

# HIGHWAY CONSTRUCTION, ADMINISTRATION AND FINANCE

*By*

**E. W. JAMES**

*Chief, Division of Design, United States  
Bureau of Public Roads*



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PLANNING A NATIONAL HIGHWAY SYSTEM

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The marked improvements in design and structural efficiency of the automobile during the last 15 years, the tremendous increase in motor vehicle registration in Western Europe and in North and South America during the last twelve years, and the possibility of the satisfactory use of motor trucks demonstrated during the World War, unquestionably create the assurance that the modern world has a new element which must be provided for and developed in any complete system of national transport.

This new vehicle requires a system of highways on which to operate. Italy is recognizing the new demand by the construction of motor routes; Spain is once more turning attention to the improvement of a road system which has been little changed since the Napoleonic period; Portugal is awakening to the possibilities of commercial and tourist development; and France is proposing an ambitious improvement in the famous system of Routes Nationales by instituting a new classification of super routes to be provided with modern pavements.

In Canada the Dominion has provided for a system of grants to the Provinces for road construction, and in the United States, under the provisions of the Federal Aid Acts, a program of road construction has been instituted which can only be described as magnificent in its size and conception. It is only a question of a few years before the less developed nations of the Western Hemisphere will strongly feel the same need and impulse toward road construction on a scale larger than they have ever before considered. Already Mexico, the Argentine Republic and Chile are taking the first steps toward the development of highways having a truly national significance.

With such great developments in sight it is timely to consider ways and means of assuring that funds shall be spent wisely and to the best advantage, for the financial problem involved in the highway program is in all countries the fundamental and difficult one to solve. To keep expenditures to a minimum we must attempt three things: (1) to select the right roads to be improved; (2) to determine the correct types to build at any time; and (3) to build progressively, but so that all work done may be salvaged in future work.

To handle these matters most effectively the best method is deliberately to plan a national highway system. The fact that pioneer roads and trails have developed, that some roads have already been improved, that cities have grown and the rural districts have been put under cultivation should not deter us from attempting such a plan.

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Page ~~5~~<sup>5</sup>, line ~~5~~<sup>5</sup>, should read:

"developed—in at least two directions, fixed the limit at seven per cent of the"

Page ~~sixty-eight~~<sup>46</sup>, line ~~down~~<sup>down</sup>, should read:

"eighteen gallons to each cubic yard of stone. The coated stone is then"

This may disclose errors made in the past, but it will enable us to avoid such mistakes in the future. It may lead to a change in location and priority of construction for many miles of highways, but if it does it saves money. Studies of state highway systems made in the United States during the past three years clearly demonstrate the value of such work even at a late date. But obviously the earlier in the highway history of a country such studies are made the greater good will flow from them.

Highway systems may be planned as in England, France and Spain for the nation as a whole by the central government or, as in the United States, by separate political units with a necessary authority to correlate and connect the several State or provincial systems left to the central government.

No State has an entirely free hand in laying out a highway system. Aside from the topographic influences, the major drainage channels and the effects of climate, there is always a network of existing roads and trails to be considered. Fortunately, these existing roads have developed naturally to meet growing demands and they usually are located so that they can advantageously be brought into a scientific system of highways. But such routes have grown up under the law of least resistance, and frequently have local defects that must be changed and improved. The most common defects are excess curvature and consequent length resulting from insufficient grading, excess gradients resulting from the same cause, and not infrequently, too many lines of travel develop, because in the past it was just as easy to take one bad road as another.

