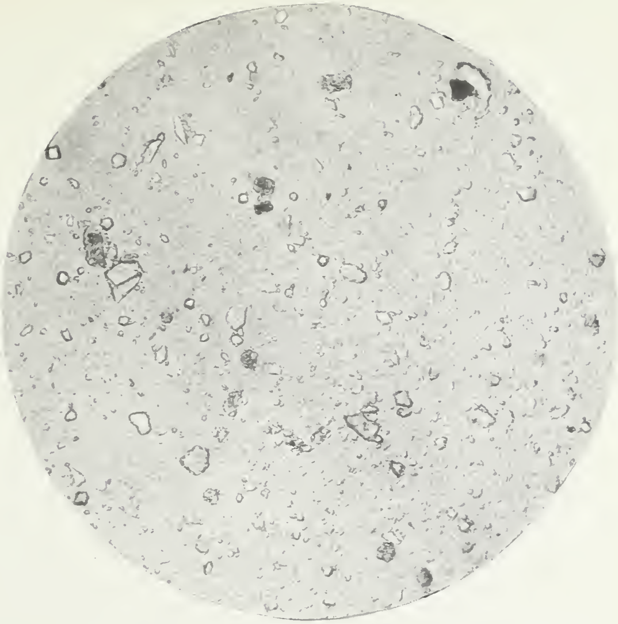

FIG. 1.—RAW CLAY (ENLARGED 150 DIAMETERS).

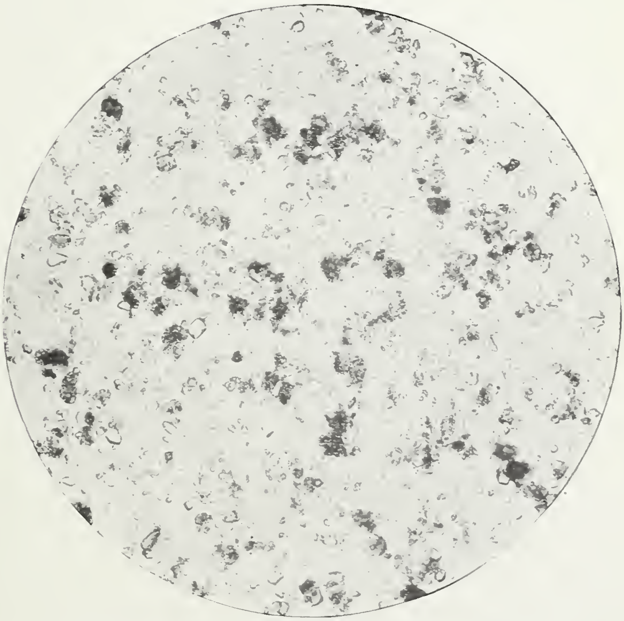

FIG. 2.—BURNT CLAY (ENLARGED 150 DIAMETERS).

Whenever a clay of high binding power is heated to a red heat, its binding power, together with the absorbent porous structure which is characteristic of the colloid, is totally destroyed. This is equally true of these artificial preparations and of high-binding rock dust. It is impossible not to conclude that the same structure is present in all three cases. In Plate I reproductions of micro-photographs are shown which are highly instructive. No. 1 is an active clay, and the illustration clearly shows the coherence of the finer noncrystalline particles. No. 2 shows the same clay heated sufficiently to destroy the colloid structure. Owing to incipient fusion, there has been some clumping, but the free spaces discernible all over the field between the grains show that there can be no question as to the destruction of the adherent quality of the particles.

GEOGRAPHICAL DISTRIBUTION AND CEMENTING VALUE OF ROAD MATERIALS.

Those who are interested in a scientific study of road materials will undoubtedly acknowledge the importance of understanding the fundamental causes of all the useful qualities these materials possess. It is natural, however, that the average man should desire more particularly such information as will enable him to select the best material for his purpose. If the actual results of service have not already been determined there is no alternative but an appeal to the testing laboratory. A study of Table III will show that cementing value is not confined to any particular species of rock. The highest trap tested among a large number of samples had a cementing value of 500, the lowest a value of 1. In the same way the limestones will be found varying from 231 to 4.

