Publications Committee



# University of Texas Bulletin

No. 1922: April 15, 1919

# ROADS AND PAVEMENTS

**Papers Presented Before the Short Course in Highway Engineering Held at the University of Texas, March 31-April 12, 1919, Under the Auspices of the Department of Engineering**

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**The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.**

**Sam Houston**

**Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.**

**Mirabeau B. Lamar**

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# ROADS AND PAVEMENTS

## EARTH ROADS

BY R. G. TYLER
Adjunct Professor of Highway and Sanitary Engineering

It will be many years before even the majority of the highways of Texas are improved by the construction of a permanent road surface, and it is necessary, therefore, to consider at the beginning of this short course in Highway Engineering the subject of the construction and maintenance of earth roads. Every engineer in charge of work for a county or a road district will have, in addition to his duties of constructing permanent road surfaces, a considerable amount of work to do with the ordinary earth highway. The importance of this subject, then, is due to the very large comparative mileage of this type of road at present in use. Below is given the mileage of the various classes of road surfaces in Texas as obtained from the State Highway Department, and is as nearly accurate as any information available on this subject at the present time. From this, it will be seen that 85 per cent of the roads of Texas are earth roads. An engineer, therefore, who is uninformed on this class of construction is poorly equipped to practice his profession under existing conditions.

| | |
|---|---|
| Total miles of road in Texas | 148,000 |
| Earth roads | 126,000 |
| Sand-clay | 12,818 |
| Gravel | 7,325 |
| Shell | 1,138 |
| Bituminous surfaced | 395 |
| Macadam | 276 |
| Concrete | 43 |
| Wood-block | 2 |
| Brick | 0.33 |

An earth road is a very desirable type of road so long as it is dry. It is usually quite smooth, and, except with certain classes of soil, may not be extremely dusty. It is to be preferred for horse-drawn traffic to the harder road surface during suitable weather conditions. Its disadvantages are principally due to the effect of wet weather, when it is practically impassable. A further disadvantage lies in the excessive cost of proper maintenance.

There are certain preliminary investigations which should be undertaken before locating an earth road, and these same investigations should, of course, be considered in questions of relocation. Since the location of a road of any kind is one of the permanent features of its construction, the importance of a thorough study of all considerations having a bearing thereon is evident. Although the earth road is considered a cheap type of construction, it is probable that a location, when once determined upon, will not be materially changed, even when the road is eventually improved. All the factors, therefore, that are considered in the location of a permanent highway should be considered at this time.

It is probable that more freedom may be had in the location of an earth road than in that of the more permanent types of highways, because, in the first place, the road is to be located through virgin territory, where no road at present exists. In the case of the more permanent types, it is probable that an earth road will have already been constructed near the desired location, and it may be difficult to make a change in the location when improving the road, as farm houses will have been located with reference to this road and fences and property lines established with reference thereto. There are certain fixed points, such as cities, permanent bridges, etc., which are determining factors in the location of the highway, but the engineer should be given considerable latitude in the location between these points. The same principles apply as in railroad location to a considerable extent, in that the road must be laid out so that it will serve the maximum traffic and be the shortest distance between the termini consistent with the proper grades and drainage. It is not always desirable to locate the road along the line of existing maximum travel, as this traffic may not be following the logical route. The direction of traffic often shifts materially after the improvement of a highway.

Drainage is the most important consideration arising in the study of the problem of locating or relocating highways. The effect of water on the road may be either the softening of the surface by the water standing immediately upon the surface of the roadway; the washing and cutting of side-ditches, due to excessive flow or steep grades; the softening of the foundation from seepage, where water is permitted to stand along side the road; or the overflow and washing of the surface of the road itself. To remedy these conditions, it is necessary to provide for surface drainage, cross-drainage, and underdrainage. The surface drainage is taken care of as far as the immediate road surface is concerned by giving the roadway the proper crown. This crown should be sufficient to remove the water quickly from the road surface, and should be as flat as possible consistent with good drainage. Steep crowns are objectionable, as they cause traffic to track or localize along one narrow area down the center of the roadway. With a flatter crown, traffic is encouraged to distribute itself over the roadway, thus preventing the formation of ruts and the excessive wear which results in wheel tracks down the center of the road. The amount of crown for any road, therefore, depends on the degree of permeability of the road surface, and is expressed in inches fall per foot of half-width. For earth road, the crown is usually about one inch per foot of half-width. A 24-foot roadway, then, would be twelve inches higher in the center than at the shoulders.

After the water has been removed from the road surface, it must be carried away by means of side-ditches. These ditches should be wide and shallow, and, preferably, have sufficient grade to be self-cleaning. The ditch as cut by the road grader has a very desirable shape, in that the maximum depth, which is the point of maximum velocity and also of greatest cutting from the water, will be on the side farthest from the roadway, while the side adjacent to the road is shallow and therefore will not cut appreciably during floods. If the longitudinal grade of the ditch is greater than from three to five per cent, depending upon the class of soil, it will cut and erode rapidly; and it will be necessary to take steps to prevent such action, since, if permitted to continue unchecked, the roadway itself will eventually be entirely cut out and only a drainage ditch will remain. A number of low cross-walls made by driving 2x8 lumber at right angles to the ditch will provide a series of steps or drops, which will localize the washing and allow the grade to flatten out between. The tops of these walls should be low enough to provide ample area of waterway above, so as to prevent damming and flooding the road, and should extend far enough into the ground to prevent being undermined by the action of the water pouring over them. In some locations the grade of the center line of the road may be absolutely level and the drainage taken care of entirely by giving the side-ditches proper slope. It is desirable to give these ditches at least a one per cent grade, as they will be very troublesome due to the growth of vegetation, and will require constant cleaning, if constructed on a flatter grade.

Another feature which is frequently overlooked is to prevent water from being carried a considerable distance on the uphill side of a road. This water should be carried through the roadway at frequent intervals by means of proper cross-drainage structures, so that the road shall not be overflowed by too great an accumulation. A large amount of water on the downhill side of the road is not so troublesome, as the crown of the road is higher than the adjacent property in most cases, and any overflow from the ditches would spread out over the property rather than the roadway itself.

It has been the practice in the past, and continues to be in the present, to drain all farming land as much as possible on to the highways. The roads are made to act as drainage ditches for adjacent property. This is exactly the reverse of what the conditions should be. Since the road surface is much more expensive than an equal area of farm land, it is desirable to drain the water away from the roadway at frequent intervals, and never should it be allowed to be carried along the road and accumulate in sufficient amounts to cause damage from washing. Water should be carried by the shortest route possible to the creeks and principal drainage-ways.

Where water stands on the surface of the road due to a layer of impervious material beneath, no amount of working of the surface will appreciably benefit the situation. No amount of working on the surface of a tub filled with mud will cause it to become dry and firm, though a hole in the bottom of the tub will quickly bring about thorough draining and a satisfactory condition of the material. The same thing applies to a roadway. An underdrain must be provided where seepage occurs, to intercept or carry off the water as it accumulates, in order to hope to maintain successfully any type of road surface. These seeps must frequently occur on hillsides, where water is brought to the surface by an outcropping of clay, rock, or other impervious material. It is customary to place the underdrains below the side-ditches, but these on steep grades are likely to wash out, as the material of the newly filled ditch will cut more easily than the adjacent soil. These underdrains should also be carried away from the road as quickly as possible.

As a general rule, it is well to avoid cuts, as they are hard to maintain. It is better to raise the grade slightly and build the entire roadway on a slight fill, or to go around some of the hills, rather than to cut through, as the material gradually washes down the steep slopes of the cut, and continuous maintenance is required to keep the side-ditches clean and in working order. Where a cut is necessary, a ditch should be placed on the uphill side above the cut to intercept surface drainage and prevent unnecessary damage to the side slopes of the cut itself.

Wherever possible, it is advisable to follow a ridge rather than to go across it, as a minimum of drainage ditching and drainage structures will be required in this case. It is advisable under some conditions to swing a little out of the general direction desired in order thus to decrease the difficulties due to improper drainage.

Obviously, mashes and sand should be avoided as much as possible. It is undesirable also to lay out a road parallel and adjacent to a stream, unless this location is absolutely necessary, for it is impossible to maintain such a roadway properly, as the foundation will be soft from seepage and the road in danger of damage from floods. It is advisable to cross all river bottoms as nearly at right angles as possible, so that the minimum mileage of roadway will be located in low lying lands subject to overflow.

The question of grades comes up next for consideration. The steepest grade on a road will limit the size of the load that can be hauled over that road, since the load that a team can pull on various grades decreases rapidly as the percentage of grade increases. It is desirable to keep the maximum grade within reasonable limits. Usually the maximum permissible grade is taken at from 3 to 5 per cent. A two-horse team can pull about 4,000 pounds on the level on a good earth road. On a 3 per cent grade, the same team can pull only 2,200 pounds; while on a 5 per cent grade, it can pull only 1,600 pounds. From these figures, it is seen that a team's pulling power is cut in half by a 3 per cent grade, and approximately to one-third by a 5 per cent grade. This shows the necessity of cutting down the steeper grades to a reasonable maximum limit.

It is sometimes advisable to go around a hill rather than to go over it, as the distance around may not be any farther than that over the hill. While the latter is usually termed a straight line, it is straight only with regard to horizontal dimensions, and may be very crooked with regard to vertical dimensions.

Since this matter of grades is usually determined once and for all, and is not changed materially with a change of road surface, it may be considered one of the permanent features of the construction, and a proper proportion of highway funds spent thereon.

While tangents are usually desired in determining the alignment of a highway, curves are not always objectionable, unless very sharp and of too short radius for the type of traffic to be handled, or with an obstructed view. It is desirable wherever possible to arrange so that a 500-foot clear view is available.

A discussion of the construction of an earth road resolves itself principally into a discussion of road-building equipment. Before the construction is started, however, it is necessary that certain surveys be made. Such surveys have been thought superfluous in the case of earth roads in the past, and the lack of them accounts for the usual poor location of this type of highway. It is essential that the drainage areas should be run out in order that the proper size drainage structures may be put in. Furthermore, a profile should be made of the proposed road in order that longitudinal drainage may be properly taken care of. These two classes of surveys should at least be undertaken before any kind of road is located.

Much of the earth road construction work can be done by means of a road-grader with the assistance of a grading-plow. This machine will shape up the road surface in a satisfactory manner, unless a considerable amount of cut and fill is required, in which case the earth can be most economically moved by slip or drag scrapers and fresnos for short hauls up to about 100 feet. It is perhaps advisable to use wheeler-scrapers for hauls of from 100 to 600 feet, and wagons of some of the numerous types of dump beds for distances above 600 feet. A discussion of this equipment will not be gone into, as it is something with which you are all familiar.

The maintenance of the highway after it has been constructed is one of the most important problems, and one which has been most sadly neglected in the past. If an earth road is properly maintained, this work is very simple in character and does not require a great amount of skill in its performance. The machine most often used in maintaining earth roads is the road-drag, which may be constructed of wood or of the more modern type made up of some two or three steel blades similar to the blade on a grader, only smaller. The use of this machine should be familiar to every one interested in road construction and maintenance, and the rules for using a road-drag as laid down by the Illinois Highway Commission are given herewith.

RULES FOR DRAGGING

Use a light drag.

Haul it over the road at an angle so that a small amount of earth is pushed to the center of the road.

Drive the team at a walk.

Ride on the drag; do not walk.

Begin at one side of the road, returning up the opposite side.

Drag the road as soon after every rain as possible, but not when the mud is in such condition as to stick to the drag.

Do not drag a dry road.

Drag whenever possible at all seasons of the year.

The width of traveled way to be maintained by the drag should be from eighteen to twenty feet; first drag a little more than the width of a single wheel track, then gradually increase until desired width is obtained.

Always drag a little earth toward the center of the road until it is raised from ten to twelve inches above the edges of the traveled way.

If the drag cuts too much, shorten the hitch.

The amount of earth that the drag will carry along can be very considerably controlled by the driver, according as he stands near the cutting end or away from it.

When the roads are first dragged after a very muddy spell, the wagons should drive, if possible, to one side until the roadway has a chance to freeze or partially to dry out.

The best results from dragging are obtained only by repeated application.

Remember that constant attention is necessary to maintain an earth road in its best condition.

A system of road dragging has been inaugurated in Austin County, Texas, which might be followed with profit by other communities in this State. Dragging clubs have been organized along the various roads, each member paying an annual fee of $2.50 into a fund to be used for dragging the particular road in question. Each member has the privilege of putting in one day's work at dragging the roads of his club, for which he will be paid the customary wages. This work, however, is not compulsory. A superintendent is appointed for the road district or the club, and after every rain, or at any other time when it seems desirable, he calls upon some member of the club to drag the road, and pays him for his labor. This plan has worked very efficiently, as evidenced by the splendid condition of these highways, despite the unusual inclement weather of the past winter.

One state highway engineer recently made the statement that in his state it became necessary during the war to curtail highway construction work. He centered all of his energies, therefore, upon the dragging and maintenance of the earth roads and roads of other types under his jurisdiction. So much success did he have in this work, that he has decided that some of the highways of his state can be maintained in such a satisfactory condition at all times throughout the year at small expense that it will not be necessary to construct a high class pavement thereon. While this position can not usually be endorsed by highway builders, nevertheless it shows what satisfactory results can be accomplished by a proper system of highway maintenance.

It is especially important to get the road surface in proper shape to carry it through the winter season. No earth roads should be permitted to enter the winter with a flat crown or with stopped-up side-ditches, and in localities subject to freezing temperature it is desirable, when possible, to have the road dragged to a smooth surface preceding severe cold. A frozen, rough earth road is extremely disagreeable for traffic, while a smooth or dragged surface when frozen will be as satisfactory as a pavement. While it is not always possible to drag the road at the proper time, it should be kept as well dragged as possible, especially through the winter.

One of the objections to an earth road is due to the formation of dust. This dust is produced from various causes, some of which can be easily prevented. A very common cause of a dusty road surface is the constant dragging of vegetation out of the side-ditches in grading up the road and depositing them upon the road surface. This material will bring about a loose condition in the road surface, and prevent its proper packing, thus producing dust. Inert material hauled upon the road will also be ground up into dust. The road surface, also, which is not properly dragged and has been allowed to become rough and uneven, will have these inequalities worn down by traffic, thus causing an appreciable amount of dust. Lastly, the ordinary wear of a road surface from abrasion will cause a certain amount of dust, but this will be very small in comparison with that brought about by the causes stated above.

The remedies for the dust nuisance, then, will be to drag the road properly, to prevent roughness of surface, and to see to it that no vegetation is dragged out upon the road surface. The dust due to abrasion can only be remedied by a proper oiling of the road. This will not be discussed here, as it will be handled in another paper on Bituminous Road Surfaces. It is sufficient to state, however, that oiling a road should not be attempted where the traffic is heavy, and precautions should be taken in any case to have the road well graded and compact before the application of a suitable road oil.

In conclusion, the large mileage of earth roads makes it important that engineers should give the proper attention to problems alike of the location, construction, and maintenance of these roads. So long as a proper system of maintenance is provided, the earth road will provide a very satisfactory branch road suitable for feeding the main improved highways.