The first detail in approaching a national or state highway plan is to make a general survey of the entire area to be covered by the proposed system in order to determine the general character and condition of economic development. Such a survey should be statistical and the data should be tabulated for both broad and specific comparisons, and also placed upon a suitable map by graphic means in order that the conditions may be visualized and their geographic relation fixed. The data most useful are population; agricultural production in tonnage for general crops and in cost for special crops, such as dairy products and food stuffs delivered directly for consumption; and manufactured products by cost. The areas supplying these facts should be defined, and in entering the information on the map, not only should the locations be shown, but also by an appropriate series of colors or shading each area should be given a quantitative distinction. In regions where there is confusion of data, and this may frequently occur, it may be necessary to use several maps, one to show population, another to carry agricultural areas and production, and another to show industrial regions and their output. A most unusual map has recently been prepared for the State of Pennsylvania, U. S. A., showing quantitatively 24 separate items throughout the State. On the basis of such a map alone a state highway system can be laid out, at least diagrammatically, and the roads would have to be altered only as required by topography. A map so involved as this one is not recommended, however. It will be found much more convenient to

group related data and use separate maps for showing the related information.

After such an economic survey has been made the question of topography should be studied. It would always be helpful to have complete and detailed topographic maps, but seldom are these available until long after the time when a highway system should be planned. In the United States such a survey is today only about 45 per cent complete and so the absence of such detailed information can not be allowed to prevent adequate planning to meet the current and early future needs of highway transportation. When the time comes to fix the exact location of a road for improvement, then a detailed survey of that road will be needed and in the absence of general topographic data the road surveys will themselves have to be extended sufficiently to disclose the most economical location. Much of this information can be secured by reconnaissance surveys.

Finally, it will be necessary to have a careful and full study of the existing traffic on the roads as they are. Such data in some cases will not represent the conditions that must be met in the future, but they will furnish a satisfactory measure of the relative importance of routes.

The details of a traffic survey are important. They should be both quantitative and qualitative. The various counts should be classified appropriately to cover the different kinds of traffic flowing on the highways. Local practice and customs will indicate the classifications. Probably no two countries can use exactly the same subdivisions. For instance, in England heavy steam or gasoline tractors called lorries are not uncommon. On the other hand they do not exist for general use in the United States. The large two-wheeled cart is used rather generally throughout South America. It is very localized in the United States and the high wheeled type is confined almost exclusively to lumbering operations in the Southern States.

It is probable that ultimately the classifications of traffic will approach a sort of standard form because as motor transport develops the successful types, themselves highly standardized, will comprise a larger and larger part of the total traffic.

Traffic data when in hand should also be tabulated in summary form for various routes; and diagrammatic presentation of the density and type of traffic should be shown on a suitable map. In the Pennsylvania State map already referred to all traffic data were included; but the use of separate maps will be found more convenient in most cases.

With the information in hand as described above, we are ready to attack the details of the problem. We shall assume that we are dealing with a national system rather than a state or provincial system. The first thing to be considered is the probably

adequate mileage of roads in the system as a whole and in the several political or economic subdivisions of the system. The nation will be made up of a wide and interesting variety of areas each characterized on an economic map both as to the type or quality and as to the development or quantity. Some areas will be agricultural, perhaps whole States may be so classed. Others will be chiefly industrial. There will be desert areas, mountainous areas, forested areas. Some regions will have large cities or towns in considerable number, others will have a single, central metropolis and a sparse and scattered population in the rural sections. To arrive at some reliable data as to the amount of road mileage, widely distributed, that will serve these various subdivisions of a nation, we must turn to a study of other countries. In England, France and the United States, respectively, we have a great variety of economic and natural conditions for which such data are at hand. England is largely a manufacturing country highly developed. France is a manufacturing and agricultural nation. In the United States there are separate political subdivisions known as States, that are characteristically divided into manufacturing states, agricultural states, mountainous states, desert states, etc., and the conditions affecting the distribution of population are as varied as will be found in any western nation.

England, a manufacturing nation, has 2.6 miles of public highway per square mile of area. Massachusetts, U. S. A., a manufacturing State, has 2.34 miles per square mile. Pennsylvania, another manufacturing state with, however, a large north central agricultural section, has 2.03 miles per square mile. Ohio, not unlike Pennsylvania economically, but much less mountainous, has 2.07 miles per square mile. Connecticut and Rhode Island, both typically manufacturing States, have 2.52 and 2.13 miles per square mile respectively.