TABLE III.—*Range of cementing value in different rock species.*

Kind of rock.	Number of samples.	Maximum.	Minimum.	Average.
Amphibolite	8	36	3	10
Andesite	3	337	14	129
Basalt (trap)	22	500	2	91
Chert	19	500	2	101
Conglomerate	3	327	12	154
Dolomite	20	161	2	31
Diabase (trap)	39	110	2	26
Diorite (trap)	13	137	1	20
Eclogite	5	20	1	7
Felsite	7	101	2	34
Flint	1	31	31	31
Gabbro	8	131	3	30
Gneiss	22	21	1	6
Granite	37	77	1	10
Pyroxene granulite	1	1	1	1
Limestone	77	231	4	63
Marble	1	5	5	5
Peridotite	1	3	3	3
Quartzite	10	9	1	4
Rhyolite	9	500	1	152
Sandstone	26	323	1	63
Schist	25	272	1	23
Shale	3	500	62	314
Slate	2	202	151	176
Syenite	2	11	2	7

Considering only the crystalline rocks and excluding clays and gravels, Table IV, given at the close of the report, reveals a decided tendency toward high-binding rocks in certain sections of the country and to exceedingly low ones in others. The amount of data so far collected does not as yet justify a definite conclusion being drawn on this point, but it is highly significant that in one State, out of some 30 samples tested, not one had a higher value than 10, while in another State, out of an equal number of samples, only 1 fell below that figure. It is perhaps too soon to say that these results are not fortuitous, but it is quite apparent that in those localities where good road materials are abundant good roads will be found, and it is a fact that the samples which are sent to the laboratory from the two States noted for having the best roads and greatest mileage represent almost invariably high-binding materials. It is evident that the possession of good road materials will stimulate their use, whereas the discouraging results of failure in less-favored communities will keep the people shut in by mud and ruts for much longer periods. This point of geographical distribution, which perhaps has never been brought out before these investigations were instituted, is sufficient to justify and encourage all scientific study of road materials. Undoubtedly what is needed is more data, much more indeed than can be supplied by one laboratory, however complete its equipment. State laboratories under the direction of or in collaboration with the State highway commissioners would soon accumulate data which would make possible road-material maps giving all the physical data in as accurate a manner as possible. Before, however, such cooperation can be of the slightest value, the methods of testing must be standardized so that all results may be comparable. To this end the writers in 1903 urged the American society for testing materials to appoint a committee to consider the whole subject and report on standard methods. This committee has been appointed and is at work with every prospect of arriving at a successful conclusion.

One great obstacle to the growth of road-material testing is the cost of the machines. An important problem which is engaging the attention not only of this laboratory but also that of the Maryland geological survey is the simplification of the various tests, and more particularly of the various machines necessary, so that the cost of equipment of a road-material laboratory shall be brought within the means of all.

TABLE IV.—*Cementing values of road materials determined in the Division of Tests, Bureau of Chemistry, Department of Agriculture.*

Serial No.	Locality.	Name of material.	Cementing value.
	ALABAMA.		
388	Birmingham, Jefferson County	Chert	31
389	.....do	.....do	84
391	.....do	.....do	127
392	.....do	.....do	113
393	.....do	.....do	58
394	.....do	.....do	102
395	.....do	Blast-furnace slag	137
442	.....do	Dolomite	14
443	.....do	Chert	390
425	Farmsdale, Hale County	Calcareous clay	500+
426	.....do	Limestone	111
390	Tuscaloosa, Tuscaloosa County	Gravel	11
724	Tuskegee, Macon County	.....do	400
725	.....do	.....do	75
805	Berry, Fayette County	Limestone	71
966	Leeds, Jefferson County	Chert	10
967	.....do	.....do	3
869	Tuskegee, Macon County	Chert gravel	19
870	.....do	.....do	15
852	Livingston, Sumter County	Calcareous clay	500+
	ARKANSAS.		
651	Batesville, Independence County	Gravel	17
652	.....do	.....do	8
739	Fort Smith, Sebastian County	.....do	34
740	.....do	.....do	500
741	.....do	.....do	21
742	.....do	Sandstone	90
743	.....do	.....do	79
438	Hot Springs, Garland County	Chert	10
	ARIZONA.		
946	Kofa, Yuma County	Clay	500+
	CALIFORNIA.		
578	Los Angeles, Los Angeles County	Granite	4
538	San Jose, Santa Clara County	Chert	13
	COLORADO.		
398	Lakeshore, Hinsdale County	Rhyolite	577
399	Capitol City, Hinsdale County	Brecciated felsite	12
406	Lakeshore, Hinsdale County	Rhyolite tuff	513
407	Lake City, Hinsdale County	Andesite	35
408	.....do	.....do	14
409	.....do	Diorite (trap)	18
396	.....do	Rhyolite breccia	327
397	Sherman, Hinsdale County	Granite	39
	CONNECTICUT.		
354	Ansonia, New Haven County	Basalt	10
349	Branford, New Haven County	Diabase (trap)	49
467	Meriden, New Haven County	.....do	91
953	Rockville, Tolland County	Biotite gneiss	2
940	.....do	Gneiss	0
	DELAWARE.		
858	Greenbank, Newcastle County	Quartzite	1
862	.....do	Quartzite (micaceous)	1
872	Newark, Newcastle County	Decomposed rock	12
865	Wooddale, Newcastle County	Granite	13
863	.....do	Hornblende schist	5
864	Wilmington, Newcastle County	Pyroxene granite	1
	DISTRICT OF COLUMBIA.		
510	Washington	Shell marl	58
511	.....do	.....do	500+
512	.....do	.....do	500+
901	.....do	Limestone	13
900	.....do	.....do	31
899	.....do	.....do	20
875	.....do	Kaolin	95
860	.....do	Clay	500+

