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CONCRETE FAILURE DUE TO THE COMBINATION OF HEAVY LOADS AND WET SUBGRADE

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U. S. DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

PUBLIC ROADS

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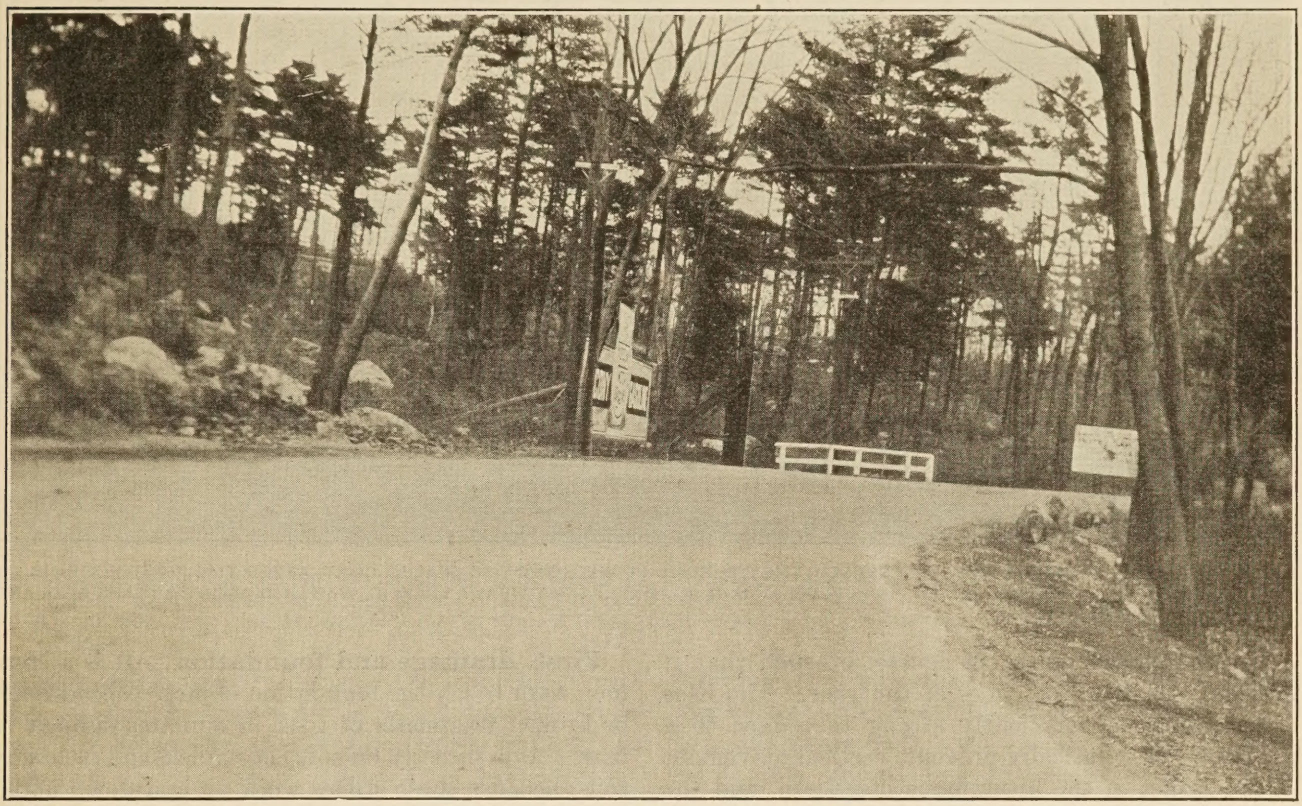
SOME REASONS FOR SUCCESS AND FAILURE OF BITUMINOUS MACADAM.

By F. C. PILLSBURY, Division Engineer, Massachusetts State Highway Commission.



BPR 16696

GLOUCESTER, MASS., SHOWING BANKED CURVE ON STATE ROAD RECONSTRUCTED IN 1917. THE BINDER WAS ASPHALT. THE PHOTOGRAPH WAS TAKEN IN MARCH, 1919.

MANY miles of very good roads and streets have been built of bituminous macadam, and, though subjected to more or less heavy travel for several years, in many instances show little, if any, effect of wear. While they are not as permanent as some of the more expensive types of paving, they may, when well laid, with the better materials, be safely adopted if they are not to be subjected to extremely heavy traffic.

Bituminous macadam possesses the advantages of being comparatively simple of construction, low first cost, and simplicity in maintenance. There are several varieties of this type of pavement, but all are very nearly the same in essentials. In all, broken stone is laid, rolled more or less, and the voids filled or impregnated with bitumen and the surface finally covered with smaller particles of mineral and finished off with or without a seal coat. These various types may be divided into three classes:

First class: One layer or one course.

Second class: Two or more layers or courses.

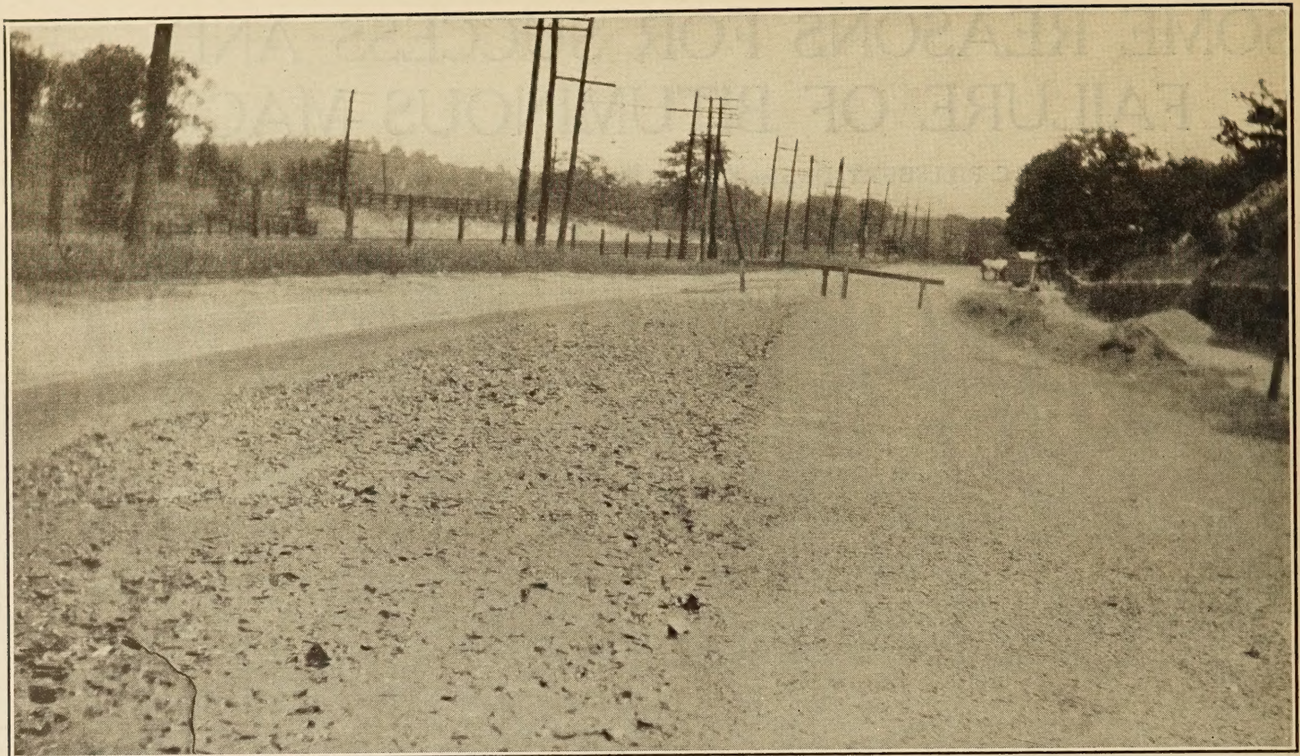
Third class: Bitumen and sand mixed grouts as distinct from the bitumen without sand.

The second and third classes include many different processes and methods, while with the first class there is but one method which, with some deviations, has been found to give really satisfactory results. The writer's experience with penetration work has been almost entirely with this class, so that it would seem better to confine the remarks to the first class, which includes only the bituminous surface laid in one course; in other words, when the wearing course is formed with one layer of stone penetrated with bitumen with or without a seal coat. This type is the simplest to specify and lay, and presents the least opportunity for difficulties.

DESCRIPTION OF CONSTRUCTION.

Its actual construction may be described as follows:

On a suitable foundation is laid a base or bottom course of broken stone partially bound like water-bound macadam, on which is built or laid the top course or bituminous macadam.



TAR SAND GROUT, SHOWING ONE-HALF SEALED, THE OTHER HALF WITHOUT THE SEALED COAT, AFTER THE FIRST POURING OF SAND AND TAR, AT NATICK, MASS. THIS IS ON A MAIN ROAD OF FAIRLY HEAVY TRAFFIC, WAS LAID ABOUT 4 YEARS AGO, AND IS IN GOOD CONDITION.

The foundation must, of course, be such that it will be suitable at all times of the year. The base course must be sufficiently strong to reduce to a minimum, or practically prevent, vertical movement of the stones in the bituminous macadam, and the bituminous macadam itself should be so laid that the bitumen will surround all the particles of the stone, practically filling the voids and sealing the surface.

FACTORS OF SUCCESS OR FAILURE.

The bituminous macadam to attain this success must be laid according to approved methods. Bituminous macadam does not give good results when it is not so laid; that is, good results may not be expected from bituminous macadam when the materials or methods employed are not what they should be. There is frequently a complaint of the waviness of this type of pavement, but it need not be built so as to be wavy; sometimes it becomes rutted or depressions or holes develop, but this can be avoided if the work is done properly.

The causes which lead to failure usually are the features which, if carefully considered and taken care of properly, will lead to success, and these causes for success or failure may be divided into four classes or subjects:

First, drainage and foundation.

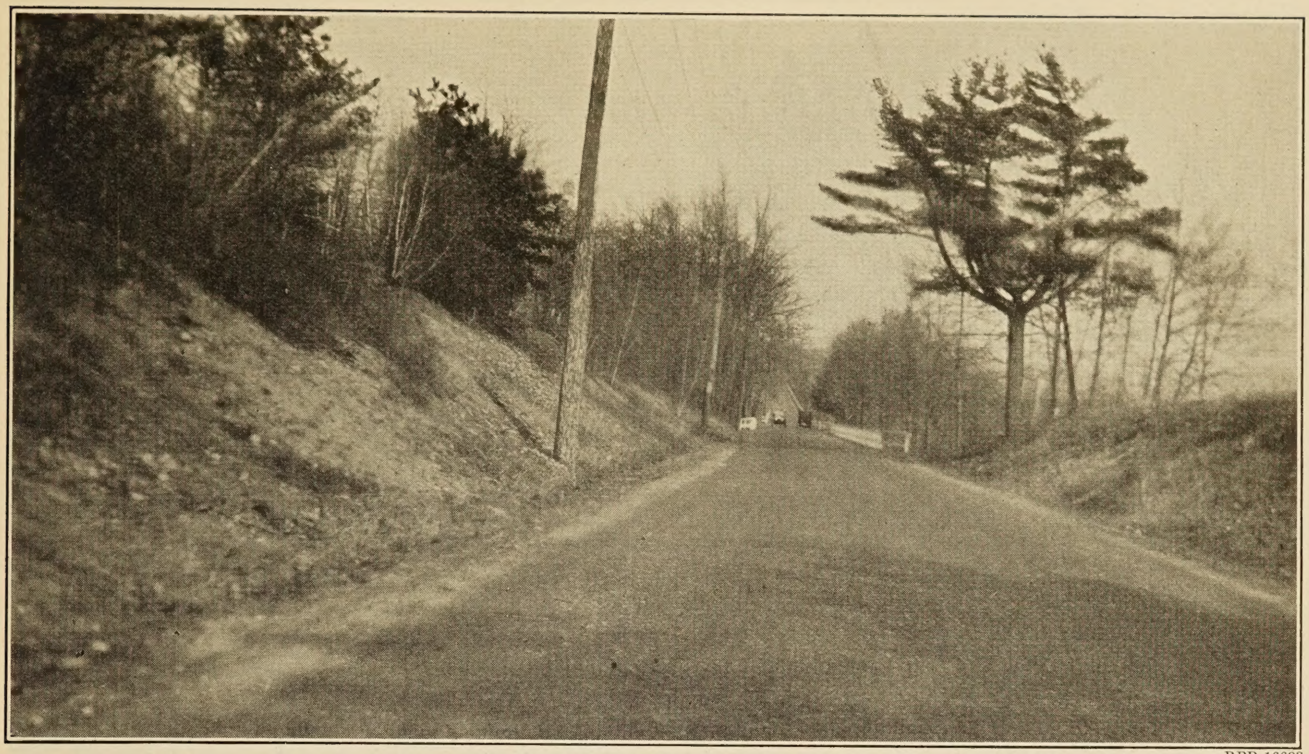
Second, construction of the base as distinct from the foundation, meaning the bottom course of broken stone.

Third, top or bituminous course.

Fourth, the workmanship.

First, drainage and foundation.—It is a common error to lay the foundation of large cobblestones or broken fragments of rock in climates subject to frost action directly on soft clay quicksand or loamy soils, because these stones work up and down under traffic and frost action, the voids between them become filled with the fine earth beneath, and ultimately, frequently in only a short time—sometimes less than the winter season—the mud thus reaches right up to the bottom of the macadam. Of course, moisture accompanies mud, and there is a very unstable foundation which is more or less constantly in motion except when frozen solid or when thoroughly dried out. Finally, the bituminous macadam crust separates as it bends under traffic, and as it breaks apart in this way moisture from beneath works into the cracks or interstices at the bottom and from the top. Then destruction, more or less extensive, is only a question of time.

What should have been done is to lay a foundation of clean gravel or even clean sand or fine broken stone in preference to the large stone fragments, or if such stone fragments must be used because there is a scarcity of other material, they should be broken up much smaller, say, about 3 inches and less. Of course, when necessary the ground water should be removed with adequate drainage. These results obtain whenever the base is laid on material that will be affected by moisture or frost sufficiently to cause much movement. Moisture working up from beneath always shortens the life of any surface, and,



BPR 16693

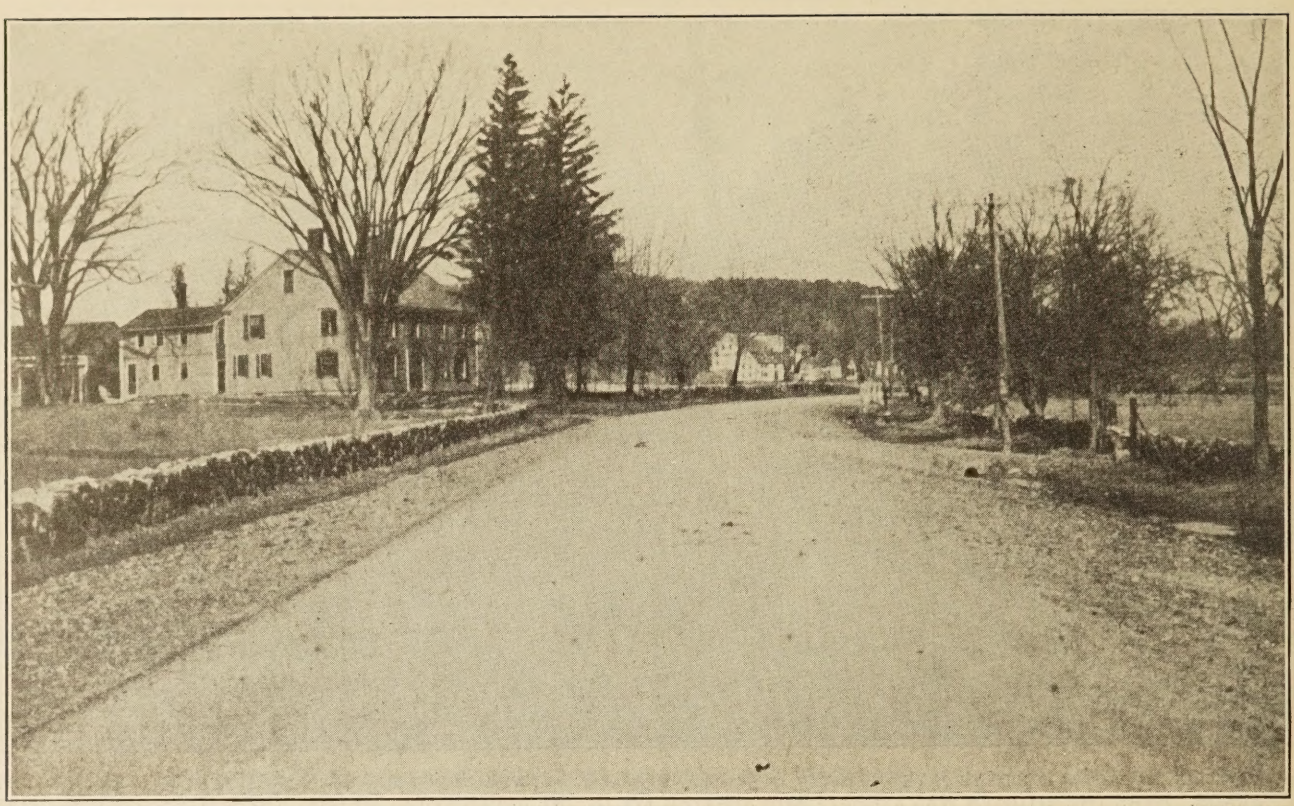
BITUMINOUS MACADAM ON THE STATE HIGHWAY IN WAYLAND, MASS., BETWEEN BOSTON AND WORCESTER, ON A 5½ PER CENT GRADE. HERE THE BITUMEN WAS ASPHALT AND SPRAYED ALL IN ONE APPLICATION, SO THAT THE ROAD DID NOT RECEIVE A SEAL COAT, BUT THE STONES WERE LEFT PROJECTING, THUS GIVING A ROUGH SURFACE WHICH WAS NOT SLIPPERY FOR HORSES.

strange to say, partly because the bituminous surface is such a simple one to lay ordinarily, there seems to be an idea that it is not worth while to lay a proper base and foundation. It is probable that more than half the failures are due to this reason. Success is impossible unless the foundation is correct.

Second, construction of the bottom course or base.—The bottom course should be of sufficient strength to hold up the top course, that is, to support it so that it will not rut under traffic and will not be affected by any movement of the foundation or soil beneath the base. This is essential. The size of the stones in the base may vary from ½ to 3 inches or even 4 inches, provided there is a reasonable proportion of the larger with the smaller sizes. It would not be good practice to use over 50 per cent under 1¼ inches in size, but would do no harm if they were all 3 inches large. Then this bottom course must be very carefully spread and rolled so as to be uniformly parallel with the finished surface. This provides for a uniform thickness of the bituminous macadam. In the base it is well to partially bind it with sand, fine screened gravel, or stone screenings, using the steam road roller, and, if necessary, sprinkling occasionally with water. But this bottom course should not be so rolled as to be absolutely firm; it is better for it to be slightly loose because this looseness will permit the taking up of the very slight unevenness unavoidable in spreading the broken stone of the top course, and thus resulting in a smoother surface. In other words, this bottom course should not be too rigidly bound, as is sometimes done, with the usually accompanying result of a slightly uneven finished surface in the road.

Third, the top or bituminous course.—This brings us to the bituminous macadam itself, the materials of which are the stone and the bitumen.

The broken stone should not be so soft as to crush under the roller so as to fill the voids before the bitumen is applied. When this occurs the bitumen does not fill the voids, and from such spots slack of bitumen there may arise two bad results. There may be a wave, due to the surplus of bitumen on top because it could not penetrate down into the stones, or there may be a breaking up of the surface because the stones have nothing to bind them together. The best results are obtained when hard rocks are used, such as trap rocks. There are many localities where it is impossible to get trap rock or stone with a coefficient of wear sufficiently high to obtain results required. In such cases bituminous macadam should not be laid. For ordinary traffic such as exists on most of the main through State roads bituminous macadam can be laid economically, provided broken stone has a coefficient of not less than about 15, and provided the bitumen is of suitable quality. The size of the broken stone should be 1¼ to 2½ inches or 3 inches, according to the thickness of the course. A top course 2 inches thick may



BPR 16697

BITUMINOUS MACADAM STATE HIGHWAY IN NORTH ANDOVER, MASS. A 4-INCH BROKEN STONE BASE, 2-INCH BITUMINOUS TOP, DOUBLE OIL PENETRATION, THAT IS, ON THE BASE, WHICH WAS PARTIALLY BOUND AND FILLED WITH SAND, ¾ OF A GALLON OF 90 PER CENT HOT OIL WAS SPRAYED, THEN A SUFFICIENT QUANTITY OF ¾ TO 1¼-INCH BROKEN STONE TRAP ROCK, TO ROLL DOWN TO 2 INCHES, WAS SPREAD. ANOTHER ¾ GALLON OF OIL WAS APPLIED AND A COVERING OF SAND SPREAD BEFORE THE FINAL ROLLING. THE TRAFFIC IS MEDIUM. THIS IS ON THE ROAD BETWEEN BOSTON AND HAVERHILL. IT WAS LAID IN 1912. THE SURFACE IS WAVY AND RUTTING SLIGHTLY, SHOWING THAT THIS OIL IS NOT A VERY STABLE BINDER.

be obtained with the 2½-inch stone, while a 3-inch course may be obtained with the larger size. If the traffic is very heavy it is better to lay the thicker course with the larger stones.

The quantities of the bitumen for the 2-inch road are 1¾ gallons for the first application and one-half gallon for the second, or seal coat, and should be very closely followed. For a 3-inch road these quantities will be increased about three-fourths gallon in the first application, although this depends somewhat upon the hardness of the stone and the weight of the traffic. If the stone is very hard it would be better to use a little more bitumen, as the voids will be greater with the harder stone. For the same reason, if the traffic is light, there may be a little more bitumen used than when the traffic is heavy. The quantity should not vary more than one-half gallon per square yard on a 3-inch road and one-fourth gallon per square yard on a 2-inch road.

Fourth, workmanship.—The general process of laying a bituminous macadam is such a simple one in theory that nearly everyone considers it unnecessary to go into the details of construction carefully and does not realize the many little things that have to be done with the greatest care to get good results. This is a matter of *good* workmanship. Carelessness in any respect at any time is sure to lead to imperfect results. It may be that specifications are not sufficiently complete to cover all these details.

The work of laying of the top course of the bituminous macadam consists of the following operations, in the order in which they occur:

(1) Spreading the large broken stone.

(2) Rolling of this stone.

(3) Correction of imperfections in spreading or any unevenness developing while rolling.

(4) The first application of the bitumen.

(5) The first light spreading of the peastone, brooming around of the first spreading of the peastone so as to have it absolutely uniformly distributed that there may not be an accumulation in any depression which may have occurred under the distributor or for any other reason, so that there will be absolutely just a very thin sprinkling for the first spreading over the entire surface to be rolled.

(6) The second rolling.

(7) Sweeping off of the surplus peastone, dust, etc., in preparation for the second application of bitumen or seal coat.

(8) The second application of bitumen or seal coat.

(9) The final covering of peastone, to be very uniform and broomed about after being spread by the shovels to insure uniformity in thickness.

(10) The final or third rolling—and here I should state that the second rolling is the most important.

BPR 16691

A ROAD UNDER RECONSTRUCTION WHERE THE SOIL WAS CLAYEY AND THE OLD ROAD BROKE UP BADLY UNDER FROST ACTION. NOTICE THE EXCAVATED ROAD BED READY TO RECEIVE A 12-INCH GRAVEL BASE ON WHICH IS PLACED A 6-INCH STONE SURFACE.

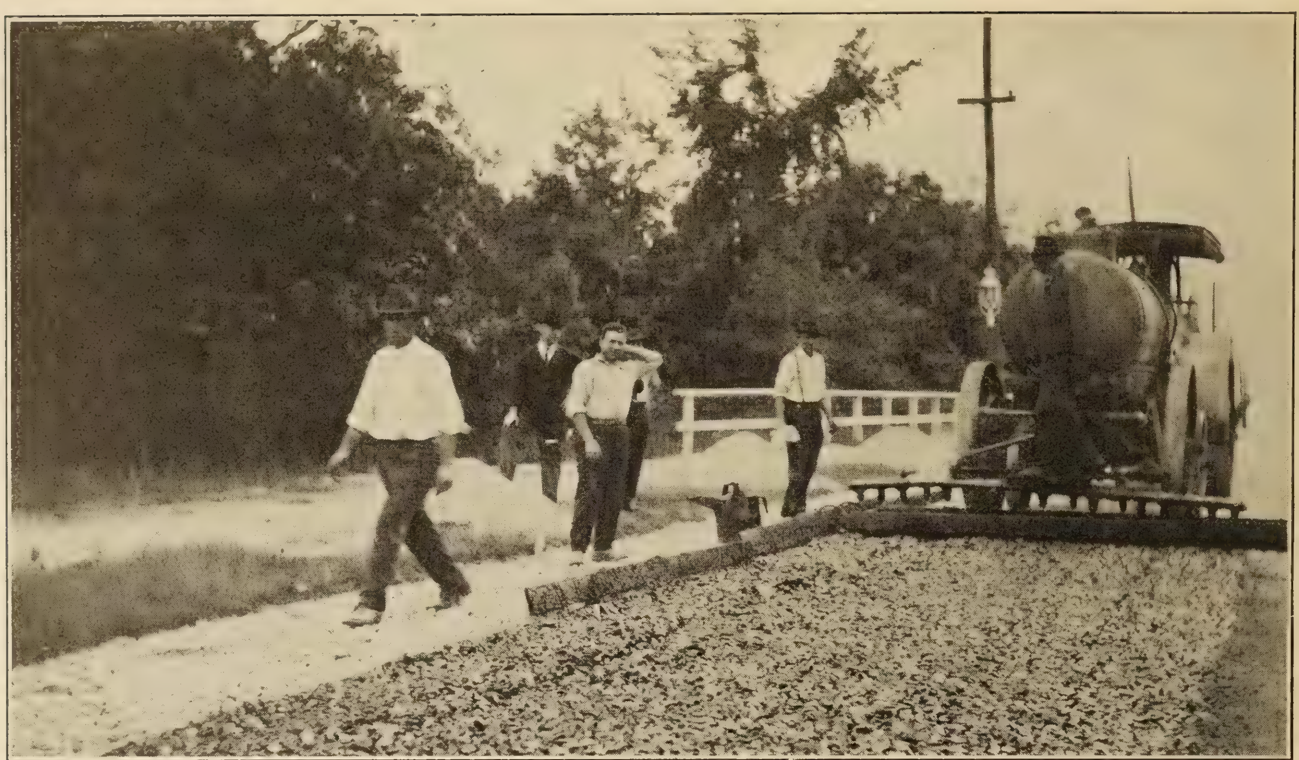
Each one of these operations in itself is of sufficient importance to warrant some further mention, and they are taken up in detail as follows:

(1) *Spreading the large broken stone.*—Broken stone will be brought in either on cars or trucks, and if possible should be dumped on dumping boards and spread with shovels, or if the stone should contain much dirt or dust, with forks, not with the large rakes sometimes used for this purpose; or stone may be spread from piles where it has been previously dumped on the roadside, but this is not the best practice. Greatest care must be taken to spread the stone with absolute uniformity. If dumping boards are not used, the entire pile of stone which has been dumped should be rehandled to provide for the removal of any accumulation of dust or particles of stone too fine, and prevent unevenness which is almost sure to follow if the stone is not rehandled.