Well developed agricultural States like Illinois, Iowa, and Missouri, have respectively, 1.72, 1.87 and 1.62 miles per square mile. Indiana, an especially advanced agricultural state, with many mining and small industrial centers, has 2.12 miles per square mile. Southern agricultural states, devoted to cotton and corn production, like Georgia, Alabama and Mississippi, have 1.62, 1.14 and 1.14 miles per square mile. Arizona, a desert state, has 0.19 miles; Nevada, a similar state, has 0.24; and Colorado, a distinctly mountainous state, has 0.46.

France, which as a nation, is probably the most advanced so far as concerns the highway plan as distinguished from construction, has 2.1 miles per square mile.

These figures represent the total mileage of public highway which will serve areas of different general economic classes when those areas are highly developed for each respective class.

Based on conditions of general development in Europe and the United States, which may be considered as representing the

typical development of national areas, we find then, that a characteristically manufacturing region should eventually have approximately 2.3 miles of highway per square mile. Other types of area can likewise be classified in the same manner and we can compile a table like the following:

	<u>Miles of Highway</u> <u>Per Square Miles of Area</u>
Highly developed manufacturing areas	2.3
Highly developed flat agricultural areas	1.7
Well developed hilly agricultural areas	1.4
Mountainous areas	0.7
Desert areas	0.3

These figures comprise all those pioneer roads and trails that necessity has established including the later wagon roads cleared through forests, marked across prairie and plain, and finally created by law as the public highways of the state or nation. For our purposes these roads represent the ultimate requirements. In some less developed countries such a mileage may not now exist; eventually it will. It represents the human demand for avenues of communication. These are the roads that must be considered in laying out a national highway plan. The problem becomes largely one of selection and discrimination with some necessary additions and much needed correction of detailed alignment and location. No possibility exists in any country today that all of this large mileage could be highly improved. It would be uneconomical to improve such a mileage, as well as financially ruinous. The actual traffic is so small on much of this mileage that improvement is not justifiable.

In laying out a national system of roads for improvement at the general expense the mileage resulting from the application of this table to the areas must not be used, but a certain empirical fraction only. This will be a surprisingly small fraction, but it will constitute the national highway system. The state road system in Massachusetts comprises 8 per cent of the total public road mileage. It was the second state in the United States to originate a state highway department. In New Jersey, which has the oldest state highway department, organized in 1893, the state system comprises 824 miles, or approximately 6 per cent of the total mileage. California has about 9 per cent in its very adequate state system; Maryland approximately 14 per cent in the most advanced state system in the country; Pennsylvania about 11 per cent; New York 10 per cent, and Rhode Island 12 per cent.

The Federal Aid Highway Act of the United States drafted on the basis of providing at least one highway entirely across each state—even the least developed—in at least two directions, fixed the limit at 7 per cent of the total public road mileage, with a provision for ultimately increasing this as development should require. In France the national roads are 5.7 per cent of the whole mileage; in England 18.7 per cent. In the long run it appears that

greater difficulties ultimately attend the execution of a program that is too large, than one that is smaller, even though the initial designation is eventually found to be too small. It is always easy to meet local demands or national demands by adding mileage. It is almost a hopeless task to reduce the scope of a national layout once it has been made and published.

Actual traffic counts over large systems of highways and empirical analysis indicate that about ten per cent of the total public road mileage will care for about 75 per cent of the traffic. In some States which are in large part desert or mountainous, the percentage should no doubt be larger, not so much because of purely local requirements, but in order that adequate connections may be made with the roads of contiguous territory.

The wisdom of experience, common sense, expediency and public policy therefore indicate, especially in partly developed countries whose revenues have not yet begun to mount with rapidly increasing wealth, that a low per cent be chosen. The seven per cent adopted in the United States may be taken as a basis, remembering that there are in that country state systems, which include from 50 to 100 per cent greater mileage than the Federal aid system.

We find that by applying this factor to the figures in the table above that we get a new set of figures representing the actual miles of highway per square mile that should be included in a national system according to the type of area.