TABLE IV.—*Cementing values of road materials, etc.*—Continued.

Serial No.	Locality.	Name of material.	Cementing value.
	FLORIDA.		
701	Tampa, Hillsboro County	Calcareous clay	500+
702	.....do	Dolomite	94
	GEORGIA.		
422	Atlanta, Fulton County	Hornblende gneiss	3
419	Augusta, Richmond County	Gneiss	8
417	Bartow County	Dolomite	17
583	Canton, Cherokee County	Eclogite	3
424	Chickamauga, Catoosa County	Limestone	99
415	Coweta County	Olivine diabase (trap)	2
421	Lithonia, Dekalb County	Granite	2
416	New Elberton, Elbert County	.....do	2
420	Roberts Station, Jones County	Olivine diabase (trap)	6
698	Savannah, Chatham County	Gravel	233
699	.....do	.....do	176
423	Stone Mountain Station, Dekalb County	Granite	13
468	Toccoa, Habersham County	Gneiss	2
413	Walker County	Limestone	74
414	.....do	Chert	12
418	.....do	.....do	35
	HAWAII.		
904	Honolulu, Oahu County	Basalt	6
905	.....do	Fine rock dust	300
906	.....do	Vesicular basalt fragments	500+
907	.....do	Soil	500+
908	.....do	Weathered basalt fragments	500+
909	.....do	Clay	500+
910	.....do	.....do	500+
911	.....do	.....do	500+
	ILLINOIS.		
716	Chicago, Cook County	Dolomite	18
756	.....do	.....do	28
451	Dixon, Lee County	Dolomite gravel	9
437	Elco, Alexander County	Novaculite (chert)	72
584	.....do	.....do	15
465	Forreston, Ogle County	Gravel	14
454	Kenney, Dewitt County	.....do	16
452	Menominee, Jo Daviess County	Limestone	27
450	Ullin, Pulaski County	.....do	127
787	Streator, Lasalle County	Sandstone	80
770	Smithton, St. Clair County	Limestone	89
786	.....do	.....do	52
	INDIANA.		
540	Bicknell, Knox County	Dolomitic limestone	23
515	Freelandville, Sullivan County	Limestone	38
588	.....do	Dolomite	36
456	Merom, Sullivan County	Gravel	10
719	North Vernon, Posey County	Dolomite	....
516	Spencer, Owen County	Limestone	166
880	Williamsport, Warren County	Calcareous sandstone	8
	IOWA.		
383	Butterville, Tama County	Limestone	22
557	Mason City, Cerro Gordo County	Clay	250
438	Montour, Tama County	Limestone	129
455	Peosta, Dubuque County	Dolomite	32
462	Raymond, Blackhawk County	.....do	161
384	Montour, Tama County	Dolomitic limestone	129
	KENTUCKY.		
446	Lexington, Fayette County	Limestone	58
447	.....do	.....do	56
457	Kuttawa, Lyon County	Sandstone	55
461	Cedar Bluff, Caldwell County	Limestone	80
	LOUISIANA.		
968	Shreveport, Caddo Parish	Grav	141
969	.....do	.....do	11
970	.....do	.....do	105
971	.....do	.....do	1
972	.....do	.....do	196
973	.....do	.....do	20

TABLE IV.—*Cementing values of road materials, etc.*—Continued.