(2) *Rolling of this stone.*—This should, of course, be done carefully and with more or less intensity, according to the hardness of the stone. It should not be sufficient to crush the stone and need be only enough to lay it with sufficient firmness to prevent material tracking or rutting when the spraying machine passes over it in the first application of the bitumen. Slight tracking by wheels of the spraying machine will roll out.

(3) *Corrections of imperfections in spreading or rolling.*—Any depressions or bunches which develop during this first rolling should be very carefully eliminated by adding more stone to fill the depressions or by the pulling off into the depressions stone from spots where there is too much. It is at this time, while rolling, that any unevenness in the surface should be corrected, as it is extremely difficult to correct it after the bitumen has been applied. It is frequently necessary to correct the slight depressions by placing only a few pieces of broken stone in them. The man having charge of this spreading should, if necessary, get down on his hands and knees and search for the inequalities in correcting them.

(4) *The first application of the bitumen.*—This is sometimes done successfully by hand pouring, but never as well as when properly applied by a suitable pressure distributor. When poured by hand it should always be done longitudinally with the direction of the traffic, never across the road, for there will always be, when hand poured, more bitumen where one pouring meets another, particularly when asphalt is used. Under wear of traffic slight projections on the surface occur where there is more bitumen. For the same reason it is much better not to apply from a single nozzle from the pressure distributor but from a single or double row of nozzles. The applications from the pressure distributor may be of any width desired, usually from 7 to 10 feet, so that on the ordinary road two applications will cover the entire width, but on wider surfaces there may be additional applications. Where, however, there are irregularities in the widths, the areas outside of the regular width may



BPR 16689

BITUMINOUS MACADAM UNDER CONSTRUCTION, STATE HIGHWAY IN CITY OF BOSTON. ASPHALT IS BEING APPLIED UNDER PRESSURE. THE STONE ON THE RIGHT FOREGROUND HAS RECEIVED THE FIRST APPLICATION OF ABOUT 2 GALLONS OF ASPHALT TO THE SQUARE YARD. HERE THE WEARING SURFACE WAS 3 INCHES THICK, AND THE TOTAL QUANTITY OF ASPHALT USED WAS ABOUT 2¾ GALLONS. THIS WAS AN EXPERIMENTAL ROAD AND GREAT CARE WAS TAKEN TO OBTAIN SPECIFIC RESULTS. ON THE LEFT IN THE FOREGROUND IS STONE SPREAD AND ROLLED WHERE THE ASPHALT HAS NOT BEEN APPLIED. THIS PORTION WAS FINISHED UP AS A WATERBOUND MACADAM SHOULDER AND SURFACE TREATED WITH OIL TO GIVE A SURFACE THAT WOULD PROVIDE BETTER FOOTING FOR HORSES. BETWEEN THE PORTION ON THE LEFT AND THAT WHERE THE ASPHALT HAS BEEN APPLIED, NOTICE THE BOARDS SET ON EDGE. THESE WERE FOR THE PURPOSE OF PREVENTING ASPHALT FROM BEING SPREAD BEYOND A CERTAIN LINE, SO THERE WOULD POSITIVELY BE NO LAPPING OVER OF THE ASPHALT. THE SPRAYING MACHINE ATTACHED TO THE STEAM ROLLER MAY BE SEEN WITH THE TROUGH IN PLACE UNDER THE NOZZLES TO PREVENT THE DRIPPING OF THE BITUMEN ON THE ROAD. THIS IS A DIRECT PRESSURE SPRAYING MACHINE, THE PRESSURE BEING AIR PRESSURE PROVIDED BY AN AIR PUMP OPERATED BY STEAM FROM THE ROLLER. A POURING POT, WHICH IS SEEN, WAS USED WHEN THERE WERE ANY IMPERFECTIONS IN THE OPERATION OF THE SPRAYER.

be penetrated with a single nozzle or by hand pouring.

In some cases bitumen may be heated at a single plant and sent out in motor-drawn distributors, sometimes as far as 30 or 40 miles, and successfully applied. In the absence of such central heating plants the bitumen usually is delivered on the work in barrels and heated in kettles. It is much better to have kettles with a heating capacity of about 400 gallons. Two or three such kettles will provide for the application of from 1,500 to 2,500 gallons per day, and one spraying machine will distribute this quantity of bitumen. Care should be taken in heating not to burn. Bitumen should be strained when passing from the kettles into the distributor as well as when being taken into the distributor at the central plant, otherwise there will be particles of foreign substances getting into the distributors and clogging the nozzles. This causes imperfect application. Asphalt always should be heated to not less than 300° F. not more than 400° F., and tar to not less than 225° F.

Just before the bitumen is applied from the distributor the outlets from the distributor and the nozzles should be tested out carefully to see that they are all free. There always should be a trough on hand in which any drippings from the nozzles may be caught instead of being allowed to fall on the road, as these drippings would form bunches in the surface. Care should be taken not to lap over a previous application. This may be done by laying rough paper covered with sand or stone dust, for 5 or 6 feet back from the end of the previous application; or even sand alone, if paper is not available. Then a flying start may be made and the distributor opened just before reaching the end of the previous application. The overlapping bitumen then can be removed by taking off the paper and sand.

When the load of bitumen has been distributed the distributor should not be allowed to go on with the valves open, thus tracking bitumen along over the road, but as soon as the full spray ceases the operator should close the valves instantly and men should be on hand with the trough to catch the drippings. After each load has been distributed the pipes of the distributor should be blown out and cleaned out before it is refilled.

MANCHESTER, MASS., ASPHALT PENETRATION ROAD LAID IN 1916. PHOTOGRAPH WAS TAKEN IN MARCH, 1919.

The actual operation of the application of a tank load from the distributor occupies only a few minutes, provided there is no stoppage of the nozzles or difficulty in the operation, so that there should be no hesitation about taking all the time necessary to insure the free working of the nozzles before commencing the application, and taking every precaution between applications to obtain the same result. Some one skilled always should be on hand to see to it that the application of the bitumen is perfectly done because if not perfectly done the results are going to be imperfect and to that extent a failure.

(5) *The first light spreading of the peastone.*—The first light spreading of the peastone after the first application of bitumen is for the purpose of filling the surface voids and providing a sufficient covering to permit the roller to pass over without sticking to the bitumen. The least quantity of peastone that will accomplish this purpose is best. Any more than enough is superfluous and a waste, as it interferes somewhat with the compression of the stone and all surplus has to be swept off before the seal coat is applied. This spreading probably will consist of about 5 pounds to the square yard. It never should be allowed to be any thicker in one place than another, and should be so thin that the bituminous surface below shows through it everywhere.

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(6) *The second rolling.*—The roller may be the usual 10-ton steam road roller or heavier, much better heavier, and when asphalt is used with trap rock should weigh not less than 15 tons, as the asphalt cools quickly and the stone then compresses with difficulty. It is economy to use a heavy roller because the results are accomplished in much less time and the expense of operating the heavy roller is very little greater. Best results with asphalt can be obtained only with a heavy roller. This second rolling can not be overdone unless the ground beneath develops a softness and depressions begin to occur. Sometimes after heavy rain the ground beneath does become soft and then rolling has to be done with care, if not postponed altogether until after the ground is dried out. Should any distinct unevenness occur which can not be rolled out during this second rolling, it should be corrected by removing such imperfect area altogether and replacing neatly with new broken stone and new bitumen by the methods already outlined.

(7) *Sweeping off of the surplus peastone, dust, etc.*—After the second rolling and before the seal coat is applied all loose particles of dust, stone and dirt should be carefully and completely swept off. If allowed to remain they will cause a separation between the second application of bitumen and that in the bottom course, so that the second application may peel off.

(8) *The second application of bitumen.*—The second application of the bitumen, forming the seal coat, should be made with great care, in the same way as to method as the first application, the same precautions being taken in heating, loading the spraying machine, and applying. When the seal coat is hand poured it should be done with even greater care than the first pouring, and a sufficient number of men should be on hand with rubber squeegees or rattan push brooms to spread the surplus bitumen around immediately after pouring, so as to carry a uniform quantity everywhere.

(9) *The final covering of peastone.*—Immediately after the second application of asphalt it should be covered with a final coating of peastone, the quantity of which will be about 20 pounds to the square yard or more, sufficient to take up the asphalt of the seal coat and prevent it from sticking to the roller or wheels of vehicles. This is frequently spread carelessly. It should never be dumped on the road surface before spreading, but should be either spread from a dumping board or from carts or piles at one side, and should be broomed after spreading before it is rolled.

(10) The rolling of the final covering of peastone should ordinarily be as intense as the rolling after the first application of bitumen, but if for any reason it has been impossible to secure the desired results with the first rolling, the second rolling should be done so as to remedy any defects.

This completes the operation of constructing a road which may be said to be manufactured in place, the different materials having been previously prepared, brought to the road, and put together there.

If all the conditions are carefully studied and met by proper treatment, the bituminous macadam will be successful. The chief objection, if it may be so called, in the perfect bituminous macadam, lies in its slipperyness for horses, but nearly all first-class bituminous pavements are slippery in this respect and when seriously so there should be a slight covering of sand spread occasionally, the cost of which is very little.

CAUSES OF WAVINESS.

I have previously stated that waviness may be due to using a small size of stone in the bituminous surface. This is quite sure to follow the use of stone which does not exceed 1½ inches in largest dimensions, which some of us know as No. 2 stone; in other words, this size of stone when used will almost invariably wave sooner or later under heavy or medium traffic. Under very light traffic the stone will stay in place and not wave unless there is a surplus of bitumen. Where the smaller stones are used the voids will be smaller and a smaller quantity of bitumen should be used. There should be fully one-half gallon less than when stone of the larger size is used, but then it has been the writer's observation results would seem to show that this size of stone should never be used except where the traffic is very light, simply because of its tendency to wave or move about under the traffic.

With the large-sized stone, even if there is a surplus of bitumen there will be no movement of the stone nor waving of the surface unless there may be such a surplus of bitumen on top of the stone that it has the appearance of waving. But this surplus can be removed with grub hoes or hot shovels and should be taken off immediately after it has been put on during construction. If the weather at that time should be too cool it will not be very serious if left on the road until warm weather comes again.

BEST TIME FOR LAYING.

There is no reason why this type of bituminous macadam will not give good results in any climate, but it should not be laid in the late fall in the Northern States, as the bitumen cools in place so quickly that it prevents proper compacting of the stone. There have been instances where the work was done late and it was necessary to apply a second seal coat on account of the openness of the surface, leading to considerable additional expense.

In spite of every precaution, as in the case of any pavement, some imperfections may sometimes develop. Frequently miles of road are built without any of these imperfections developing; at other times when the men are not fully experienced or will not take proper care after the road has been open to traffic, small spots will appear where there does not seem to have been sufficient bitumen and the stone starts to ravel. Examination has shown that this frequently is due to the presence of a foreign substance on the surface when the bitumen was applied. Care should be taken to see that before bitumen is applied there is nothing in the stone which would prevent it from penetrating the voids. In the fall of the year, when leaves are dropping from the trees, it is sometimes necessary to have a gang of ten men or more taking the leaves off the surface of the road immediately before the application of the bitumen.

Usually imperfections of workmanship will develop within about 12 months of the time the work is done, and they may be corrected by patching, which should be done just as the work was done in the first place, except that bitumen may be hand poured, but stone and bitumen of the same kind, and the steam roller should be used.

WATER AND THE SUBGRADE.

By J. L. HARRISON, Highway Engineer, Bureau of Public Roads.

BPR 16702

IN SPITE OF THE HEIGHT OF THE EMBANKMENT THIS BITUMINOUS MACADAM FAILED BECAUSE ENOUGH WATER WAS TAKEN UP AND HELD SO THAT HEAVY TRUCKS EASILY BROKE THROUGH THE SURFACING.

THE DEVELOPMENT of the heavy truck has brought to the front a number of problems in highway design which demand consideration, but of these none are of more pressing importance than those which arise in designing the subgrade of a modern highway. This is because as a structure the subgrade is less reliable than the pavement that is laid on it, with the result that more money must be expended on the pavement than would be necessary if the stability of the subgrade could be so adjusted that its supporting power would become a reasonably uniform quantity.

There have been some efforts to develop the supporting power of the subgrade into a known quantity, and textbooks on highway engineering have generally recognized the need of improvement in this particular by urging that one of the most important considerations in the design of a highway is that the subgrade be kept dry, there being in this presentation of the matter two obvious assumptions, first, that it is possible to keep the subgrade dry, and, second, that if the subgrade is kept dry it will have a supporting power of such uniform quantity that it will offer a reliable foundation for any pavement which is laid over it.

These assumptions are interesting because the last is almost unquestionably the result of the common experience that during the summer months when subgrades are relatively dry their carrying capacity (except in the case of sands and gravels) is higher than when they are wet. On the other hand, the first assumption seems to have arisen from the logical deduction that by keeping subgrades dry the strength and the comparative uniformity of supporting power which subgrades show during the summer months would persist throughout the year.

DRAINAGE AND THE SUBGRADE.

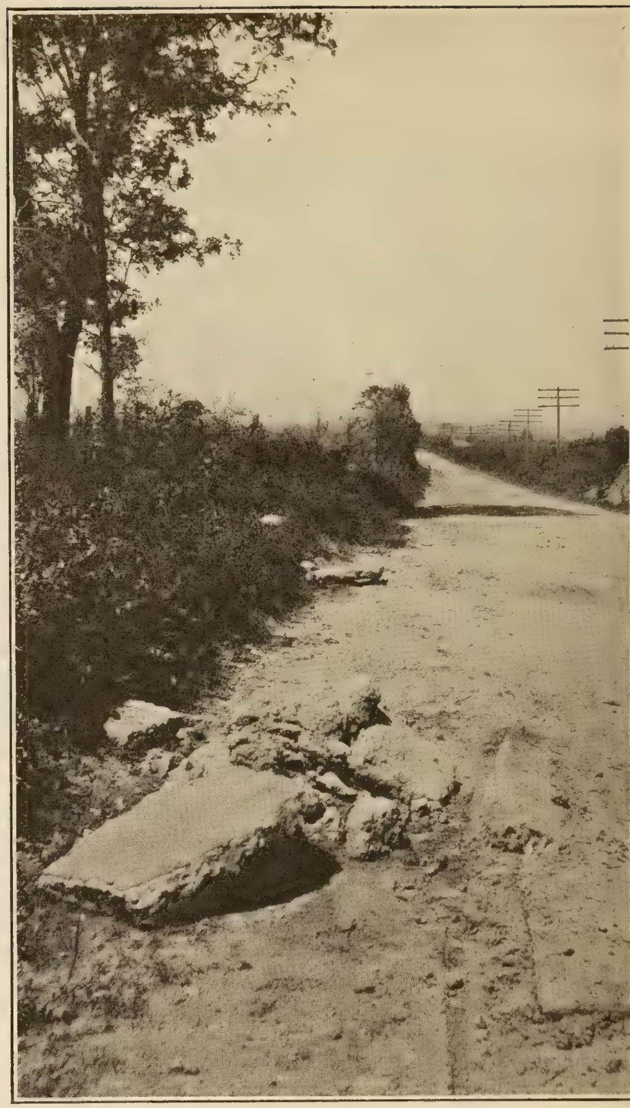
For some reason there has been connected with this obvious deduction the idea that an impervious pavement and proper drainage will produce the desired condition of the subgrade. However, the emphasis which has been placed on proper drainage as a factor in producing this result has been greater than the facts warrant, for drainage, in the strict sense, deals only with the removal of that water in the soil and on its surface which is subject to the action of gravitation. But under many conditions the water which is causing trouble in a subgrade is held in the soil in spite of the action of gravitation.

Therefore drainage, no matter how complete, often has been unsatisfactory, for it has quite generally failed to get at the real seat of the trouble. On the other hand, this fact did not become as conspicuous when light loads were moved over the pavements as it has become since heavy trucks came into common use.

Subgrades are constructed of all sorts of soil, the general practice being to build subgrades of whatever soil happens to be on the right of way. As a result of this practice, the soils found in ordinary subgrades vary from rock and coarse gravel to clays which are so fine that much of the kaolin of which they are largely composed exists in a colloidal state. But all soils contain moisture, and here lies the great difference in the behavior of different soils under the same conditions of drainage, for part of the moisture in these soils is moved by gravitation and part by capillary attraction. (We have no particular interest in that part of the moisture content of soils which exists as surface films on the soil particles.) It is a well-known fact that the percentage of pore space in different soils does not vary over a very wide range, but the size of the pores varies a great deal. In coarse gravel the pores may be quite large, in clay they are very small. Practically all of the water which exists in gravel is gravitational—that is, moved by gravity—while in a very fine clay, as fire clay, whatever free water is present is capillary water, there being almost no gravitational water at all. Between the coarse gravels and the fine clays, which are used as types because one contains practically no water held by capillary attraction and the other almost none that is subject to the action of gravitation, lie most of the soils used in constructing highway subgrades. Unfortunately, these soils tend to resemble the clays more than they do the gravels.

WHERE DRAINAGE FAILS.

It is not surprising, therefore, to find that the soils ordinarily used in highway subgrades contain a good deal of water which is held there by capillary attraction—water which can not be "drained" out by the installation of any sort of a drainage system for it is not moved by gravitation. Nor, then, should it be surprising to find that ordinary drainage systems—open ditches and tile drains—so commonly fail to produce reasonably dry subgrades, for the amount of water which normal soils will absorb and hold in spite of the action of gravitation is often sufficient to reduce the carrying capacity of such soils to a point far below their supporting power when they are dry. Indeed, in the case of clay the contained water held without regard to gravitation may exceed 50 per cent of the total volume of the clay mass. This is, of course, enough to render the mass too plastic to be depended on to carry heavy loads. Other soils, depending largely



BUILT THROUGH A CUT AND WITH THE DITCH FLOORS ABOVE THE BASE OF THE CONCRETE, THIS ROAD FAILED RAPIDLY UNDER HEAVY TRAFFIC BECAUSE THE MOISTURE FROM THE HIGHER GROUND FOUND EASY ACCESS TO THE SUBGRADE AND KEPT IT MOIST.

on the amount of clay in them, have this same power of absorbing and retaining water, that is they can absorb and retain until it is dried out of them by contact with the air quite enough water to materially reduce their load supporting power.

When such soils are used in highway embankments the water so absorbed is commonly obtained in one of two ways, from (1) the normal precipitation on the shoulders and slopes of the highway from which areas it is distributed through the subgrade by capillary attraction and from (2) the water table which underlies the highway, from which level it is raised into the subgrade by this same force. Modern practice in highway design almost always leaves the shoulders and the slopes open to the rain and, more frequently than is generally supposed, the water table is close enough to the surface of the ground so that capillary attraction will raise water into the subgrade.

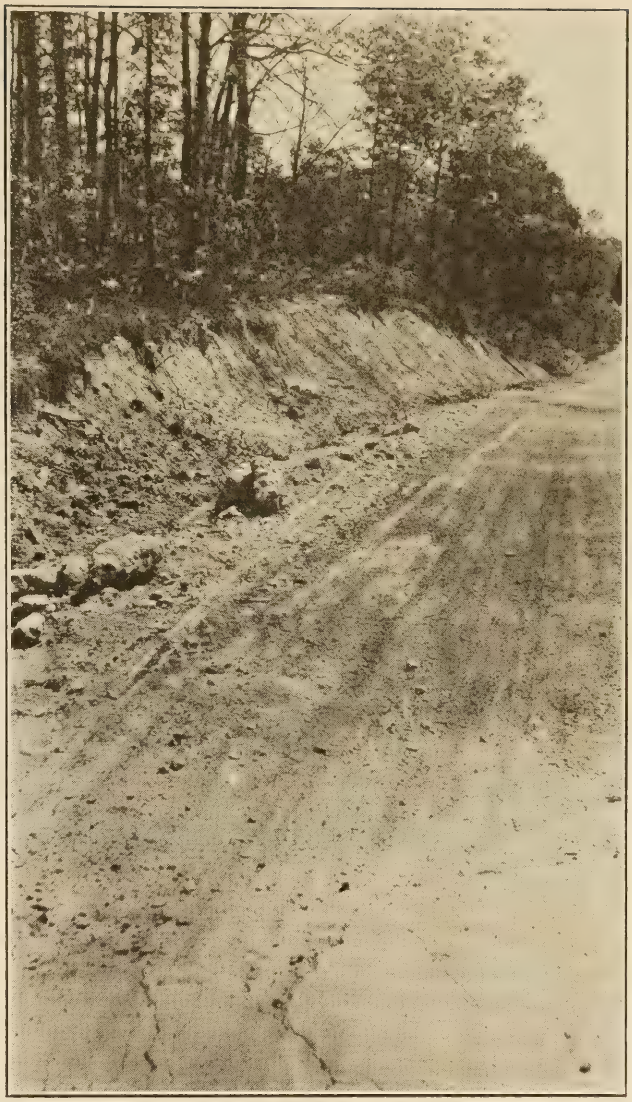
RAINFALL AND SOFT SUBGRADES.

The normal rainfall on the shoulders and slopes of a subgrade is not usually looked at as the cause of any trouble with soft subgrades though it is, in fact, quite often responsible for such trouble. The percolation of water into the soil is a large subject by itself, but a number of the salient features may deserve notation in this connection. One of these is that while water percolates very slowly into a soil which is so dry that the films of moisture which normally surround the particles in the soil have been largely removed, it moves quite rapidly where the soil is moist. Moreover, percolating water moves both down and out, the outward movement being negligible when the pores in the soil are so large that the movement of the water is largely by gravity, but quite high when the movement is by capillary action. It therefore transpires that during a protracted rain, particularly in the spring when the soil is apt to be moist at all time, dense clay subgrades may, and, in fact, do absorb a large amount of the rain which falls on the shoulders and that this absorption may carry the water considerable distances under the edges of the pavement.

The moisture so absorbed is retained very persistently by the finer grained varieties of clay. In fact, it is no uncommon thing to find that, under the pavement, the pockets of such clays as fire clay or dense blue clay are quite plastic for weeks after ordinarily porous material has dried out to a point where a satisfactory bearing power has been developed. Many failures on hard surface pavements are due to the presence of pockets of materials of this sort, materials which, when protected by a relatively impervious pavement, retain enough moisture so that with what is absorbed through the shoulders and slopes during every rain they never become dry enough to be stable. The writer has seen fire clay taken from such pockets in July which was as plastic as good putty—the moisture in this clay having been prevented from direct evaporation by a bituminous concrete pavement, and the moisture which was drawn away by capillary attraction to make up for the evaporation from the shoulders having been resupplied from time to time by the rain which fell on the shoulders and slopes of the highway.

CLAY SUBGRADE NEAR WATER TABLE.

In the case of a water table which is near the surface of the ground a similar condition prevails. Water is raised by capillary attraction through various heights, materials through which this force will raise water 2 or 3 feet being common, while materials through which capillary attraction will raise water as much as double these heights are by no means rare. The presence of a large amount of clay in a subgrade which is within 6 feet of a water table is, therefore, an invitation to trouble, for there are a great many clays which will absorb enough moisture under conditions of this kind to remain constantly plastic if their moisture content is protected from evaporation by an impervious pavement.



BPR 16358

RUNNING WATER HARDLY VISIBLE, KEPT THE SUBGRADE UNDER THIS CONCRETE PAVEMENT WET, AND HEAVY TRAFFIC BROKE IT UP.

In this connection there is one point which deserves mention: the moisture content in the top layer of the soil is the result of two opposing conditions, the rate of evaporation and the rate at which moisture is supplied from below by capillary attraction. In an open field the surface of the ground may become very dry during the day, due to a high rate of evaporation, and then may become quite moist during the night because the rate of evaporation has fallen very low while the rate at which moisture is being raised by capillary attraction has remained constant. Through a pavement, on the other hand, there is obviously almost no evaporation, so a pretty constant moisture

BPR 16367

BITUMINOUS CONCRETE ON A PORTLAND CEMENT CONCRETE BASE. WET CLAY WAS FOUND UNDER THIS BREAK. END OF SHOVEL HELD BY THE BOY SHOWS WHERE THE PAVEMENT SURFACE LAY ORIGINALLY AND DEMONSTRATES THE FACT THAT WET CLAY IS A POOR FOUNDATION. THIS SPOT IS ON A HILL, WELL DRAINED, BUT SEEPAGE THROUGH THE SHOULDERS KEPT THE CLAY MASS WET.