## THE PREPARATION OF ROAD PLANS INVOLVING STATE OR FEDERAL AID

By M. C. Welborn
Road Engineer, State Highway Department

Plans and specifications for any construction work are the basis for an agreement between the parties interested in the work. Before the State Highway Department can definitely appropriate money on a job of road work, it must know how the road is going to be constructed. Before the State Highway Department can obtain federal funds on road construction, it must be able to show the Federal Burea of Public Roads what is going to be done. Before a contract can be entered into for the construction of a road, it is necessary that the contractor know what he is supposed to do; and, before a contract can be signed between the county and a contractor, it is necessary to have plans and specifications upon which to base the agreement.

Any one who undertakes to build anything without plans, no matter how small the job, invariably discovers about the time he finishes it, that he could have built it better and for less money if he had the job to do over again. The reason for this is that unforseen difficulties have arisen during the progress of the work, which, if they had been foreseen, could have been either entirely avoided or surmounted with much less difficulty and expense. The engineer who builds without plans invites "surprise attacks." The successful engineer avoids surprises by carefully planning his campaign and determining what he is going to do before he has done it.

The plans on any piece of construction work are simply a description of the work to be done by illustrations and drawings, rather than by lengthy written documents. If it were necessary to describe in detail by a written description each item of the work to be done on a road construction job, it would require several volumes to handle it properly—

in fact, each mile of road would require the writing of a good sized book. By those who have not been accustomed to making up complete plans for their road work, our system may be looked upon as involving an unreasonable and unnecessary amount of "red tape." They should consider the amount of work that would be necessary if these details were described in writing.

In order properly to prepare a complete set of road plans, the engineer must know what is necessary to be done at every point along the road. Of course, this information is necessary before any kind of construction work is undertaken, but it often happens in road construction work that the work is started before the plans are completed. Often the plans are not made at all, in which case there are three things that are sure to happen: at some points, inferior work is going to be done; at other points, the work is going to be unnecessarily expensive; and the money appropriated for the job will be expended before the work is completed.

In brief, the following requirements must be met in the preparation of road plans wherever state or federal aid is used in the construction of roads.

*Size of Sheets:* The standard size of sheets required by the State Highway Department and the Federal Bureau of Public Roads is 22x36 inches, outside dimensions. Border lines are to be placed so as to provide a two-inch binding margin on the left and half an inch margin on the other three edges.

*Scales:* On the plan-profile, the sheets shall be drafted to a scale of one inch to one hundred feet horizontally, and one inch to ten feet vertically. The scale to be used on cross sections must be one inch to five feet, both vertically and horizontally.

The different sheets necessary to be included in a set of plans are as follows:

Title Page.
State Map.
County Road Map.
Sheet of Typical Cross-Sections.
Estimate and Quantity Sheets.

Haul Diagrams.
Plan-Profile Sheets.
Cross-Section Sheets.
Structural Plans.

*Title Page:* The title page should show the following:

Title.
Scales.
Layout map.
Index to the sheets.
The conventional signs used.
The net length of the project.

Any exception included in the layout but not included in the project (giving station numbers of the beginning and end of such exceptions).

The number of the project (in the upper right hand corner).

The signature of the county engineer (in the lower right hand corner).

The necessary blank spaces for dates and signatures of approving State and Federal officials.

The layout map should show the proposed route, indicating county and state lines, the north point, the principal connecting roads, streams, railroads, cities, etc.

*State Map:* A copy of the state map must be included in all federal aid projects. On this map, the location of the county must be indicated by means of coloring the boundaries of the county so that it is plainly discernable. Blue prints of the state map can be furnished upon request to the State Highway Department.

*County Road Map:* One copy of the county road map must be included in each copy of the plans. On this map, the section of road to be improved must be plainly indicated.

*Typical Cross-Sections:* Immediately following the county road map should be included a sheet of typical cross-sections. These sections will show the various slopes for cuts and fills; the width of the graded sections in the cut, and on embankment; the crown or shape of the finished surface, shoulders, gutters, etc.; the width and thickness of the various courses of pavement, or surfacing; and the position of the grade line relative to the typical cross-sections.

*Estimate and Quantity Sheet:* This sheet should consist of a tabulation showing all grading and surfacing quantities by sheet of the plans, or by the mile, and a summary of drainage structures, each structure being listed separately. In this latter summary, the quantities of the various materials used in each structure are listed. From the two tabulations of quantities, the estimate summary is then to be prepared. However, in regard to the latter, this department desires that no estimated unit price, or amounts, for the work be shown on the estimate sheet, but that such estimated cost be furnished the department on a separate typewritten sheet.

*Haul Diagrams:* As provided in our Standard Specifications, surfacing material such as clay, gravel, crushed stone, etc., is to be paid for according to the distance hauled. It is therefore necessary that the plans include information as to just what sections of the road are to be surfaced from the different material pits, or from the various railroad stations from which the material is to be hauled, and to show the amount of material hauled into each quarter-mile section in order to determine the amount of the item for "additional quarter-mile-yard-hauls." The simplest and most satisfactory way of detailing this information is by means of a haul diagram. This haul sheet should be inserted immediately after the Estimate and Quantity Sheet.

*Plan-Profile:* Standard plan-profile sheets may be obtained from all the larger supply houses, and it is more economical to buy properly ruled sheets for this purpose than to try to use plain cloth or paper. The standard ruling on cloth or paper can be obtained either by the yard or by separate sheets cut to dimensions.

The plan of the road shall show the center line of the construction, bearing of tangents, right-of-way lines, stations of beginning and ending of curves, length of curves, approximate radii of curvature, station points, equations of stations, streams, railroads on or near the right of way, poles for wire lines, obstructions on the right of way, the location of proposed culverts and bridges with their sizes and an accurate description of the proposed new structure, and all unusual or special features which can be anticipated. The direction of ow of rivers, creeks, and drains should be indicated by arrows.

The profile should show the surface line, the grade line, length of vertical curves, percentage of gradient, grade elevations at changes of gradient, and, in case the standard profile ruling on paper or cloth is not used, surface elevations and grade elevation shall be shown at each station and at changes of gradient. The surface line of the stream beds as well as bridge floors should be shown.

It is desired to refer all elevations to sea level. U. S. G. S. bench marks and railroad bench marks will be helpful in this respect. When no sea-level datum information is available, this department will accept an assumed elevation. The bench marks shall be established from 1,500 or 2,000 feet along the road, and such bench marks shall be accurately located and noted on the plans.

A compact description of existing and proposed drainage structures shall appear on the profile. On all culverts, the elevation of the flow line at the center of the road shall be given. The tributary drainage area shall be noted at each structure. When structures are to be used in place, it shall be so noted.

The plans should be plotted with the stationing from left to right. The north point should be placed on each sheet. All curve points and angles on the construction line should be marked by small circles. Indicate by means of descriptive notes, or topographical symbols, the nature or use of the soil or country 500 feet each side of the road. It is desired to know whether it is cultivated or wild, good farming land or barren, etc.

*Cross-Sections:* Whenever earth grading quantities are to be calculated, cross-sections shall be taken, and plotted, at intervals of 100 feet or less. In case it is found that the work may be done with a road machine, cross-sections need be taken only every thousand feet. The sections shall be plotted from the bottom of the sheet upward and so as not to interfere unduly with one another. The ground and grade elevation shall be shown at each section, together with proper station number. Show the area of each section and the yardage between sections.

*Structural Plans:* Structural plans shall be submitted for all structures included in the project. When standard designs issued by this department are used, blue prints of such designs may be obtained upon request.

*Binding of Plans:* All sheets should be arranged in their numerical order and securely bound on the left hand margin. In binding the sheets, care should be taken that all sheets are properly arranged and evenly matched before binding.

*In General:* In brief, a set of road plans should contain all information necessary to enable the engineer who checks your plans also to check up the items listed on your estimate sheet. Please avoid errors in arithmetic.

From the foregoing, it will be seen that, in order to properly prepare a set of road plans, much field work must be done. In many respects, highway construction differs widely from railway construction, but the actual field work on the surveys is very similar to that required for railway location.

The termini and often several intermediate points are determined before any field work has been done, and often before the engineer has been employed, so his work of locating will involve merely the connecting up of these points with the most feasible route upon which the road can be economically constructed and maintained.

Before any field work is started, it will be necessary for the engineer to make a careful and studied reconnaissance. Sometimes this reconnaissance will consist merely of choosing between one or more definite existing roads.

After the general location of the line has been determined upon, it is then necessary to make a careful location survey, which should be made as follows:

Make the center line survey, measuring all angles and running in all curves. A stake should be set at each 100 foot station, and closer on curves. On new location and where the stakes will not be disturbed, set them on the center line. Where the located center line is within the limits of the traveled way, set stakes on an offset line and record their distance from the center line.

To this location line, tie on all topography for a distance of 500 feet on each side.

Run center line levels, establishing, bench marks not farther apart than 2,000 feet.

From the information now in hand, the location plan and center line profile can be made and a tentative grade line established. From this drawing, it can be determined what portions of the work can be done with a blade grader, and what portions must be figured as yardage.

On those portions upon which yardage is to be figured, take cross-sections at each 100-foot station, and take any intermediate sections that may be necessary to calculate accurately the amount of earth work to be done. These sections must be plotted as previously described, and the earth work computed from them.

For each drainage structure, the boundaries of the drainage basin must be actually surveyed and its area carefully ascertained, from which information the size of the drainage structure will be determined.

After the surveys have been made, the alignment has been plotted, the grade line tentatively laid, quantities have been figured and the sizes and types of drainage structures tentatively determined upon, call upon the highway engineer to have an inspection of the plans made by one of his division engineers. This inspection is made by the division engineer in company with the county engineer, and the ground is carefully gone over, plans in hand and the information on the plans being compared with conditions on the ground.

The grade line should never be inked in until after this inspection has been made and the grade line approved by a representative of the Highway Engineering Department. Also, where you are in doubt about any part of your location or other features of your plans, do not ink in until these features are definitely determined upon by consultation with the Highway Department's engineer.

## DRAINAGE AREAS AND CULVERTS

By G. G. Wickline
Bridge Engineer, State Highway Department

*Drainage Areas:* In determining the type of drainage structure for a particular location there are a number of things to be taken into consideration, as the amount and frequency of rain storms, stream characteristics, watershed area and the slopes, whether they are prairie, timber, or cultivated, or whether they are steep or flat, and the grade line of the stream bed and other elements affecting the safety of the culvert or bridge. An observation of existing structures on the same stream or in the same locality, will furnish some information that will be of assistance in determining the proper size and type of structure to be used.

*Formulas:* Where data on existing structures are not available on the same stream, there are a number of formulas which may be used that will give the approximate area necessary, provided care is taken in using the proper terms in the formula to fit the local conditions; but, wherever possible, the area so calculated by a formula should be compared to the area of an existing structure for a similar location, if there be any. Particular attention should be paid to ascertaining the high-water marks by the observation of drift or by interviewing the residents in the vicinity. In the selection of the proper waterway area, the engineer should make careful field observations and use his best judgment. There are a number of waterway area formulas and tables, no two of which will give the same results for all conditions. Most of them are prepared for special conditions in some particular locality, and do not fit other localities, unless conditions are the same. The use of tables and formulas should not be made unless, as stated above, all conditions affecting them are known.

*Duns Drainage Table:* This table was devised by James Dun of the A. T. & S. F. Railroad, and is widely used by the railroads in the Middle West. Dun's drainage table is intended to be used for all sized structures. The slopes are not taken into consideration as much as the Talbot formula.

*Talbot's Formula:* This formula was devised by Professor A. N. Talbot, and is used extensively for the determination of waterway area for highway culverts by the Federal Bureau of Public Roads and various state highway departments. Since the greater portion of the work of the State Highway Department is in conjunction with the Federal Bureau of Public Roads, Talbot's formula is used almost exclusively for the determination of waterway drainage structures and is stated as—

$$A = C\sqrt[4]{M^3}$$

Where A represents the area of the opening of culvert in square feet; *M*, the watershed area in acres; and *C*, a coefficient depending upon the slope, soil, and vegetation of the watershed area.

Professor Talbot recommends the following values for *C:* 1.0 for abrupt slopes; 1/3 for rolling agricultural country; and 1/5 for fairly level country. Provision should be made in the selection of the water area of culverts for all ordinary floods, with a good margin of safety. The Talbot formula as given above is supposed to provide for this margin of safety, but, as indicated above, it is well to compare the results with those of other structures upstream or downstream from the proposed structure. There are a great number of waterway area formulas that are used for determining the storm water run-off for sewer designs, and should not be used in connection with the design of culverts, unless a very long culvert is to be used in which the water on the upstream side can be impounded by the roadway embankment, so that no danger of overflowing the road will result.

*Grade Line of Stream Bed:* The grade line of the stream bed should be taken into consideration for the upstream and downstream sides of the culvert. Should the downstream side have a flat grade, there is danger of the stream channel becoming filled with silt, and the flow line of the culvert being raised, thereby decreasing the waterway area of the culvert. In most cases, it is possible to clean out the channel so that the flow line may be maintained at a constant elevation.

*Character of Watershed Area:* If the watershed area is cultivated land, prairie, wooded, or covered with vegetation, judgment should be used in the selection of the proper size of water area for culverts, for cultivated land is likely to carry considerable amount of silt. In watershed areas upon which there is a heavy growth of weeds and vegetation there is likelihood of trash accumulating at the upstream end of the culvert, restricting the flow of water through the culvert. The channel of the stream should be cleared and opened on each side of the culvert a sufficient distance to admit an amount of the storm water to develop the full capacity of the culvert. A contracted rough, irregular, channel has considerable effect on the carrying capacity of the culvert.

*Selection of Proper Type of Culvert:* For the small culvert requiring only a few square feet of water area, the circular type is usually selected. A box type of concrete culvert of a minimum size of 2x2 concrete culvert can be built with a special type of collapsible form. A smaller type than this is usually of the precase circular type, if concrete is used. All small culverts should have a good margin of safety in size of waterway area, for the cost for the different sizes will not vary greatly. On most highways through the flat prairie country, clear height of culvert can not be obtained without making the grade of roadway higher than necessary. Low wide waterway areas are preferable to high narrow ones. From the principle of hydraulics, a criterion is established that for a rectangular opening of equal perimeter a maximum discharge is given when the width is twice the height. The ordinary box culvert as shown in the plans of the State Highway Department conform approximately to this rule.

*Pipe Culverts:* Pipe culverts may be constructed of concrete, brick, stone, vitrified clay tile blocks, segmental clay tile blocks, corrugated galvanized iron, each material having more or less merit, depending upon the locality in which it is to be used. All of the foregoing types of culverts should be constructed of the best of the respective materials, in a careful workmanlike manner. For further information, see the specifications (Item 23), and the plans for pipe culverts of the State Highway Department.

*Head Walls:* All pipe culverts should be provided with substantial head walls of a type equally permanent and substantial as the culvert itself. See plan of the State Highway Department.

*Vitrified Tile, Corrugated Iron, Cast Iron, Pipe:* These types of circular culverts require special care in arrangement of bed for placing, in order to secure an even bearing. The back-fill around the lower portion of the culvert should be thoroughly tamped. It is also important that a proper depth of fill be provided over the culvert.