Serial No.	Locality.	Name of material.	Cementing value.
	MAINE.		
784	Knox County	Hornblende quartzite	15
866	Machias, Washington County	Diabase (chloritized)	2
	MARYLAND.		
759	Baltimore, Baltimore City	Clay	60
760	.....do	.....do	35
580	Fort Washington, Prince George County	Gravel	2
487	Frederick, Frederick County	Limestone	26
427	Cumberland, Allegany County	Sandstone	44
428	.....do	Calcareous shale	380
429	.....do	Limestone	133
430	.....do	.....do	143
363	Dickerson, Montgomery County	Diabase (trap)	60
343	Frederick, Frederick County	Dolomite	32
439	.....do	Limestone	33
830	Groves Quarry	Siliceous limestone	38
661	Allegany County	Sandstone	10
881	Powhatan, Baltimore County	Diabase	4
882	.....do	Limestone	13
873	.....do	Diabase	3
829	Savage Station, Howard County	Amphibolite	3
	MASSACHUSETTS.		
368	Brookline, Norfolk County	Rhyolite	24
369	.....do	Diabase	9
718	Quincy, Norfolk County	Chlorite schist	28
611	Salem, Essex County	Augite diorite (trap)	18
444	Taunton, Bristol County	Gravel	13
445	.....do	Granite	13
411	Webster, Worcester County	Schist	18
517	Westfield, Hampden County	Diabase (trap)	76
386	Winchester, Middlesex County	.....do	21
790	Winchester and Woburn, Middlesex County	Siliceous limestone	38
843	Stoughton, Norfolk County	Diabase	10
	MINNESOTA.		
854	Marshall, Lyon County	Clay soil	500+
859	Rushmore, Nobles County	Black clay soil	500+
807	Duluth, St. Louis County	Olivine gabbro	21
	MISSISSIPPI.		
460	Brookhaven, Lincoln County	Gravel	16
464	Sardis, Panola County	.....do	58
453	Stonington, Jefferson County	Sandstone	53
763	Vicksburg, Warren County	.....do	212
	MISSOURI.		
351	Gumbo, St. Louis County	Gravel	12
	NEBRASKA.		
360	Bluesprings, Gage County	Chert	102
	NEW HAMPSHIRE.		
370	Hanover, Grafton County	Granite	3
371	.....do	Schist	32
372	Lebanon, Grafton County	Hornblende schist	25
373	.....do	Biotite schist	49
	NEW JERSEY.		
357	Chimney Rock, Somerset County	Basalt	72
720	Gladstone, Somerset County	Shale	985
387	Lambertville, Hunterdon County	Gabbro (trap)	131
405	Middle Valley, Hunterdon County	Diabase (trap)	19
341	Millville, Cumberland County	Gravel	500+
350	New Providence, Union County	Diabase (trap)	19
478	Wanaque, Passaic County	Peridotite	3
566	Shady Side Quarries	Diabase (trap)	38
637	Somerville, Somerset County	Basalt tuff	6
669	.....do	.....do	14
638	.....do	"Ground trailings"	1
912	Springfield, Union County	Basalt	22

TABLE IV.—*Cementing values of road materials, etc.*—Continued.