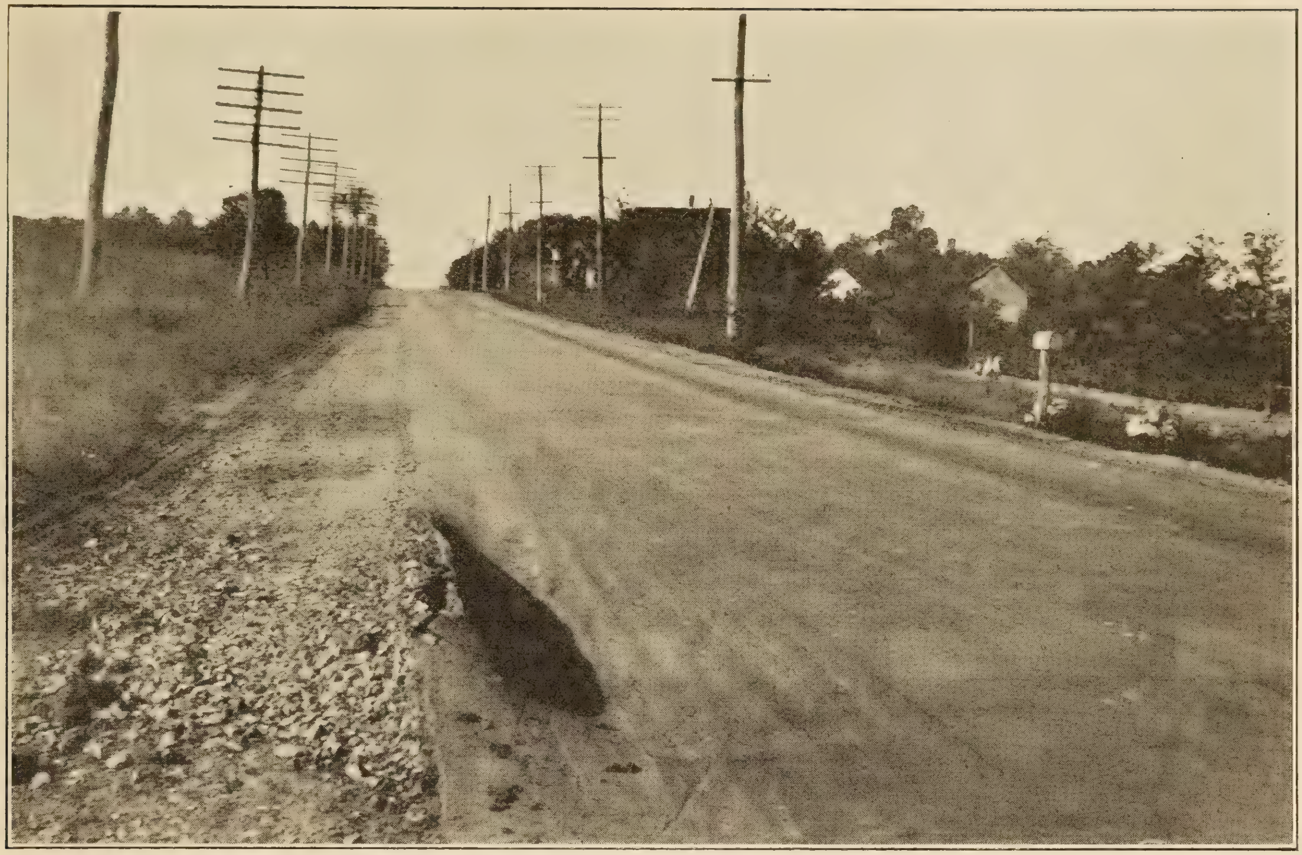
content may be maintained in the subgrade just below it by even a low rate of capillary flow, there being no need to supply moisture faster than the normal rate of capillary flow from the interior of the subgrade to the shoulders, to keep up a condition of high moisture content under the pavement. That this condition prevails more often than is generally supposed is evident from the fact that during his investigations of this matter the writer has encountered moisture contents as high as 18.88 per cent by weight (about 60 per cent by volume) and has found that 30 per cent of water by volume is quite a common moisture content in the clay immediately under an impervious pavement. Of course, any clay in a road embankment which contains as much water as this is so plastic that it cannot be depended on to carry very heavy unit loads.

The obvious remedy for this condition of affairs is to use less clay in highway subgrades. For this reason the modern practice of balancing cuts and fills is to be regretted, for while economical as to first cost it carries with it the constant temptation to use a great deal of material which should never form a part of a highway embankment. To what extent it will be advisable to waste material which is now regularly used will depend very largely on what loads the highways are ultimately to be called on to carry, but, as the data now at hand serves to show that many of the clays act very much like sponges and absorb so much water that they are plastic much if not most of the time, the rejection of many of the clays would seem to be advisable if anything like uniform stability is to be secured in a subgrade.

DRAINS NOT ALWAYS EFFECTIVE.

The advocates of tile drainage, as a panacea for all of the ills that befall pavements, will argue that much can be done by using tile drains if the tile drains are placed deep enough. Tile drains can be so placed, it is admitted, that they will lower the water table. If placed from 6 to 8 feet or more below the surface they would probably stop most of the water now raised into the subgrade by capillary action. On the other hand the writer has found as high as 11.2 per cent of moisture by weight (about 30 per cent by volume) in a clay soil under an asphalt pavement (2 inch asphalt top on a heavy concrete base) where the water table was so far below the surface that a service opening 10 feet deep had not yet encountered it.

This would seem to indicate that there are times when water is raised a long distance, for there did not appear to be any other source from which this moisture could have come. The sheet asphalt



BPR 16703

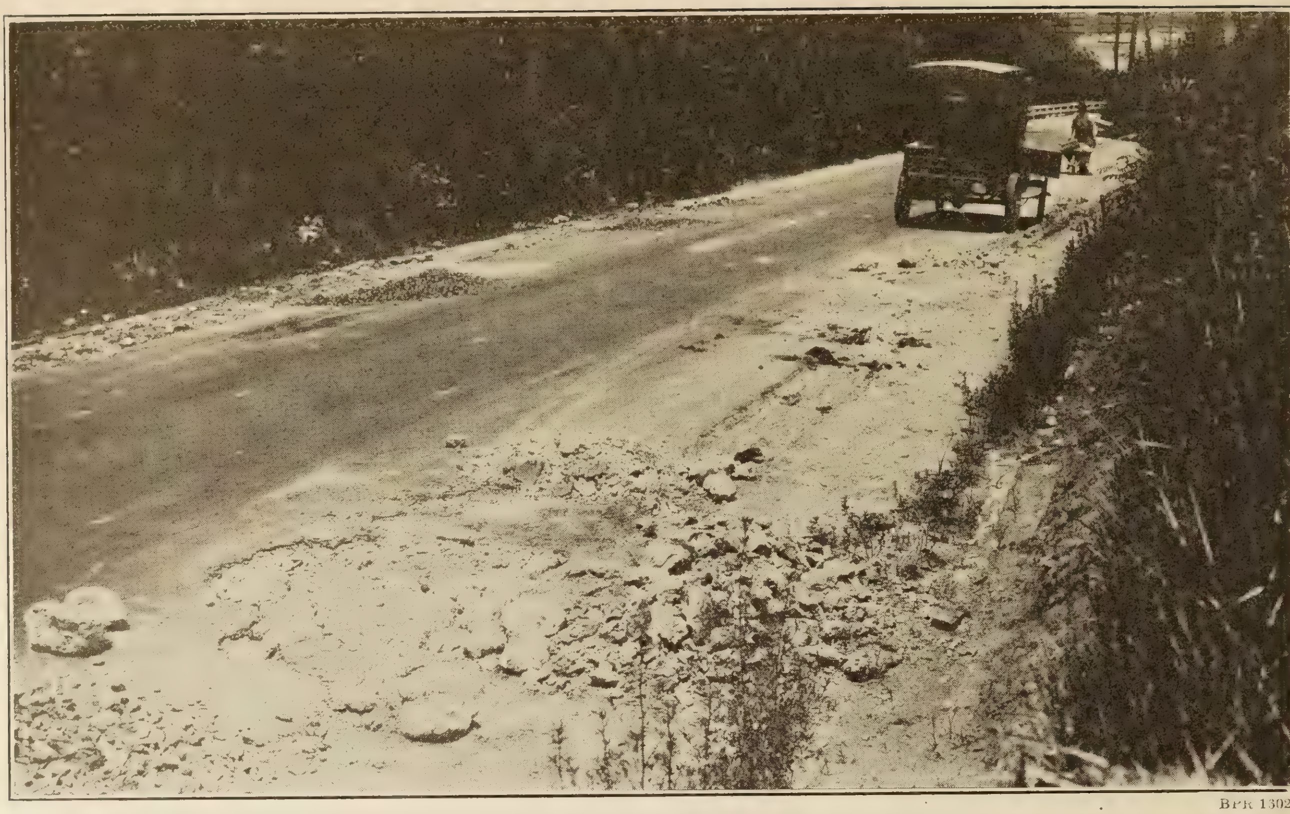
FAILURE DUE TO A SATURATED CLAY SPOT UNDER A BITUMINOUS CONCRETE ROAD IN NEW JERSEY. THIS HOLE IS SO DEEP THAT THE TRUCK AXLES HAVE RAKED THE BUNCH AT THE LEFT OFF FLAT.

pavement precluded any assumption that this water had come through the pavement. The sidewalks are of concrete and the building space for hundreds of feet in all directions is under roof. The obvious conclusion is that where there is no direct evaporation and where there is no shoulder evaporation, water either may be gradually lifted to heights much above the ordinary limit of capillary attraction or that condensation on the under side of the pavement may eventually develop a high water content in the underlying soil, if this soil is dense enough to retain moisture.

In any case the use of tile drains to unwater clay subgrades is pretty largely a waste of money, for clay as it is compacted into a highway subgrade can not be unwatered in this way unless the tiles are placed deep enough to keep the water table beyond the range of capillary attraction, which means that to accomplish the desired results the tile must be placed much deeper than is now common and even then the results will be very doubtful. Indeed this should be clear for another reason. Clay is so impervious that it is constantly used to make cofferdams water-tight. In the construction of cofferdams a thickness of a very few feet of clay is often used to hold back a considerable head of water. Used in this way, clay is a standard construction material. Just why, then, engineers should try to drain this same material by running a few tiles through it is not clear. A clay subgrade may contain a large amount of water, but this water is contained in pore spaces which are so small that gravity is not strong enough to overcome the capillary attraction which holds it in these pores, so little or no good attends the use of tile drains in such material, except as such drains are used to cut off the supply from which the water in the wet strata is drawn.

PROBLEM IN SPRING THAWS.

Another phase of the general problem of dealing with water in the subgrade is presented by the spring thaws. It is a notorious fact that at this time of the year subgrades, especially in northern regions, are more apt to give trouble than at any other time. The cause is not hard to locate, but the undesirable conditions which result are extremely hard to correct. Briefly, during the severe weather of the northern winter, the moisture in the ground freezes to a depth of from a few inches to a number of feet. Even though the moisture content in the soil is not very high, it is usually sufficient to convert the frozen stratum into a solid mass through which no water can percolate. Indeed, even if the mass is not impervious, no water can pass through it, for its temperature is so low that any moisture which reaches



BPR 13028

THE BREAKS IN PROCESS OF REPAIR OCCURRED OVER POCKETS OF CLAY WHICH ABSORBED AND RETAINED ENOUGH WATER TO KEEP THE CLAY PLASTIC.

it will be converted into ice. It is, therefore, a barrier through which no water can pass.

When spring comes, the warmer weather first converts whatever snow and ice there is on the ground into water and then gradually melts the ice which is in the soil itself. The melting of the ice in the frozen ground is a slow process—one which, when the spring opens gradually, may take from two weeks to a month or more. But during all of this period—that is, as long as there is any of this frozen stratum left under the surface of the ground—none of the water which is formed by melting the snow and ice which lay on the ground when the thaw began, and none of the rain which falls while this frozen stratum persists, can penetrate the ground farther than the top of whatever remains of the frozen stratum. Thus, if the ground was originally frozen 3 feet thick and 6 inches of this distance has melted, any moisture which melts on the surface or which falls as rain and is absorbed by the soil must be retained in this 6 inches of melted soil, for it can not, in the nature of things, percolate into the 2½ feet of ground which is still frozen.

This condition is not so hard to handle on rolling ground for here the surface run-off is high, but on flat ground the results of this condition are apt to prove serious, for here the run-off is slower; indeed, there is apt to be an accumulation of water from surrounding high ground, and when this water has been absorbed in the thin layer of thawed-out ground complete saturation often results. In this way a condition is created which is exactly similar to that which would result if the water table were raised to the surface of the ground. Of course, the strength of any subgrade which is subjected to such a condition is adversely affected by it, and when the pavement is laid so that the top of the subgrade is only a few inches above the surrounding ground or even, as too often happens, a little below the surrounding ground, the complete saturation of the subgrade immediately under the pavement naturally results.

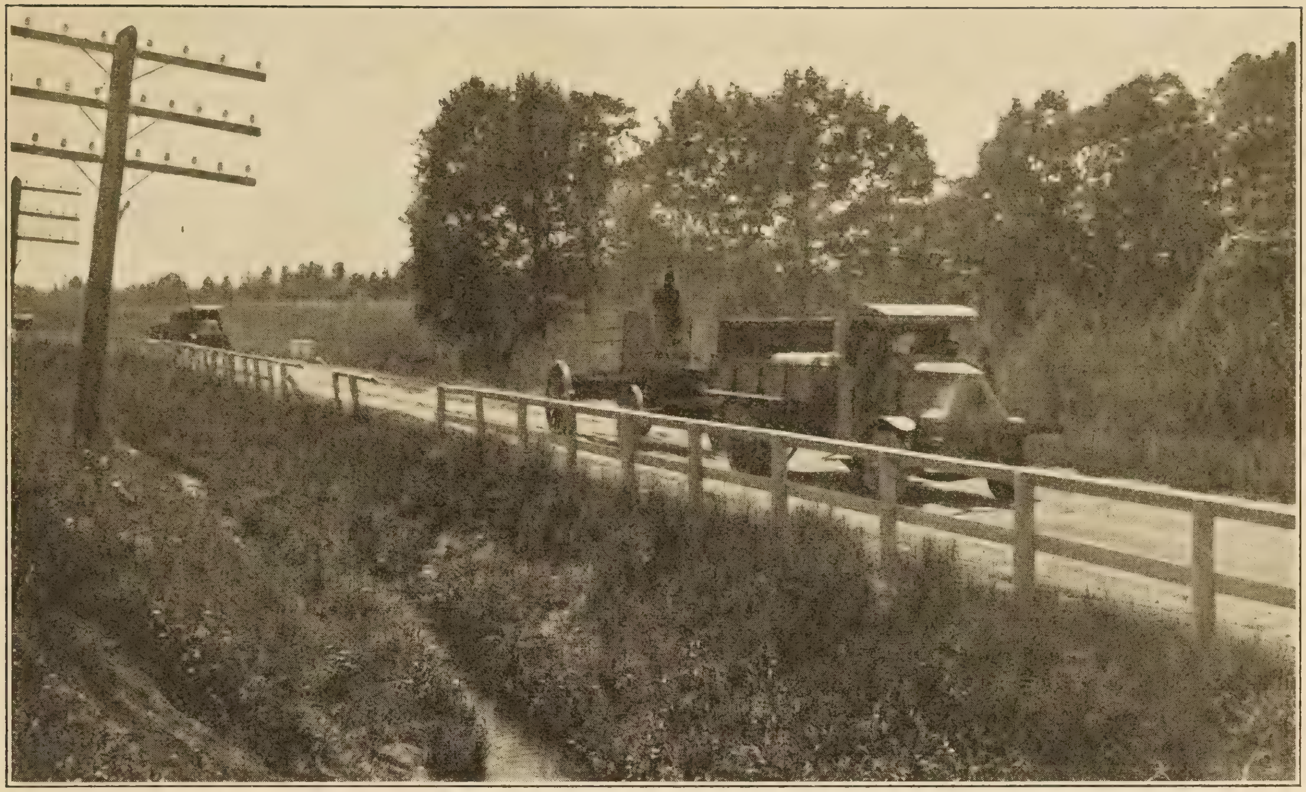
There is nothing strange or unusual about this phenomenon unless it be the amount of water which is sometimes found in the top layers of the ground during these periods. As throwing some light on this, some samples taken from rather porous ground last spring showed:

Top inch, 29.3 per cent of water, by weight.

Top of frozen ground 6 inches below surface, 24.9 per cent of water.

Ten inches below surface (4 inches below frost line), 14.7 per cent of water.

The ground had frozen after rather a wet period and so the moisture content of the frozen ground was higher than would be normal. The other percentages are, however, quite normal for light soil, and while the water content in the first inch is very high this merely serves to show what commonly results at



BPR 16704

A HIGH FILL HAS ABSORBED SO MUCH WATER THAT THIS MAT COVERED MACADAM HAS BEEN CUT TO PIECES.

this time of the year. It is needless to remark that soil as wet as this can not support any heavy loads; indeed, a man walking over it sinks into it 2 or 3 inches, so it is not strange that pavements fail during the period when the frost is coming out of the ground.

Tile drainage does not help this condition. It should be clear that tile drainage can do nothing for such a condition as this, for the essence of the trouble is that the normal percolation of surface water into the lower strata is cut off by the sheet of frozen soil which underlies the surface. As all tile drainage is located some feet below the surface, any sheet of frozen ground so entirely cuts it off that it can have no effect in removing the water on the surface.

SURFACE DITCHES HELP.

On the other hand, a good system of surface ditches is an assistance during spring thaws. Such a system usually does not, however, meet the condition as well as could be desired, for it requires a great deal of attention to keep surface ditches free from obstructions, especially ice, and as a result it is not at all uncommon to find ditches, which in ordinary weather are entirely adequate, standing full of water during spring thaws because ice dams have formed in all of the shaded sections of them.

Another factor of no little importance at this period is the tendency of the least depression to catch and hold water. This is not only because of the saturated condition of the soil as above described, but is also due to the fact that when the air is only slightly above the freezing point, as is its normal condition in the early spring, a relatively small amount of water can be taken up and carried away in the air. There is, then, at this time of the year, a combination of conditions—the absence of normal subdrainage, the clogging of surface drainage, and the low moisture absorbing power of the air which all tend to keep subgrades in a wet and weakened state. At least two of these conditions are of such a nature that they must be recognized as phenomena over which there is no control. Even the third, the formation of ice dams in shaded sections of the drainage ditches, is one which is extremely difficult to deal with, but which must be handled if any relief from this condition is to be secured.

There is much which can be said as to the proper functions of drainage systems in the protection of subgrades, but the salient features of good ditch design are matters which are too well known to deserve much comment in this connection. One point, however, deserves mention, and that is that ditches should always be kept open and evenly graded so that they will not impound water. Water impounded in ditches works under the pavement easily and rather rapidly. Running water in highway ditches is to be condemned for the same reason. Where the subgrade is sandy and porous the seepage from water impounded in a ditch or running in a ditch does not

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spread out very far laterally, but where the soil is heavy the lateral seepage is more of a factor, and, in fact, a good many pavement failures can be traced to these very causes.

TESTS OF SOILS FOR SUBGRADE.

Looked at from a little different angle, the important point in this discussion would seem to be that, as there is no justification for the common assumption that drainage will keep a highway subgrade dry, it is neither logical nor correct to design pavements on the theory that their subgrades will be dry. On the other hand, there being every reason to assume that there will be times when very little subgrade is in an entirely satisfactory condition and that, in any locality, subgrades of some materials will almost never be as strong as they should be, it would be far more advisable to accept as normal bearing powers a good deal lower than the maximum attained during dry weather, and to discard as unfit for use in the subgrade materials which are known to fall below this limit of strength whenever capillary attraction fills their pores with water. This would imply an examination of the strength of compacted soils containing a relatively high water content, and accepting as inevitable the high water content of soils which is known to be common during the spring months. This would also, as suggested above, imply wasting soils which fell below the established standard of supporting strength under the conditions as to moisture which are normal at this time of the year.

At first glance this may seem to be a visionary scheme, but on careful study it will usually be found that the amount of testing, which would be required in order to eliminate undesirable soils, would be no greater and no more expensive than the testing now done by every well-managed highway department in order to insure the satisfactory nature of other building materials. As there can not be the slightest doubt that the heavy loadings now carried on the highways makes it as important that the subgrade should be composed of materials of proper characteristics as it is that the base should contain good cement or the top good brick, an equal amount of care in the selection of materials for the subgrade would seem to be in line with the general progress which is being made in the art of highway construction.

BONDS FOR HIGHWAY.

Sussex County, Del., will issue bonds to the amount of $500,000 to construct a concrete road across the county from Lewes and Rehoboth Beach to the Maryland line.

NEW HAMPSHIRE LEGISLATION.

This year's session of the New Hampshire Legislature passed the annual appropriation of $125,000 for road maintenance and appropriated $250,000 for State-aid roads; enough money was appropriated from the State treasury to secure Federal aid to the amount of $800,000. The old law fixing the limit of cost of State-aid roads was repealed.

In New Hampshire, under a new law, the power to locate new State highways is now vested in the governor and council, and not with the highway commission.

CONVENIENT PROJECT RECORD.

ONE OF the most important functions of a district office is to keep detailed and readily accessible records of the routine transactions on all projects under the supervision of the district office. A form devised by the Portland office, and shown on the opposite page, is unusually well suited for this purpose, for it is comprehensive, easily referred to and of general utility. The form is self-explanatory.

As a district record the form is bound in a looseleaf binder of a size convenient for a desk record. Projects are entered serially by States and the form filled in as the project is developed. In a number of districts the territory is subdivided, and an engineer placed in charge of each subdivision. Where this is done, a copy of this record may also be kept for each subdivision.

With slight changes the form is also adapted for use in State offices, not only as a ready desk record but also as a permanent record, for it enables the compact recording of practically all of the administrative and fiscal data which it is desirable to have in studying the progress of a project and in determining when and why special attention should be given to it.

Records of this nature are invaluable when kept up to date. They become practically valueless when there is even a suspicion that they are inaccurate or incomplete. For that reason, wherever this form or one of similar design is adopted, the work of keeping it up should be intrusted to a responsible clerk, and it may even be advisable to require a notation on all documents from which entries on this form are to be made, that the proper entries have been made, before such documents are transmitted. Where such a check is used, this will prove to be a valuable record, both for use in the office and in the field. The form is as follows:

PROJECT RECORD FORMS.

BUREAU OF PUBLIC ROADS

POST ROAD PROJECTS

State of Oregon County of Malheur *Project No.* 17

John Day *Highway* Cow Valley-Brogan *Local Sec.*

Project statement.				Plan, spec. and estimate.
RECEIVED	February 20, 1919			
LENGTH	8.5 miles			
TYPE	Grading earth road			
ESTIMATE	$69,300.00			
F. A. REQUESTED	$29,650.00			
INSPECTED	Nov. 16 1918-T. M. Keene			
FORWARDED	3/11-19			
APPROVED				
FUNDS—STATE $	29,650	Co. $	10,000	ADVERTISED
REVISED—STATE $		Co. $		
SUPPLEMENTARY AGREEMENT				AWARDED TO
FOR $		TOTAL $		
				$

FACE OF PROJECT RECORD FORM.

VOUCHER RECORD

Number.	Period.	Amount.	Fwd.	Approved for.	Deduction.	Remarks.

BACK OF PROJECT RECORD FORM.

REPORT ON RURAL CONCRETE ROADS.

Results of the Conference of the Mississippi Valley Association of State Highway Departments.

A CONFERENCE on recommended practice for rural concrete road construction was held by the Mississippi Valley Association of State Highway Departments at Hotel La Salle, Chicago, February 10 to 11, 1919.

As a basis for the consideration of various subjects the conference had at hand the recommended practice for concrete road and street construction of the American Concrete Institute, which is to be found in full in the Proceedings of the Institute for 1918 (Vol. XIV, p. 518).

It was the general understanding that for the present the Mississippi Valley Association would not issue a complete recommended practice covering all features and all details. It is expected that this may be done by future conferences. The present report, therefore, is confined to those points where there was a difference of opinion between the Mississippi Valley Association conference and the American Concrete Institute, where the American Concrete Institute recommended practice was silent, where amplification was thought desirable, and where the American Concrete Institute recommended practice was not considered sufficiently definite.

In general, therefore, the recommended practice of the American Concrete Institute is to be followed in so far as there are no conflicts with the findings of the Mississippi Valley Association conference.

Throughout the text of this report will be found references to the recommended practice of the American Concrete Institute, which references are made by section number, chapter numbers being disregarded. The subject alone of those topics discussed by the Mississippi Valley Association conference concerning which there was no essential difference of opinion from the recommended practice of the American Concrete Institute, is mentioned with appropriate reference thereto.

TESTS.

Testing of cement.—(See secs. 1 and 2, A. C. I.)

Tests of fine aggregate.—(See secs. 1, 3, and 4, A. C. I.) It is recommended that the following tests be made to determine suitability of fine aggregate for use in concrete roads and pavements:

1. Organic impurities (colorimetric tests) (see sec. 1, A. C. I.).
2. Sieve analysis.
3. Mortar strength test (see sec. 1, A. C. I.). Tension tests of standard briquettes are recommended in addition to compression tests.
4. Volume of silt.

Field tests.—Field tests for grading should be made with a nest of sieves of the following mesh:

Sieve No. or size.	Size opening in inches.	Size of wire in inches.
100	0.0058	0.0042
48	.0116	.0092
28	.023	.0125
14	.046	.025
8	.093	.032
4	.185	.065

Volumetric tests for silt determination are recommended, in which sand and water are shaken together in a graduated glass cylinder. The depth of the deposit on top of the sand is a measure of the foreign material present. Volumetric tests for silt determination should be considered as approximate for determinations to be made in the field, but material should be accepted only after the quantity of silt is determined by the weight method, except in those cases where the volumetric test shows not to exceed 7 per cent of silt at the end of one hour.

MATERIALS.

Fine aggregate.—(See secs. 1, 3, and 4, A. C. I.) Fine aggregate should consist of particles of durable rock that will pass a laboratory screen having four meshes per inch. The fine aggregate may consist of natural sand or of a mixture of natural sand and screenings from durable crushed stone or gravel, provided the screenings are free from dust and the volume of screenings does not exceed 50 per cent of the volume of fine aggregate. It is important that all fine aggregates be tested for organic impurities as described in section 1, A. C. I.

Coarse aggregate.—(See secs. 1 and 5, A. C. I.) The coarse aggregate for one-course pavements and for the base course of two-course pavements should be composed of pebbles or crushed stone. All of the particles should be sound and durable. Slag of suitable quality and uniformity may be employed. The crushed stone should be durable and of uniform quality and should have a French coefficient of wear of not less than seven.

The aggregate should be free from flat and elongated particles. The sizes of the particles should be graded reasonably uniformly from coarse to fine, such that all will pass a 2½-inch screen, and not less than 95 per cent retained on a ¼-inch screen.