*Stone Culverts:* Stone culverts can be used to advantage in certain localities where ledge stone of good quality is plentiful, and if properly built give good results. Concrete mortar should be used wherever possible, although many railroad companies have built stone culverts without the use of mortar. Stone culverts may have the top slab of ledge stone, if of the proper thickness. The bridge engineer of the Federal Bureau of Public Roads recommends the following thickness for small culverts:

| Span in Feet | Thickness in Inches | Width in Inches | Length in Inches |
|---|---|---|---|
| 2 | 10 | 20 | 4 |
| 3 | 12 | 24 | 5 |
| 4 | 15 | 30 | 6 |

In most localities, it would be difficult to secure ledge stone that would conform to the requirements of the foregoing table, so it would probably be better to provide for a reinforced concrete top slab. See Plan G 250, on file in the State Highway Department.

*Concrete Culverts:* The monolithic type of reinforced concrete culvert is strong and durable, and a very popular type of construction at the present time. The following plans are used by the State Highway Department:

C 1, reinforced top and bottom slabs with plain side walls and plain head walls parallel to the center line of roadway.

C 2, reinforced top and bottom slab with reinforced wing walls at right angles to the center line of roadway. For low small clear heights, this type of culvert is the most economical, but it has the objection that when carrying its full capacity the water has a tendency to slop over the sides of the downstream wing walls and wash away the embankment slope, particularly where new embankment is constructed. If a small amount of rip-rap is used, or the embankment sodded with bermuda grass, this objection can be eliminated.

C 3, with reinforced top and bottom slabs and reinforced wing walls at an angle of sixty degrees with the center line of roadway gives a very good type of culvert and is most commonly used on state and federal aid projects. The flaring wing walls allow the water to spread out after leaving the culvert, without damage to the embankment slopes on the downstream side.

C 4, reinforced concrete top slab plain side walls resting on a spread footing with a reinforced wing walls at an angle of sixty degrees with the center line of roadway. This type of culvert is adapted to localities which have good foundation of shale or clay, and the danger of undermining is not very great.

*Segemental Clay Tile Block Culverts:* Plan SB 1 of the State Highway Department provides for the use of segmental clay tile blocks. A test was recently made on this type of culvert which demonstrates that, if properly constructed with the proper amount of fill over top, this type of culvert would have ample strength, and doubtless this type of culvert can be used to advantage in many parts of the state.

*Corrugated Galvanized Iron Culverts:* This type is widely used and easily placed, and great claims for permanency and strength are made by its manufacturers. No doubt if pure ingot iron, properly galvanized, and rivets equally permanent are used, this type can be employed to good advantage for various types of highway construction. Some slight allowance should be made in calculating waterway area for the corrugations.

*Plain Concrete Arch Culverts:* This type of culvert can be used in some localities where rock foundations can be secured and where the concrete aggregates necessary can be laid down at the culvert side at a low price. See Plan G 248-249 of the Federal Bureau of Public Roads, on file in the State Highway Department.

*Timber Culverts:* These culverts should not be used on permanent road construction, but may be used temporarily in localities where timber of the proper kind is available locally and where the culverts to be built are a considerable distance from the railroad. There are some localities in East Texas where the land is poor and available money for highway construction is very limited that use timber culverts to fair advantage.

*Paved Concrete Fords or Dips:* This is a type of overflow crossing, and is used in the place of culverts in certain localities where the rainfall run-off is rapid. This type is more particularly adapted to West Texas, where rain storms are infrequent. They may be concrete, flat stone, asphalt, macadem, or a good compacted quality of gravel. Good judgment should be exercised in the use of concrete dips, as they should not be used if there is any liability of the stream's filling up on the downstream side and leaving the dip covered with mud.

*Maintenance of Stream Channel:* All culverts should be inspected at regular intervals after floods. The stream channel should be kept clear from drift and trash. Deposits of silt should be removed both upstream and downstream, more particularly on the downstream side. There are some localities in Texas where a number of culverts are completely choked up with silt and trash and where water has washed out the road.

This illustrates the necessity of providing plenty of head room and a slight margin of safety in the size of the waterway area selected.

# PREPARATION OF SPECIFICATIONS AND CONTRACTS

By R. G. Tyler,
Adjunct Professor of Highway and Sanitary Engineering

Specification-writing is as difficult as it is important. All too frequently, rather than go to the trouble of making a thorough study of the problem in hand so as to be able to specify intelligently just what is desired, the engineer patches up so-called Standard Specifications to meet local conditions, lets his contract, and finds later that they may or may not fit.

A thorough knowledge of materials and methods is necessary for the proper construction of specifications. It is absolutely essential that the engineer should have a clear and definite conception of just what he wants, and be thoroughly familiar with all of the details entering into the problem in hand, in order to set down these details in a clear and concise manner. The ideal to be striven after in preparing the specifications is to state exactly what is desired, and in such accurate, specific, and adequate language that it will be impossible to mistake his meaning and give it a wrong interpretation. The practice which formerly prevailed, of inserting ambiguous blanket-clauses in an attempt to cover a point upon which the engineer was not entirely clear in his own mind, is to be condemned as being unfair to the contractor and likely to bring about misunderstanding between the contractor and the engineer.

As highway construction is not an exact science like mathematics, it is to be expected that there will be differences of opinion among the authorities and leading engineers in this branch of work. With regard to many of the details as to materials and methods of construction, and in preparing specifications, it is well to study the various opinions of experts in passing judgment on the problems being considered.

It is customary to include several documents in what may be termed the general contract, each of these documents being important and necessary thereto. These documents are usually as follows:

1. The advertisment for proposals.
2. Instructions to bidders.
3. The proposal submitted by the contractor.
4. The specifications.
5. The contract proper.

The law requires that municipalities and other units of government shall advertise for bids on all work or purchases costing $500 or more. These advertisements should appear in the leading papers published in the locality where the work is to be done, and should be published a given length of time before the opening of bids. The engineer who desires to secure the best results for his employer will advertise his contemplated work where it will receive the attention of the largest number of contractors in the particular line of work in which he is engaged, in order that he may secure as many bids as possible, thereby insuring a fair price for the municipality or county by which he is engaged.

It is desirable to let the work in large enough contracts to invite contractors having strong and well organized concerns to submit bids, and to keep the cost of shipping-in the necessary plant from running up the unit cost to any considerable amount. There are other considerations, also, which should be taken into account in deciding upon the size of the contract, such as the amount of work which can be done in one working season and the desirability of making the contracts small enough to permit the more numerous smaller contracting firms to enter the competition. These questions must be given thorough consideration by the engineer, and local conditions will assist in deciding what should be done. The tendency now is, however, to let road work in larger contracts, thereby inviting the stronger and better equipped firms, who are able to carry out a larger amount of work in a given season, to submit bids. Obviously, the contractor who can work on a large scale can give a closer price, since he is not forced to figure on prices of material and labor conditions so far in the future as the smaller contractor, and it is to the advantage of the municipality or county to have its work done quickly in order to be as small an inconvenience as possible to the local population.

As to the advertisement itself, there are two general classes in use. One is brief, and states merely that bids will be received for a given type of work at a fixed time and place, and the amount of the certified check which must accompany the bid. This class of advertisement specifies that complete plans, specifications, and contract covering the work in question may be seen in the offices of the engineer, and it has the advantage that the contractor is referred directly to the source of authentic information, so that he can get all the information desired and that there shall be no misunderstanding arising from a possible conflict in statement between the advertisement and the specifications.

The second type of advertisement is longer, and gives a condensed statement of the kind of work to be done, the schedule of quantity of work involved, and various other particulars pertaining to the contract to be let. This class has the advantage of giving the prospective bidder enough information so that he can determine without going over the plans and specifications whether the work will be of the kind or amount which he is equipped to handle. This longer form of advertisement is sometimes reuired by law, but, if not, the shorter form usually seems preferable, as it refers the inquirer directly to the official source of information as above mentioned, thereby avoiding all possible confusion. From a standpoint of cost, also, this is desirable and is often a matter of some importance.

## INSTRUCTION TO BIDDERS

The instructions to bidders should include only such information as may be necessary to assist the bidder in properly and intelligently preparing and submitting his proposal. It is proper in the instructions to refer to the specifications and contract for all general and detailed information concerning the work to be done but it should not be permitted to overlap in any way the field of the specifications and contract. It should be made as brief as possible, and its usefulness should be at an end when the contract has been signed.

### PROPOSAL

The proposal should contain definite statements as to what the bidder proposes to do. He should submit both unit prices and totals for each item specified, and it is customary to put these amounts both in writing and in figures in order to avoid error. The total costs are figured on the approximate quantities given in the engineer's estimate, and these quantities are subject to change under the conditions set forth in the specifications. The proposal, also, contains the address of the bidder, and is accompanied by a certified check payable to the order of the contractee; the check to be returned to the bidder if he is unsuccessful or upon the execution of the contract and the filing of the bond called for by the contract.

### SPECIFICATIONS

There are three general classes of engineering specifications. In the first class, the engineer specifies in detail the class of materials which he desires to be used, and the methods which, in his judgment, will bring about the desired result. In the second class, the engineer specifies as to the results to be obtained, leaving the materials and methods, at least partially, to the judgment of the contractor. In the third class, the engineer specifies both as to the materials and methods and as to the results to be obtained.

Either of the first two classes of specifications is permissible, and the one may be chosen which the engineer believes will produce the best results. The third class, however, though frequently met with, should never be tolerated, as it is obviously unfair to the contractor to specify what materials he shall use and exactly the methods to be followed, and then demand that certain results be obtained. Obviously, it is entirely possible that the result desired may not be secured by the use of the specified materials and methods, and either one or the other should be covered in the specifications, but not both.

In highway work where the type of road to be built is of a standard form, and where the materials and methods have been standardized by years of experience and paving practice, it is preferable to use the first type of specifications. Here the engineer is supposed to have sufficient experience to be able to state what he desires in the way of materials and how he wishes the work to be done. The result that will be obtained depends largely upon the experience of the engineer, and so long as he properly supervises the work and supplies the necessary inspections to see that his specifications are carried out, he should assume the responsibility as to the results to be secured. It is unfair, also, to expect a contractor to guarantee work done under this type of specifications, and he should not be expected to do so.

Where, however, the type of construction is patented, or some of the methods to be employed or the materials to be used are new, it is advisable to use the second type of specifications, and state only as to the results to be obtained rather than as to materials and methods to be employed. In this class, it is perfectly proper and legitimate to require the contractor to furnish bond guaranteeing the work to come up to certain standards and to insist upon the making good of any defects which may appear after the completion of the contract and during the life of the guarantee. In this case, the work is being done with materials or methods based upon the judgment of the contractor, and he should assume the responsibility as to the results obtained.

In writing up specifications covering patented pavements or processes, it is not usually advisable to copy in the specifications furnished by the patentor, as he will naturally make his specifications as brief as possible, and not bind himself down any more than he thinks absolutely necessary to secure the contract. While firms that have been doing business on a large scale undoubtedly present specifications which are fair, and which can be relied upon, there are times when such specifications may be carefully drawn up so as to evade final responsibility. It is desirable, therefore, that the engineer should use his own judgment and make any changes that he may deem necessary in these specifications, leaving it up to the company concerned as to whether they desire to submit a bid on his revised specifications covering their patented process or products.

Very often specifications are encountered whiih are one-sided and manifestly unfair. In the drafting of specifications, this, naturally, should be avoided; but there is a tendency to bind the contractor in every way possible, and to make the requirements so binding and drastic as to prevent many bidders from submitting figures on the work. And the prices received will be higher than they would have been had the contractor had a reasonable assurance of receiving a square deal.

The rights and authority of each party to the contract should be accurately set forth, so that there shall be no possibility of a misunderstanding. It has been customary in many cases to specify that the engineer shall be the final authority on all questions arising between the city or the county and the contractor. This, however, is often unwise, and perhaps illegal. The reason for such a clause in specifications is the supposition that the engineer is a disinterested party in the transaction, and one who is competent to pass judgment on the questions which arise. The engineer, however, is not always disinterested, as it is his desire, and properly so, to secure the best results for his client for the funds available. He is paid by his employer to look out for his interests, and may be inclined to look at all questions from this point of view. It is true that his sense of justice and professional honor will in the majority of cases cause him to pass a fair judgment upon the questions involved, but no engineer desires to be placed in so difficult a position, and it is both unfair and unwise to require him to assume it.

There are, however, some matters where the decision of the engineer should be final, unless improper motives can be shown. He should be the final judge as to whether the quality of the materials and grade of workmanship are in accordance with specifications, and as to the quantity of work which has been actually performed.

Methods of measuring the work completed and paying therefor should be stated in a definite manner, as carelessness in this feature may be the source of misunderstanding and disputes. The method of determining prices to be paid for extra work should, also, be set forth, as it is impossible to forsee all contingencies which may arise and require prices on every feature which may be encountered. A quite satisfactory method of meeting this situation is to specify that the contractor shall be paid cost plus a given percentage which would allow a fair profit for all work for which unit prices had not been submitted. It is desirable, however, to require that prices be submitted on each class of work which it is contemplated shall be done, and upon all features which may arise during the performance of the work. This seems better than submitting a price of so much per square yard of completed road surface, as the contractor is able to submit a price on each individual item which may arise, and is not required to make additions for such items as can not be readily foreseen, and the prices so submitted are likely to be fairer to both parties than in the latter case.

The relationship existing between the engineer and contractor should be one of cooperation, and it should be the engineer's desire to assist the contractor in every way possible in securing the results desired at the lowest possible cost consistent with good workmanship and materials. No engineer desires to let a contract at such a low figure as to require the contractor to work at a loss; and in receiving bids, if the engineer has reason to believe that the contractor has omitted some item and figured too low to come out even and with a fair profit on the work, it is not to his advantage to accept such a bid, because where such conditions exist the contractor will naturally endeavor to put in the work as cheaply as possible in order to prevent losing more than is absolutely necessary on the contract, and if he is not entirely honest he will skin the job wherever possible, and unfair results will be obtained.

The engineer's plans, therefore, should be as complete in every detail as possible, and he should call attention to any unusual features, both as to plans and as to specifications, so that the contractor may be fully informed as to all problems which are expected to arise.

As to the carrying out of specifications after the contract has once been signed, it appears that strictness in interpretation and absolute rigidity in requirements is not only justifiable but the only fair method to all conerned. If the contractor has gone over the specifications and contract before submitting his bid, he knows what is to be required, and has submitted his figures accordingly, and there should be no endeavor to evade any of the requirements of the contract or to secure leniency from the engineer. The engineer should provide adequate and efficient inspection of all materials and methods, and should cooperate in this regard so as to prevent unnecessary loss from unsuitable supplies which may have been received. It is true that strict adherence to specifications will in many cases mean a higher cost, but this, also, is fair to both parties, as the municipality or county should be willing to pay a fair price for the class of work desired and the contractor will find it necessary to ask a higher price than he would were he not compelled to live up strictly to specifications.