Serial No.	Locality.	Name of material.	Cementing value.
	NEW YORK.		
404	Bellona, Yates County	Limestone	55
356	Brockport, Monroe County	do	9
400	Canandaigua, Ontario County	do	54
344	Deerpark, Orange County	Sandstone	54
382	do	Shale	62
346	Geneva, Ontario County	Limestone	8
347	do	do	14
340	Hudson, Columbia County	do	95
385	do	Slate	202
410	Leroy, Genesee County	Flint	31
532	Littlefalls, Herkimer County	Gneiss	2
732	North Leroy, Genesee County	Limestone	138
733	do	do	74
335	Rockland Lake, Rockland County	Diabase (trap)	110
470	Tomkins Cove, Rockland County	Dolomite	80
791	Florida, Orange County	Dolomitic sandstone	28
775	Ithaca, Tompkins County	Limestone	58
983	Newark, Wayne County	do	31
941	Briar Cliff Manor, Westchester County	Garnetiferous hornblende schist.	1
	NORTH CAROLINA.		
514	Ashboro, Randolph County	Felsite	2
469	Asheville, Buncombe County	Hornblende schist	6
627	do	Granite	6
628	do	Diorite	1
705	do	Hornblende schist	7
434	Concord, Cabarrus County	Granite	3
435	do	Mixed stone	12
436	do	Granite	2
513	do	Syenite	2
431	Elm City, Wilson County	Granite	3
539	Fayetteville, Cumberland County	Gravel	43
504	Hot Springs, Madison County	Dolomite	2
535	Morganton, Burke County	Basalt	2
380	Newbern, Craven County	Clay	45
381	do	Limestone	79
366	Pinehurst, Moore County	Gravel	24
432	Wilson, Wilson County	Granite	9
433	do	do	20
401	Wilmington, New Hanover County	Conglomerate	125
402	do	Limestone	127
403	do	do	110
822	Haw River, Alamance County	Chlorite epidote schist	5
825	Wadesboro, Anson County	Diabase	5
809	Monford, Buncombe County	Microgranite	4
777	Asheville, Buncombe County	Gneiss	4
778	do	Schist	5
812	Concord, Cabarrus County	Hornblende granite	2
839	Silver City, Chatham County	Chlorite epidote schist	5
813	Bethania Station, Forsyth County	Olivine basalt	6
838	Franklin, Franklin County	Olivine diabase	8
816	Jamestown, Guilford County	Granite	1
815	do	Diabase (uralitic)	5
823	Greensboro, Guilford County	Diorite	6
821	do	do	4
820	do	Gabbro	8
819	do	Diabase	8
818	do	Dolomitic sandstone	4
817	do	Granite	3
810	Balfour, Henderson County	Granite gneiss	1
868	Marion, McDowell County	Dolomite	4
867	do	Biotite gneiss	1
772	Hot Springs, Madison County	Dolomite	20
771	do	Quartzite	8
811	Charlotte, Mecklenburg County	Granite	5
913	Toe Cane, Mitchell County	Micaceous eclogite	2
840	Carthage, Monroe County	Olivine diabase	4
841	do	Diabase	15
835	Hillsboro, Orange County	Altered diabase	6
834	Chapel Hill, Orange County	Olivine basalt	3
826	Rockingham, Richmond County	Hypersthene gabbro	3
808	Granite Quarry Station, Rowan County	Granite	3
764	Elkin, Surry County	Hornblende schist	8
814	Mountairy, Surry County	Granite	1
	OHIO.		
663	Columbus, Franklin County	Limestone	12
664	do	do	41
666	do	do	58

TABLE IV.—*Cementing values of road materials, etc.*—Continued.

Serial No.	Locality.	Name of material.	Cementing value.
	OHIO—continued.		
665	Columbus, Franklin Connty	Dolomite	10
582	East Liberty, Stone County	Dolomitic limestone	28
707	Kirtland, Lake County	Fieldstone (erratics)	7
345	Lorain, Lorain County	Blast-furnace slag	19
570	Medina, Medina County	Gravel	4
977	Urbana, Champaign County	Calcareous sandstone	11
978	do	do	1
765	Chagrin Falls, Cuyahoga County	Sandstone	307
788	Oak Harbor, Ottawa County	Limestone	95
799	do	Dolomite	18
774	do	do	17
828	Howland Township, Trumbull County	Sandstone	5
	OREGON.		
982	Eugene, Lane County	River gravel	4
	PENNSYLVANIA.		
339	Cedar Hollow, Chester County	Dolomite	2
365	Hatboro, Montgomery County	Sandstone	323
352	Northampton County	Diorite (trap)	5
730	Redington, Northampton County	Dolomite	36
731	Rockhill, Huntingdon County	Diabase (trap)	30
697	Wilkesbarre, Luzerne County	Sandstone	202
855	Bucks County	Granite gneiss	4
964	Coatesville, Chester County	Marble	5
965	do	Limestone	4
914	Williamsport, Lycoming County	Sandstone	18
936	Fort Hunter, Perry County	do	25
	PORTO RICO.		
797	Arecibo, Arecibo County	Limestone	108
802	Manati, Arecibo County	do	64
795	Bayamon, Bayamon County	do	16
798	Carolina Bayamon County	do	27
799	Rio Piedras, Bayamon County	do	91
803	do	Basalt tuff	25
801	Uttado, Arecibo County	Quartz diorite	28
794	Cayey, Guayama County	Limestone	28
793	(Caguas) Rio Piedras, Guayama County	do	30
800	Comerio, Guayama County	do	135
804	Gurabo, Guayama County	Basalt breccia	146
796	Juncos, Guayama County	Quartz diorite	1
	RHODE ISLAND.		
659	Providence, Providence County	Augite diorite (trap)	19
889	Bristol, Bristol County	Gneissoid granite	3
886	do	Chloritic quartzite	9
890	Warren, Bristol County	Chloritic sandstone	10
891	East Greenwich, Kent County	Biotite gneiss	3
896	Middletown, Newport County	Quartzite	3
895	Smithfield, Providence County	Granite	1
893	Johnston, Providence County	Gneissoid granite	1
897	do	Amphibolite	3
892	East Providence, Providence County	Indurated sandstone	12
888	North Providence, Providence County	Micaceous quartzite	3
887	Cranston, Providence Country	Granite	6
894	do	Feldspathic quartzite	2
	SOUTH CAROLINA.		
488	Barnwell County	Gravel	50
374	Columbia, Richland County	Granite	5
375	Pacolet, Spartanburg County	do	7
783	Abbeville, Abbeville County	Chert	2
956	Steel Creek, Barnwell County	Gravel	500+
957	Beach Island, Aiken County	do	500+
	SOUTH DAKOTA.		
449	Rowena, Minnehaha County	Quartzite	2
	TENNESSEE.		
440	Bartlett, Shelby County	Gravel	174
448	Chattanooga, Hamilton County	Limestone	47
503	do	do	54
342	Columbia, Maury County	Chert	500+
336	Graytown, Hickman County	Limestone	158
337	do	do	59
338	do	Chert	240
359	do	Limestone	114
361	do	do	158
441	Memphis, Shelby County	Gravel	249
376	Nashville, Davidson County	Limestone	231