The coarse aggregate for the wearing course of a two-course pavement should meet the above requirements except that the maximum size should not exceed that which will pass a 1-inch screen.

Proportions.—One-course road: The concrete for a one-course pavement that is to be machine finished should be mixed in the following proportions: 1 sack of cement, 2 cubic feet of sand and 4 cubic feet of coarse aggregate. For work that is to be hand finished the proportions should be 1 sack of cement, 2 cubic feet of fine aggregate and 3½ cubic feet of coarse aggregate.

Two-course road: The proportions of the concrete for a two-course pavement should be as follows: For the lower course, 1 sack of cement, 2 cubic feet of fine aggregate and 4 cubic feet of coarse aggregate.

The proportions for the wearing course should be 1 sack of cement, 2 cubic feet of fine aggregate and 3½ cubic feet of the coarse aggregate prescribed for the wearing course of the two-course pavements.

Quantity of water: It is recommended that extreme care be employed in proportioning the mixture as regards water content, and that this fact be checked by the slump test as follows: For the test, 6 by 12 inch cylinders should be tamped full of the concrete as mixed and the cylinder immediately removed. For work that is to be finished by hand, the slump of the concrete upon removing the cylinder should not exceed 6 inches and for work that is to be machine finished the slump should not exceed 2 inches.

DESIGN.

Thickness.—(See sec. 13, A. C. I.) The thickness should be not less than 7 inches at the sides nor 8 inches at the center for two-track roads up to 20 feet in width. The thickness for single-track roads should be not less than 7 inches at any point.

Widths.—(See sec. 12, A. C. I.) It is inadvisable to build concrete roads less than 18 feet in width. Where a single-track road must be built it should be made 9 feet in width and the 9 feet should be centered on the center line. Pavements with widths between 10 feet and 16 feet should not be built.

The width of grade to be traveled should be not less than 24 feet for any width of pavement and the minimum over-all width of shoulders should be at least 8 feet more than the pavement width.

Crown.—The crown should be a total of 1 inch for two-track roads not exceeding 20 feet in width. If on center line the crown for single-track roads should be one-half inch. If placed with one edge on the center line the surface should be sloped all one way with a total slope of 1 inch.

Alignment.—No radius should be less than 200 feet on center line of turns.

Widening turns.—(See sec. 16, A. C. I.) On all turns the center line of the road should be marked by a white strip 8 inches wide.

Superelevation of curves.—(See sec. 15, A. C. I.) Except when drainage condition may prevent, the grade of the original center line before widening is to be maintained where pavement is superelevated. The crown of the surface is to be flat where pavement is superelevated.

GRADING AND DRAINAGE.

Grades.—(See sec. 19, A. C. I.) Concrete pavements can be successfully constructed on any maximum grade likely to prove best from general economic consideration. In the middle west maximum grades exceeding 6 to 8 per cent should not be adopted under ordinary circumstances.

Considering the permanency of concrete surfacing a greater expenditure of money is justified in eliminating frequent and minor breaks or changes in grade than is the case with a less permanent type of road.

Vertical curves on steep grades should be sufficiently long to give an unobstructed view of at least 250 feet.

Drainage.—(See sec. 20, A. C. I.) On sections where deep ruts have been made through clay soils subdrainage should be provided throughout the entire length of the cut.

Culverts and bridges.—All culverts and bridges should be constructed of reinforced concrete built in place. For purposes of this report spans up to and including 12 feet should be considered culverts. Spans over 12 feet should be considered bridges.

The clear width between culvert end walls should be not less than the full width of the grade as constructed.

Bridges should have a clear width of not less than 20 feet and should in every case have a clear width of not less than 2 feet more than the pavement width. If sidewalks are necessary, they should be provided for in addition to the above widths.

Subgrade.—It is recommended that if possible the subgrade for a concrete pavement be not trenched out and that it be kept higher than the berms, so as to provide drainage directly to the side ditches.

Very careful attention should be given to the rolling of the subgrade. It is recommended that a macadam type of roller be used, weighing not less than 10 tons. If the rolling at any time causes the subgrade to become wavy, the rolling should be stopped immediately over the wavy parts, and the soft material investigated. In clays this is almost always due to moisture and unless it is possible for it to dry out by the sun and wind without delaying the work, it should be removed and replaced with dry clay or other suitable material that can be rolled in a satisfactory manner. If any depressions develop they should be filled with acceptable material as the rolling progresses. Sand and sandy soils require a minimum amount of rolling.

It is recommended that the rough grading be completed very closely to the intended cross section of the subgrade and to the full width of the shoulders. Avoid shallow filling without plowing. Avoid filling narrow, deep ruts without plowing and disking. The finished subgrade immediately ahead of the concrete should be corrected to proper cross section, using a template.

Where the method of depositing the aggregates on the subgrade is followed (see sec. 25, A. C. I.), the subgrade should be completed fully in sections not exceeding 600 feet in length immediately before the aggregates are deposited. The surface should be brought to true cross section, using a template or other acceptable method. The roller should be kept in constant operation while the aggregate is being delivered. Any ruts or irregularities caused by the handling of the aggregates should be filled up and thoroughly tamped. Wherever possible, hauling over finished subgrade with teams or motor trucks should be avoided.

Where necessary, to avoid formation of an objectionable layer of dust the subgrade should be sprinkled in advance of placing materials.

EQUIPMENT.

Unloading yard and equipment.—(See sec. 23, A. C. I.)

Hauling equipment.—(See sec. 24, A. C. I.)

Industrial railway.—Use is recommended. (See sec. 24, A. C. I.)

Dumping on the subgrade and into the mixer.—(See sec. 25, A. C. I.)

Mixer.—The mixer should be of a standard paving type having a capacity of at least two-bag batch, commonly known as size No. 14.

The mixer should be equipped with a boom and bucket or some other mechanical device that will deliver concrete of a proper consistency, also with an automatic timing device and a device that will accurately measure the water for each batch.

The attention of the mixer manufacturers is directed to the advantages of perfecting a mixer that will shorten the time necessary for proper mixing and permit the inspection of the batch before delivery.

Water supply.—(See sec. 26, A. C. I.) In addition to the general recommendation of the American Concrete Institute recommended practice, the water supply should be free from injurious substances, duplicate pumping machinery should be provided, booster pumps should be provided on long pipe lines, and in all pipe lines there should be provided unions at intervals not greater than 1,000 feet.

Tees for supply water to the mixer and for sprinkling should be placed at intervals not greater than 100 feet.

MIXING AND PLACING.

Time of mixing.—(See sec. 27, A. C. I.). Materials should be mixed at least one minute after the entire batch is in the drum. The speed of the drum should be not less than 12 revolutions per minute.

Measuring materials.—(See sec. 28, A. C. I.). All materials should be accurately measured in receptacles of such size that the minimum number of units when struck off level will give the proper quantity for a batch.

Side forms.—(See sec. 29, A. C. I.). Steel side forms should be used and after the forms are set the joints should be inspected carefully using a straight edge to insure proper horizontal and vertical alignment.

Placing concrete.—(See sec. 30, A. C. I.). The operation of depositing, spreading, and finishing the concrete should be as nearly continuous as possible for the full width and thickness of the pavement. When delays, of sufficient length to permit the concrete deposited to attain initial set, are necessary a suitable header should be placed at right angles to the road and the concrete finished to this header to true elevation and cross-section.

The concrete may be transported from the mixer to place on the subgrade in any convenient manner which avoids the segregation of materials. Any device or method of operation which tends to segregate the materials in such a manner that later operations do not completely eliminate such segregation should not be permitted.

Placing concrete in cold weather.—(See sec. 31, A. C. I.). Every effort should be made to arrange for closing concrete road work in the fall or on about such date as the Weather Bureau reports for the locality for the past 10 years indicate the probability of temperatures materially below the freezing point. If circumstances necessitate continuing work for a short period after freezing weather is likely to occur, precautions should be observed which will insure positively that the concrete may not become frozen under the most extreme conditions of temperature for the period, as indicated by weather reports for the past 10 years. Concrete should be protected absolutely from freezing by suitable means for at least 7 days after placing.

JOINTS AND REINFORCING.

Expansion joints.—(See secs. 32 and 33, A. C. I.). Expansion joints should be used only in specific cases, such as, junctions between the pavement and other fixed objects.

Expansion joints when used should consist of either high grade wool felt or a fibrous material combined with a coal tar or asphalt compound. The filler should contain, by weight, not more than

8 per cent of mineral matter and not less than 5 per cent nor more than 25 per cent of fiber.

Contraction joints.—(See secs. 34 and 35, A. C. I.). Contraction joints should not be used. Construction joints should be made at the end of each day's work or when mixing is stopped for any reason longer than one hour.

Reinforcement.—(See sec. 37, A. C. I.). For pavements up to 18 feet in width with good foundation the value of any practicable amount of reinforcement is questionable.

For pavements over 18 feet, and especially where foundations are not thoroughly satisfactory, reinforcements, mainly in a transverse direction, may be used to advantage.

Where reinforcement is used it should be wire mesh or separate bar reinforcement, not less than 40 pounds per 100 square feet, and the proportion of transverse to longitudinal steel should be not less than 3 to 1.

The reinforcing should be placed not less than 2 inches from the finished surface of the pavement. Adjacent widths of the fabric should be lapped not less than 4 inches when the lap is made perpendicular to the center line of the pavement and not less than 1 foot when the lap is parallel to the center line.

Circumferential reinforcing—(See sec. 38, A. C. I.)

FINISHING.

Machine finish.—(See sec. 39, A. C. I.) When mixtures of relatively dry consistency are used, such as those necessary to secure maximum strength as far as such strength is determined by the water content, mechanical strikers and tampers should be used. Machines should be so constructed and operated that they strike off and thoroughly tamp the concrete. They should be so constructed that they may be readily operated over the same area repeatedly. Machines to serve the purposes above indicated should be subject to the approval of the engineer. The mechanical device or devices used should be so made and operated as to leave the finished slab true to grade, crown, and surface and absolutely free from porous places.

Hand tamping.—If a mechanical finisher is not used and the consistency of the concrete is to be as above described, after spreading the concrete should be thoroughly hand tamped by means of a tamper of the nature of a strike board operated by one or two men stationed at each end of the tamper on opposite sides of the roadway. Hand tamping should be vigorous and sufficient to consolidate the concrete in such a manner as to close all voids. The hand tamper should be followed by a final strike board and all operations carried on in such a manner as to leave the surface behind the final strike board true to grade, crown, and surface, and absolutely free from porous places.

Roller and belt finish.—(See sec. 40, A. C. I. If a medium consistency is used, the concrete should be spread, agitated, and tamped in such a manner as to insure positively the avoidance of stone pockets or porous places. It should be struck off true to grade, crown, and surface. It should then be rolled by a light hand roller of approved design operated in such a manner as to remove the surplus water and leave the surface true to grade and crown.

When hand methods of striking and tamping are used the final finishing should be executed by means of an approved belt operated in such a manner as to leave the pavement true to crown and free from waves, ridges, depressions, or other irregularities and with a uniform mat surface.

Curing.—(See sec. 41, A. C. I.) As soon after finishing as may be possible, without marring the surface, the slab should be covered with canvas. When the concrete has set sufficiently to obviate the possibility of marring, and where local conditions permit, suitable longitudinal and transverse dikes should be built and water supplied to cover the surface of the concrete to a uniform depth of 2 inches. The water should be maintained on the surface for not less than 14 days. Under conditions where it is impractical to adopt the ponding method of curing the surface of the concrete should be covered with not less than 2 inches of earth and kept moist for at least 14 days by wetting not less frequently than intervals of 12 hours.

Traffic should not be permitted to use the pavement in less than 21 days if the pavement has been subject to favorable curing conditions; nor in less than 40 days if subject to unfavorable curing conditions.

Traffic should not be permitted to use the pavement for a period of at least three days after removal of the water or earth covering.

Traffic should not be permitted to use the road until all dike or earth coverings have been completely removed.

INSPECTORS AND INSPECTION.

Inspectors.—Inspectors should be selected with great care.

The remuneration of an inspector should be sufficient to secure a man of the following qualifications: Practical experience, knowledge of specifications and construction, absolute integrity, quick decision, sound judgment, forceful personality, common sense, and the ability to command the respect of the contractor. The inspector should have broad perspective and should be able to distinguish between essentials and nonessentials. It is recommended that inspectors of concrete construction be given a preliminary course of training in their duties, including a study of materials and the interpretation and significance of laboratory and field tests.

Inspection.—Inspection must be intelligent and thorough, and should include inspection of materials and inspection of construction. The nature of the work requires a man familiar with the specifications and the fundamental principles underlying each clause.

Poor work in concrete construction can not be corrected as the work progresses and poor inspection will nullify the best prepared specifications. Inspection should include a daily report on the progress of the work and should be subject to supervision by the proper engineering authority.

Notes and Suggestions For Inspectors On The Construction of Concrete Pavements.

THE FOLLOWING notes on the inspection of concrete highway construction, prepared and submitted to the Bureau of Public Roads by Clyde E. Learned, highway engineer, assigned to the Denver office, are the result of his experience on concrete road construction in the Southwest. The cuts accompanying these notes give details of the tools used and, while similar tools are commonly found on concrete pavement jobs, these are worthy of special study because of the many interesting details in which some of them differ from what might be termed ordinary practice.

MATERIALS.

Cement.—As all cement usually is tested before shipment, the field engineer should receive copies of these tests, together with car number and amount shipped. This data should be filed for ready reference, and as the cement cars arrive the engineer or inspector should break the car seals and remove the shipping cards, which should be checked with the original shipping notification.

Fine aggregate.—The fine aggregate shall consist of natural sand or screenings from hard, tough, durable crushed rock or gravel, graded from coarse to fine. The following requirements are recommended:

	Per cent.
Total passing ¼-inch screen	100
Total passing No. 20 sieve not less than	50
Total passing No. 20 sieve not more than	80
Total passing No. 50 sieve not more than	20
Total passing No. 100 sieve not more than	5

Not more than 3 per cent by weight of clay or loam.

Before starting operations on a contract the various supplies of sand are tested in the laboratory and the source of supply determined upon. It is very essential to insure that the material being used is practically as good a quality as the sample originally tested, and it often is necessary to determine upon the probable suitability of a new source of supply. In such cases it is necessary to make field tests on the materials. These tests should include the following:

1. Visual inspection by means of the physical senses, this being to a great extent dependent upon the training and experience of the individual who makes the inspection.
2. Grade by means of a set of portable sieves, the set to be made up of a ¼-inch screen or a No. 4 sieve and No. 10, No. 20, No. 50, and No. 100 sieves.
3. To test for cleanness, made by the volumetric method, shake a small sample of the sand to be tested in an excess of water in a bottle or measuring glass, allowing any suspended matter to settle on top of the sand. This test will reveal the presence of clay or loam but does not indicate the proportion in which these materials are present in the sand.
4. To test for organic impurities, place 4½ ounces of the sand which is to be tested in a 12-ounce graduated bottle and add enough of a 3 per cent solution of caustic soda to fill the bottle to the 7-ounce mark. Shake well and then let stand over night. If the color of the solution becomes dark red to black, the sand contains enough organic material so that it should be accepted only after very careful mortar strength tests.

Coarse aggregate.—The coarse aggregate shall consist of clean, hard, tough, and durable crushed rock or gravel. It shall be free from soft, flat, or elongated particles. The coarsest particles shall pass a 2-inch round opening, and not more than 10 per cent by weight shall pass a ⅜-inch round opening or ¼-inch square opening.

If gravel is used, watch it for coated material and clay lumps.

The coarse aggregate should be fairly well graded, the following grading being recommended:

Total passing 2-inch screen, not less than 100 per cent.

Total passing 1-inch screen, 40 to 75 per cent.

Retained on ¼-inch screen, not less than 90 per cent.

Water.—The water should be reasonably clear, and free from alkalis, acids, and organic matter. To determine alkalinity or acidity, test with litmus paper. Use colorimetric test to determine presence of organic matter.

Apparatus.—The following apparatus for field tests usually will be sufficient:

A set of portable sand sieves containing a $\frac{1}{4}$-inch screen or a No. 4 sieve and No. 10, No. 20, No. 50, and No. 100 sieves.

A set of portable stone screens containing $2\frac{1}{2}$, 2, $1\frac{1}{2}$, 1, $\frac{3}{4}$, $\frac{1}{2}$, and $\frac{1}{4}$ screen.

One 250 c. c. graduated glass beaker.

Six 12-ounce bottles, wide mouth.

One set of balances.

One quart caustic soda (3 per cent solution).

One 32-ounce bottle, wide mouth.

One engineer's scale.

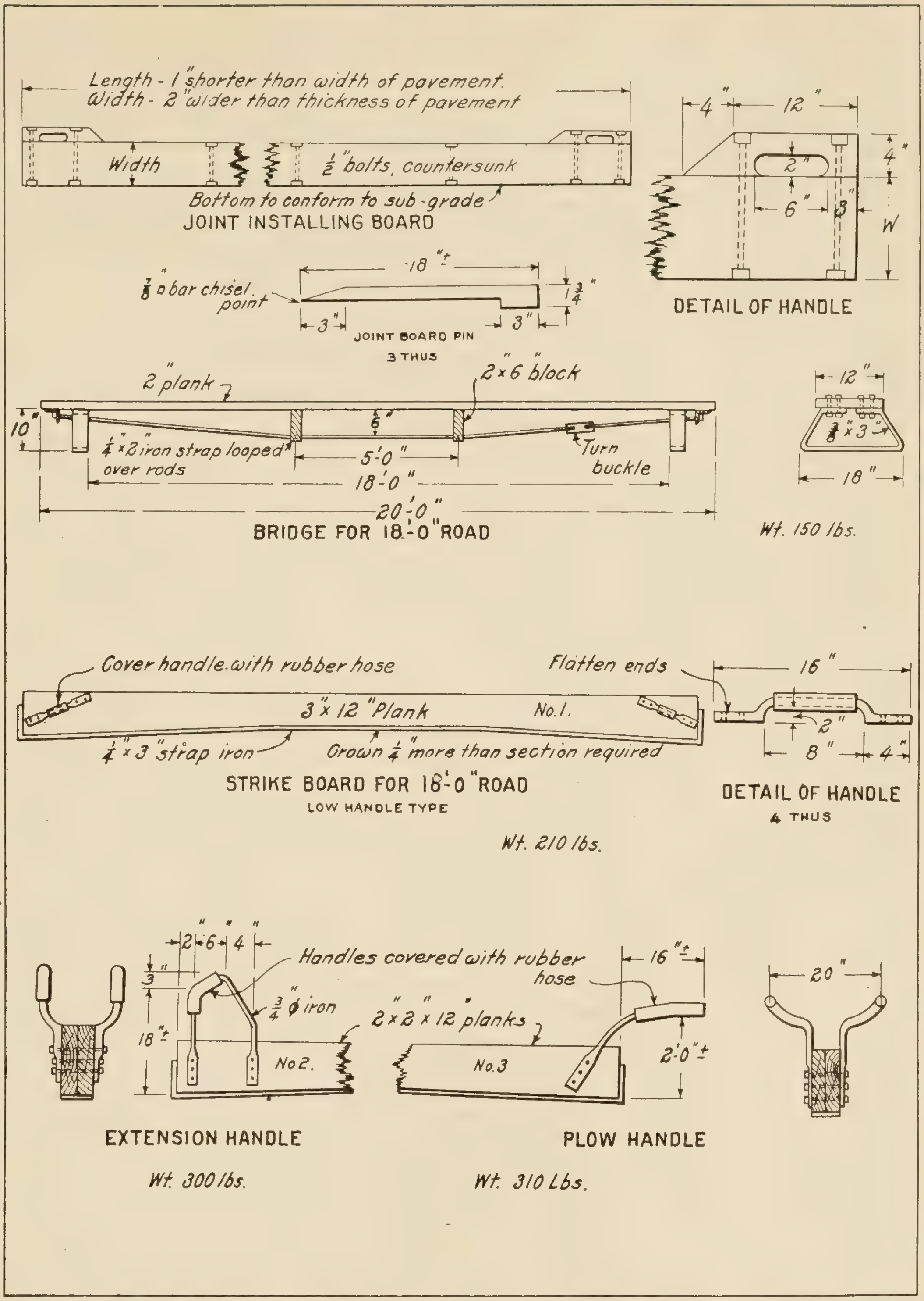


PLATE I. TOOLS USED IN THE CONSTRUCTION OF CONCRETE PAVEMENTS.

DRAINAGE AND PREPARATION OF THE SUBGRADE.

During construction it may often develop that the plans have not made adequate provision for the drainage of the subgrade and that wet spots exist which should be taken care of. The usual procedure in such cases is to put in a system of tile under-drains laid in trenches 2 to 3 feet deep, using 4-inch tile, and backfilling these trenches with crushed stone or large-size gravel. In some cases a mat of some pervious material, such as sand, crushed stone or gravel is laid and upon this the pavement is built. Whenever this is done, the mat should be drained to the ditches by means of blind drains. A combination of the two above methods often is warranted.

In the construction of pavements it should be insisted upon that the side ditches are down deep enough to provide for the adequate drainage of the foundations.

Rainfall is disposed of by surface drainage. Therefore, as far as possible, the road surface, shoulders, and ditches should be designed and built with this end in view.

As the concrete work progresses many places will be found where the subgrade is low and the contractor, to save concrete, may desire to use sand or other materials which are handy to bring the subgrade to its proper level. Whenever this is done, care should be used to insure that all such material is well tamped, also that the total width of the pavement is uniformly compacted and that a pervious mat of such material as sand is not used for filling on one side, when impervious material, as loam or clay, is used on the other, for where such differences do occur unequal settlement in the foundation is likely to take place with resulting longitudinal cracks.

Before any concrete materials are dumped on the subgrade, they should be checked so as to eliminate delays in front of the mixer, and to provide against disturbing the uniformly rolled subgrade.

If proper attention is given to rolling the subgrade accurately, and if no traffic is allowed on it after it is rolled, there will be no necessity for keeping one or two grade men in front of the mixer during concreting.

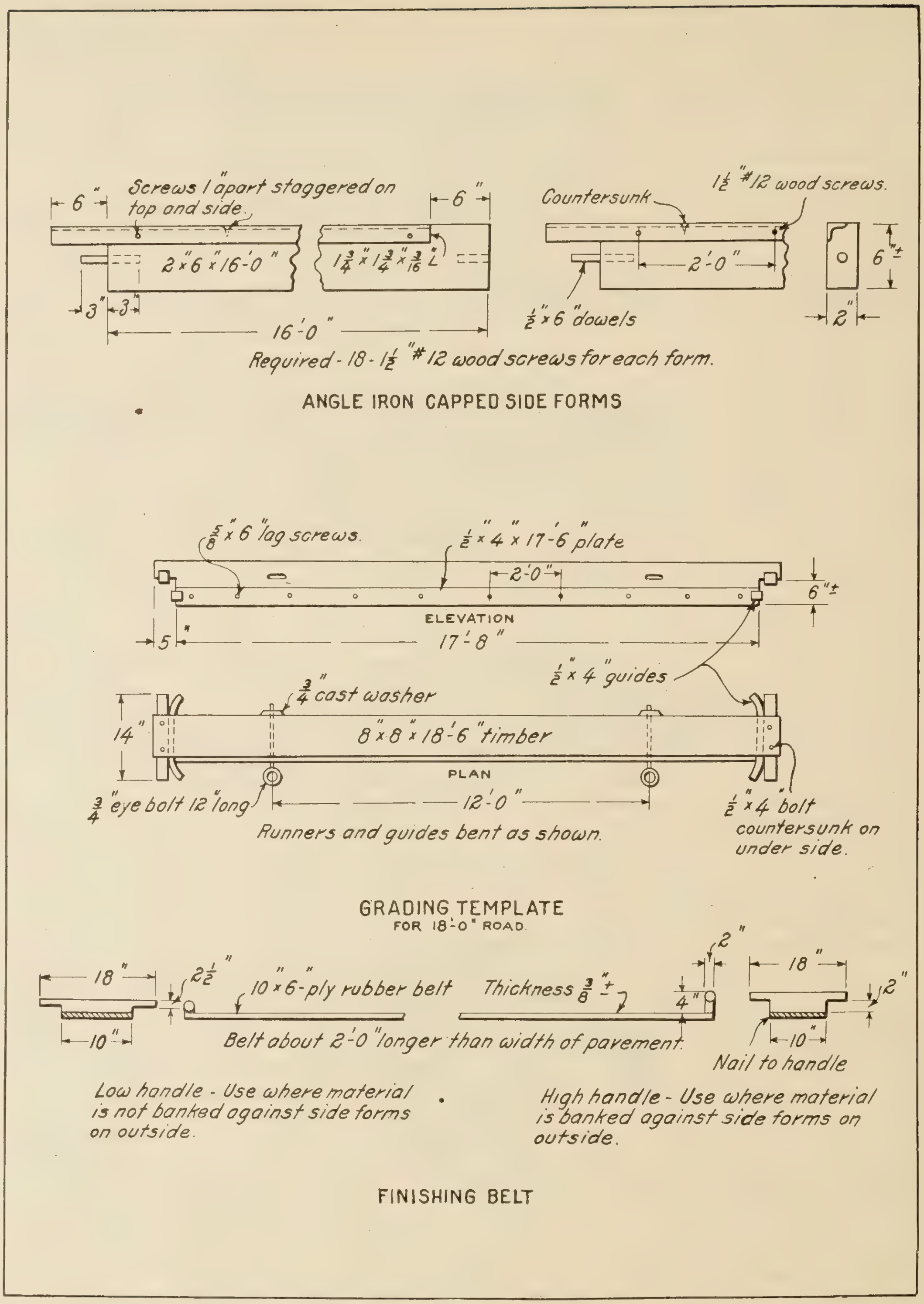


PLATE II. TOOLS USED IN THE CONSTRUCTION OF CONCRETE PAVEMENTS.

Before placing any concrete on the subgrade, it should be well wet down. In the case of sand and gravel subgrades a large amount of water is necessary. It usually will require from ½ to 1½ gallons of water per square yard of surface, depending upon whether the subgrade is of clay or sand.

CONCRETE MIXING.

Hold the materials in the drum of the mixer for at least one minute.

Do not use an excess of water in mixing, 30 to 35 gallons per cubic yard of 1–2–4 concrete is sufficient.