Miles of Highway  
Per Square Miles of Area

Highly developed manufacturing areas	0.161
Highly developed flat agricultural areas	0.119
Well developed hilly agricultural areas	0.098
Mountain areas	0.049
Desert areas	0.021

By determining the respective areas of the several economic divisions into which the national territory has been classified, we can at once determine the equitable road mileage which should be included in each division. This mileage will furnish the basis for laying out the national highways. It will be impossible to adhere to these figures rigorously but the closer they are followed the fewer relative inequities will be introduced into the system. Frequently, especially in small desert areas, not enough mileage will be found to cross the area, and because of its location it must be crossed by any adequate system of roads. In such cases obviously some concession must be made.

A broad consideration of highway needs, the study of highway development, and the history of actual construction as dictated by popular opinion, willingness to provide funds and actual requirements to meet ever increasing traffic enable us to lay down some

convenient principles to guide us in our selection of the national system. These principles are supported and confirmed by our economic and traffic studies.

(1) Development of local roads is fundamental. This postulates a radiating group of short roads around important centers of population. Except in metropolitan areas, such as New York, Chicago, St. Louis, London, Paris, Marseilles and Buenos Aires, it is seldom that more than seven such radiating roads are needed. In ordinary large cities, like Tucuman, Mendoza, Santiago de Chile and La Paz, five or six will serve; and in a great number of cities having a population up to 30,000, four will answer.

(2) The extension of local roads should be made in properly chosen directions, which can be determined by the existence of other large centers of population. Provision should be made to carry roads through a line of lesser centers, and across highly developed areas.

(3) The ultimate joining of routes radiating from different centers.

The method of procedure is relatively simple. With the economic data available it is possible to designate areas of relative importance and to locate the various cities, large towns, and even smaller settlements that represent the major and minor population centers. The economic data is supported by the topographic data in most cases, and these two are always to be considered together. By a study of the facts the country can be divided into areas of relative development and of topographic types. These areas will be desert, mountainous, forested, cultivable or cultivated in varying degrees and will be densely, moderately or sparsely inhabited. It is not necessary that these divisions of the nation shall coincide with lesser political divisions, although if the provinces or states are set off by natural boundaries like mountain ranges, large streams, or marked alterations in topography, then the economic divisions and the political divisions may coincide more or less completely.

In any case we shall have a rational subdivision of the national area into regions of economic classification.

On a national map as a working basis, with the economic areas platted, the work of laying out the system may proceed. The layout should be diagrammatic, similar to the map of New Jersey shown herewith. No close attention need be given at the moment to the existence of public roads and straight lines may be used to connect points which control the laying out of the roads. The selection should be governed by the traffic data available. The first choice should be the most important road in the area; the other roads to be selected should follow in degree of importance until the allowable mileage is exhausted for the area.

The same process should be followed in each of the other



economic areas. Where traffic data are available it will be found that the system will be connected and correlated. If traffic data are not used and general information, the engineer's judgment, or popular opinion is followed, it will be found in all probability that at the boundaries of the contiguous economic areas the roads sometimes do not meet. This is a condition commonly found, especially with respect to political subdivisions. It occurs between towns in the New England States, U. S. A., where the town is the basic political unit. It occurs between counties in practically all the other states. One town or county will insist that its east and west road is most important. An adjacent town or county on the north will equally insist that its north and south road is most important. This condition results from the strictly local point of view of the officials and citizens, and often from inaccurate information as to the facts. In all such cases correlation must be insisted upon. If the existing amount of traffic requires the inclusion of the road that does not fit as a through connection such road may be left in the system as a radiating road from some convenient and more or less important center.

To visualize this process of selection a map of Peru can be used. The radiating roads, with certain roads extended to meet adjacent similar extensions from other centers, are shown around the cities of importance. This map does not show a complete national system, but it illustrates a condition that will no doubt exist in many countries of Central and South America.