## CONTRACT

It has been customary in some cases that have come under the writer's supervision to include requirements in the rontract which were not found in the specifications. This, of course, should not be done; but, since the contractor is supposed to familiarize himself with the terms of the contract, as well as with the specifications before submitting his bid, there should be no just cause for complaint. The engineer can not usually state just what a contract should contain, as there are many points of law which must be considered and with which he can not be supposed to be familiar. It would seem proper, however, to separate the contract and specifications in such a way that each shall cover its own particular field, and that there shall be as little overlapping as possible. The contract, then, should set out only the legal and contractual relations of the parties pertaining thereto, and should refer to the plans and specifications for all detailed instructions as to materials, methods, and results to be obtained.

It is customary on some classes of work to require maintenance bond, usually covering a period of five years after completion of the highway, and guaranteeing the upkeep of the roadway except for ordinary wear and tear. It is questionable whether this bond is either fair or desirable. As previously mentioned, many engineers believe that after they have specified as to the materials and methods to be used the contractor should not be held responsible or be required to guarantee the results obtained, but that this should be done by the municipality or county concerned. The writer believes that this is the best method, and in his experience has found it the most satisfactory method, since it frequently requires time and inconvenience, and in some cases legal proceedings, to secure the proper maintenance of a highway by the contractor or bonding company.

In conclusion, it is suggested that the young engineer in writing up his specifications should model them on the specifications of some engineer in whom he has confidence until he has had sufficient experience to qualify him to pass judgment on the various questions involved. In studying the specifications prepared by an organization such as the State Highway Department, it will be found that the specifications represent the best practice of experienced engineers in highway construction. But they should not be considered as infallible, and the practicing engineer will doubtless find that he can improve upon them in some of their requirements, and in such cases he should be permitted to do so.

## ROAD SURFACES

BY J. D. FAUNTLEROY
District Engineer, Bureau of Public Roads

The War brought home to us very forcibly the necessity of a complete system of highways, and also served to develop the weak spots in our highways.

It is self-evident that in times of great stress, such as we have been through recently, a substantial system of highways, properly laid out, can be of the greatest value to the country, by relieving the traffic on the railroads, and insuring the getting of crops to market and of food and supplies from the cities to the country people.

Even in those states of the Union which have for many years been improving and building up their highways, the War was a revelation, as road surfaces which up to that time had been considered to be of the most enduring types rapidly went to pieces under the destructive influence of heavy and concentrated motor-truck traffic. Here in Texas, we have also noticed the heavy wear to which our roads have been subjected. All of this has served to create in the minds of the people a desire for better roads, and this desire has been greatly strengthened and increased by the unusually wet winter through which we have just passed, and which has made thousands of miles of our highways impassable for motor vehicles on account of mud. There is at the present time a tremendous enthusiasm in the state of Texas for building roads, and roads of the higher types. This is being manifested day by day in new bond issues, some of them running into the millions of dollars.

We approve of this enthusiasm, because we believe that money invested in the improvement of highways is well spent and results in a permanent increase of values in the country through which the highways pass, and in a very great increase in the happiness and prosperity of the people.

However, before we take up the question of the construction of roads, we should carefully consider the purpose which such roads will serve after being constructed. We should go very carefully into the question of the traffic that is going over roads now, and that which will pass over them after they are completed. For example, the experience of centuries has proved that for farm wagons a well constructed macadam gives satisfactory service. We know, also, that the wider the tires of the wagon the less wear there is on the road surface, the use of heavy loads on wagons with narrow tires having a destructive effect.

In some of the states of the Union, on roads which are traveled almost entirely by automobiles, fairly satisfactory results have been obtained by the use of graveled roads. Here, again, we notice that the larger and swifter automobiles are more destructive to a road surface than are the smaller and slower going vehicles. Experience has demonstrated, also, that auto trucks, especially when heavily loaded and traveling from 20 to 30 miles an hour, are very destructive to the lower types of road surfaces, and that only the highest and strongest types can stand up under such traffic. Therefore, in selecting a road surface, we should consider not only the traffic traveling over the road now, but we should consider also the most destructive traffic that is likely to travel over the road in the future.

## HISTORY OF ROAD TYPES

It may interest you to know what has happened in other states in regard to the selection of road types. In New York, about twenty years ago, they began building a state system of highways. Water-bound macadam was then regarded a very satisfactory type for country roads, and in many places it was thought that a well-built gravel road would answer all requirements. These roads gave satisfaction for several years, until the use of automobiles became general. In 1909, it became evident that the combined effect of heavily loaded steel-tired farm wagons and of swiftly moving automobiles with rubber tires, was very destructive to these types of road surfaces, and attempts were made to cover the surface of the road with some sort of bituminous surfacing which would prevent the finer particles of "binder" from blowing away and leaving the coarser aggregate exposed to the steel tires. Under the steel-tire traffic, you will note that the surface of the road was nearly always covered with a thin layer or carpet of the finer material or dust, which served to protect the coarser particles of stone from undue wear. The effect of the swiftly moving automobiles was to suck up and blow away the finer materials, and this led to the trial of road oils and tar to try to form a bituminous carpet coat so that the finer particles would not blow away. The next step was to try to introduce sufficient bituminous material into the top course of the macadam road, thereby converting it into bituminous macadem. A third improvement was to put all of the different ingredients into a mechanical mixer, somewhat as we do in Portland cement concrete, and then apply the product to a Macadam base and roll it, thereby securing a somewhat smoother and dense mixture than in the case of bituminous macadam, or what is known as the "Penetration Method." A still further step was to replace the macadam base with a base of Portland cement concrete. In many cases in the state of New York, concrete roads have been built, as well as roads resting on concrete bases; and it now appears that as a result of the experience gained during the War the state will in the future construct only the heaviest and most durable surface on its principal trunk-line highways.

Take the case of New Hampshire, for example. The roads of New Hampshire are used for about half the year by a very heavy tourist traffic, almost entirely automobiles, and for the remainder of the year they are used very little except by local farm wagons. It is said that the summer traffic on these roads runs as high as one thousand vehicles a day; yet, by care and efficient maintenance organization, these gravel roads are kept in good condition and are economically maintained as gravel roads. We under-stand, however, that they are not subjected to any large amount of truck traffic.

In North Carolina, it soon became apparent that the use of macadam roads under combined automobile and farm-wagon traffic was decidedly unsatisfactory; and there are many miles of roads in North Carolina, built originally as macadam roads, which have been covered with a sand-clay surfacing, and are now maintained as sand-clay roads and are giving satisfcatory results. This is because it is much easier to shape up and maintain a sand-clay road than it is to provide the necessary material to resurface a macadam road, and also because the reshaping of a macadam road generally involves scarifying the roadbed and the closing of the road to traffic.

In California, they have gone about the improvement of their roads in a very satisfactory manner, and have secured excellent results by using a thin concrete base with a carpet coating of bitumen.

In considering any surface for a road, we should look beyond the construction period and visualize what it is going to cast us to maintain this road after its construction; and, to be able to act intelligently in this matter, we are compelled to investigate carefully the traffic which is now using the road and to consider also what the probable traffic will be after the road is improved. For example, a road may now serve as a source of supply to a country population of perhaps four or five hundred people scattered over 15 or 20 miles; but, when improved and tied on at either end with the state highway system, it at once becomes a link in the highway system and the traffic will increase by leaps and bounds. It is this maximum traffic that we should consider in designing our road surfaces. In a general way, we know the following: That for light automobile traffic, combined with a moderate number of farm wagons, roads built of gravel, shell, a good quality of sand-clay, or of top-soil, will give satisfactory results. In fact, where such material can be secured close to the road, the use of these types of road surface has proved very satisfactory. Where the traffic is to consist of a large number of automobiles, of heavily loaded farm wagons and of heavy auto trucks, the road surface should be of one of the higher types. In this connection, I desire to call your attention to the thorough and systematic method now being pursued in Dallas County, where the county engineer in cooperation with the State Highway Department is designing a county system of highways (including the state highways in Dallas County) which it is estimated will cost when completed approximately seven million dollars. These roads will vary with the traffic which is expected to go over them. Some of the roads in the rural districts will probably be graveled roads with a bituminous surface treatment; others will probably consist of a heavy stone base with a two-inch bituminous top; others will consist of a concrete base with a bituminous top; while still others will be constructed entirely of concrete and of unusual thickness, in order to resist the heavy traffic to which they will be subjected. The main trunk lines in this county will have a road surface 20 feet wide, and all of the roads to be improved by the bond issue will have a surface at least 18 feet wide.

At the present time, we have 78 federal aid projects in the state of Texas, and the types of surfaces on these different roads are as follows: 10 are to have sand-clay or natural soil surfaces; 33 are to be provided with gravel, caliche, or iron-ore surfaces; 23 of these roads are to be gravel with some sort of bituminous surface treatment; 7 of the projects will be entirely of concrete; and 5 are of the heavier bituminous topped types.

In Arkansas, we have 22 federal aid projects, of which 2 have heavy bituminous tops resting on macadam bases; the other 20 are gravel roads.

In Louisiana, out of 22 federal aid road projects, we have 2 of bituminous concrete, resting on macadam bases; 20 are of gravel.

In Oklahoma, we have 5 projects, of which one is a gravel road, and the other 4 are of concrete or heavy topped bituminous roads.

Of course, on all roads we advocate (1) the best possible location; (2) the proper drainage of the road bed itself, for whether the road be of a high or a low type, it will soon go to pieces unless the sub-grade is kept well drained. We also advocate culverts and bridges of proper design and of the most substantial types. It is poor economy to use makeshift culverts and bridges.

### TRAFFIC CENSUS

Coming back again to the selection of the road type, we must first determine the traffic which goes over a road and estimate as best we can the traffic which will probably go over the road after it is completed.

In St. Louis County, Missouri, where some years ago they voted two million dollars for the construction of a county system of highways, every care was taken for a period of one month during the summer and for one month during the winter to ascertain what the mean and the maximum daily traffic amounted to; and men were kept at specified places on these roads all day long and required to tally down the vehicles that passed, and to show under the respective heading whether they were automobiles, auto trucks, motorcycles, buggies, wagons, etc. When such information is carefully worked up, we then have a base to work from.

We can also assume with safety that after a road is improved the land will become too valuable to lie idle, and that, as a result, more of it will go into cultivation, larger crops will be raised; and from this source alone there will be a great increase in the traffic using the road. We should also consider that after the road is improved, instead of being used largely by local traffic, it will probably be subjected to a heavy through traffic. Then, guided by the experience of other states, we can act intelligently in selecting the type of surface which we believe will best stand the traffic. However, we should carefully consider the soil conditions, and whether the road is in a humid section of the country or in the semi-arid section. A gravel road, for example, that might give excellent service in eastern

Texas, where there is plenty of rain, would rapidly go to pieces when subjected to the long droughts that occur in the western portion of the state.

The State Highway Department, the county officials, and the highway engineers of Texas are now favoring the period of great activity in highway construction. It is up to them to see that the people get the best results for the money which they are so lavishly voting for road improvement. It is a mistake to vote a bond issue without first considering the cost of the roads which are to be built. If a county or a district desires to vote a bond issue, the services of home highway engineer should be secured to make up an estimate of the cost of the roads to be built, and such estimate should take into consideration the probable traffic that will use these roads, and also the type of surface which is required to stand up under this traffic. Do not be afraid of the people; after the matter is thoroughly explained to the intelligent voters of this state, I feel sure that they would much rather vote a large bond issue for a suitable type of road surface than to vote a small bond issue and secure a road surface which is unsatisfactory and will not carry the traffic.

The people of the state want good roads, roads that they can use 365 days in the year, and I am sure that they will not haggle about the prices if they can only feel when they vote a bond issue that they are going to get back their money's worth in hard-surfaced roads.

## BITUMINATED ROADS

BY M. C. WELBORN
Road Engineer, State Highway Department

Within the past few years, a new type of road has been developed, which seems to fill a long felt want for a road surface intermediate in strength, durability, and cost between the ordinary gravel or macadam road and the permanently paved road. I refer to the bituminous surface treated or bituminated road.

This type is suitable for highways carrying from 500 to 2,500 vehicles a day, and if properly constructed will give satisfactory service upon highways which are subjected to moderately heavy traffic, although it is not suited for heavy traffic of the city streets.

This type of road surface is a development of the idea of oiling roads in order to prevent their becoming dusty during dry weather. During its development period, many failures have resulted, due to inexperience of those undertaking to use it. At the present time, there are several satisfactory processes in use on surface treatment work, and the use of any of these methods is now generally successful. The object of each of these processes is the same, that is, to produce a stable surface mat composed of bitumen and mineral aggregate and adhering tightly to the road's surface at every point.

*Description of Process:* Briefly stated, the process followed in bituminating a gravel or macadam road surface is as follows:

1. Carefully clean the surface, removing all dirt, dust, or other foreign material.
2. Apply the bituminous material, consisting either of tar or asphaltic oil, uniformly over the surface in one or two coats, depending upon the process adopted.
3. Cover the bituminous material previously applied with sand or stone chats.

4. In case heavy bituminous material has been applied and large-sized stone particles have been used for cover material, thoroughly roll the surface with a roller weighing from five to ten tons.

In the following, I shall attempt to point out a few of the important points to be observed in this work.

*Drainage:* As in the case of other types of roads, drainage is the first and most important point to be looked after. It has been aptly stated by a distinguished road-builder that the three most important points to be cared for in the construction of a road are: (1) Drainage; (2) DRAINAGE; (3) DRAINAGE.

Proper culverts and bridges are necessary to care for the drainage reaching the road from areas outside and beyond the limits of the road itself. Drainage of the surface is necessary to take care of the water falling upon and within the limits of the roadway, and proper sub-drainage is necessary to protect the base from the softening effect of springs and seeps.

Of course, everyone understands the importance of properly caring for the cross-drainage by means of bridges and culverts, and of proper side-ditches and roadway crown; but often the drainage of the base or foundation of the road is neglected, and improper sub-drainage of a bituminated road is likely to cause more trouble than in any other type of road.

A bituminated surface has within itself no ability to sustain heavy loads, and is dependent entirely upon the stability of the base for its support. If the base is unstable, the bituminated surface will soon be broken up. If the base should become softened by water seeping into it from the under side, the surfacing will be quickly broken up and the road at this point must be rebuilt.

*The Cross-Section:* In planning a cross-section for a bituminated road, it is desirable that the surface be made rather flat, in order to eliminate, as far as possible, the tendency of the bituminous material to run or to be pushed out toward the gutter. It should be borne in mind that when a bituminous coat is applied to a road's surface, the surface is made impervious to water. In effect, a roof is constructed over the road; hence in order to provide proper drainage for this surface a steep slope is not necessary. For convenience of traffic, a steep slope is never desirable.

However, it must be borne in mind that, when the crown is flattened, more care must be taken to prevent small irregularities, and a smoother surface must be obtained, in order to prevent small depressions that will not drain out properly.

In this connection, it is the writer's opinion that for a bituminated surface the crown should not be flatter than an average of 1/4 inch to 1 foot, or steeper than an average of 1/2 inch to 1 foot. Possibly a mean between these two figures, or, say, 3/8 of an inch to a foot, would be right.

*Material For Base:* Bituminous surface treatment can be successfully applied to brick or concrete pavements, gravel or crushed stone macadam, and to gravel surfaces. It has not been successful when applied upon sand-clay, caliche, or adobe surfaces.