When concrete has not been mixed enough and when too much water is used it will be noted that, as the batch comes out of the mixer, it lacks in uniformity.

Concrete should stay in the mixer at least one minute. This is done so that the water will be thoroughly worked through the mass. If a mixer having a chute for distributing the mix is used, a fairly steep slope will be required. Otherwise there will be a tendency to use too much water to make the concrete flow. It is better to increase the pitch of the chute than to increase the amount of water in the concrete, although it may be hard to convince some contractors of this. If a bottom dump bucket of the boom type is used watch it to see that it does not leak too freely and allow the mortar to escape.

PLACING CONCRETE.

Keep the strike board, joint installing board, roller, and finishing belt clean.

Break in the strike-board men to use care in screeding at the joints, having them make sure all excess concrete is removed, and that no low places are left at the joints. It may be necessary to try a number of men on the strike board in order to get those who are reliable and will take a little pride in their work.

A smooth riding surface depends more upon proper striking off than upon any other operation. The smoothness of a concrete pavement is very important, as imperfections increase the impact generated by the loads passing over it.

Work the concrete mixer uphill when feasible, as smoother results at the joints are thereby obtained.

Use a notched straightedge straddling the joints to determine if there are any raises or depressions on either side.

When a sidewalk edging tool is used at the expansion joint, make sure that it is not used until the concrete has taken a slight set; also that the work resulting from its use shows a good, clean rounded edge.

Have the asphalt joint strips kept flat before installing, as strips scattered all over the ground get kinks in them which are hard to remove and which may appear later in the concrete.

Use care in installing asphalt strips, as crooked points in a pavement are very unsightly.

The following method for installing asphalt strips produces very satisfactory results: A joint board is made of a 2-inch surfaced plank about 2 inches wider than the thickness, and 1 inch shorter than the width of the pavement, and is provided with handles at both ends. (See plate I.) The board is held in place on the subgrade by two or three iron pins driven behind it, and the asphalt strips are placed flat against the board. A few shovels full of concrete are placed against the strips to hold them in place until the pavement has been advanced to that point. As soon as enough concrete is dumped in front of the joint board to fill the block, work is started on a new block by dumping concrete on the other side of the joint board.

The strike board having finished on the first block, and a part of the next block is ready for the strike board, the iron pins are removed and the joint board slowly withdrawn, leaving the asphalt strips in place in the pavement. In withdrawing the joint board have a man take hold of each of the handles and first tip the top of the board away from the strips. This results in freeing the strips and keeps them from adhering to the board. The joint board is then worked slowly up and down. This action results in pumping enough concrete against the strips to hold them in place. The joint board is then lifted clear of the concrete at one end and this end raised slowly till the whole of the board is freed. As the board is lifted one of the spreaders follows along behind the board, pushing concrete into the opening left by the board. When the joint board is removed entirely, the strike board is placed against the projecting part of the strip on the mixer side, enough concrete added in front of it to make up the deficiency caused by the removal of the joint board, and the striking off of the next slab begun.

In place of the wooden joint board, metal strips can be used, these having the advantage of leaving a smaller space behind the filler as they are withdrawn. However, this advantage is more than offset by the fact that they are constantly being bent by rough handling.

After the pavement is cleaned the joint filler should be cut to a uniform height by means of a square pointed shovel shod with two steel runners riveted to the under side of the blade, which is notched and provided with a sharp cutting edge. (See plate III.)

JOINTS.

Have the joints cut off high enough to provide for the extra volume needed to fill the space resulting from the use of the edging tool. After the joints are cut, a heavy asphalt smoothing iron is heated and the joints are ironed out. By doing this the joints are sealed and protected by a mat of asphalt. (See blue plate III.)

SPLIT FLOAT.

Use a large size split float on all joints, so that the pavement on both sides of the joint will be in the same plane. Many finishers get the impression that after a while they are experts and do not need a split float. However, under no circumstances should they be allowed to discontinue the use of this tool. (See plate II.)

It is well to round off the edges of the pavement with a sidewalk edging tool.

Do not allow the finishers to use metal floats for finishing, as they produce too smooth a surface.

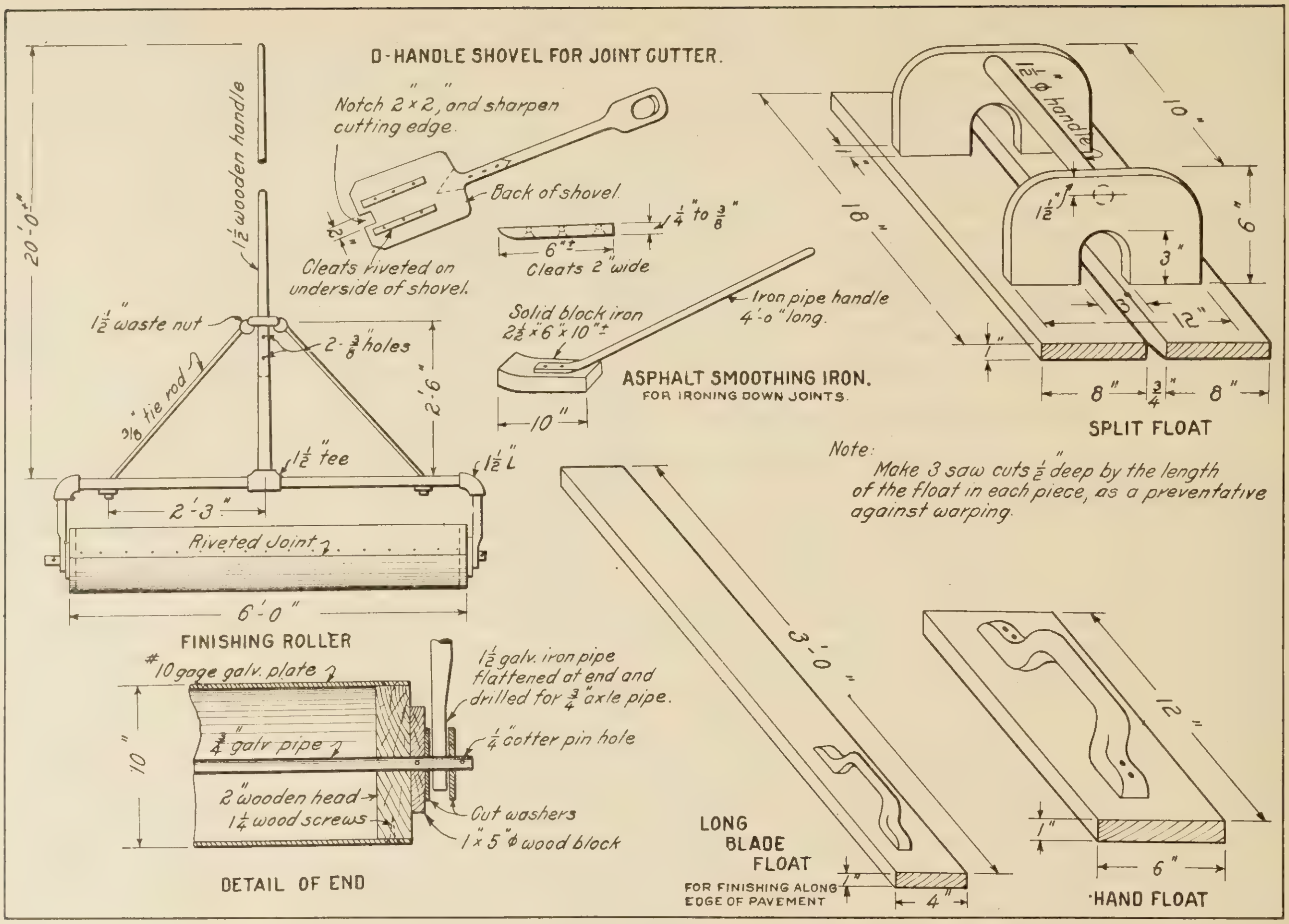


PLATE III. TOOLS USED IN THE CONSTRUCTION OF CONCRETE PAVEMENTS.

TESTING SURFACE.

The finished surface should be tested with a 10-foot straightedge laid parallel to the center line of the road, and there should not be a variation by over ¼ of an inch in the surface over this length, and where variations do occur they should be gradual.

STRIKING OFF.

The strike board or screed is built from 3 to 4 inches wide and about 12 inches high. Its length should be about 2 feet greater than the width of the pavement, and it should be shod on the finishing edge with an iron strap from ¼ to ½ inch in thickness (see plate I). It should have a crown about one quarter of an inch greater than the crown of the pavement, to allow for deflections when it is used as a tamper. Substantial handles should be attached at each end.

The following method is used for striking off and tamping the pavement surface. Have the spreaders keep a small wave about one inch high in front of the strike board the first time over, making sure that no daylight appears between the concrete and the board. The first time over advance the strike board with a combined longitudinal and crosswise motion, this first passage leaving the surface a series of small transverse waves with a slight excess of concrete. Sometimes when too much concrete is deposited in front of the board it is necessary to first pull the concrete down to an approximate surface by means of the strike board, this being performed by a straight pull ahead on the board. On the second or return passage the board is used as a tamper to compact the surface, this being performed as follows:

One of the strike board men holds his end of the board on the side form, while the other tamps the concrete by a succession of short, quick up and down strokes, at the same time advancing his end about 2 or 3 inches each stroke, the total advance being three or four feet. This operation is then repeated by the other strike board man moving his end ahead, while the first man pivots his end on the side form. In this manner the entire surface is tamped, each man covering a series of fan-shaped sections. This tamping fills all pockets and pushes down all protruding stones. The strike board is then passed over the surface using the same motion of the strike board as in the first passage over the slab, and making sure that, during this passage, it rests on the side forms at all times.

It is sometimes necessary to pass the strike board over the surface four or five times in order to get the desired results, but ordinarily the three passages above described, are sufficient.

ROLLING.

After striking off the pavement it should be rolled. This is done with a roller 10 to 12 inches in diameter, about 6 feet long, and weighing about 1 pound for each inch in length. The roller is provided with a long handle which enables the operator to reach across the pavement. In rolling, roller is advanced about 2 feet for each complete passage (see plate II). The effect is that of a rolling squegee. It consolidates the top layer and removes practically all the surplus water, besides removing any transverse waves, thereby improving the riding qualities of the road. Do not use the roller too soon after striking off the pavement, as it tends to flatten the crown. The proper time varies from one-half hour to two hours, after the concrete is placed. The roller facilitates the use of the finishing belt, especially where crushed stone is used, as it pushes down the sharp projecting edges and corners. It is possible to use the roller much quicker where crushed stone is used than where gravel is used.

The roller often causes longitudinal waves adjacent to the side forms at the end of each crossing. These should be eliminated with a hand float before the application of the finishing belt. (See plate II.)

BELT FINISHING.

For finishing the pavement a 10 or 12-inch canvas or rubber belt is used. This should be about three-eighths of an inch thick, at least 2 feet longer than the pavement is wide, and have wooden handles bolted to each end (see plate III). The following method produces very satisfactory results. The pavement is first gone over with the belt, using a sweeping stroke about 18 inches in length with a longitudinal advance at each stroke of from 4 to 6 inches. On the return trip a shorter, quick stroke about 8 inches in length is used, the advance being from 6 to 8 inches for each stroke. The third and final passage of the belt is performed by holding the belt down close to the side forms and advancing it rapidly over the surface with as little side movement as possible. After the belt finishing the pavement should present a smooth, uniform surface.

CURING.

In curing concrete two methods are in general use: *First*, by covering the pavement with a layer of dirt from the shoulder materials, and keeping this wet down.

Second, by checking off the pavement by means of small earth dams and covering checks with small ponds of water.

The second method of curing is more positive, and should be used when sufficient water can be obtained. It has its disadvantages when used on grades and banked curves but usually these can be overcome by building smaller size checks. The first method, *i.e.*, covering with dirt, may be cheaper in most cases, but when clay or other adhesive material is used for covering, trouble is apt to be experienced in its removal, especially if traffic gets onto the pavement while the covering is still in place. Furthermore, most contractors wish to remove an earth cover with blade machines, by which method the asphalt strips at the joints are likely to be damaged.

Curing by ponding shows up the irregularities in the surface and in the setting of the side forms, which, while of no value in correcting completed work, helps to determine what improvements should be made on work still to be done.

Canvas covers should be provided for at least a third of a maximum day's run in order to eliminate sun and wind checks; also as a provision against rain-washed surfaces. If a surface does become washed by rain, sprinkle it over with neat cement and pass the finishing belt over it two or three times.

When the average temperature is below 50° it is better to omit covering and ponding, and sprinkle the surface with water whenever it appears to be drying out.

SIDE FORMS.

Look over the side forms every few days and note whether there are any with warps or deflections which should cause them to be thrown out. If there are, be sure to disfigure them enough so that they will not appear in the next day's run.

See that the contractor uses care in setting the side forms, and that they are held firmly to line and grade. Tamping with the strike board often results in settling them. Check the forms with a level every once in a while, as it has a very beneficial effect on the work of the form setter to know that his work is being checked.

Do not let the form setters use stones to hold the forms up to grade, but have the contractor provide them with blocks. A still more satisfactory method for setting forms is to drive stakes about every 8 feet and set the forms on them.

CEMENT.

Count the cement sacks at the end of each block. This keeps every one informed as to the cement content of the pavement.

Have the contractor remove all cement sacks every night. If sacks are left on the work they are apt to be mixed with those from the next day's run.

In piling cement ahead of the mixer, have boards placed under any that will remain out over night.

BARRICADE AND DETOURS.

Have a sufficient number of strong barricades to shut traffic off of the road, and have a sufficient number of red lanterns.

Detour signs should be provided, and care should be exercised to see that they are in place, especially at night. A traveler on a strange road at night requires a great deal of information as to the route he is trying to follow. This need should be met as fully as possible, for if it is not met barricades will be broken down and valuable work may be damaged.

The local papers should be used freely to inform the public as to what parts of the road are closed and as to where detours must be made.

Memorandum on Construction of Concrete Roads.

By L. I. HEWES, General Inspector, Bureau of Public Roads.

AT A RECENT meeting of the Washington State Association of County Engineers in Spokane I suggested that the study of labor-saving devices in the construction of concrete roads would be a fruitful subject for investigation and report. An analysis of the operations involved shows that they consist of the following:

1. Collection and storage of materials.
2. Measuring and mixing of materials.
3. Depositing and manipulation of the concrete mass.
4. Curing of the concrete in place.

Assuming a standard design, to economize labor in the above operations without overburdening the cost by interest and depreciation on machinery remains the main subject. A brief analysis of the customary operations shows that current methods involve considerable theoretical waste. It is common, for example, to elevate material several times before it is finally in place: (1) It is raised by a derrick from cars on the side track and deposited in a storage pile; (2) it is raised from the storage pile to a storage bin; (3) it is raised in the delivery truck and shot into the mixer skip; (4) it is raised in the mixer skip and dumped into the mixer.

Any combination of these operations that would eliminate one or more motions would theoretically decrease the cost. A study of the four main operations is suggested by the following:

COLLECTION AND STORAGE OF MATERIALS.

The collections and storage of materials tends to be on an increasing scale as operations demonstrate the economy of longer jobs. Limitations on the length of a job appear to be (*a*) financial; (*b*) seasonal; (*c*) organization of construction operations. The financial limitation could certainly be overcome by more intelligent administration which could concentrate funds allotted for several years or borrowing money by bond issues to make funds available. The season limitations in the length of jobs must be overcome by the early execution of plans and contracts and by the use of larger machine units or a larger number of smaller machine units, The organization of operations tends to greater speed, but offers much opportunity for betterment.

It is reasonable to assume, therefore, that an analysis of a possible method for handling larger jobs is pertinent. For such larger scale operations material will doubtless be delivered by freight at railroad sidings. The use of a derrick and bucket to unload cars into bins or storage piles has already come. Recently measuring bins have been added to the storage bins and motor trucks with batch compartments have been used to transport the partially mixed sand and aggregate to the portable mixer at the point of placement. This chain of operations has eliminated the services of a number of shovelers at the cars and the mixer, but is not a further combination of the process possible?

MEASURING AND MIXING.

In the process of collection and storage outlined above, the measuring of the sand and aggregate has occurred in the measuring bin and is preserved in the compartment motor truck. A discussion of the relative cost of an increasing size of the measuring bin or an added number of measuring and storage bins as against the cost of a second elevation from the storage piles to such bins is open for investigation. It may be assumed, however, that the economy of the measuring bin in itself is undisputed. Is it not possible, then, to use the potential energy of the sand and aggregate in the measuring bin to combine and mix them when passing from the bin to the motor truck or conveyor to the job? The mixing of dry aggregate and sand, or of the complete list of concrete ingredients is now based somewhat on the principle of the mixing bowl in the kitchen. Essentially, however, mixing of different ingredients requires their dispersion in order that they may recombine in a homogeneous distribution. Possibly a combination chute for sand and aggregate passing from the bin to the truck could be designed for simultaneous dispersion and recombination of these materials.

CONCRETE MASS DISTRIBUTION AND MANIPULATION.

The transportation by motor truck, or otherwise, of the sand and gravel to the mixer is really a part of the operation of depositing the concrete. While the truck-haul method is doubtless superior to piling sand and aggregate along the subgrade and the use of shovels and wheelbarrows, it is not yet perfect, for it is necessary (*a*) that the truck more or less damage the completed subgrade, (*b*) that the motor truck turn around and back up to the mixer to deposit the sand and aggregate in the skip. The damage to the subgrade is particularly severe in the turning and the loss of time correspondingly great. The actual mixing time while the batch is in the mixer is but a fraction of the interval between the arrival of the truck load of mixed sand and aggregate and the depositing of the wet concrete on the subgrade. The progress of the work is largely limited by the speed with which the material arrives.

If wooden header planks, "ribbons," or side forms for the concrete road were replaced by channel irons, such irons could probably be used as rails and material brought to the point of placement by a self-propelled truck running on this broad-gauge track. Already machines spanning the width of the paved way have been used in so-called monolithic brick construction at Paris, Ill., and on the Wayne County, Michigan, roads for tamping and smoothing concrete.

MUST CONSIDER OBJECTIONS.

It might be possible to go a step farther in the construction operations on concrete roads and (*a*) either mix the concrete in stationary plants or by semiportable plants at a limited number of positions and dump into a swiftly traveling carriage running on the side channel rails to the point of placement, or, (*b*) to introduce the dry ingredients of the concrete properly mixed into a modified carriage and to perform the necessary mixing and addition of water in the combined mixer and carriage while in transit to the point of placement from the measuring bins.

Both methods offer objections to be considered. Concrete must not be "killed" in transit and under method (*b*) it would be necessary to operate heavier rolling units on the channel rails and they would require careful foundation to preserve the grade. There is apparently no reason why such broad-gauge channel rails could not successfully be constructed with the necessary switches, turnouts and loops connecting the road to be constructed with the railroad sidings or sources of material, but ample play for wheel flanges would be required on the sharper curves of highways. The possibility of increased speed with a number of such rolling units combined with the use of approved striking, tamping and smoothing machines deserves consideration.

CURING OF THE CONCRETE IN PLACE.

Additional speed in handling the curing process of concrete roads may be secured by mounting the canvas protection on rolling frames at any desirable height above the surface of the road. Such an arrangement is particularly desirable to protect new work from sudden rain and may be designed with an outer flange wheel. The necessary water supply for curing the concrete must be planned with great care. The system of flooding the surface in "checks" is to be preferred wherever the prevailing grades will permit its use.

FEDERAL-AID RECORD SHOWS BIG ROAD-BUILDING PROGRAM.

TWO SIGNIFICANT facts feature the record of Federal-aid projects considered during March. One is the large number of project statements approved and which went to final agreement, the estimated cost of the roads, and the amount of the Federal allowance. The other is that 30 per cent of all the mileage is to be of brick, concrete, bituminous, or other high-grade type with a high average cost per mile. Many of the projects calling for such construction are for roads 8 to 30 miles in length, indicating that in nearly all parts of the country road officials, supported by the people, have made up their minds that construction of permanent highways to meet every traffic condition is demanded and is the economical solution of the road problem; and that well-defined systems of roads have been adopted.

Never before was anything like such activity shown in highway construction. Thirty-eight out of the 48 States were represented in the projects approved or which went to final agreement. Practically all the States not appearing in the month's record have recently had many projects approved or agreements signed.

Project statements approved during the month numbered 103 and the agreements signed 47. Four projects were both approved and went to final agreement during the month. The estimated cost of the 1,270.22 miles of highway to be built under these projects is $17,558,610.32, and the Federal-aid allowance is $6,739,839.11. These figures greatly exceed those for any previous month since the Federal-aid law was enacted. The 103 projects approved call for the expenditure of $14,425,114.87, for which there is a Federal-aid allowance of $5,462,156.72. The 47 agreements signed carry Federal aid to the amount of $1,471,189.80, and an estimated cost of construction of $3,536,153.51.

Included in the new projects approved are three for roads which will cost over $1,000,000, two of which will receive Federal aid exceeding $500,000. The largest project is in Illinois. It is to be concrete, 61.80 miles long, a part of the Lincoln Highway, running across Sangamon, Menard, Mason, Peoria, and Tazewell Counties. The estimated cost is $1,596,996.60, greater by $281,000 than the next largest project of the month and far greater than any previously approved for Federal aid. This is an average of over $25,841 a mile. The Federal-aid allowance will be $618,000.

Pennsylvania has the honor of submitting the next largest project approved, 29.9 miles of road in Adams, Cumberland, and York Counties, to be concrete or bituminous construction, at an estimated cost of $1,315,600 and with a Federal-aid allowance of $598,000.

A single county in Kansas, Finney, will build a 28-mile brick road to cost $1,296,996.60 according to the estimate, for which there will be Federal aid to the amount of $194,416. This road will cost over $46,289 a mile. This is not the only county in Kansas at the front with an important project. A Sedgwick County statement approved is for 12.5 miles of brick road estimated to cost $574,366.64, or over $45,849 a mile, while a project in Shawnee County for which an agreement was signed is for 10 miles of brick highway estimated to cost $472,970.17 at the rate of $47,297 a mile. The Federal allowance for the former project is $143,591.56 and for the latter $109,749.18. Of eight Kansas projects considered during the month five were for brick or concrete roads, one for macadam, and two for gravel or macadam. Three of these projects were revisions increasing the amount of Federal-aid allowance, the estimated cost being increased in one case. The total allowance to Kansas roads for the month was $677,106.05, and the estimated cost of construction reached the noteworthy sum of $2,689,444.22. The latter was greater by $1,092,449.62 than the estimated cost of projects from any other State, while the former was exceeded in only one State, and that by less than $1,000.

The largest allowance for the month was to Maryland roads, $678,001.46 for 7 projects covering 41.42 miles of concrete construction, estimated to cost $1,365,600. The Illinois and Pennsylvania projects mentioned, in each case the only project from the State approved or reaching a final agreement in March are third and fourth in the total allowance to a single State.

Other States prominent in the record for the month include Michigan with a total allowance of $333,861.12 for 5 projects, estimated to cost $751,557.43; Georgia, with 12 projects estimated to cost $683,166.63 and an allowance of $333,628.42; Ohio with 6 projects to cost $1,054,030.21 and an allowance of $316,133.33; Missouri, 5 projects, estimated cost $776,406.05 and an allowance of $250,720.29; New Jersey, 2 projects for 10.744 miles of concrete roads, having an estimated cost of $732,360.51, for which the allowance is $107,440; and Wisconsin, which had 16 projects approved and 2 for which the agreement was signed. The total mileage of these Wisconsin roads is 72.93. All are to be gravel roads, and the total estimated cost is $585,009.16 and the allowance $194,593.47. No other State had so many projects considered.

Georgia, with 12 came next to Wisconsin in the number of projects, Montana and Nebraska following with 9 each, while Virginia presented 7. The Nebraska mileage, 162.71, lead all the rest. The allowance for the State's projects was $184,077.50, with the estimated cost of the roads $368,353.70. The Wisconsin and Illinois mileage followed that of Nebraska, while that of Georgia, 60.7884, was fourth.

RECORD OF FEDERAL AID PROJECTS IN MARCH, 1919.