TABLE IV.—*Cementing values of road materials, etc.*—Continued.

Serial No.	Locality.	Name of material.	Cementing value.
	TENNESSEE—continued.		
377	Nashville, Davidson County	Limestone	195
378	.....do	.....do	87
379	.....do	.....do	63
	TEXAS.		
536	Austin, Travis County	Limestone gravel	77
	VERMONT.		
726	Wallingford, Rutland County	Amphibolite	16
792	Panton, Addison County	Gravel	195
	VIRGINIA.		
612	Albemarle County	Chlorite schist	8
613	.....do	Gneiss	1
412	Alexandria County	Mica schist	13
493	Basic City, Augusta County	Quartzite	2
537	Blacksburg, Montgomery County	Dolomite	10
531	Burrowsville, Prince George County	Clay	500+
364	Charlottesville, Albemarle County	Amphibolite	36
489	.....do	Limestone	13
490	.....do	Diorite	5
491	.....do	Chlorite schist	9
494, 495	.....do	Uralite diabase (trap)	25
496	.....do	Hornblende schist	9
497	.....do	.....do	7
498	.....do	Biotite schist	2
533	.....do	Clay	500+
534	.....do	.....do	475
548	.....do	Amphibolite (trap)	5
549	.....do	.....do	3
550	.....do	.....do	6
551	.....do	.....do	6
552	.....do	Hornblende schist	10
500	Shadwell, Albemarle County	Chlorite schist	14
492	Craigsville, Craig County	Limestone	22
750	Fredericksburg, Spottsylvania County	.....do	15
721	Jackson City, Alexandria County	Yellow clay	500
722	.....do	Blue clay	424
723	.....do	Yellow clay	500+
362	Lawrenceville, Brunswick County	Clay	500+
499	Monticello Mountain, Albemarle County	Quartzite	4
581	Occoquan, Prince William County	Gneiss	2
717	Manassas, Prince William County	Sandstone	8
353	White Cut Station, Warren County	.....do	160
876	Manassas, Prince William County	Gabboritic diabase	2
782	Catletts Station, Fauquier County	Diabase	9
871	Mineral, Louisa County	Chlorite gneiss	3
	WEST VIRGINIA.		
767	Morgantown, Monongalia County	Limestone	85
	WASHINGTON.		
476	Seattle, King County	Sandstone	47
477	.....do	Basalt (trap)	25
508	.....do	Chlorite schist	272
878	Toledo, Lewis County	Gravel	15
877	.....do	.....do	17
	WISCONSIN.		
667	Berlin, Green Lake County	Rhyolite	2
668	.....do	.....do	1
746	Madison, Green Lake County	.....do	3
695	Utley, Green Lake County	.....do	5
696	.....do	.....do	5
747	.....do	Dolomite	60
734	Tomah, Monroe County	Gravel	500+
735	.....do	.....do	295
736	.....do	.....do	197
	CUBA.		
472	Campo Florida	Diorite (trap)	137
471	Cienfuegos	Andesite (trap)	337
473	Habana	Limestone	90
575	.....do	Diorite	8

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