If a sheet of metal is permitted to lie upon the ground during a cold night, a considerable amount of moisture will collect upon its under side. This is due to a condensation of moisture given off from the earth, caused by its coming in contact with the cold and impervious surface of the metal, and it is no doubt the case that a cold and impervious bituminous surface likewise causes a condensation of moisture on its under side; and, if the base is of clay or other material that will be readily affected by moisture, it will be softened by this accumulation of moisture and will be slightly displaced when the wheels of traffic pass over it. Such slight displacements will cause a loosening of the bituminous surface from the surface of the road, and breaks will soon occur.

It has been found to be practically an impossibility to maintain a bituminated surface upon a sand-clay road. On the other hand, if the base is made of a firm and unyielding material, such as a good quality of gravel or a regular macadam, the moisture collecting underneath the surface sheet will have no such softening effect upon the base, and hence no displacement of the surface will result.

*Preparation of Base:* Too much emphasis can not be placed upon the importance of a firm and unyielding base, and great care should be exercised to the end that the base may be thoroughly solidified before the bituminous material is applied. It is also very important that the base be brought to a true and even section, and the waves, chuck-holes, and depressions eliminated before the bituminous material is applied.

In the preparation of an old roadway for a base, it is usually necessary to add a certain amount of new material. In doing this, care should be observed to scarify the old surface thoroughly before the new material is added. It is important that this new material be thoroughly bonded to the old base; otherwise a thin crust of new material will be produced in places, and this thin layer will heave and slip on the old surface and will cause the breaking up of the bituminous coat.

*Cleaning the Surface:* Before any bituminous material is applied, it is necessary to have the surface entirely free from dust and loose material of every kind. The usual custom is first to clean the surface with a rotary wire street broom. It is sometimes necessary to pass over the road twice or possibly three times with this street broom, after which the work of sweeping is finished with a hand broom. The rotary broom will not remove the dust from slight depressions in the surface, and it is necessary to sweep out these places with the hand broom.

After the sweeping has been completed, the remaining dust particles are sometimes removed by air blast and sometimes by sprinkling lightly with water. If the latter method is used, care must be taken that no pools of water are left standing on the surface, for, while the bituminous material can be successfully applied on a base slightly moist, the base must not be wet when the bituminous material is distributed.

If the base is not thoroughly cleaned, a good bond can not be obtained between the bituminous material and the road's surface, and the resulting bituminous coat will be picked up and carried away by the wheels of traffic.

*Bituminous Material:* The bituminous material applied may be either water gas, tar, or oil asphalt. In our general specifications for this class of work, we have provided for a number of different grades of asphalt, and two different grades of tar. Each of these materials is valuable in some one of the several different methods of treatment, as follows:

The tar product specified under item 8.2b is suitable for the penetration or first coat in a two-coat treatment.

The refined coal tar specified under item 8.2a is suitable for the second coat in a two-coat treatment.

Asphaltic oil, Class A, specified under item 8.2c is suitable for a single coat treatment to be used with coarse cover material thoroughly rolled down.

Asphaltic oil, Class Aa, specified under item 8.2b is practically the same as the Class A material above.

The asphaltic oil, Class B, specified under item 8.2e is suitable for the second coat in a two-coat application.

The asphaltic oil, Class C, specified under item 8.2f is suitable for the first coat and the second coat in a two-coat application.

The asphaltic oil, Class D, specified under item 8.2g is suitable for the first coat in a two-coat application.

As you will note, we have specified a number of different bituminous materials for use in this work. It would seem that to specify a single material would be more consistent and would bring about the standardization of the process more quickly, but when the State Highway Department was organized we found that all of these materials were being used and that the use of each was being attended with considerable success. For some conditions, one of these materials is best; for other conditions, an entirely different material may be better; but the process is new and there is available little or no data by which it could be established that any one material or process is superior to any other material or process. In other words, the process has not entirely emerged from its experimental stage, and until a considerable amount of data has been obtained through the use of different processes and materials, it will not be logical for us or for any one to say just what materials and processes are superior to other materials and processes in all cases.

*Application of Bituminous Material:* Before the bituminous material is applied, it is necessary to heat it somewhat, and the degree of heat to which it must be raised depends upon the character of the material, the atmospheric temperature, and the character of the surface to be treated, and varies from 100° F. for our Class D material, to 350° F. for our Class A material. For a previously treated and comparatively smooth surface, it is not necessary to heat the material to so high a degree in the case of a new and untreated surface. It is necessary to regulate the temperature of the bituminous material to such a degree that it will not flow too much toward the ditches after it has been applied and still be sufficiently fluid to permit of an even distribution. It is necessary to heat the bituminous material to a higher degree in cold weather than in warm weather; in fact, the proper temperature for the bituminous material should depend solely upon the character of the material, the temperature of the atmosphere, and the character and conditions of the surface to be treated.

It is sometimes the case that a distributing machine is the factor governing the temperature to which the material must be heated in order to produce an even distribution, but this should not be. If the distributing machine can not apply the material at the proper temperature based upon the surface and weather conditions, it should be put off the job and a machine should be used that *can* meet these conditions.

There are a number of different makes of distributing machines, most of which are good, and there should be no trouble in obtaining the proper machine for the work.

Uniform distribution of the bituminous material is absolutely essential, and great care should be taken to see that the distribution is uniform. It is possible to obtain an even distribution of every class of material that we have specified in our standard specifications, and the engineer on the job should be on the watch to see that this material is put down properly.

One point in the distribution of this bituminous material which is frequently overlooked, and which should be attended to most diligently, is the necessity for preventing unusually heavy deposits of bituminous material in spots along the road. Often in starting or stopping a distributing machine, much more material is deposited in spots than is pread over the other section of the road. Any excessive deposits of material should be immediately broomed to the side of the road. If this is not done, a disagreeable "bump" is formed, which must be eventually be removed with a pick and shovel.

For a two-course treatment, the amount of the first application varies from 0.2 to 0.3 gallons per square yard, and the amount of the second coat varies from 0.3 to 0.4 gallons per square yard. For the single coat application, the amount of bituminous material varies from 0.5 to 0.7 gallons per square yard.

*Cover Material:* You will note that we have specified several different classes of cover materials. For use with the lighter bituminous materials, and where the surface is not to be rolled after treatment, coarse sand and pea gravel make a fairly satisfactory cover material; but, with the heavier bituminous materials, granite gravel, crushed limestone, and crushed trap rock are better than the sand or gravel. The principal requisite is a cover material that is hard, angular, and fairly well graded as to size. On this latter point, however, there is practically no data available as to proper grading, and the percentages of the different sizes of particles which are likely to give the best results under given conditions have not been determined. It is on this account that our specifications here have been left open.

In order to determine these factors, an extensive series of laboratory tests should be conducted and the results checked against the action of the materials on the road. At present our knowledge of the subject is too limited to warrant our drawing the lines too close.

*Application of Cover Material:* After the bituminous material has been applied, the cover material, which has been previously distributed along the side of the road, is spread over the surface by hand. In this part of the work, it is necessary to observe considerable care, to the end that this material is also distributed uniformly. The material must be thrown on the road with a sweeping motion, and experienced workmen should be employed for this work. There are machines made for distributing cover material, but the writer has never seen one in use, and is somewhat skeptical as to just how the machine is to be drawn over the newly applied bituminous material without picking it up, thereby leaving spots on the road bare of any bituminous material, and causing an uneven and ununiform surface. However, if it were possible to use such a distributing machine, a better job would undoubtedly be produced than where the distributing is done by hand.

In discussing the application of this cover material, it must be borne in mind that there are a number of different methods of constructing a bituminous surface coat on a road's surface, each requiring a different manner of applying both the asphalt and the surfacing material, but they are all intended to produce the same final results.

In one method of construction, the idea is to apply a thin coat of light bituminous material, known as the penetration coat. Let this material remain uncovered for about twenty-four hours, at the end of which time a second coat of a heavier bituminous material is spread over the first coat, and is left to be developed by traffic. However, if a coarse cover material is used in this method, the surface must be rolled with a comparatively heavy roller after the cover material has been applied.

There is also another method very similar to the former one, the only difference being that the cover material is applied immediately after the application of each coat of bituminous material. In this method, the first coat of asphalt and cover material should be subjected to traffic for at least three days, at the end of which time it should be swept clean and the second coat should be applied, followed immediately with the cover material, after which the surface is rolled or not, depending upon the character of the bituminous and cover material.

The writer has also known of very successful results being produced by the application of two coats of a light bituminous material as specified in our Class D, sanded after each coat and left for traffic to develop, without the use of a roller.

Another method used is sometimes called the inverted penetration method, which consists of application of 0.5 to 0.7 gallons of bituminous material per square yard and covered with a coarse cover material, graded from ¼ to 1 inch and the whole thoroughly rolled.

*Amount of Cover Material:* The amount of cover material for a surface treatment varies with the character and specific gravity of the asphaltic material, and ranges from 1 cubic yard to 100 square yards of surface for light treatments, to 1 cubic yard to 40 square yards for the heavier asphalts applied at the rate of 0.5 to 0.6 gallons per square yard. Asphalt requires a considerably greater amount of cover material per gallon than is necessary to be used with tar.

*Natural Limestone Rock Asphalt:* Another method of surface treatment not mentioned heretofore is the construction of a bituminous surface mat, using for this purpose natural limestone rock asphalt, which process is fully explained in our specifications, Items 8.9 and 8.10. This method has been used for a comparatively short time, but the results produced are remarkable; and, while the cost is somewhat greater than that for surface treatments using the liquid bituminous material, it is considered by some authorities to be very much superior to any of the other types of construction. The writer also has seen fine crushed natural rock asphalt used as a cover material in retreatment work in Bexar County. It was spread over the road just as stone chat or sand would be used after the liquid asphalt oil had been applied. The results produced have thus far been entirely satisfactory, although only six weeks or two months have elapsed since it was put down.

# PENETRATION BITUMINOUS PAVEMENTS

BY R. G. TYLER
Adjunct Professor of Highway and Sanitary Engineering

So many errors have been made in the construction of penetration bituminous pavements, and so many failures have resulted therefrom, that some engineers have become convinced that a satisfactory pavement can not be constructed in this manner; and, until the principles involved are thoroughly understood, failures will continue to result. Just because this pavement can be laid without the expensive plant needed for the mixed method of construction, it does not follow that any foreman who can handle laborers can lay a penetration pavement. Even more care is necessary in respect to the various details of construction with this pavement than with some other types. It is a fatal mistake to attempt any paving construction, except under the supervision of a competent engineer.

There are so many things to be said in favor of this type of construction that it is to be hoped that it will receive proper consideration from the engineers who contemplate street improvements. Especially is this true for the smaller towns. Contractors will bid on smaller contracts, since there is no expensive plant required. The unit cost of the pavement is less than for mixed pavements, in the majority of cases. Patch work can be done by the municipality more satisfactorily, and there is no very good reason why the community should not build its own pavements in the first place.

The object of this paper is not to tell something new and startling, but to review the best practice in penetration work, and to call attention to some of the more important details, based upon work which has come under the speaker's experience and observation.

The same care must be given to securing a proper foundation as is done for other pavements. The base course may be either macadam, gravel, or concrete. The first two are, of course, cheaper; and, since penetration macadam is used in order to secure a cheaper pavement, a macadam or gravel base is the logical one to be used.

The customary thickness of this base is from 4 inches to 6 inches. The thicker courses are usually laid in two layers, to facilitate rolling. Certain precautions need be observed in this operation. The material should never be dumped in rows from dump wagons and then spread with a grader or drag. Roads so constructed are quite sure to be wavy and uneven. When the material is dumped in this fashion, the finer stone works to the bottom of the pile, and, in spreading, only the larger sizes of stone are carried to the outer edges of the roadway. The materials will not compress evenly under the roller, and an uneven surface results. The better plan is to dump on boards, and spread on to the roadway with shovels, or to use certain types of wagons by which the materials may be spread quite uniformly in dumping. If the stone must be dumped in windrows, it should, at least, be harrowed when spread.

The base should be filled with a finer material, which keeps the foundation material from working up into the base, or the bituminous binder from the top course from penetrating down into it and being wasted. Any inequalities of surface are also remedied with this material, and the base brought to the desired crown and grade. A road gravel may be used for this purpose, if cheaper than stone screenings.

This base may be constructed of a softer and cheaper grade of stone than for the wearing surface. It is often possible to use a local material for this purpose, but, the poorer the material, the thicker should be the course.

In constructing the wearing surface, a hard and tough stone is desirable. The course is laid in the same manner as the base course, and usually is from 2 inches to 3 inches thick. It is necessary that the stone be absolutely clean and free from dust, and dry, so that the bitumen will stick to it. For a 2-inch top, stone from 1½ inches to 2½ inches is the most desirable size. Stone passing a 2½-inch screen will roll down satisfactorily in a 2-inch top course. The size of the stone depends somewhat on the hardness. It should all be nearly the same size, in order to leave this course open to receive the binder. The stone should then be rolled as long as the character of the stone will permit. An experienced roller-man will be able to detect when the stones begin to crush and wear on each other, when it has been rolled sufficiently. The softer materials can not be rolled very much, as the voids will be closed and the surface will go together too much to permit of the proper penetration of the bitumen. If the proper size stone is used for this course and it is well rolled, much will be added to the stability of the pavement by the proper interlocking of the stone. A penetration pavement depends upon this interlocking of the stone in the wearing surface, to prevent rolling and pushing under traffic, quite as much as upon the binding together by the bitumen.

The next step in the process of construction is the application of the binder. This is an asphalt or tar of suitable consistency and characteristics, which is applied hot, either by hand or from pressure distributors. If the wearing surface has been properly laid, it will take up from 1½ gallons to 1¾ gallons per square yard of road surface. This application should be very carefully applied, so as to obtain uniformity of treatment, or fat spots will result. Follow up the treatment with a thinly spread layer of stone, passing the ½-inch or ¾-inch screens, with the dust screened out, and roll this well into the wearing surface. After rolling, the surface is swept free of all dust and loose material, and a seal coat of ¼ gallon per square yard applied. This is followed by a coat of cover material of stone screenings, and rolled, if desired. This cover material is worked into the voids between the surface stones, and a smooth and compact surface results. If on hillside work, the seal coat may be left off, so as to form a rough surface. A pavement of this type will improve after it has been down a short time and the binder has worked up to the surface and formed a mat.

In practice, the plant necessary for laying this type of pavement is very inelaborate. The bitumen may be heated in portable kettles, taking care not to allow the temperature to approach the burning point. Three hundred and fifty degrees Fahrenheit is the maximum temperature that should be allowed. If there is water in the bitumen, it will have to be heated gradually and the temperature raised slowly, to prevent foaming. The material can then be applied by hand or from pressure distributors. While the latter is preferable, the former gives satisfactory results with proper care.

A pouring pot having a broad spout should be used, the operator walking backward, without swinging the pot from side to side. The uniformity of the pavement surface depends very much on the uniformity of this treatment. A 10-ton steam roller and a few teams for hauling complete the plant equipment. With this simple plant a city may easily and economically build its own pavements.