State.	Project number.	County.	Length in miles.	Type of construction.	Project statement approved.	Project agreement signed.	Estimated cost.	Federal aid.
Alabama	33	Dale	2.72	Sand-clay		Mar. 5	$16,292.61	$8,146.30
	37	Jackson	7.1788			do	33,964.92	16,982.46
	41	Pike	6.89	Sand-clay	Mar. 21		32,907.93	16,453.96
Arizona	3	Navajo	3.22	Gravel		Mar. 4	37,414.16	18,707.08
	7	Pinal	12.707	Earth, surfaced in part	Mar. 10		122,667.91	61,333.95
Arkansas	19	Craighead	5.00	Asphaltic concrete	Mar. 7		102,013.56	30,836.16
Colorado	9	Larimer	20.00	Earth	do		89,980.00	44,990.00
	10	Adams	2.00	Concrete or bituminous	Mar. 17		42,999.87	21,499.93
	12	Weld	1.00	do	Mar. 25		20,999.47	10,499.72
Delaware	3	Kent and Sussex	4.00	Concrete	Mar. 5		174,075.00	32,553.78
	4	Sussex	4.39	do	Mar. 31		177,936.00	87,800.00
Florida	3	Jackson		Bridge		Mar. 31	204,714.73	102,357.36
	6		5.59	Sand-clay		Mar. 18	21,481.21	10,740.60
	9	Holmes	5.11	do		Mar. 19	25,525.06	12,762.53
	10	Columbia	9.16	do	Mar. 7		25,048.87	12,524.43
	11	Duval, Nassau, Baker	16.611	do	Mar. 10		82,101.12	41,050.56
Georgia	8	Montgomery and Wheeler	.6	Includes bridge		Mar. 7	156,839.73	78,419.86
	9	Rabun	7.88	Graded and drained earth		Mar. 26	89,677.68	44,800.00
	11	Lowndes	.42	Two bridges		Mar. 11	58,235.57	24,906.43
	12	Thomas	.7575	do		Mar. 14	63,033.06	30,000.00
	15	Coweta		Top soil or sand-clay		Mar. 17		[1] 3,000.00
	20	Carroll	14.967	Top soil		Mar. 28	64,803.45	30,000.00
	21	Heard	8.143	Top soil or sand-clay		Mar. 13	36,516.64	18,000.00
	22	Milton	9.996	Top soil		Mar. 14	42,239.54	20,000.00
	24	Cherokee	11.6049	Gravel and topsoil		Mar. 26	83,418.31	40,000.00
	32	Columbia		Topsoil or gravel		Mar. 19		[1] 900.00
	34	Haralson	6.42	Topsoil		Mar. 26	33,186.39	16,000.00
	38	Brooks		10 bridges	Mar. 17		55,216.26	27,608.13
Idaho	3	Custer		Graded earth		Mar. 26		[1] 9,586.36
	4	do		do		do	[1] 116.79	[1] 2,103.88
	5	do		do		do		[1] 6,241.89
Illinois	6	Sangamon, Menard, Mason, Peoria, Tazewell.	61.80	Concrete	Mar. 13		1,596,996.60	618,000.00
Kansas	1A	Labette		Gravel or macadam		Mar. 19	[1] 25,071.12	[1] 14,039.00
	1B	do		do		do	[1] 26,417.99	[1] 18,188.00
	4	Shawnee	10.00	Concrete		Mar. 13	472,970.17	109,749.18
	11	Sedgwick		do		Mar. 21	[1] 42,850.69	[1] 33,510.56
	17	Geary	.8641	Brick		Mar. 29	39,773.77	8,641.00
	22	Finney	28.00	do	Mar. 10		1,296,109.34	194,416.00
	24	Sedgwick	12.50	do	Mar. 14		574,366.64	143,591.56
	25	Wyandotte	3.75	Concrete	Mar. 31		111,941.50	55,970.75
Kentucky	5	Mercer	5.00	Macadam		Mar. 4	42,909.47	21,454.73
Louisiana	21	Baton Rouge	11.69	Gravel	Mar. 4	Mar. 31	72,994.35	32,000.00
	26	Ouachita	6.33	Sand-clay, gravel	do	do	44,504.13	22,252.06
	31	Avoyelles	4.27	Gravel		do	38,182.64	19,091.32
Maryland	4	Garrett	2.12	Concrete	Mar. 15		50,018.32	21,200.10
	8	Talbot	13.10	do	Mar. 17		453,860.00	226,030.00
	9	Frederick	5.50	do	Mar. 28		170,500.00	85,250.00
	10	Montgomery	8.20	do	Mar. 24		254,100.00	127,050.00
	11	Frederick	1.86	do	Mar. 27		63,342.73	31,671.36
	12	Carroll	10.64	do	Mar. 24		374,000.00	187,000.00
Massachusetts	17	Middlesex	4.849	Bituminous	Mar. 14		144,829.50	72,414.75
Michigan	24	Berrien	7.915	Macadam surface treated		Mar. 24	173,739.26	73,823.29
	28	Branch	5.092	Concrete or bituminous	Mar. 5		122,952.50	50,920.00
	30	Case	7.095	do	Mar. 3		178,530.00	70,950.00
	32	Allegan	7.00	Concrete	Mar. 28		194,480.00	97,240.00
	34	Washtenaw	2.483	Concrete or bituminous		Mar. 29	81,855.67	40,927.83
Minnesota	21	Wabasha	13.96	Graded earth		Mar. 20	45,984.27	15,000.00
	25	Stearns	20.04	Gravel	Mar. 7	Mar. 26	106,749.12	50,000.00
	29	Ottertail	19.80	do	Mar. 14		100,982.35	45,000.00
Missouri	6	Clay	22.50	Bituminous macadam	Mar. 10		355,157.44	88,789.36
	10	Scott	27.50	Gravel	do		198,774.68	49,693.97
	11	Callaway	7.66	do		Mar. 11	45,898.19	22,949.09
	17	Jasper	6.10	Concrete	Mar. 7		120,505.00	60,252.50
	18	Jackson	3.10	Bituminous macadam	Mar. 10		56,070.74	28,035.37
Montana	12	Gallatin, Broadwater	3.25	Earth	do		21,868.00	10,984.00
	22	Ravalli	6.00	Gravel	do		19,173.55	9,586.77
	26	Fergus	9.50	Earth	do		19,999.99	9,999.99
	27	do	8.00	do	do		19,999.99	9,999.99
	28	do	7.00	do	do		20,109.99	10,054.99
	34	Yellowstone		Bridge over Yellowstone River	Mar. 21		165,000.00	82,500.00
	36	Wibaux	4.50	Gravel	Mar. 3		16,002.25	8,001.12
	37	Powell	5.00	do	Mar. 4		14,507.90	7,253.95
	38	Blaine	6.00	do	Mar. 10		22,000.00	11,000.00
Nebraska	11	Elwood and Smithfield	8.00	Earth	Mch. 7		18,700.00	9,350.00
	18	Gage and Lancaster	37.00	do	do		98,615.00	49,307.50
	20	Douglas	18.90	do	do		69,410.00	34,705.00
	20	Burt and Washington	14.80	do	Mch. 28		[1] 1,008.70	[1] 405.00
	25	Gage and Jefferson	29.71	do	Mch. 11		54,972.50	27,486.25
	28	Cass and Otoe	26.50	do	Mch. 31		57,750.00	28,875.00
	35	Douglas	9.30	do	Mch. 25		27,005.00	13,502.50
	47	Buffalo	7.50	do	Mch. 4		17,600.00	8,800.00
	48	do	10.00	do	Mch. 5		23,292.50	11,646.25
Nevada	8	Lyon	2.78	do		Mch. 4	47,070.06	23,535.03
	15	Elko	8.10	do	Mar. 5		51,726.95	25,863.47
	18	do	16.00	Gravel	Mar. 4		108,668.45	54,334.22
	19	Humboldt	31.10	Earth	Mar. 6		109,828.40	54,914.20

[1] Revisions. Figures given are amount of increases over estimated cost of project and Federal-aid allowance in previous project statement or agreement.

RECORD OF FEDERAL AID PROJECTS IN MARCH, 1919—Continued.

State.	Project number.	County.	Length in miles.	Type of construction.	Project statement approved.	Project agreement signed.	Estimated cost.	Federal aid.
New Hampshire	2	Cheshire		Gravel and macadam		Mar. 14	[1] 3,861.66	[1] 1,000.00
	14	Coos		Bituminous macadam		Mar. 28	[1] 3,993.01	[1] 1,973.88
	20	Merrimack, Grafton	1.36	Gravel	Mar. 10		15,988.50	7,994.25
New Jersey	2	Mercer	6.90	Concrete	Mar. 17		486,673.88	69,000.00
	3	Somerset and Middlesex	3.844	do	Mar. 5		245,686.63	38,440.00
New Mexico	26	Bernalillo	9.62	do	Mar. 25		184,126.47	92,063.23
New York	18	Wayne	5.58	Bituminous macadam or concrete.	Mar. 6		111,600.00	55,800.00
	20	Delaware	5.10	Bituminous	Mar. 25		118,400.00	59,200.00
North Carolina	33	Montgomery	10.78	Topsoil	Mar. 7		21,693.51	5,000.00
	36	Durham	7.48	Concrete and top soil		Mar. 19	193,429.73	23,000.00
	38	Rockingham	10.924	Topsoil		Mar. 18	33,187.55	12,100.00
North Dakota	35	Logan	22.00	Earth	Mar. 5		33,000.00	15,000.00
	36	Barnes	50.50	do	do		63,822.00	15,938.67
	39	Grant	16.50	do	Mar. 10		40,000.00	18,151.18
	41	Grand Forks	21.00	do	Mar. 7		29,992.60	14,996.30
Ohio	8	Knox	4.12	Brick or concrete		Mar. 11	173,000.00	33,333.33
	29	Scioto	6.90	do	Mar. 25		254,102.51	69,000.00
	30	Delaware	6.20	Concrete or macadam	Mar. 7		217,660.30	62,000.00
	31	Union	8.38	do	do		296,366.40	83,800.00
	32	Crawford	2.80	Brick or bituminous	do		134,000.00	28,000.00
	33	Clinton	9.17	Macadam	Mar. 28		132,000.00	40,000.00
Oregon	17	Malhuer	8.50	Earth	Mar. 27		69,300.00	29,650.00
	18	Polk	7.00	Hard surface	Mar. 14		155,133.00	70,000.00
Pennsylvania	20	Adams, Cumberland, York	29.90	Concrete or bituminous	Mar. 28		1,315,600.00	598,000.00
Rhode Island	2	Washington	2.04	Bituminous macadam		Mar. 19	90,714.25	40,800.00
	3	do	1.15	do		Mar. 4	39,886.00	11,500.00
	4	do	4.98	Bitiminous	Mar. 14		178,406.53	89,203.26
South Carolina	5	Chesterfeld		Gravel		Mar. 7	[1] 3,236.10	[1] 1,915.00
	22	Charleston	4.008	Concrete	Mar. 31		130,454.26	40,080.00
South Dakota	1	Codington	11.21	Gravel		Mar. 5	53,810.79	26,905.39
	7	Deuel	8.60	do		Mar. 24	28,941.77	14,470.88
	8	Butte	11.81	Earth		Mar. 11	31,001.00	15,500.50
Tennessee	6	Washington	21.349	Macadam		Mar. 7	287,709.64	143,854.82
	7	Henry	15.392	Gravel	Mar. 3	Mar. 28	178,410.71	89,205.35
Texas	13	McLennon	3.00	Bituminous gravel	Mar. 10		25,088.80	12,544.40
	78	Freestone	17.22	Gravel and sand-clay	Mar. 6		54,845.88	27,422.94
Utah	17	Millard and Juab	30.50	Concrete	Mar. 31		458,579.00	229,289.50
Virginia	15	Washington	6.75	Earth	Mar. 10		45,291.95	22,645.97
	21	Frederick	5.37	Macadam	Mar. 31		100,968.44	50,484.22
	22	Caroline and Essex	4.72	Gravel		Mar. 25	32,827.99	16,413.99
	28	Henry	3.53			Mar. 31	26,978.05	13,489.02
	29	Princess Anne	2.775	Concrete	Mar. 21		70,435.16	35,217.58
	30	Roanoke	2.27	Macadam	Mar. 25		34,392.60	17,196.30
	33	Nelson	2.69	do	Mar. 7		34,936.00	17,468.00
West Virginia	30	Randolph	1.51	Earth	Mar. 10		8,668.00	4,334.00
	31	Lewis	2.00	Brick	Mar. 7		56,457.00	19.000.00
	32	Roane	3.75	Concrete	Mar. 25		93,621.00	44,000.00
Wisconsin	35	Dodge	4.65	Gravel or macadam		Mar. 24	44,956.13	14,985.38
	54	Adams	5.75	Sand-clay		Mar. 7	35,778.38	11,926.13
	59	Jefferson	1.61	Gravel	Mar. 13		24,906.53	8,302.18
	60	Green Lake	7.61	Grading and concrete	Mar. 10		44,205.05	14,100.00
	63	Waukesha	2.76	Concrete	Mar. 13		52,723.22	17,574.41
	64	Monroe	1.14	Earth	Mar. 10		13,018.83	4,500.00
	66	Richland	2.07	Concrete	do		50,980.60	16,993.53
	68	Wood	4.63	Gravel	Mar. 11		24,854.61	8,284.87
	69	Sheboygan	3.18	Concrete	do		62,992.05	20,997.35
	70	Waupaca	5.46	Gravel	Mar. 10		29,083.45	9,694.48
	71	Marathon	4.92	Earth and gravel	do		37,177.36	12,392.45
	72	Dodge and Jefferson	3.53	Gravel	Mar. 13		39,366.25	13,122.08
	73	Forest	4.49	do	Mar. 15		24,000.13	8,000.04
	74	Oneida	3.17	Earth	Mar. 17		17,694.05	5,898.01
	75	Price	6.06	Gravel and earth	Mar. 14		20,912.33	6,970.77
	76	Portage	6.37	Gravel	do		31,019.23	10,339.74
	77	Waushara	4.03	Top soil	do		21,526.03	7,175.34
	78	Pepin	1.50	Gravel	Mar. 28		10,004.17	3,337.72
Total	150		1,270.1353				17,558,610.32	6,739,839.11

[1] Revisions. Figures given are amount of increases over estimated cost of project and Federal-aid allowance in previous project statement or agreement.

LOUISIANA ROAD WORK.

The office of the State highway department of Louisiana reports that it is fairly deluged with applications for highway construction, and that it can not hope to make the surveys required in time to please the people of all the parishes. Within a few days applications were received covering road construction in Concordia, Madison, St. Bernard, and Cameron Parishes which will mean the expenditure of at least $2,000,000 and the building of 200 miles of roads. Most of this mileage will be of Federal-aid roads.

The Madison Parish projects represent the construction of a section of the Ozark highway, a short cut from New Orleans to the North, and the building of a part of the Dixie Overland highway, from the Richland Parish line to the Mississippi River at Vicksburg, Miss. This will complete Louisiana's portion of the Dixie Overland.

ILLINOIS BOND ISSUE VALID.

The Supreme Court of Illinois has decided in a test suit that the $60,000,000 roads bond issue approved by the voters last November is valid. The suit was a friendly one, brought that a decision from the court might be secured which would remove all doubt as to the validity of the bonds, so there would be nothing in the way of carrying out the program of road building authorized by the vote.

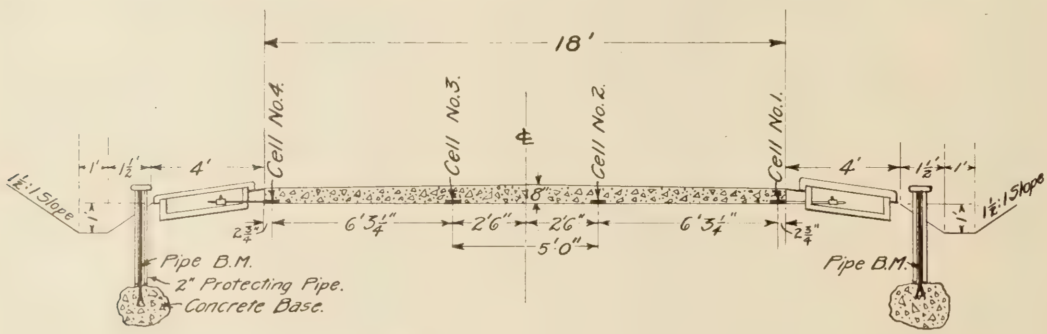
THICKNESS OF CONCRETE SLABS

Report on Pressure Measurements Under the Camp Humphreys Concrete Road

By A. T. GOLDBECK, Engineer of Tests, Bureau of Public Roads

AT THE present time it is impossible to calculate the proper thickness of a concrete road slab with much certainty. It is known that a thicker slab is required where the subgrade is soft than where it offers a good bearing, and that heavy loads require a thicker supporting slab than light loads; how much thicker, however, has not been determined. The stress in a slab depends upon the bending moment produced in the slab, and this in turn is dependent largely upon the distribution of pressure over the subgrade.

It is recognized that ununiform subgrade pressures are due to causes other than the heavy traffic loads carried by the slab, but this investigation was initiated more particularly to discover how the road slab is stressed directly under the wheels of heavy trucks and to determine whether this stress is apt to be a governing influence in the design of the slab. This test is to be considered only as one of a series of investigations outlined to include an adequate range of the different varieties of subgrades and slab thicknesses. The thicker the slab, the greater will be the distribution of a concentrated load over the subgrade. For a given load, therefore, a higher bending moment should be produced in a thick slab than in a thin one. The softer the subgrade, the wider will be the distribution of the subgrade pressures. Thus, an almost liquid subgrade should receive almost uniform subgrade pressures from traffic loads, whereas a well compacted rigid subgrade would probably bear the entire wheel load over a relatively restricted area. A soft subgrade should, therefore, produce higher bending moment than a rigid subgrade.



CROSS SECTION OF CAMP HUMPHREYS ROAD.

POSITION OF THE FOUR PRESSURE CELLS IN MAKING TESTS.

TEST MADE ON 8-INCH SURFACING.

The site of the present investigations was at a point 5.9 miles south of Hunting Creek, Alexandria, Va., at survey station No. 302+30, opposite Chesapeake & Potomac telephone pole No. 286 on the concrete road between Camp Humphreys and Alexandria. The road surfacing at this point is 18 feet wide, 8 inches thick at the center, and 6 inches at the sides. A 1:1–1/2:3 gravel concrete was used, having a crushing strength, as determined by 6 by 12 inch cylinders cast in the field at the time the road was laid, of 3,190 pounds per square inch. The aggregates in the concrete at this point were Potomac River sand and gravel. Here the road runs through a 6-foot cut and the subgrade in the past has remained rather wet and soft. The soil is composed of a sticky clay, which, when wet, has very low bearing value.

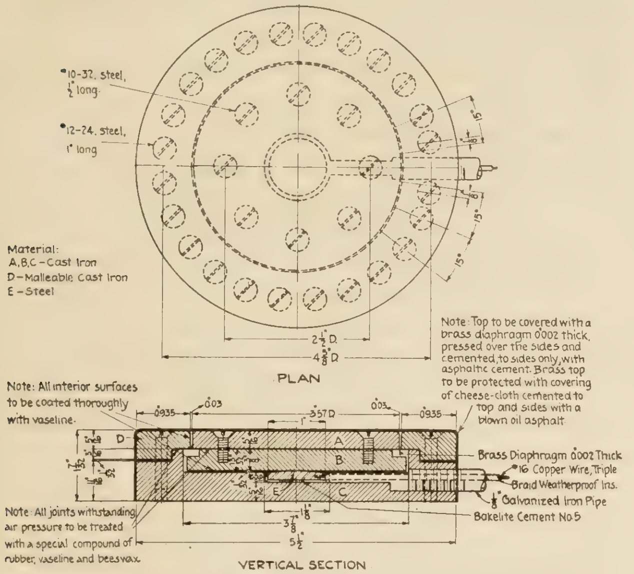
In order to measure the pressure distribution, four pressure cells designed in the Bureau of Public Roads and described elsewhere,[1] were placed on the subgrade at station No. 302+30, with their weighing face down. The position of the cells is shown in the accompanying sketch. One-eighth inch pipes connected with the cells lead across the subgrade to the gutter and terminate in concrete boxes placed there for their protection.

THE PRESSURE-MEASURING INSTRUMENT.

The principle used in the device for measuring the pressures is that of (*a*) equilibrating the subgrade grade pressures against the exposed face of the measuring cells by means of air pressure within the cells, (*b*) detecting the instant this equilibration takes place by the breaking of an electrical contact within the cell, and (*c*) reading the air pressure on a delicate pressure gauge connected with the air pipe leading to the cell. This cell consists of a hollow,

[1] The Distribution of Pressures Through Earth Fills, by A. T. Goldbeck in 1917 Proceedings of the American Society for Testing Materials.

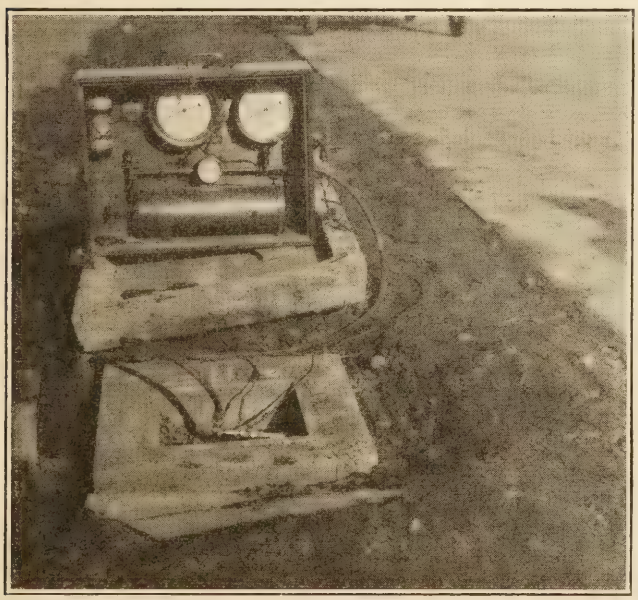
flat cylinder capped with an exceedingly thin brass diaphragm clamped between two cast-iron disks. The entire device is encased in a waterproof coating for protection. The lower cast-iron disk "B" presses against the steel button "E" with a pressure



CROSS SECTION OF DIAPHRAGM CELL FOR DETERMINING SOIL PRESSURE.

equal to that exerted by the subgrade against the cast-iron disk "A".

When taking pressure readings, an air hose leading from an air-pressure tank in the indicating box is connected with the ⅛-inch pipe leading to the cell.

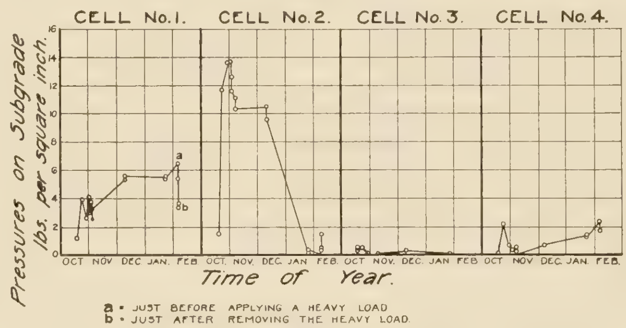


INDICATING BOX FOR MEASURING PRESSURES.

Electrical connections are then made, one of them to the ⅛-inch pipe, and the other to the insulated wire inside of the pipe. When the circuit is thus completed a small electric light in the indicating box is lighted. Air is now allowed to escape from the pressure tank into the cell, and the air pressure within the cell gradually increases. When the pressure within the cell very slightly exceeds the subgrade pressure on the cell, the diaphragm is moved, perhaps not more than one ten-thousandth of an inch, and electric contact is broken between the cast-iron disk "B" and the steel button "E." The electric light in the indicating box is thereby extinguished and the air pressure is instantly read on one of the two large gauges shown in the illustration. The air pressure is immediately released from the cell in order not to invalidate future readings.

REACTION PRESSURES NOT UNIFORM.

All of the pressure readings taken up to date are shown on the curves, reference to which reveals the striking point that under zero load on the slab, the reaction pressures under the slab are not uniform, and moreover they are far from constant and vary from day to day. The curve shows this variation very



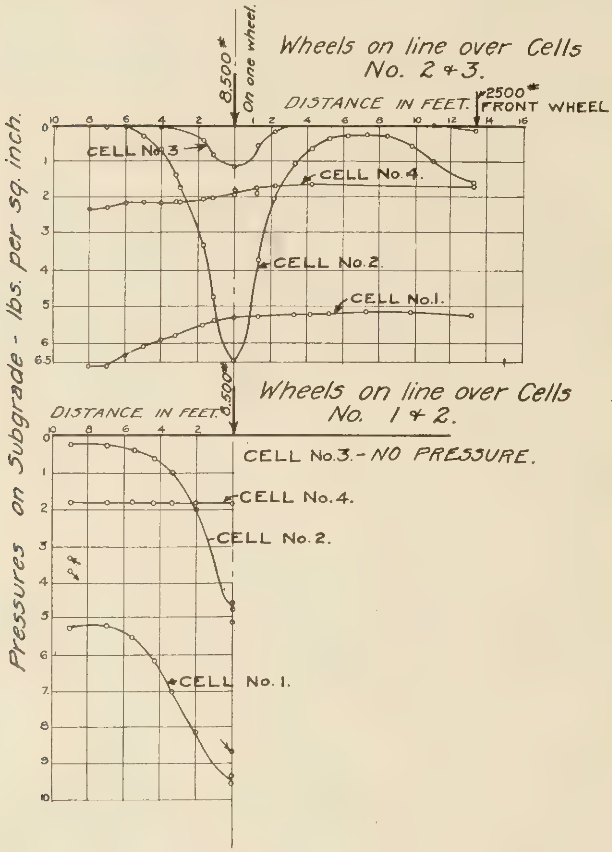
CURVE (1) SHOWING RECORD OF PRESSURE READINGS.

plainly. It has been observed that when readings are taken after the passage of a heavy load over the pavement there is enough disturbance of the subgrade to change the pressure readings very appreciably.

In order to determine the distributuon of pressures under heavy wheel concentrations, a class B standard Army truck was loaded with 5 tons of sand. The front wheels and rear wheels of the loaded truck were weighed separately and the axle loads were found to be 5,000 pounds and 17,000 pounds, respectively.

On February 5, 1919, a test was made on the Camp Humphreys road with this loaded truck. It was backed 1 foot at a time up to the central measuring cells, Nos. 2 and 3, beginning from a position beyond that at which the readings of the cells began to increase on account of this heavy load. When the rear wheels reached a position directly over the cells, the truck was backed 1 foot at a time still farther until the front wheels were just over the cells. During the progress of the test it was necessary to drive the truck away from the test location several times in order to allow traffic to pass.

As a second test the truck was backed with the wheels as close to the side of the road as possible so that they would be made to come directly over cell No. 1 placed at the extreme side of the road. The pressure readings obtained may be seen best on the curve 2. Referring to curve 2, note that as the truck was gradually backed up, the pressures on



CURVE (2) SHOWING DISTRIBUTION OF PRESSURES—LOADED U. S. ARMY TRUCK.

cells Nos. 2 and 3 gradually increased and reached a maximum with the truck wheels directly over these cells. As the truck continued still farther, and the rear wheels were 7 feet away, the pressures again became very small and as the backing continued and the influence of the front wheels began to be felt, the pressures again increased. Cells Nos. 1 and 4 showed readings of 6.7 and 2.3 pounds per square inch, respectively, at the beginning of the test, but as the truck backed up along the center of the road the pressures on these cells decreased apparently because of the downward bending of the slab at the center, which depressed the subgrade here and permitted the extreme sides to be raised slightly, thereby relieving the side subgrade pressures.

VARIATION OF THE PRESSURE.

From the curve of pressures it will be seen that the highest intensity of pressure exists directly under the load and very rapidly dwindles a short distance away from the lead. The influence of a single wheel load of 8,500 pounds, such as was borne on the rear wheels of this truck, is felt over an area having a radius of about 6 feet, although the greater portion of it is carried to the subgrade over a radius of 4 feet.