The tendency now is to break away from the practice of having a pavement built under a five-year guarantee. Engineers are finding it cheaper and more satisfactory to specify what they want in a pavement, to have their inspectors see to it that the specifications are lived up to, and to maintain the pavement with city forces. Not only is this method cheaper, but the pavement may be kept in good condition at all times, and cuts made by public service corporations repaired without delay. Here the penetration pavement is particularly advantageous, as small repairs may be done economically by a municipal repair squad.

Considerable repairing of penetration pavements has been done in the East by cold mixtures. About 18 to 20 gallons of the asphalt oil or tar are added to a cubic yard of graded aggregate. The whole is thoroughly mixed, the hole to be patched cleaned out, painted and filled, and the patching material patted down with a shovel, leaving it a very little higher than the surrounding pavement, to allow it to pack under traffic. These patches may be mixed on the job in the desired amounts, and should prove inexpensive. It is not usually considered good practice to use a different kind of material on patchwork than in the original construction.

In all types of bituminous pavements, it is necessary to keep a thin surface mat of bitumen and sand or screenings covering the pavement proper. This, in the speaker's opinion, is the secret of longevity of a pavement. When this mat wears off, the mosaic appearance so familiar to us all is in evidence. The stone begins to wear, and the wearing course becomes thinner. This should never be permitted. The wearing course would wear entirely away in a few years, and have to be replaced at considerable expense, while a fresh flush coat can be applied every few years, as it may be needed, at a cost of only a few cents per square yard.

We read of pavements in the East that have been down forty years, and upon investigation we find that, as soon as the stone begins to show up, as above stated, the street received a paint coat of bitumen and cover material, which took the wear until the stone again began to appear, when the treatment was repeated. There seems to be no good reason why the life of a pavement, whether penetration or mixed, should not be prolonged indefinitely in this manner. We would not think of letting the top course wear away and expose the base course to traffic, so why should we let the thin surface mat wear away and expose, the top course to wear? In the speaker's opinion, this bituminous mat is just as important a part of the pavement as either the top or base courses.

One cause of ravelling of penetration pavements is the splintering of the fragments of stone by blows from the caulks on the horses' shoes. These fragments pick out, and a hole is the result. If a large per cent of the traffic is motor driven, it may be able to keep these places ironed out, but the trouble will probably not occur if the surface mat is intact.

The penetration road is a satisfactory road when properly constructed. It should have a wide field of usefulness in streets not having heavy traffic, and should become a popular type of construction for highways outside our municipalities. Undoubtedly it is destined to come more and more into use in county and state highway construction, as has been the case elsewhere; and this will be fortunate, since this pavement is cheap, durable, and suitable for all kinds of vehicles which may be used thereon.

# TRAP ROCK AS THE MINERAL AGGREGATE IN HARD-SURFACED ROADS AND STREETS

BY A. H. MUIR AND E. L. DENNIS, JR.
Of the Texas Trap Rock Company

The increase not only in population, agriculture, and industry, but also in vehicle traffic, particularly motor traffic, that has been going on so rapidly in Texas in the past 10 or 15 years, has placed a burden on the country roads of the state, which is more than they can bear. The result has been that our communities have found progressively that dirt and gravel and other water-bound types of construction not only are more expensive to the communities' road funds in the long run than the hard-surfaced type of road; but also impose a great burden of expense upon the owners of vehicles which must travel them, because of the damaging effect of rough and muddy roads to the vehicles themselves and because of the low tonnage that can be hauled per vehicle per day of operation. This general assertion applies, of course, to the main and heavily traveled roads. Just how far the extension of hard-surfaced construction on the more lightly traveled roads would be more economical than dirt or gravel construction, is a question which can be determined only by a careful and unprejudiced experience and observation over a period of years.

It is a source of congratulation to the state of Texas that its State University, through the technical branches of this institution, and its state legislature, through the Highway Board, are already collecting and giving out information and organinzing and directing and planning the construction of roads before any large proportion of the roads of the state have been built with the more expensive types of construction.

This policy on the part of the University and the Highway Board will save great sums of money from being spent unwisely in extensive road construction, which might otherwise be so expended. It is an unfortunate fact that large sums of public money in various parts of the United States have been spent in expensive and supposedly economical types of highways, without the fullest and most intelligent investigation of the entire construction from subgrade to finished surface, with the result that in a number of cases the road has not been as economical or as well-suited to the conditions of location and traffic as it should have been.

A properly constructed hard-surfaced road is an improvement whose benefits, both financially and in the matter of comfort and convenience, extend over a number of years; and for this reason it is fundamental that the surface of this road should be made resistant both to the weight and wear and to the shoving or pulling action of the traffic.

The surface of such a road is composed essentially of two classes of materials: a mineral aggregate or wearing material, and a binding material to hold the wearing material together. The binding materials in bituminous surfaced roads are asphalts and tars, which are combined in various proportions and manners with the mineral aggregate. In concrete roads, the binding material is Portland cement, or it might better be stated to be the cement mortar (composed of cement and sand), which mortar is the agent binding together the particles of stone of the coarse aggregate in the concrete. In both classes of road surface, the mineral aggregate, or wearing agent, forms by far the greatest proportion of the total materials which make up the surface.

Therefore, it is not unnatural to expect that the qualities of the stone used in the surface have a great influence on the resistance of the surface to the action of traffic, regardless of how good may be the qualities of the binder, whether concrete or bituminous.

The stone in both bituminous and concrete roads is subjected to the same action of grinding and pounding by various classes of traffic as in the macadam road, and it should have the same qualities, except in the matter of producing a natural recementing dust. The binding together of the stone particles by the cement mortar in concrete roads, and by the bitumen in bituminous roads, takes the place of the recementing action of the rock dust in the macadam road. Therefore, the qualities we should look for in the mineral aggregate for our hard-surfaced roads, are hardness, toughness, and resistance to wear, together with a desirable shape of rock fragment to promote interlocking and solidity of the bed of mineral aggregate.

Not only should the stone have these qualities, but it should have them rather uniformly. Expressed in a different way, we may state that many stones can be found where a few individual pieces of stone are of high quality, but a considerable portion of the average run of the stone produced does not have these qualities in a high degree. The result of such varying character of stone is a road surface which wears unevenly and does not give the length of life which laboratory tests on certain selected samples of such stone would indicate.

The extremely hard and tough dark gray igneous rock known commercially as trap rock has been considered the best aggregate for road and pavements in the parts of the United States where it is obtainable; and an excellent grade of trap rock has been quarried in Texas for the past five years.

Laboratory tests of this Texas trap rock compared with other stones now on the market are as follows:

RESULTS OF UNIVERSITY OF TEXAS TESTS AT AUSTIN, TEXAS, OF SAMPLES OF THE VARIOUS ROCK PRODUCED IN TEXAS

| | Weight pounds per cubic foot. | Water absorpton pounds per cubic foot. | French Coefficient of water | Hardness | Toughness | Crushing Strength pounds per square inch |
|---|---|---|---|---|---|---|
| Trap Rock from Knippa, Uvalde County ....... | 193 | .39 | 22.2 | 17.5 | 15 | 34,000 |
| Granite from Llano, Llano County .............. | 165 | X | X | 18.8 | 15 | 20,300 |
| Granite from Granite Mountain, Burnet County | 165 | X | X | X | X | 15,225 |
| Granite from Llano, Llano County .............. | 163 | .48 | X | X | X | 11,990 |
| Limestone from Alvord, Wise County ......... | 168 | .31 | 10.2 | 15.0 | 6 | 11,425 |
| Limestone from Mineral Wells, Palo Pinto County | 165 | .54 | 9.2 | 12.5 | 7 | 8,425 |
| Limestone from New Braunfels, Comal County ... | 162 | .89 | 6.6 | 9.8 | 4 | 7,725 |
| Limestone from New Braunfels, Comal County ... | 156 | 2.87 | 5.9 | 8.2 | 3 | 6,000 |
| Limestone from Chico, Wise County .......... | 168 | .36 | 6.6 | 14.6 | 6 | 4,240 |

NOTE: "X" denotes "not tested."

Its great superiority in the qualities usually desired for a road-making stone, together with its much greater uniformity in such qualities, have made trap rock practically a material by itself for road surfacing and paving in Texas. These qualities make it difficult and expensive to quarry an crush, and the amount of wear and breakage of machinery in a trap rock plant is incredible to plant operators who have handled only other kinds of stone. The writer knows of a plant where recently in the ordinary course of business one 15-inch crusher shaft was bent and another one was snapped off by reason of the hardness and toughness of the rock that was being crushed having gradually weakened these immense steel shafts. This and similar breakage would not occur in the same crusher in a limestone or gravel plant in 20 years. There is also very rapid wear of all iron and steel surfaces that the trap rock touches in the plant. But it is these same qualities of enormous resistance to any kind of destruction which we wish to get into our road surfaces, and for this reason trap rock is used extensively at locations several hundred miles distant from its point of shipment.

It should be borne in mind, however, that in bituminous or concrete road surfaces the stone represents a much smaller proportion of the total cost of the finished road than in the case of a macadam road; and, therefore, a better grade of stone than is obtainable locally can be imported for use in hard-surfaced construction with a much less proportionate increase in cost of the finished road than in the case of the macadam road. In other words, the cost of cement, tar, asphalt, mixing, heating, hauling, and laying are the same for a square yard of road surface, regardless of the quality of the stone used; and the sum total of these cost items is much greater than the cost of the stone; but it is the stone that supplies the resistance to wear and pounding in the case of concrete and bituminous road surfaces, and the resistance to shoving and crawling in the case of bituminous surfaces. The expenditure of a few extra cents per square yard of surface in order to get a mineral aggregate of the highest quality may represent an extension for a number of years in the life of the entire job, as well as a considerable annual saving in cost of maintenance.

Of course, the obtaining of the full value of a high-class mineral aggregate in your road surface depends on giving that aggregate a chance to bring its qualities into play. By this we mean that, unless the drainage and subgrade are properly constructed, and unless the pavement base is properly constructed, and unless the road surface itself is properly constructed, the road in all probability will fail, regardless of what quality of material you put in your road surface. But, if all details as to engineering, materials, and construction are properly and skillfully carried out, then the use of the highest quality aggregate will pay for itself many times over during the life of the road.

During the period of a number of years, the writers have had occasion to observe the action of various aggregates in bituminous surface treatments, bituminous macadam, and bithulithic road surface, and concrete roads and streets. A brief statement of some of these observations will serve to illustrate the ideas which I have attempted to state in a general way in this paper.

## BITUMINOUS SURFACE TREATMENT

The application of bitumen to the surface of a gravel or macadam road, and covering it with mineral aggregate, originally began as an outgrowth of the method of road preservation sometimes referred to as "oiling." Many of us can remember the time when roads were covered with a thin application of oil or other bitumen for the purpose of laying the dust and binding the rock particles of the surface together. Experience in this process, however, demonstrated the necessity of a cover material to get the full value of the bituminous seal-coat on the road. The first cover materials used were fine sand and pea gravel, but later stone chips were tried and found to produce a more substantial and enduring surface, and one which equalized the smaller inequalities in the old road surface. Since that time, there has been an increase in the size of chips used, so that now ¾-inch or ⅞-inch stone is generally used, and with most excellent results in the character of surface produced.

The largest stone or gravel particles in the cover material extend down through the entire thickness of the surface treatment. The shattering or picking out of such pieces starts the process of wear and rolling at such places, and also admits moisture under the surface there. An examination of treated roads in which limestone, sand gravel, limestone gravel, and trap rock has been used, will show plainly the value of a non-shattering aggregate of uniform quality as a cover material. Also, the resistance of the aggregate to grinding is essential in preserving the surface with sufficient thickness to be a protection to the base.

Wilson Street, San Antonio, which runs between Fort Sam Houston and Camp Travis, was treated in December, 1915, using hard limestone of 1-inch size, and the surface required retreatment in October, 1916, when it was given a treatment of coarse sand gravel, composed of quartz, feldspar, and some limestone and sandstone particles. When the establishment of Camp Travis increased the traffic in the early summer of 1917, the surface rapidly got on a very bad condition and full of holes. In September, 1917, it was given a retreatment, using trap rock, and without filling the holes in the base, as the traffic was so great that in the judgment of the constructing officers there was no time for patching. In spite of the immensely increased traffic (the construction department counting more than 9,000 vehicles in one regular business day), this surface remained unbroken till March, 1919. All the roads in Camp Travis consist of a hastily constructed base of gravel with a large portion of clay, and on this base immediately upon its completion was laid a trap rock bituminous treatment; and they have given a most remarkable demonstration of endurance under heavy traffic in the 20 months since this camp was built to accommodate 70,000 troops.

In August, 1916, the Fredericksburg Road, in Bexar County, was given a retreatment of sand gravel. On one portion of the road there was a shortage of the sand gravel after the bitumen had been applied, and trap rock screenings were used to cover a section of about 200 yards length. The sand gravel portion of the road showed marked picking and wear in one year, and was retreated in August, 1917. By August, 1918, the sand gravel portion was again in need of a retreatment, while the trap rock portion was still in good condition. The entire road was given a retreatment in the winter of 1918.

## BITUMINOUS MACADAM

In this class of construction, not only does the hardness and toughness of the surface particles of the mineral aggregate have an effect on the life of the paving, but the crushing strength and resistance to wear of the particles contained within the bituminous paving itself are required to meet the internal friction and pressure which attack all pavings to a greater or less degree. The shape of the particles of which the paving is made also seems to have a certain effect in promoting greater or less stability.

Laurel Street, in San Antonio, is a trap rock bituminous macadam, constructed in February, 1915. It is subjected to a good deal of traffic, as it is the only paved street crossing Main Avenue in a considerable distance, and it leads to several important country roads. This street today, after more than four years, is in excellent condition. Its surface is not pitted or worn in uneven patches. It has not rolled or shoved, and to all appearances will be a smooth and satisfactory street for many years to come. The same is true of Eads Avenue, San Antonio, built in March, 1916, of the same materials, which is part of the South Loop drive. These are the two oldest examples of thick rock bituminous macadam in the state, and a comparison of the service and amount of money spent in maintenance and present condition of these streets with bituminous macadam in Dallas, Fort Worth, and other cities where crushed limestone was used instead of trap rock, demonstrates the ultimate economy of using the highest class of mineral aggregate for this kind of construction.

A rather remarkable demonstration of the endurance of a light bituminous macadam, where the mineral aggregate has the right qualities, is found on New Braunfels Avenue, San Antonio. In August, 1914, the Quartermaster at Fort Sam Houston retopped with trap rock to a thickness of slightly more than 1 inch a part of this gravel street which extended through Fort Sam Houston. This particular part of street has never received retopping or retreatment, though it has now been under heavy government traffic for nearly five years. In the last few months, it has developed a number of holes, indicating that its life is nearly finished, although the general surface of the street has not yet disintegrated. Another portion of the same street was surfaced with 2 inches of a natural mixture of asphalt and limestone in 1916, and this portion of the street has received general maintenance and repairs at three or four intervals. Yet, in spite of being constructed two years later and having received a great deal of maintenace and being originally nearly twice as heavy construction, this portion of the street at the present time is in hardly better condition than the old and thinner portion of trap-rock aggregate.

## BITHULITHIC PAVING

The bithulithic pavements in San Antonio were made with trap rock exclusively as their mineral aggregate. The great uniformity in method of construction, and the care exercised by the bithulithic contractors in Texas to maintain this uniformity, furnish a most excellent and accurate method of testing whether a change in the quality of mineral aggregate does have much effect on a bituminous paving. If such effect does exist, we would expect to find a difference in the appearance, wearing qualities, and cost of maintenance of the bithulithic pavings in San Antonio, as compared with these pavings in Austin, Dallas, Houston, Corpus Christi, and other cities where stones other than trap rock were used as the aggregate.

The contractors for this paving have been most scrupulous and painstaking in maintaining their paving throughout the State, and whenever the wear on the surface reaches the point where it becomes pitted and uneven they promptly resurface the paving.

The oldest bithulithic street in San Antonio is Main Avenue, which is the principal thoroughfare from the business district out to the most populous section of the city. This street was constructed in August, 1914, and its surface is as smooth today as it was nearly five years ago. If you ask practically any citizen of San Antonio what in his opinion is the best street in San Antonio, in nine cases out of ten you will get the answer "Main Avenue." Yet, neither this street nor any other of the bithulithic streets in San Antonio has required resurfacing of any kind. The surface has become so smooth and even under traffic that it is almost impossible to find the rock particles showing in the surface of the heavily-traveled streets, which certainly is not the case with the streets of this construction in other cities of Texas; and the resurfacing process has been been very generally applied after a few years of wear to the bithulithic streets in the cities of Texas where stone was used without the hardness, toughness, and other qualities of trap rock.

The asphaltic concrete streets do not offer as good an illustration of this, for the reason that in most of these streets that the writer has observed the surface shoves or rolls into deep waves, so that the street requires resurfacing from that cause before the mineral aggregate has a chance to demonstrate its effect in resistance to wear.

## CONCRETE PAVING

That the coarse aggregate in concrete subjected to traffic must be largely depended upon to offer the pavement's resistance to wear, is amply demonstrated by many examples of actual pavings, headers, etc., that have been laid.

Laboratory tests have been devised with the hope of imitating the effect of traffic on concrete paving surfaces. The deductions from these laboratory experiments are helpful, provided they are compared and checked by actual traffic conditions. The test consists essentially of the pounding and sliding of pieces of metal, etc., upon the surface of the concrete to be tested, in a revolving machine. The feature of this test which is not truly representative of actual traffic is that these metal pieces tend to pick at the surface rather than grind it away or deliver heavy blows in the same manner that wagon tires treat a pavement. There is, of course, a certain amount of pounding and picking effect from horses feet; but the proportion is nothing like that obtained in the test referred to. However, even such a laboratory test shows the resistance of the harder rocks, in that the concrete made of the harder and tougher rocks, when so tested, comes out with a surface consisting of knobs of rock surrounded by depressions of mortar, which is not the case when the softer rocks are used in the concrete. Where the hard material is of round and smooth pieces, or where it does not have high toughness, a number of its particles will be fractured or picked out of the surface of the concrete.

The above reference to a largely theoretical test is made for the reason that this test helps to explain the value of a hard and tough rock in a concrete wearing surface.

Cameron Street, in San Antonio, was laid in 1915, consisting of a 1.2:4 mix, the coarse aggregate being trap rock from 1½ inches down. The heaviest traveled portion of this street is in the downtown business district, and extends from Houston Street to Commerce Street, both of which are wood-block pavings. The surface of this concrete paving is today in perfect condition. The joints have not spalled, and the general appearance of the street is as smooth as when first laid. However, a close examination will show that the particles of trap rock protrude an exceedingly slight distance above the surface of the mortar, and these particles show the grinding that is occurring on their tops. The difference in elevation of the rock from the mortar is not enough to be noticed except on close examination; but it shows plainly from what *source* the street is deriving its *resistance to wear.* An examination of the limestone 1:2:4 concrete streets in San Antonio shows the stone and mortar remain at absolutely the same level, but that at certain places a general depression of a few inches to a few feet in diameter is worn in the surface of the concrete. The existence of these general depressions is undoubtedly due to the varying hardness of the stone in different parts of the paving.

Another illustration of the resistance to wear in concrete being furnished by coarse aggregate is shown in a number of places in the downtown business district where concrete headers have been placed at points where a wood-block paving joins a bridge or other paving. In a number of cases, these headers are made of a coarse aggregate consisting of a mixture of limestone or gravel and trap rock. In such cases the trap rock stones protrude and show the same wear on their upper surfaces as is described in the concrete paving, while the other stone and mortar are worn down to a lower level.

These illustrations can be repeated many times; but we are dealing in a general principle, and the examples above given bring out the point involved.

When the traffic on a hard-surfaced road of any type has worn off an average thickness of about 2 inches, the road has become too rough to be considered a good surface.

It would, therefore, seem to be an economical policy to construct concrete streets and roads with the aggregate of the main body of concrete composed of the cheapest local aggregate which will make a satisfactory concrete from the standpoint of strength, while the upper 2 inches of the concrete should have as its aggregate an extremely hard and tough material, such as trap rock. In this manner, the cost of the pavement will be held down and at the same time the greatest service value will be built into the pavement. That this principle is recognized by those who have had the greatest experience with concrete roads is demonstrated in Wayne County, Michigan, which is nationally famous for its early adoption and extensive construction of concrete roads. In the 1916 report of the highway commissioners of this county, a definite stand was taken for the two-course construction, with trap rock or a tough granite as the aggregate for the upper course of the concrete. This county imports trap rock a distance of about 400 miles, and has had experience in the past 10 years with a number of different kinds of aggregates in concrete roads.

In conclusion let us say that while the foregoing paper may seem at times to be merely the praising of one certain material, yet the facts are plain and open and speak for themselves, and I feel it is no more than right and proper that this information and the principles involved should be presented to a body of men who will have a great deal to do with the expenditure of millions of dollars of public money in Texas roads. Whether any commercial substitute for trap rock as a road aggregate will be discovered remains to be seen. Any material, regardless of its name or origin, which shows the same qualities under actual service, would do as well; but up to the present time such a material has not been discovered.

# CONCRETE CONSTRUCTION

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In the development of this subject, I shall use the following outline, in the order named:

A. Proportioning Concrete.
B. Form Construction.
C. Inspection and Checking.
D. Mixing Concrete.
E. Placing Concrete.
F. Removal of Forms and Curing of Concrete.
G. Relation of Fundamental Designing Knowledge to Proper Supervision of Construction.

It will be necessary at times to discuss some phase out of its order in order properly to develop some other phase. Concrete construction is so interrelated that the various steps can not be independently developed to their fullest extent.

## A. PROPORTIONING CONCRETE

1. *Methods in Use:* It is recognized generally that for maximum strength a concrete should be as dense as possible, which means that it should have the smallest practicable percentage of voids. The various methods aiming toward this result are as follows:

(*a*) Arbitray selection, such as 1:2:4 or 1:3:6 mixture.

(*b*) Determination of voids in sand and stone. Proportioning materials so that the volume of sand equals voids in stone and the cement slightly in excess of voids in the sand.

(*c*) Proportioning of sand and cement by judgment to form a mortar. Proportioning this mortar so that it is slightly in excess of voids in the stone. This is the French method.

(*d*) Mixing sand and stone and proportioning cement slightly in excess of the voids of the combination.

(*e*) Making volumetric tests of trial mixtures of concrete with different proportions of cement and aggregates and selecting the mixtures producing the smallest volume of concrete.

(*f*) Mixing aggregates and cement according to a given mechanical analysis curve.

(*g*) Prof. D. A. Abrams, of the Lewis Institute, has recently devised a method of proportioning concrete by a function of the aggregate called "fineness modulus." By this method, the concrete mixtures are indicated by a single ratio of cement to combined aggregate, such as 1:4 instead of 1:2:3. The size and grading of sand he considers less important than usually supposed. Professor Abrams says: "The only advantage gained from using a coarse well-graded aggregate is due to the fact that the concrete can be mixed with less water than is required by a finer aggregate."

2. *Mechanical Analysis Method:* It is generally accepted today that the most practical method for accurately determining the proportion of each material is by mechanical analysis of the aggregate. This method was developed by Messrs. Fuller and Thompson. It consists of separating the particles of a sample of any material—such as broken stone or gravel—by passing the material through screens of various sizes, and plotting the mechanical analysis curve by using the percentage passing a given sized opening as the ordinate and the size of the opening as the abscissa.

In proportioning by mechanical analysis, the object is to grade the fine and coarse aggregate so that the densest concrete will result from the use of a given amount of cement. An ideal mechanical analysis curve for gravel would be a straight line. This would show an ideal grading of sizes with a resulting minimum percentage of voids.

The best mixture of cement and fine and coarse aggregate is obtained by a combination of the separate mechanical analysis curves for the fine and coarse aggregates, respectively. This mixture of cement and aggregate has a mechanical analysis curve, called the curve of maximum density and familiarly known as Fuller's Density Curve, which resembles a parabola. It is a combination of a curve approaching an ellipse for the sand and a tangent straight line for the stone.

The proportion by weight should be changed to proportion by volume for practical use.

3. *Size of Aggregates:* For mortars, it has been found that sand in which there are no medium grains gives the greatest density and strength.

Theoretically, it may appear that the best concrete can be made with a coarse stone of uniform size and a sand whose particles are all small enough to fill its voids. Experiments indicate that graded materials give about the same density and work smoother in handling and placing.

The form of the density curve referred to before is nearly the same for all sizes of stone. It follows that scientifically sand is a relative term. With 2¼-inch stone, the best sand ranges from 0 to 1/20-inch diameter.

The larger the stone the stronger the concrete, for a given mix. This is because there is less surface area to the volume of the larger stone. For reinforced concrete work, this size is limited by the Joint Committee from ½ inch to 1½ inches. For reinforced pipe culverts, a maximum size of ½ inch to ¾ inch is preferable.

It is now generally recognized that the largest aggregate for concrete roads may well be 2 inches, and many engineers are using aggregate as large as 2½ inches.

The importance of testing aggregates, particularly the fine aggregates, for organic impurities has received prominence in recent practice. The colormetric test devised for this purpose can be readily made in the field. The test is made with a 3% solution of sodium hydroxide, in which the fine aggregate is shaken, the organic impurities being readily detected by the dark color of the liquid after settling. Light yellow or amber color indicates freedom from organic impurities that will injure the concrete.

4. *Proper Proportioning of Water with Aggregate:* There is no single development in the making of concrete of more significance than a proper water content. By controlling the water content, the strength of the concrete can be increased from 50 to 100 per cent.

The water content per sack of cement recommended for the ordinary mixes for road work is as follows:

| | Gallons per Sack Cement. | |
|---|---|---|
| Mix | Min. | Max. |
| 1—2—4 | 6 | 6½ |
| 1—2—3 | 5¾ | 6¼ |
| 1—1½—3 | 5½ | 6 |
| 1—1¼—2½ | 5 | 5½ |

In order to place the concrete snugly around the reinforcement for many reinforced concrete structures, it is often necessary to add an extra quantity of water. For such cases, the mix should be made rich enough to care for the decrease in strength due to the large water content.

1 : 1½ : 2 mixes are generally used for the wearing course of 2-course pavements.

1 : 2 : 3 mixes are used for 1-course roads.

1 : 2 : 4 mixes are used for reinforced concrete culverts and superstructures of reinforced concrete bridges.

1 : 2½ : 5 mixes are used for abutments and wing walls above ground.

1 : 3 : 6 mixes are used for mass concrete and footings.

## B. FORM CONSTRUCTION

1. *Material:* The material used for form work may be either wood or steel. Often for outside forms the earth itself is used. When such is the case, the earth should be well sprinkled so as not to absorb the water of the concrete.

The kind of lumber to use for forms depends upon the character of the work and the supply in the local yards. Partially-seasoned lumber should be used if possible. Green lumber dries out and shrinks. When using well-seasoned lumber, care should be taken not to drive the work up too close, since some swelling will occur.

Sheathing lumber should be dressed at least on one side, even for non-exposed surfaces, as the removal and cleaning of the forms is greatly facilitated thereby. For face work, the lumber should be dressed on three sides. Dressed in this manner, lumber is easy to work up and place, and this fact alone usually more than offsets the cost of dressing.

The thickness of lumber to be used in form work depends to some extent on the number of times the forms are to be used. Generally speaking, 1-inch stock dressed to $\frac{7}{8}$ inch is employed for floor and wall sheathing; 1 to $1\frac{1}{2}$ inch stock dressed to $1\frac{3}{8}$ inches for columns and for the sides of beams and girders; and $1\frac{1}{2}$ to 2 inch stock dressed to $1\frac{3}{4}$ inches for beam and girder bottoms.

Vertical studs for 1-inch wall or abutment forms are usually placed not farther apart than 2 feet. Vertical studs for $1\frac{1}{2}$ to 2 inch forms are spaced from $2\frac{1}{2}$ to 3 feet. It is customary to use wire spreaders to hold wall and abutment forms true to line, and to use triangular moulding for chambering exposed corners.

Horizontal forms are designed to carry the wet concrete, usually taken at 144 pounds per cubic foot, and the construction load usually taken at 75 pounds per square foot. Vertical forms are designed to resist the hydraulic pressure of a liquid weighing 144 pounds per cubic foot, the head used taken as the depth poured in the time required for concrete to begin to set. This varies in summer and winter.

For small culverts, collapsible forms are often used. These are very convenient, and where used to any great extent are economical. Various designs have been used for circular and arch culverts. There are being used at present on one job under my supervision circular forms in two parts. Each part consists of heavy tin, braced on the inside by semicircular steel bands. At the top and bottom, they are separated by beveled 2x4's. In pulling the forms, the beveled 2x4's are first removed, and then the circular parts; the steel bands permitting sufficient spring for pulling the forms away from the concrete,

On a 10 foot horseshoe-arch storm sewer, after the bottom and side walls had been built, I once used a semicircular form hinged at the crown. The construction features were such that the outside forms for the arch could not be held in place by bracing. Then outside forms were successfully secured to the inside forms by means of 2 longitudinal 4x6's on each side, and ¾-inch bolts spaced about 3 feet apart.

2. *Construction Notes:* Nails should be used sparingly, except in those sections that are to be used over and over again without change. Unnecessary nailing adds to the labor of wrecking, and renders the lumber unfit for continued use.

Trouble in the erection of forms may usually be traced to inaccuracies in form measurements. A variation of more than ¼ inch from sizes shown in drawings should not be permitted.

A good method for erecting rectangular column forms is to nail three sides together lightly before raising them to place, and then to set the remaining side after the reinforcement has been placed.

Beam-and-girder forms should be raised at the center, in order to prevent sagging. If this is done, deflection and compression of the supports will finally leave the beams and girders level. A deflection of ⅜ inch to every 10 feet is usually provided for.

The sides of the beam-and-girder forms should project over the edges of the bottom plank. By so doing it becomes possible to leave the beam-and-girder bottoms in place after the sides have been removed.

All shores, uprights, studs, etc., should rest in wedges driven in pairs to an even bearing.

Concrete poured under horizontal or inclined forms will exert an upward pressure which should be provided for.

### C. INSPECTION AND CHECKING

1. *Forms:* The forms should be inspected during construction to see that they are of the proper dimensions and that they have sufficient strength. After erection, they should be inspected to see that they are spaced the right

distances and that they are true to line and grade. Especially should the braces and supports be inspected.