Cell No. 3 did not receive as much load as cell No. 2 owing to the arching of the concrete over the subgrade at this point. A considerable load was required here to deflect the slab enough to bring it in contact with the subgrade. When the load was removed from this part of the slab it sprang back into shape, away from the subgrade, so that no electrical contact was made in cell No. 3, thus showing that the subgrade was exerting no pressure here. It should be noted particularly that at the beginning of the test on February 5 the concrete slab was supported largely at its sides, as indicated by the comparatively high readings on cells Nos. 1 and 4, and the zero readings on cells Nos. 2 and 3. During the test the maximum increase in intensity of pressure of about $6\frac{1}{2}$ pounds per square inch was obtained when the rear wheel of the truck was placed directly over cell No. 2. When the truck was placed along the side of the road with one rear wheel directly over cell No. 1 and the other rear wheel about 1 foot to the side of cell No. 2, the highest increase in intensity of pressure of 4.3 pounds per square inch occurred in cell No. 1. As seen in curve 2, with the load at the side of the road over cells Nos. 1 and 2, cell No. 3 showed no indication of pressure whatever, and cell No. 4, on the other side of the road, showed no change in pressure. The load thus caused a bending down of the slab at the side of the road with compression of the subgrade under the load, but did not affect the other side.

EFFECT OF LIGHT LOADS.

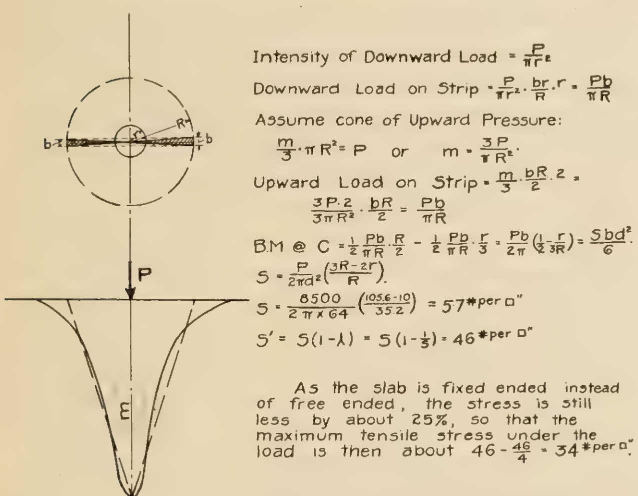
During the progress of the preliminary measurements, taken over a period of four months, opportunities offered themselves for obtaining some idea of the effect of light loads on the subgrade pressures, and these are presented in the following table:

		Ford.	Boiler.	Front Army truck.	Rear Army truck.
Load on slab	[1] 200	[1] 350	[1] 3,680	[1] 2,500	[1] 8,500
Maximum intensity of pressure	[2] 0.2	[2] 0.4	[2] 3.5	[2] 1	[2] 6.5
Radius of area of distribution		[3] 2	[3] 5½	[3] 3	[3] 6

[1] Pounds. [2] Pounds per square inch. [3] Feet.

Having obtained the pressure distribution, the question arises as to what stress is produced in the slab by a concentrated load on the slab, and whether its thickness is adequate for the support of heavy loads. Referring to the curves it is seen that a very close approximation of the actual intensities of the subgrade pressures may be made by considering them in the form of a cone. It will be noted from curve 2 that a cone of about 4 feet in radius seems to approximate the actual pressure distribution. Let it be considered that the concentrated wheel load is carried by the surface of the slab over a small area which for convenience will be con-

APPROXIMATE CALCULATION OF STRESS IN SLAB.



sidered with a radius equal to r. Let R equal radius of the cone of upward pressure, and let P equal the load applied. The slab may now be considered as a plate which, however, is more or less fixed at its circumference. Let it first be considered that this plate is free ended.

It is evident from the above calculation that there is little likelihood of the slab being stressed excessively in tension under the load when the subgrade provides support such as furnished by the present fairly soft subgrade. Judging from the results obtained from this test the probability is that the tensile stress produced directly under the load will never influence the design of a road slab which rests on a fairly homogeneous subgrade. If, however, conditions arise such that the slab is left entirely without support under the load, excessive tension can be developed.

CONDITIONS THAT MAY CAUSE CRACKS.

It might be well to consider briefly some of the conditions of loading and subgrade support which can arise to cause a road slab to crack. As the subgrade reactions are more or less distributed instead of concentrated, as has been assumed, the formulas in Cases II to V are somewhat severe.

It will be seen that Cases III and IV are most severe. Let it be required to find the thickness (d) of a concrete slab which will just fail under a load of 8,500 pounds. Assume $S=600$ pounds per square inch, $s=18$ feet.

In order to be safe from cracking when loaded as in Case III,

$$S=8.6\frac{P}{d^2}\left(\frac{s-9}{s-3}\right)+9.4\frac{s^2}{d}$$

$$600=8.6\times\frac{8500}{d^2}\left(\frac{18-9}{18-3}\right)+9.4\frac{18^2}{d}$$

$$d=12\tfrac{1}{4}\text{ inches.}$$

Case IV,

$$S=8.6\frac{P}{d^2}\left(\frac{s-6}{s}\right)+9.4\frac{s^2}{d}$$

$$600=8.6\times\frac{8500}{d^2}\left(\frac{18-6}{18}\right)+9.4\frac{18^2}{d}$$

$$d=12\text{ inches.}$$

In order to prevent the corners of the slabs from breaking off under the above load where the subgrade is very soft,

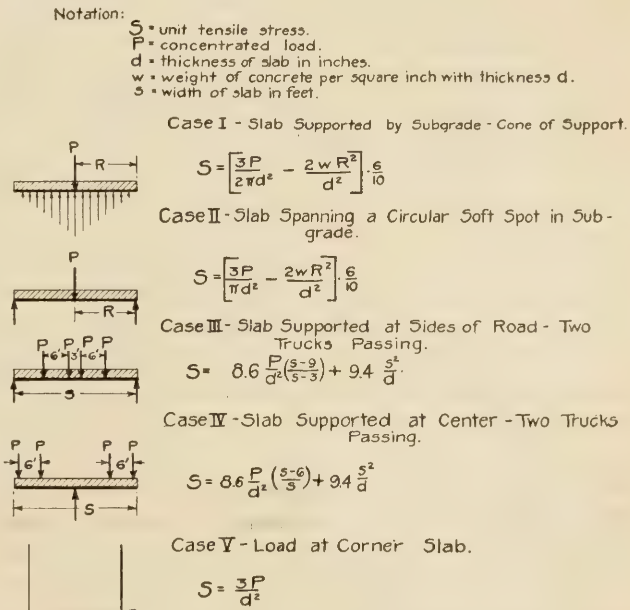
$$S=\frac{3P}{d^2}$$

$$600=\frac{3\times 8500}{d^2}$$

$$d=6.5\text{ inches.}$$

It is recognized that the above calculations are based on very severe conditions of subgrade sup-

APPROXIMATE FORMULAS SHOWING STRESS IN ROAD SLABS UNDER STATIC LOAD.



port, but at the same time the loads were considered as statically applied. It is probable that the application of these loads with impact will at least compensate for the assumed severe subgrade conditions, making the above thicknesses reasonably correct.

The fact must not be lost sight of that these calculations apply only to the very worst subgrades and that when the subgrade is composed of a well-drained material having good supporting value, the thicknesses may be materially reduced. The many miles of concrete roads from 6 to 8 inches thick, free from longitudinal cracking, bear out this statement.

TENTATIVE CONCLUSIONS.

The following tentative conclusions may be drawn as a result of this preliminary investigation:

1. That a concrete road slab under the action of traffic or perhaps under the influence of frost and different percentages of moisture in the subgrade is continually bending, so that the reaction pressures between the subgrade and slab are neither constant nor uniform in intensity.

2. The reaction pressures due to heavy wheel loads are a maximum directly under the loads and vanish to zero in a comparatively small radius, which partially depends upon the intensity of the load. A heavy wheel load is distributed over a larger radius than a light wheel load. For this particular subgrade, a load of 8,500 pounds has a radius of distribution of pressure of about 6 feet, most of the pressure, however, being exerted over a radius of about 4 feet.

3. As the concrete slab recovers from its deflection after the passage of a load more readily than the soft subgrade, there is a tendency for the continual deflection of the slab to produce areas having very little or no bearing. If the traffic is concentrated at the center of the road, as it is on many concrete roads, the continual deflection tends to depress a soft subgrade away from the center of the slab, which would then be more largely supported at its sides. In extrême instances this might account for some longitudinal cracking in concrete roads.

4. As nearly as can be estimated from the results of this test, the tensile stress in an 8-inch concrete slab directly under an 8,500 pound wheel load at rest on the road is only 34 pounds per square inch when the slab is well supported on the subgrade. As the modulus of rupture of 1:1–1/2:3 concrete is about 600 pounds per square inch, it is seen that this pavement should be able to withstand considerable impact before cracking. Should the concrete arch, over very soft spots, so that there is no support directly under the load, the tensile stress may become very high. Such a condition arises when the sides of the slab are raised by frost action or possibly when the subgrade is worked any from under the slab by continual deflection.

5. It is probable that the tensile stress which results in the slab directly under heavy wheel loads is never very great as long as the slab rests on the subgrade and it is unlikely that the slab design would ever be controlled by this stress.

CAN FAIL ONLY UNDER IMPACT.

It must be emphasized that the present investigation has to do merely with the question of cracking of concrete road slabs under static loads, and this is only one phase of the determination of the thickness of concrete roads. The preceding calculations consider the slab in the same light as a bridge structure, in which cracking would be absolutely fatal. The cracking of a road slab, on the other hand, does not necessarily impair its usefulness, assuming proper maintenance, and in fact no matter how thick the slab is made, transverse shrinkage cracks are bound to occur.

When the cracks in a slab become so frequent that there is danger of complete disintegration or of the formation of depressions, the slab can be considered as having failed. It is hard to believe that such a failure could occur in any manner except by impact, and the present preliminary investigation serves but to emphasize that fact. A complete investigation of the determination of slab thickness must therefore include impact effect, and plans are now under way for making suitable impact tests.

The writer wishes to express his appreciation for the cordial cooperation of Major Guy Withers, in charge of the Camp Humphreys road, in arranging for this investigation, and also for the assistance of W. E. Rosengarten, J. R. Boyd, W. H. Barton, who made the observations, to R. Harsch, who prepared the illustrations, and to all others who lent their assistance.

STATE AID FOR SMALL TOWN ROADS.

The Massachusetts Legislature recently provided $200,000 for the maintenance and improvement of roads, except State highways, in towns having an assessed valuation of $3,000,000 or less. The act authorizing such work was passed in 1918, and an appropriation of $100,000 was made for the year. It provided that contributions must be made by the towns in order to secure aid from the State, but because of this provision and the late date at which it was passed the act was of very little assistance in 1918.

The amount which the State highway commission spends in any one town must not exceed $50 per mile, based on the total mileage of roads in the town, it being necessary in order to secure this aid for the town to raise from $12.50 to $125 a mile, the exact amount depending upon the valuation of the town per mile of highway it has to maintain. The work must be done on roads outside the thickly populated portions of the town.

This is a departure from the policy heretofore followed in Massachusetts, in that it recognizes the claim of the poorer towns to State aid in keeping their roads in good condition. There are 165 towns to which funds may be allotted.

DETERMINING SIZES OF CULVERTS.

By O. L. GROVER, Bridge Engineer, Bureau of Public Roads.

THERE are many ways in use for determining the sizes of culverts. A few of the tables and formulae which have come to our attention and are frequently referred to, also notes showing the practices of some of the States and railroads, have been brought together and placed in convenient form for reference. A very brief discussion accompanies the tables.

Doubtless many other ways of determining sizes of culverts have been used with satisfactory results and it is hoped that much more information on the subject may be obtained and added to this meager set of notes so that eventually it may be of sufficient scope to include data applicable to most parts of the United States. It is recognized that rainfall and run-off conditions are so diverse that no general rules or formulae are applicable for all conditions. The best to be expected from this brief outline is that it may be of some assistance, and serve as a check or guide in arriving at a proper solution of the problem.

No general scheme should take the place of reliable data regarding elevations reached by high water during floods in determining the size of opening for each location.

WATERWAYS IN SQUARE FEET FOR CULVERTS, PENNSYLVANIA STATE HIGHWAY DEPARTMENT.

Area		Mountainous				Hilly				Rolling		Flat			
Acres	Sq. mi.	S	Sq. ft.	S	Sq. ft.	S	Sq. ft.	S	Sq. ft.	S	Sq. ft.	S	Sq. ft.	S	Sq. ft.
2½	0.004	70.0	1.5	35.0	1.3	18.0	1.1	9.0	0.9	4.5	0.8	......	....	......	....
5	.008	64.0	2.5	32.0	2.1	16.0	1.8	8.0	1.5	4.0	1.3	......	....	......	....
10	.016	58.0	4.1	29.0	3.3	14.0	2.9	7.0	2.4	3.5	2.1	2.0	1.8	......	....
15	.023	54.0	5.5	27.0	4.6	13.0	3.9	7.0	3.3	3.5	2.8	1.7	2.3	......	....
20	.031	51.0	6.7	25.0	5.6	13.0	4.8	6.0	3.9	3.0	3.3	1.6	2.8	......	....
30	.047	48.0	9.0	24.0	7.6	12.0	6.4	6.0	5.4	3.0	4.5	1.5	3.9	......	....
40	.063	46.0	11.0	23.0	9.3	11.0	7.7	6.0	6.6	3.0	5.7	1.4	4.9	0.7	4.2
50	.078	44.0	12.9	22.0	10.9	11.0	9.1	5.0	7.5	2.5	6.5	1.4	5.8	.7	5.1
60	.094	42.0	14.6	21.0	12.3	11.0	10.5	5.0	8.7	2.5	7.6	1.3	6.6	.7	5.9
70	.109	41.0	16.3	20.0	13.7	10.0	11.5	5.0	9.8	2.5	8.5	1.3	7.5	.6	6.4
80	.125	40.0	17.8	20.0	15.1	10.0	12.7	5.0	10.9	2.5	9.5	1.2	8.2	.6	7.1
100	.156	38.0	20.9	19.0	17.6	10.0	15.0	5.0	13.1	2.5	11.4	1.2	9.8	.6	8.5
120	.188	36.0	23.7	18.0	19.9	9.0	17.0	4.5	14.8	2.5	13.2	1.1	11.2	.6	9.9
140	.219	35.0	26.4	18.0	22.4	9.0	19.2	4.5	16.7	2.0	14.2	1.1	12.6	.6	11.2
160	.250	34.0	29.0	17.0	24.4	9.0	21.4	4.5	18.6	2.0	15.8	1.1	14.1	.5	12.0
180	.281	33.0	31.4	17.0	26.7	8.0	23.0	4.0	20.0	2.0	17.4	1.0	15.1	.5	13.2
200	.313	32.0	33.7	16.0	28.7	8.0	25.0	4.0	21.7	2.0	18.9	1.0	16.5	.5	14.3
240	.375	31.0	38.4	15.0	32.8	8.0	28.9	4.0	25.2	1.9	21.7	1.0	19.1	.5	16.6
280	.438	30.0	42.7	15.0	37.1	7.0	31.8	3.5	27.7	1.9	24.5	.9	21.1	.5	18.8
320	.500	29.0	47.2	14.0	40.7	7.0	35.4	3.5	30.8	1.8	27.0	.9	23.5	.5	26.9
360	.563	28.0	51.4	14.0	44.7	7.0	38.9	3.5	33.9	1.8	29.7	.9	25.7	.4	22.0
400	.625	27.0	55.5	14.0	48.6	7.0	42.4	3.5	36.9	1.7	31.9	.9	28.1	.4	23.9
450	.703	26.0	60.3	13.0	52.6	7.0	46.5	3.5	40.5	1.7	35.1	.8	30.2	.4	26.3
500	.781	26.0	65.8	13.0	57.3	6.0	49.1	3.0	42.7	1.6	37.7	.8	32.8	.4	28.6
550	.859	25.0	70.5	12.0	60.8	6.0	53.0	3.0	46.1	1.6	40.7	.8	35.4	.4	30.8
600	.938	24.0	74.9	12.0	65.2	6.0	56.8	3.0	49.4	1.5	43.0	.8	38.0	.4	33.1
640	1.000	24.0	79.0	12.0	69.0	6.0	60.0	3.0	52.0	1.5	45.0	.8	40.0	.4	35.0
800	1.250	23.0	94.0	11.0	81.0	6.0	71.0	3.0	62.0	1.4	53.0	.7	47.0	.4	42.0
960	1.500	21.0	106.0	11.0	93.0	5.0	80.0	2.5	69.0	1.3	61.0	.7	54.0	.3	45.0
1,280	2.000	20.0	132.0	10.0	115.0	5.0	100.0	2.5	87.0	1.2	75.0	.6	66.0	.3	57.0
1,600	2.500	18.0	155.0	9.0	135.0	4.5	118.0	2.5	104.0	1.1	85.0	.6	79.0	.3	68.0
1,920	3.000	17.0	177.0	9.0	156.0	4.5	136.0	2.0	116.0	1.1	103.0	.5	88.0	.3	79.0
2,240	3.500	16.0	198.0	8.0	173.0	4.0	150.0	2.0	131.0	1.0	114.0	.5	99.0	.3	89.0
2,560	4.000	15.0	218.0	8.0	192.0	4.0	167.0	1.9	144.0	1.0	127.0	.5	110.0	......	....
3,200	5.000	14.0	257.0	7.0	224.0	3.5	195.0	1.7	168.0	.9	148.0	.4	126.0	......	....
3,840	6.000	13.0	293.0	6.0	261.0	3.0	218.0	1.6	193.0	.8	168.0	.4	146.0	......	....
5,120	8.000	12.0	363.0	6.0	316.0	3.0	275.0	1.4	236.0	.7	205.0	.4	184.0	......	....
6,400	10.000	10.0	418.0	5.0	364.0	2.5	317.0	1.3	278.0	.7	246.0	.3	207.0	......	....
7,680	12.000	10.0	484.0	5.0	421.0	2.5	367.0	1.2	316.0	.6	275.0	.3	240.0	......	....
10,240	16.000	9.0	596.0	4.5	519.0	2.0	441.0	1.1	392.0	.5	334.0	.3	302.0	......	....
12,800	20.000	8.0	696.0	4.0	606.0	1.9	522.0	1.0	459.0	.5	400.0	......	....	......	....
16,000	25.000	7.0	810,0	3.5	705.0	1.7	610.0	.9	537.0	.4	457.0	......	....	......	....
19,200	30.000	6.9	909.0	3.0	791.0	1.6	698.0	.8	607.0	.4	529.0	......	....	......	....
22,400	35.000	6.0	1,028.0	3.0	895.0	1.4	768.0	.7	669.0	.4	598.0	......	....	......	....
25,600	40.000	5.0	1,103.0	2.5	960.0	1.4	855.0	.7	744.0	.3	628.0	......	....	......	....
32,000	50.000	5.0	1,318.0	2.5	1,148.0	1.2	991.0	.6	863.0	.3	751.0	......	....	......	....
38,400	60.000	5.0	1,520.0	2.5	1,328.0	1.2	1,147.0	.6	998.0	.3	869.0	......	....	......	....
44,800	70.000	4.5	1,690.0	2.5	1,502.0	1.2	1,297.0	.6	1,129.0	.3	983.0	......	....	......	....
54,400	85.000	4.5	1,973.0	2.0	1,678.0	1.1	1,489.0	.5	1,272.0	.3	1,148.0	......	....	......	....
64,000	100.000	4.0	2,195.0	2.0	1,910.0	1.0	1,664.0	.5	1,449.0	.3	1,308.0	......	....	......	....

S=Slope in feet per 100 feet (average of drainage basin). Sq. ft.=waterway required.

SIZES OF WATERWAYS.

There are several ways of determining the size of waterways in general use. The one of first importance is that of measuring the actual cross section of the water when the stream is at its highest stage. Evidences indicating the height of the surface of the water at flood stage are sought, and in a great many cases may be obtained. If evidence can not be found along the stream, the inhabitants may be interrogated for their knowledge of the maximum elevation of high water. The location of the proposed crossing may be such that there are no well-defined channel banks, and in this event a better location may be found for the purpose of obtaining an approximate cross section of the water at flood periods. For streams of sufficient size to carry drift, and in cold climates where ice forms, good evidence is generally obtainable by finding pieces of drift lodged in trees and the marks on the bark of trees indicating the rubbing of the bark by ice, and in some cases the discoloration of the bark by muddy water.

DETERMINATION OF WATERWAY BY MEASUREMENT AND OBSERVATION.

1. In this method the size of opening is determined by measuring the actual cross section of the water at flood stage at some point, preferably the culvert or bridge site, and providing an opening of sufficient capacity to carry the stream, including the drift, if any. The following data should be obtained:

(*a*) Measurement of actual cross section of water at flood stage at culvert site, preferably along center line of road.

(*b*) Grade of existing channel above and below crossing.

(*c*) Plan showing stream channel at both high and low water above and below crossing.

(*d*) Plan to show all obstructions, such as natural barriers, dams, breakwaters, and fences.

(*e*) Note any special or unusual conditions.

In using this method, crossings will be found for which sufficient reliable information can not easily be obtained, and some other method is used for these cases. The size of drainage areas are especially desirable for properly fixing the openings of culverts for streams of unknown volume, and the drainage areas are valuable to use in checking sizes of all culverts.

DETERMINATION OF WATERWAY BY TABLES.

2. Where the first method has been in use for some time and many streams have been measured tables are prepared containing the results of the actual measurements of streams at flood stages. Such tables are, therefore, used in fixing the size of openings.

Some of the State highway departments and several railways are using tables in determining the sizes of new structures.

The table herewith has been used by the Bureau of Township Highways of the Pennsylvania State highway department since 1911, and for openings greater than 4 square feet in area has been found to satisfy all except very extreme conditions. Smaller openings should be increased in size somewhat.

This table is also used by the Pittsburgh & Lake Erie Railroad and is based on the Burkli-Ziegler and McMath formulæ, using: $R = 3$ and $c = 0.3$, and an assumed mean velocity for culvert running full of 6 feet per second.

The Burkli-Ziegler formula is used when $\frac{S}{A}$ is greater than 1.

The Kentucky State highway department is using the following tentative table which was recently prepared to indicate roughly the appropriate size of standard culvert to use under different conditions.

SUGGESTED SIZES OF STANDARD CULVERTS FOR DRAINAGE AREAS, KENTUCKY DEPARTMENT OF PUBLIC ROADS.

Dimensions	Area	Mountainous	Hilly	Rolling	Flat	Minimum head room
	Sq. ft.	*Acres*	*Acres*	*Acres*	*Acres*	
18-inch pipe	1.77	1.0	2.0	4.5	9.0	Depends on kind.
2 x 1½ ft. concrete box	3.00	2.0	4.0	7.4	18.0	1 foot 6 inches.
24-inch pipe	3.14	2.5	5.0	10.0	20.0	Depends on kind.
2 x 2 ft. concrete box	4.00	3.0	6.0	10.8	27.0	1 foot 6 inches.
3 x 1½ ft. concrete box	4.50	3.8	7.5	11.4	32.0	1 foot 7 inches.
3 x 2 ft. concrete box	6.00	5.3	10.5	18.6	47.0	1 foot 7 inches.
2½ x 2½ ft. concrete box	6.25	5.5	11.0	19.3	50.0	1 foot 6 inches.
4 x 2 ft. concrete box	8.00	8.0	16.0	27.3	70.0	1 foot 7 inches.
3 x 3 ft. concrete box	9.00	9.5	19.0	31.9	82.0	1 foot 6 inches.
4 x 3 ft. concrete box	12.00	13.5	27.0	46.7	120.0	1 foot 7 inches.
5 x 2½ ft. concrete box	12.50	15.0	30.0	49.3	125.0	1 foot 8 inches.
5 x 3 ft. concrete box	15.00	17.5	37.0	62.9	160.0	1 foot 8 inches.
6 x 2½ ft. concrete box	15.00	17.5	37.0	62.9	160.0	1 foot 9 inches.
4 x 4 ft. concrete box	16.00	20.0	40.0	68.5	175.0	1 foot 7 inches.
5 x 4 ft. concrete box	20.00	38.0	56.0	92.2	230.0	1 foot 8 inches.
6 x 4 ft. concrete box	24.00	35.0	70.0	117.5	300.0	1 foot 9 inches.

NOTE.—Head room shown indicates total thickness of slab and cushion of fill and road metal.

DETERMINATION OF WATERWAY FROM DRAINAGE AREA BY FORMULA.

3. Several formulæ have been devised for finding sizes of waterways. Prof. A. N. Talbot's formula is the one most frequently referred to, especially in the eastern part of the United States. The following table has been prepared from Prof. Talbot's formula, which contains a variable factor "C," which is assigned a value by the engineer. The value of "C" is usually assigned to correspond with values of "C" found to give proper openings for similar conditions and known drainage areas.

DETERMINATION OF WATERWAY FROM DRAINAGE AREA AND RUN-OFF BY FORMULA.

4. The determination of the size of waterway by this method requires surveys of the drainage area and data regarding run-off and rainfall. The above information having been obtained, the volume of water flowing to the structure per unit of time may be calculated by formulæ. A culvert opening is decided upon to carry the water without exceeding the velocity which is considered suitable for the nature of the structure and surrounding conditions.

DUN'S TABLE OF DRAINAGE AREAS.

[Shows the approximate areas of waterway for various drainage areas.]