All forms require a coating of some lubricant to prevent the adhesion of the concrete. Crude oil, soap, and water are used. However, oil should not be used on forms against surfaces that are to be plastered. Wetting with water in such cases is sufficient.

2. *Reinforcing Steel:* The steel should be checked, assorted, and stored as soon as it is delivered at the site. It should be blocked up several inches from the ground, and should be stored in such a manner that the rods needed first may be easily reached.

Such a simple matter as bending of rods for concrete reinforcement might seem almost too unimportant a subject to be worth very much attention. However, even in small jobs, the economic factor demands consideration, and in addition to the economic consideration care should be taken to see that the bends are made true to the line and plane and that the steel is not injured during the bending. In general, there are three types of rods to be bent:

(1) Heavy beams and girder rods.
(2) Stirrups and column hoops.
(3) Slab reinforcement.

In making each type of bend, the work should be arranged so that all rods of the same size and shape are bent at the time.

All reinforcing steel should be put in place in the form and securely fastened in correct positions before the placing of the concrete is begun. The spacing of the horizontal and vertical steel should be checked. In order to check the spacing of a number of bars rapidly, templets having notches the correct distance apart and large enough to fit over the bars, are sometimes used.

Very often concrete spacing blocks or small stones are used to hold the steel the proper distance from the forms. In many cases, I prefer them to the chains used for that purpose. Steel should never be laid directly on the forms with the idea of raising it during the placing of the concrete by prying it up and working concrete under it.

Lapping or splicing should be carefully inspected, to see that the lapping is in accordance with the plans.

Assuming a tensile working stress for the steel of 16,000 pounds per square inch, and an adhesion of concrete to steel of 80 pounds per square inch, laps should be diameters. This is shown by the following solution:

$$16{,}000\times\frac{22}{7}\times\frac{d^2}{4}=80\times2\times\frac{22}{7}\times d\times\frac{l}{2}$$

$$16{,}000\times 11\times\frac{d^2}{4}=80\times 11\times d\times l$$

$$l=50d$$

Where $d$ = diameter of bar.
$l$ = required lap length.

3. *Old and New Work:* In bonding old to new concrete, care should be taken to see that all dirt and laitance are first removed from the old concrete. I prefer steel brushes for this work. After this, the old concrete should be thoroughly wetted and coated with a neat cement paste immediately before placing the new concrete. Dry cement thrown on a wet surface does not produce a satisfactory bond. Dwelling with steel bars is frequently used for bonding the old and new work, and in mass concrete fairly large stones or plums are sometimes used for this purpose.

### D. MIXING CONCRETE

1. *Test Specimens:* For laboratory tests, the concrete usually is mixed longer than in practice. The recommendation of the American Society is that mixing shall continue for the minimum time of 1½ minutes after all the ingredients are assembled in the mixer, with the further stipulation that a longer time than this minimum is preferable.

Up to the time of the initial set of the cement, tests indicate that a mortar or a concrete may be regaged or retempered without injury. This initial set may be delayed by constant agitation.

If this mixture is regaged after the initial set, the strength is reduced. The wetter the mix, the longer it may stand without loss of strength or regaging. Tests show that mortar mixed with 8% water loses strength if regaged at all, while mortar mixed with 10% water may stand for nearly 8 hours before regaging, with no loss of strength.

In practice, regaging of mixtures that have begun to stiffen should not be permitted. The time will depend upon weather conditions and will range from 30 minutes to 2 hours.

New concrete that has been crushed by too heavy a load may be healed under water so that it will become about as strong as it originally was. I have made a number of tests in concrete cylinders in the testing laboratories of the University of Texas and of the University of Illinois. After loading them to the breaking point, they were placed in water and at a later date were retested, showing crushing strengths nearly as high as before.

2. *Machine Mix:* For bridges and for culverts of the larger type, mixing machines are usually employed. The concrete is either chuted or placed by wheelbarrows. For this type of work, the materials should be mixed one minute after being placed in the machine. It is preferable to have an accurate measure of the ingredients. The strength of the concrete measured by wheelbarrows varies some 25%, due to the variation in the wheelbarrow measurements.

For richer mixtures, such as those required for one-course concrete pavements, the minimum time for mixing should be 1½ minutes. The dryer the mix, the longer the time of mixing should be. It has been my experience that it is very hard to get a contractor to mix a batch longer than a minute on account of the short-time methods customary in the Southwest, and it takes a good deal of moral stamina to enforce such a regulation.

Batch mixers should be used instead of continuous mixers. Variations in the amount of moisture in the sand or gravel, slightly-caked cement, or even the strings from cement sacks will unbalance the mixture when continuous mixes are used.

3. *Hand Mix:* Hand mixing should be avoided as much as possible. It may be effective if properly done, but it is not economical except possibly for small culverts. I have found that hand mixing requires very rigid inspection. It is my custom to mix the sand and cement dry, turning at least 3 times; shovel the stone on top of this mixture; add water; and turn the whole at least 4 times. The American Society calls for at least 6 times after the stone has been added. It cost 3% more to shovel the sand and cement into the stone than by adding stone to the sand and cement, and 11½% more if sand and cement is made into mortar before shoveling into the stone.

The precautions to be used are to see that the mixing board is large enough and is watertight; that the batch is not too large and is spread out so that it is not too thick to be handled well by the shovels.

4. *Cement Gun:* A method of mixing and placing mortar and small aggregate concrete which demands our attention is the Cement Gun.

In 1907, Mr. C. E. Askeley conceived the idea that, by introducing water into the cementitious material coincidentally with the placing, he could prevent the settling or hardening of the mortar before its application. His experiments resulted in the Cement Gun, which is a pneumatically operated machine dependent on the flow of air to accomplish the desired results. This means that the material can be conveyed a considerable distance and to a considerable height; it means that the material is applied under pressure, insuring a permanency and density in excess of any other method. It also means the elimination of heavy and expensive forms.

The material produced is stronger in all tests than any concrete or hand-placed mortar yet produced.

By its use, the demarkation line between work previously placed and fresh work is eliminated. The joint between old and new work is as strong as the Gunite itself.

For watertight structures this method will be favored.

## E. PLACING CONCRETE

1. *Consistency:* Proper inspection of cement during the placing demands a consistency that is dependent on several factors. For reinforced concrete structures, the consistency should be such that the cement will flow sluggishly into the forms and about the metal reinforcement. If the concrete is placed by means of a chute, it must be wet enough to flow, but care should be taken to see that the chutes are not so flat as to separate the coarse aggregate from the mortar. Nor should the chutes be steeper than 45°. If the chutes are too steep, the larger stones will run away from the smaller ones. An inclination of from 20° to 27° is usually satisfactory.

When a tremie is used to place concrete under water, care should be taken to see that it is never pulled above the concrete. A good method to start operations with the tremie is to fasten a stout cloth or some similar contrivance over the end, lower the tremie in place, fill it with concrete, then draw the cloth.

2. *Tamping:* The method of compacting the concrete, or forcing the air out after placing, and the kind of tools to use, depend upon the consistency of the mixture and the shape of the structure.

For dry concrete, a flat square tamper of sufficient weight is very good. For mushy concrete, a 2x4 does very well. There is danger of too much ramming in the wet concrete, which results in forcing the stones together and forcing the finer material to the surface. For face work, a flattened hoe is excellent. For curved forms, a piece of reinforcement curved to the proper shape gives good results. Bending the tamping end gives a greater tamping area. Tamping is necessary to reduce the voids and force out the entrained air.

Whenever concrete is laid under water, the water is likely to be clouded by what appears to be particles of cement floating up from the mass which is being laid. This whitish substance is generally termed "laitance." A similar formation occurs on the surface of concrete laid with too much water.

Chemical and microscopical analyses show that this laitance has nearly the same chemical composition as normal Portland cements, but consists largely of amorphous material and has almost no setting properties. Therefore, where concrete is laid under water, or where a large excess of water is required, about 1/6 more cement than usual should be employed. This is because a certain portion of the cement is rendered incapable of setting.

3. *Joints:* Construction joints should be located where they will be the least danger to the structure. Joints in columns should be made at a level flush with the bottom of the girder. Joints in beams and girders should be located midway between the supports. This is because the steel is designed to take all the tension, and the shear is a minimum at such section. If a beam intersects a girder at this point, then the joint should be offset twice the width of the beam. Joints in the members of the floor system should be made at or near the center of the span and should be at right angles to the main slab reinforcement. No joints should be allowed between the slab and the beam or girder. If the girder is very deep and stirrups are used, the joint may be horizontal, provided it is at least 18 inches below the top of the girder.

Joints should be made by embedding the timber in the concrete.

4. *Finishing:* In order to facilitate floor finishing, the strips or screeds should be carefully set to the correct elevation.

The dryer of cement and sand should be mixed beforehand, and as the screening progresses it should be immediately applied to a depth of about ¼ inch.

The latest method for finishing concrete roads is by using rollers, either double or single, and following them with canvas belts or wooden floats. The rolling is repeated at intervals of some 15 or 20 minutes until all the water is expelled. This calls for from 3 to 5 applications.

Tamping machines are being successfully used on concrete roads. The Baker machine carries a striking templet, a compressing plan, and a finishing float. It weighs about 3,600 pounds, and applies a pressure of about 80 pounds per square inch. It travels at the rate of about 100 feet an hour.

### F. REMOVAL OF FORMS AND CURING OF CONCRETE

1. *Time of Removal:* The time required for the forms to remain in place depends upon the load carried by the forms, and upon the climate. Forms should remain in place longer for reinforced concrete than for plain, and longer for horizontal than for vertical members. Concrete may be taken as sufficiently hard if it has a destructive ring under the blow of a hammer. Another good way is to drive a nail into the concrete. The amount of resistance is an index of the hardness.

In general, for ordinary concreting weather in Texas, abutment, wall, and circular forms may be removed in one day after the concrete is placed. It is well to remove the side forms as soon as possible, in order to finish and patch while the concrete is green.

Slab forms up to 7 feet span should remain in place from 4 to 8 days.

Long span slabs and beam and girder bottoms, 10 days to two weeks.

Small arches, 2 to 7 days.

Large arches, 2 to 4 weeks.

It is good practice to mould cubes from each day's concrete and test them in order to determine the time to remove the forms.

Forms which are to be used again should be cleaned as soon as they are taken down.

In removing forms, the green concrete should not be disturbed by prying against it.

2. *Curing:* The surfaces of concrete exposed to premature drying should be kept covered and moist for a period of at least 48 hours, and then moistened thoroughly twice a day for 7 days.

Concrete roads are usually cured by covering them with $1\frac{1}{2}$ or 2 inches of each and keeping this earth moist from 2 to 3 weeks. Concrete roads have been cured under water by damming up sections and keeping them flooded. This requires lots of water.

## G. RELATION OF FUNDAMENTAL DESIGNING KNOWLEDGE TO PROPER SUPERVISION OF CONSTRUCTION

1. *Location of Steel:* A familiarity with the principles of design is more or less essential to the proper inspection of the location of the reinforcing steel; whether or not it is anchored properly; the relation of the point of bend to the point of inflection for continuous members; and the relation of the effective depth to the stress in the steel. Often steel is carelessly placed nearer the neutral axis than the design calls for. This reduces the lever arm, or effective depth, and increases the unit stress in the steel.

To be effective, temperature steel should be placed close to the surface, in order to distribute the cracks more uniformly. Thick massive concrete, having relatively less surface area, requires less temperature steel than thinner structures.

Stirrups are provided to care for the diagonal tension. They should be spaced the closest where the combination of direct tension and shear is the maximum.

For girders, this is usually near the intersection of the beam with the girder. One familiar with the design of stirrups will know that an exact analysis is not possible, but that tests show the vertical shear may be used as a criterion. Experiments also show that the concrete may be assumed to carry one-third of the shear and the stirrups two-thirds. It would seem, then, that in simple beams, say, stirrups should be spaced the closest next to the supports. However, diagonal cracks do not start right at the supports when sufficient horizontal bars are carried straight to the supports, and consequently the stirrups should be the closest some distance away from the supports, where the concrete shearing area has been reduced by the cracks.

2. *Splicing and Lapping Steel:* All splicing should be done where the tensile stresses are zero or at a minimum. A knowledge of designing principles is a great help in this. Only recently I had some reinforced concrete circular culverts built in my district for which the plans called for the lapping of the ends to be either at the springing line or at the crown, either point being a point of maximum tension. Of course, the joint was changed to the quarter point, at the point of inflection where the tensile stress is at a minimum.

As pointed out before, splicing bars should be lapped 50 diameters, unless deformed bars with higher unit bond stresses are used.

Since in splices the stress is transferred by bond, it is preferable to have the bars about 1 inch apart.

At times this can not be done easily, and usually the bars are wired together to hold them in place. The wires themselves, as ordinarily used, transmit very little stress, and the contact of the bars reduces the area of the steel for the development of the bond. This means that, where the splicing bars touch, the intensity of the bond stress is increased on account of the reduction in the surface area along which bond is transmitted.

At one time this problem was brought to my attention. The projecting steel in an arch abutment was of a certain size and spacing. It was desired to use steel of half the area with half the spacing. The question was raised, Could the stress be properly transmitted unless the bars were of the same size and spacing, and were in contact? My answer was that since the lap was at least 50 diameters, and since the steel was separated by enough concrete to develop the bond fully without having too high a unit shearing intensity, probably better results would be derived than if the bars were in contact.

Bond tests conducted at the University of Illinois by D. A. Abrams show that plain round bars, which are usually easy to obtain, develop 12% to 15% higher adhesive bond than the square twisted bars and 15% to 20% higher than plain square bars. Plain round bars are easily bent and placed and, personally, I like to handle them. Corrugated bars give the highest bond stress of any of the commercial bars used.

3. *Joints:* A knowledge of the principles of design is essential for the proper location of construction joints. I have already mentioned the proper location for these. Take for instance a beam. The shear at the center is zero, and the tension is a maximum. Since the concrete is designed to take shear but no tensile cross, joints should be located where the shear is at a minimum. This location of the joint will not affect the compressive strength of the concrete.

4. *Loading:* A knowledge of the designing loads prescribed by good practice is a great help to supervision of construction as regards the care to use with the proper mixing, placing, consistency, etc., after taking the time factor into consideration.

In column design, for instance, the knowledge that cement is a good reinforcing material will allow the use of higher working stresses by using more cement. This was clearly demonstrated by tests which I made on 45 life-sized columns at the University of Illinois.

Instantaneous setting of concrete is accomplished by mixing cement with a boiling concentrated caustic soda solution. It is possible to build a structure by this method which may be used more quickly than an ordinary concrete structure. At least, it has been demonstrated that this is a practical method of stopping leaks in concrete work.

5. *Inspection:* A designing knowledge is very helpful in the proper inspection of form work. The condition of loading, methods of supporting, manner of construction, all may be intelligently criticized.

6. *Backfilling:* A knowledge of hydraulics and stability is helpful even in backfilling. Especially is this so against abutments and walls. Drainage holes must be provided to prevent the collection of water back of the walls. Also backfilling should be done so that the slope of the dirt is away from the walls. This will relieve the pressure of the earth against the walls.