Areas drained in square miles	Areas of waterway: Missouri and Kansas	Cast-iron pipe. For embankments over 15 feet high use 80 per cent	Box and arch culverts, first fig. = diameter; second fig. = bench	Percentage of column 2: Illinois[1]	Oklahoma[2]	Texas	New Mexico	Mountains	Areas drained in square miles	Areas of waterway: Missouri and Kansas	Percentage of column 2: Illinois[1]	Oklahoma[2]	Texas	New Mexico
1	2	3	4	5	6	7	8	9	1	2	5	6	7	8
0.01	2.0	1-24 in.	2x1 B			2.0	2.0	2	24	1,060			110	94.0
.02	4.0	1-24 in.	2x2 B			4.0	4.0	4	26	1,100			110	92.0
.03	6.0	1-30 in.	2x3 B			6.0	6.0	6	28	1,140			110	92.0
.04	7.5	1-36 in.	2½x3 B			7.5	7.5	7.5	30	1,180			110	92.0
.05	9.0	1-42 in.	3x3 B			9.0	9.0	9.5	32	1,220			110	92.0
.06	10.5	1-42 in.	3½x3 B			10.5	10.5	11.0	34	1,255			110	92.0
.07	12.0	1-48 in.	3x4 B			12.0	12.0	13.0	36	1,290			110	91.0
.08	13.5	2-36 in.	D 2½x3 B			13.5	13.5	15.0	38	1,320			110	91.0
.09	15.0	2-36 in.	D 2½x3 B			15.0	15.0	17.0	40	1,350			110	91.0
.10	16.0	2-36 in.	D 3x3 B			16.0	16.0	19.0	45	1,435			110	91.0
.15	26.0	2-48 in.	D 3x4 D			26.0	26.0	29.0	50	1,510			110	89.5
.20	32.0	3-42 in.	6x4 A			32.0	32.0	38.0	55	1,580			115	89.5
.25	38.0	3-48 in.	6x5 A			38.0	38.0	41.0	60	1,650			115	89.5
.30	44.0		6x5½ A			44.0	44.0	53.0	65	1,720			115	88.0
.35	51.0		8x4½ A			51.0	51.0	61.0	70	1,780			115	88.0
.40	56.0		8x5 A			56.0	56.0	68.0	75	1,840			115	88.0
.45	62.0		8x6 A			62.0	62.0	75.0	80	1,900			115	86.5
.50	66.0		8x6 A			66.0	66.0	81.0	85	1,960			115	86.5
.55	70.0		8x6½ A			70.0	70.0	87.0	90	2,015			115	86.5
.60	74.0		10x4½ A			74.0	74.0	92.0	95	2,065			115	86.5
.65	78.0		10x5 A			78.0	78.0	97.0	100	2,120			120	85.0
.70	81.0		10x5½ A			81.0	81.0	102.0	110	2,220			120	85.0
.75	85.0		10x6 A			85.0	85.0	107.0	120	2,315			120	85.0
.80	88.0		10x6½ A			88.0	88.0	112.0	130	2,405			125	83.5
.85	91.0		10x6½ A			91.0	91.0	117.0	140	2,500			125	83.5
.90	94.0		10x6½ A			94.0	94.0	121.0	150	2,580			130	82.0
.95	97.0		12x5 A			97.0	97.0	125.0	160	2,665			130	82.0
1.0	100.0		12x5 A			100.0	98.5	130.0	170	2,745			130	80.5
1.1	110.0		12x6 A			105.0	98.5	140.0	180	2,820			130	80.5
1.2	120.0		12x7 A			105.0	98.5	150.0	190	2,900			130	79.0
1.3	130.0		12x8 A			105.0	98.5	160.0	200	2,970			130	79.0
1.4	140.0		14x6½ A			105.0	98.5	170.0	220	3,115			130	77.5
1.5	150.0		14x7 A			105.0	98.5	180.0	240	3,245			130	77.5
1.6	160.0		16x6½ A			105.0	98.5	190.0	260	3,370			130	76.0
1.7	170.0		16x7 A			105.0	98.5	200.0	280	3,495			130	76.0
1.8	180.0		16x7½ A			105.0	98.5	210.0	300	3,615			130	74.5
1.9	190.0		16x8 A			105.0	98.5	220.0	325	3,770			130	74.5
2.0	200.0		18x7 A			105.0	98.5	230.0	350	3,900			130	73.0
2.2	220.0		18x8 A			105.0	98.5	250.0	375	4,035			130	73.0
2.4	240.0		18x9½ A			105.0	98.5	270.0	400	4,165			130	71.5
2.6	260.0		20x8 A			105.0	98.5	290.0	450	4,385			130	70.0
2.8	280.0		20x9 A			105.0	98.5	310.0	500	4,610			130	68.5
3.0	300.0		20x9½ A			105.0	98.5	330.0	550	4,825			130	67.0
3.2	321.0		22x8½ A			105.0	98.5	351.0	600	5,030			130	65.5
3.4	340.0		22x9 A			105.0	98.5	369.0	650	5,230			130	64.0
3.6	357.0		24x8½ A			105.0	98.5	385.0	700	5,420			130	62.5
3.8	373.0		24x9 A			105.0	98.5	400.0	750	5,610			130	61.0
4.0	388.0		28x7 A			105.0	97.0	425.0	800	5,800			130	59.5
4.2	403.0		28x7½ A			105.0	97.0	430.0	850	5,890			130	58.0
4.4	417.0		28x8 A			105.0	97.0	444.0	900	6,080			130	56.5
4.6	430.0		28x8½ A			105.0	97.0	456.0	950	6,230			130	
4.8	443.0		28x9 A			105.0	97.0	469.0	1,000	6,380			130	
5.0	455.0		28x9½ A			105.0	97.0	481.0	1,100	6,705			130	
5.5	483.0		28x10 A			105.0	97.0	507.0	1,200	6,960			130	
6.0	509.0		32x7½ A			105.0	97.0	532.0	1,300	7,230			130	
6.5	533.0		32x8 A			105.0	97.0	555.0	1,400	7,480			130	
7.0	556.0		32x9 A			105.0	97.0	577.0	1,500	7,725			130	
7.5	579.0		32x10 A			105.0	97.0	599.0	1,600	7,960			130	
8.0	601.0		32x11 A			105.0	97.0	619.0	1,700	8,195			130	
8.5	622.0		32x11½ A			105.0	97.0	639.0	1,800	8,390			130	
9.0	641.0		32x12 A			105.0	95.5	657.0	1,900	8,625			130	
9.5	660.0		32x12½ A			105.0	95.5	675.0	2,000	8,820			130	
10.0	679.0		32x13 A			105.0	95.5	693.0	2,200	9,240			130	
11.0	710.0		(3)			105.0	95.5	722.0	2,400	9,605			130	
12.0	740.0		(3)			105.0	95.5	749.0	2,600	9,970			130	
13.0	775.0		(3)			105.0	95.5	782.0	2,800	10,320			130	
14.0	805.0		(3)			105.0	95.5	809.0	3,000	10,640			130	
15.0	835.0		(3)			105.0	95.5	838.0	3,500	11,445			130	
16.0	865.0		(3)			105.0	94.0		4,000	12,160			130	
17.0	890.0		(3)			105.0	94.0		4,500	12,825			130	
18.0	920.0		(3)			105.0	94.0		5,000	13,500			130	
19.0	945.0		(3)			105.0	94.0		5,500	14,080			130	
20.0	970.0		(3)			105.0	94.0		6,000	14,520			130	
22.0	1,015.0		(3)			105.0	94.0		6,500	15,140			130	

B = Box culvert. A = Arch culvert. D = Double.

[1] West of Streator, use 80 per cent; east of Streator, use 60 per cent.
[2] North of Purcell, use column 2; south of Purcell, use Texas column.
[3] Bridges designed to provide area to meet local conditions.

The above classification by States is for convenience only and merely denotes the general characteristics of topography and rainfall.

Column 2 in this table is prepared from observations of streams in southwest Missouri, eastern Kansas, western Arkansas, and the southeastern portions of Oklahoma; in all of this region steep rocky slopes prevail and the soil absorbs but a small percentage of the rainfalls; it indicates larger waterways than are required in western Kansas and level portions of Missouri, Colorado, New Mexico, and western Texas.

TABLE OF AREAS OF WATERWAYS CALCULATED BY TALBOT'S FORMULA.

$a = C \sqrt[4]{A^3}$ a = Area of waterway in square feet.
A = Drainage area in acres.

Drainage area		Areas of waterways in square feet						
		Mountainous land	Hilly land		Rolling land		Flat land	
Acres	Square miles	C=1.00	C=.80	C=.60	C=.50	C=.40	C=.30	C=.20
1	0.0016	1.0	0.8	0.6	0.5	0.4	0.3	0.2
2	.0031	1.7	1.4	1.0	.8	.7	.5	.3
4	.0062	2.8	2.2	1.7	1.4	1.1	.8	.6
6	.0094	3.8	3.0	2.3	1.9	1.5	1.1	.8
8	.0125	4.8	3.8	2.9	2.4	1.9	1.4	1.0
10	.016	5.6	4.5	3.4	2.8	2.2	1.7	1.2
15	.023	7.6	6.1	4.6	3.8	3.0	2.3	1.5
20	.031	9.5	7.6	5.7	4.7	3.8	2.8	1.9
30	.047	12.8	10.2	7.7	6.4	5.1	3.8	2.6
40	.062	15.9	12.7	9.5	8	6.4	4.8	3.2
60	.094	22	17.6	13	11	8.8	6.6	4.4
80	.125	27	21.6	16	13	10.8	8.1	5.4
100	.156	32	25.6	19	16	12.8	9.6	6.4
150	.234	43	34.4	26	21	17.2	12.9	8.6
200	.312	53	42.4	32	27	21.2	15.9	10.6
250	.39	63	50	38	31	25	19	13
300	.47	72	58	43	36	29	22	14
400	.62	89	71	53	45	36	27	18
500	.78	106	85	64	53	42	32	21
600	.94	121	97	73	61	48	36	24
800	1.25	150	120	90	75	60	45	30
1,000	1.56	178	142	107	89	71	53	36
1,500	2.34	241	193	145	121	96	72	48
2,000	3.12	299	239	179	149	120	90	60
2,500	3.91	354	283	212	177	142	106	71
3,000	4.7	405	324	243	203	162	122	81
4,000	6.2	503	402	302	252	202	151	101
5,000	7.8	595	476	357	297	238	179	119
6,000	9.4	682	546	409	341	273	205	136
8,000	12.5	846	677	508	423	338	254	169
10,000	15.6	1,000	800	600	500	400	300	200
12,000	18.8	1,147	918	688	573	459	344	229
14,000	21.9	1,287	1,030	772	644	515	386	257
16,000	25.0	1,423	1,138	854	711	569	427	285
18,000	28.1	1,554	1,243	932	777	622	466	311
20,000	31.2	1,682	1,346	1,009	841	673	505	336
25,000	39.1	1,988	1,590	1,193	994	795	596	398
30,000	47.	2,280	1,824	1,368	1,140	912	684	456
40,000	62.	2,828	2,262	1,697	1,414	1,131	848	566
50,000	78.	3,344	2,675	2,006	1,672	1,338	1,003	669
60,000	94	3,834	3,067	2,300	1,917	1,534	1,150	767
70,000	109	4,304	3,443	2,582	2,152	1,722	1,291	861
80,000	125	4,757	3,806	2,854	2,378	1,903	1,427	951
100,000	156	5,623	4,498	3,374	2,812	2,249	1,687	1,125
125,000	195	6,648	5,318	3,989	3,324	2,659	1,994	1,330
150,000	234	7,622	6,098	4,573	3,811	3,049	2,287	1,524
175,000	273	8,556	6,845	5,134	4,278	3,422	2,567	1,711
200,000	312	9,457	7,566	5,674	4,728	3,783	2,837	1,891
300,000	469	12,819	10,255	7,691	6,410	5,128	3,845	2,564
400,000	625	15,905	12,724	9,543	7,952	6,362	4,772	3,181
500,000	781	18,803	15,042	11,282	9,402	7,521	5,641	3,761
600,000	937	21,558	17,246	12,935	10,779	8,623	6,467	4,311
800,000	1,250	26,750	21,400	16,050	13,375	10,700	8,025	5,350
1,000,000	1,562	31,623	25,298	18,974	15,812	12,649	9,487	6,325
1,200,000	1,875	36,256	29,005	21,754	18,128	14,502	10,877	7,251
1,400,000	2,188	40,700	32,560	24,420	20,350	16,280	12,210	8,140
1,600,000	2,500	44,987	35,990	26,992	22,494	17,995	13,496	8,997
1,800,000	2,813	49,142	39,314	29,485	24,571	19,657	14,743	9,828
2,000,000	3,125	53,183	42,546	31,910	26,592	21,273	15,955	10,637
2,200,000	3,438	57,124	45,699	34,274	28,562	22,850	17,137	11,425
2,400,000	3,750	60,976	48,781	36,586	30,488	24,390	18,293	12,195
2,600,000	4,063	64,748	51,798	38,849	32,374	25,899	19,424	12,950
2,800,000	4,375	68,449	54,759	41,069	34,225	27,380	20,535	13,690
3,000,000	4,688	72,084	57,667	43,250	36,042	28,834	21,625	14,417
3,200,000	5,000	75,659	60,527	45,395	37,830	30,264	22,698	15,132

The Burkli-Ziegler formula is frequently referred to:[1]

$$Q = Rc \sqrt[4]{\frac{S}{A}}$$

McMath formula:[2]

$$Q = Rc \sqrt[5]{\frac{S}{A}}$$

In both the above formulæ:

c = constant — 0.20 for rural sections. 0.75 for paved streets, 0.31 for macadamized streets.

R = average rate of rainfall during heaviest fall in cubic feet per second per acre.[3] R taken at St. Louis as 2.75 inches.

S = General fall of drainage area in feet per 1,000.

Q = cubic feet of water per second per acre reaching sewers.

A = drainage area in acres.

[1] From Treatise on Sewerage, by A. Prescott Folwell.

[2] Since the results obtained by these formulæ depend largely on the value of the constant "c" the proper value for it should be determined by actual observation for the general conditions involved.

[3] The intensity of rainfall is usually given in inches per hour and varies greatly in different localities. One inch of rainfall per hour equals one cubic foot per second per acre almost exactly.

The United States Weather Bureau has records of rainfall at many stations distributed throughout the United States. Information concerning the rainfall in many sections and daily stages of many large streams may be obtained from their publications.

The United States Geological Survey has measured the cross section of streams and has valuable run-off data which may be obtained from that department.

The practice of several railway systems is indicated from notes taken from the proceedings of the American Railway Engineering Association containing reports on this subject. The report by a special committee submitted to the American Railway Engineering Association in March 1909, contained the following statements:

(1) "In determining the size of a given waterway, careful consideration should be given to local conditions, including flood height and flow, size and behavior of other openings in the vicinity carrying the same stream, characteristics of the channel and of the watershed area, climatic conditions, extent and character of traffic on the given line of road and probable consequences of interruptions to same, and any other elements likely to affect the safety or economy of the culvert or opening.

(2) (*a*) "The practice of using a formula to assist in fixing the proper size of waterway in a given case is warranted to the extent that the formula and the values of the terms substituted therein are known to fit local conditions.

(*b*) "Waterway formulas are also useful as a guide in fixing or verifying culvert areas where only general information as to the local conditions is at hand.

(*c*) "The use of such formulas should not displace careful field observation and the exercise of intelligent judgment on the part of the engineer.

(*d*) "No single waterway formula can be recommended as fitting all conditions of practice."

The report in 1911 contained the following statement:

(1) "There is a general relationship between the best-known waterway and run-off formulas. This relationship may be expressed by two terms, a varying coefficient and a varying exponent.

(2) "The extent of this relationship for large and small areas is indicated by the Dun waterway data."

METHODS USED BY RAILROADS.

The following extracts have been taken from the proceedings of the American Railway Engineering Association, and indicate the methods used for determining sizes of waterways for culverts by several railroads.

Baltimore & Ohio Railroad.—"Use Talbot's formula with "C" as follows in Maryland, West Virginia, Pennsylvania, and Ohio:

Mountainous country	C=0.80
Hilly country	C= .67
Medium country	C= .50
Rolling country	C= .33
Flat country	C= .20

except that the factor may be increased according to the judgment of the engineer on account of abnormal rainfall, or if the direction of flow of water is the same as the prevailing direction of movement of summer storms. Consider it safe to take the maximum known flood and add 20 per cent unless such flood was so exceptional that a repetition is not probable."

Central Railroad of New Jersey.—"Great importance is placed on the results of study of the sites of existing culverts and bridges on same stream. It is generally possible to find such openings, and collect reliable data regarding elevations reached by high water during floods. In case no such existing opening is found, the area of the watershed is determined from U. S. Geological Survey maps, State maps, or by survey.

"By the use of Talbot's formula, the required area of waterway is determined where "C" varies from 0.33 to 1.00. For example, in the flat and wooded regions of southern New Jersey, "C" is taken as 0.33 and in the rocky regions of Pennsylvania, "C" is taken as 1.00. We have no culverts designed to operate under a head."

Chicago, Burlington & Quincy Railroad.—"Areas of drainage are ascertained by actual surveys or estimated from reliable maps. For areas up to 1,000 acres we use the McMath formula. For greater areas we use:

$Q=\frac{3,000\,M}{3+2\sqrt{M}}$ or if the velocity through the culvert is assumed as 10 feet per second

$$A=\frac{300\,M}{3+2\sqrt{M}}$$

"Where Q = total discharge from area in cubic feet per second.

A = waterway in square feet.

M = drainage area in square miles.

"We rely on formulae unless recorded high-water marks indicate that an extra large waterway is necessary. We aim to have the culvert operate under no head, but allow no excess margin for drift."

Chicago, Rock Island & Pacific Railroad.—"Use Talbot's formula with "C" having the following values:

Flat country	C=0.33
Hilly country	C= .67
Mountainous country	C=1.00

"If practical, make survey determining nature of land, declivity of drainage area, amount and kind of drift, high-water marks, etc. Where drainage areas are so large as to make a survey impracticable compute drainage areas from reliable maps. The structure should not back the water above the high-water mark which existed before the building of the road. Allow for extraordinary floods when cost of construction justifies it. Do not compute size of culvert for condition of running full or under a head. Make culvert from 50 to 100 per cent larger than formula calls for."

El Paso & Southwestern Railway.—

"$Q=17\sqrt{\frac{8,000}{A}}$

"Where Q = maximum run-off per square mile of drainage area, and

A = total drainage area in square miles.

"This formula is checked by the following table:

Drainage area in square miles.	Water-ways in square feet.	Drainage area in square miles.	Water-ways in square feet.
0.12	18.8	4.6	353
.22	31.4	5.8	428
.40	51.0	7.2	508
.70	74.0	9.5	628
1.15	102.0	12.4	756
1.55	134.0	15.8	878
2.00	170.0	19.9	978
2.50	209.0	24.6	1,088
3.50	280.0	30.2	1,199

"We endeavor to make provision for floods of ordinary magnitude."

Kansas City, Mexico & Orient Railway.—"Whenever practical, watershed is traversed and area computed. Observations are made to determine high-water mark and this is confirmed by every means available, such as marks on trees, deposit of drift and other debris, or information from residents.

"Formula used:

"$A=C\sqrt[4]{M^3}$ For drainage areas less than 8 square miles.

"$A=8C\sqrt{M}$ For drainage areas over 8 square miles.

"A = waterway in square feet.

"M = drainage area in acres.

"C = constant depending upon character of drainage area and amount of maximum rainfall, varying from 1.00 in rocky country with steep slope and high maximum rainfall to 0.20 in smooth prairie with small maximum rainfall.

"This formula is used only as a guide. In smaller streams the openings provided are designed to care for the water under extreme conditions, but not necessarily large enough for cloudbursts. Large structures such as large arches and bridges are designed to operate with sufficient waterway to carry off the water under the extreme known flood conditions without injury to the structure. The operation of a culvert under a head is avoided wherever possible."

Kansas City Terminal Railway.—"Field observations are made to determine the height and area of flood water, measurements of drainage area, and an approximate estimate of the slope of the latter. We have used the Burkli-Ziegler and Dun's formulae. We have not made systematic measurements of drainage areas, but usually make an effort to collect data immediately following heavy storms or floods. Usually allow for maximum floods, but permit operation of culvert under a head where the character of the ground to be overflowed by back water is such that no harm would be done."

Missouri, Kansas & Texas Railway.—"Use Talbot's formula with following values of "C."

Steep country	C=1.10
Medium country	C=0.85
Flat country	C=0.60

Missouri Pacific Railway.—"No one formula is relied upon in arriving at a proper size of opening but conclusions are checked in all possible ways. Where a proper coefficient has been obtained for a certain locality, Talbot's formula can be used with good results. Where rainfall data can be secured, McMath's or the Burkli-Ziegler formula can be used."

Pennsylvania Railroad.—"There can be no short rule of general application for the requisite area of waterways of bridges and culverts. It depends on the area of the watershed, the maximum precipitation in a given time, the average slopes of the drainage area, and the form of cross section and superficial material of the channel. The area of the watershed can be determined from a good map of the region; the maximum precipitation varies widely in different sections and can only be ascertained from records covering a series of years, which are not always available; the slopes of the drainage area are matters of topography and vary all the way from the steepest mountain sides to the flattest prairie. Assuming that the above data is obtainable or can be approximately estimated, the rate of run-off may be computed by the Burkli-Ziegler formula to find the volume of water reaching the site of the bridge or culvert in a given time. Then find the required area to discharge this volume as fast as it arrives, using for this purpose the well-known Kutter's formula:

"The foregoing is the only reliable method for treating this problem scientifically. But in many instances some or all of the data will not be obtainable and the only recourse will be to ascertain as reliably as possible the height of the greatest floods and use your best judgment, guided by such past experience as you may have had. But in every case be not afraid to make it too big but cultivate and maintain a wholesome fear of making it too small. Do not let present economy of construction close your eyes to a possible loss, damage, and expense from future disaster."

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS.

NOTE.—Application for the free publications in this list should be made to the Chief of the Division of Publications, U. S. Department of Agriculture, Washington, D. C. Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets, nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

REPORTS

*Report of the Director of the Office of Public Roads for 1914. 5c.
*Report of the Director of the Office of Public Roads for 1915. 5c.
Report of the Director of the Office of Public Roads for 1916.
Report of the Director of the Office of Public Roads for 1917.
Report of the Director of the Bureau of Public Roads for 1918.

BULLETINS.

(In applying for these publications the name of the office as well as the number of the bulletin should be given, as "Office of Public Roads Bulletin No. 28.")

*Bul. 28. The Decomposition of the Feldspars (1907). 10c.
*37. Examination and classification of Rocks for Road Building, including Physical Properties of Rocks with Reference to Their Mineral Composition and Structure. (1911.) 15c.
*43. Highway Bridges and Culverts. (1912.) 15c.
*45 Data for Use in Designing Culverts and Short-span Bridges. (1913.) 15c.
*48. Repair and Maintenance of Highways (1913).

DEPARTMENT BULLETINS.

(In applying for these bulletins the name should be given as follows: "Department Bulletin No. 53.")

*Dept. Bul. 53. Object-Lesson and Experimental Roads and Bridge Construction of the U. S. Office of Public Roads, 1912-13. 5c.
105. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
136. Highway Bonds.
230. Oil Mixed Portland Cement Concrete.
249. Portland Cement Concrete Pavements for Country Roads.
257. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*284. Construction and Maintenance of Roads and Bridges, from July 1, 1913, to December 31, 1914. 10c.
347. Methods for the Determination of the Physical Properties of Road-Building Rock.
*348. Relation of Mineral Composition and Rock Structure to the Physical Properties of Road Materials. 10c.
373. Brick Roads.
386. Public Road Mileage and Revenues in the Middle Atlantic States.
387. Public Road Mileage and Revenues in the Southern States.
388. Public Road Mileage and Revenues in the New England States.
389. Public Road Mileage and Revenues in the Central, Mountain, and Pacific States, 1914.
390. Public Road Mileage in the United States. A summary
393. Economic Surveys of County Highway Improvement
407. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
414. Convict Labor for Road Work.
463. Earth, Sand-Clay, and Gravel Roads.
532. The Expansion and Contraction of Concrete and Concrete Roads.
537. The Results of Physical Tests of Road-Building Rock in 1916, including all Compression Tests.
*555 Standard Forms for Specifications, Tests, Reports, and Methods of Sampling for Road Materials. 10c.
583. Report on Experimental Convict Road Camp, Fulton County, Ga.
586. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1916.

OFFICE OF PUBLIC ROADS CIRCULARS.

(In applying for these circulars the name of the office as well as the number of the circular should be given as "Office of Public Roads Circular No. 89.")

Cir. 89. Progress Report of Experiments with Dust Preventatives, 1907.
*90. Progress Report of Experiments in Dust Prevention, Road Preservation, and Road Construction 1908. 5c.
*92. Progress Report of Experiments in Dust Prevention and Road Preservation, 1909. 5c.
*94. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1910. 5c.
*96. Naphthalenes in Road Tars. 1. The Effect of Naphthalene upon the Consistency of Refined Tars. (1911.) 5c.
*97. Coke-Oven Tars of the United States. (1912.) 5c.
98. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1911.
*99. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1912. 5c.
*100. Typical Specifications for Fabrication and Erection of Steel Highway Bridges. (1913.) 5c.

OFFICE OF THE SECRETARY CIRCULARS.

Sec. Cir. *49. Motor Vehicle Registrations and Revenues, 1914. 5c.
52. State Highway Mileage and Expenditures to January 1, 1915.
59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.
62. Factors of Apportionment to States under Federal Aid Road Act Appropriation for the Fiscal Year 1917.
63. State Highway Mileage and Expenditures to January 1, 1916.
65. Rules and Regulations of the Secretary of Agriculture for Carrying out the Federal Aid Road Act.
*72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads.
73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.
74. State Highway Mileage and Expenditures for the Calendar Year 1916.

FARMERS' BULLETIN.

(The Farmers' Bulletins are a series of popular treatises issued by the Department of Agriculture. The following list includes only numbers contributed by the Office of Public Roads, and should be applied for by numbers, as "Farmers' Bulletin No. 239.")

F. B. *239. The Corrosion of Fence Wire. 5c.
311. Sand-Clay and Burnt-Clay Roads.
F. B. 338. Macadam Roads.
*403. The Construction of Concrete Fence Posts. 5c.
*461. The Use of Concrete on the Farm.
505. Benefits of Improved Roads.
597. The Road Drag.

SEPARATE REPRINTS FROM THE YEARBOOK.

(In applying for these separates the numbers should be given as "Yearbook Separate No. 638.")

Y. B. Sep. *638. State Management of Public Roads; Its Development and Trend. 5c.
*712. Sewage Disposal on the Farm. 5c.
727. Design of Public Roads.
739. Federal Aid to Highways.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH.

Vol. 5, No. 17, D-2. Effect of Controllable Variables Upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 19, D-3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.
Vol. 5, No. 20, D-4. Apparatus for Measuring the Wear of Concrete Roads.
Vol. 5, No. 24, D-6. A New Penetration Needle.
Vol. 6, No. 6, D-8. Tests of Three Large-Sized Reinforced-Concrete Slabs under Concentrated Loading.
*Vol. 10, No. 5, D-12. Influence of Grading on the Value of Fine Aggregate Used in Portland Cement Concrete Road Construction. 15c.
Vol. 10. No. 7, D-13. Toughness of Bituminous Aggregates.
Vol. 11, No 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

*Department supply exhausted.