The mileage as completed by the method here outlined provides an adequate system of national roads, based on area requirements, for a well developed country. It will, therefore, be found in many cases that this mileage is more than is needed at present to supply sufficient radiating roads at all centers of population requiring them, and to extend these to make connections necessary at this time with other radiating groups. In other words, places will be lacking at which to locate a considerable balance of the mileage. To meet this condition the values in the second table should be reduced by a further percentage to the point where the system fits the conditions. In this way the original relations are maintained, and the comparative importance of each economic area is recognized equitably and fairly.

The reduction of mileage is the practicable and common sense solution in a case of this kind. It results in a national system more nearly in consonance with existing development, wealth and population. But we may make another solution if we consider that the additions beyond such a point as that indicated on the map of Peru are speculative and to that extent tentative. We can continue adding selected routes until the total computed mileage for the national system is entirely absorbed. Such a system, if it correctly anticipates future development, will be the national highway system justified and necessary, at that future time when the national area will have developed to a point comparable with that of Europe or with the eastern half of the United States.

For instance, it may be definitely known that a certain area, although not now developed, is good agricultural land. There may be a river falls, junction of two streams, lake outlet or other point at which, on account of potential geographic value, a city will probably exist at some future time. To this point, or at least toward such point a route may be extended, and a certain mileage absorbed in radiating roads. A case like this is specifically represented by the proposed establishment of Nahuel Huapi in northern Patagonia. In the region of the Andean Lakes in Western Argentine there may be several points that could be tentatively chosen and worked into the system. This procedure clearly anticipates future development, and it is definitely understood that all such mileage is subject to alteration and shifting as actual growth and progress demand. In the United States, especially in constructing forest roads, future development is recognized; and even in the vicinity of cities some of the main routes clearly demonstrate that where the engineer can project well chosen roads, population will follow. This same thing exactly happened in the case of the railroads, and can happen again in the case of highways. But such advance planning is not to be included in current construction programs until financial conditions are sound enough to permit, and this mileage only serves to locate tentatively the balance of the total system above immediate requirements.

In studying and laying out the system a straight line, diagrammatic method has been recommended. As soon as the layout is completed the next step is to select the roads that such lines of communication shall follow. There will always be trails, wagon roads or maybe some highway improvements existing when the national plan is undertaken. In most cases there will be no difficulty in determining what actual road or trail is to be selected as the physical counterpart of the schematic route appearing on the map. In the United States, which considering their growth, wealth and needs, were really late in undertaking a national system of highways, it was found that traffic already existing between some points was so dense as to require two or more roads. This condition is most unlikely in countries of younger growth. The traffic surveys, taken on the existing roads, will always serve to show what roads should ordinarily be followed where alternatives exist. There may be necessary departure from such old roads when construction surveys are made; but in most instances such differences will be local and incident to the correction of alignment and grade. If, however, little used or entirely new routes with greatly superior physical characteristics exist the engineer should give them careful study at the proper time.

We can now transfer our schematic map to a road map of the country, usually taking the country in sections (by provinces or states), and on a larger scale. This new map will constitute the base map for legislative or other authoritative action promulgating the national system.

It will be desirable in some cases, even when so little as four or five per cent of the total computed mileage is worked into the system, to divide the whole plan into two general divisions, such as primary and secondary roads. This classification may be done in two common ways. The primary roads may be made continuous as a kind of back bone or skeleton for the whole body of roads, and the secondary classification then becomes discontinuous as a group of appendages to the primary system. This method has been prescribed by law in the United States with certain minor qualifications, and is exemplified also in the routes nationales of France as compared with the routes departementales and routes vicinaux. On the other hand the two classes may be based entirely on types of construction, certain higher types being classed as primary and roads destined to be of such types in the initial construction program are made primary. Others are secondary and of lower types of construction. This method produces a system of discontinuous primary roads as well as discontinuous secondary routes.

Some students of highway economics prefer not to attempt any classification into primary roads on a basis of importance of the routes. They adopt a division into priority groups, those to be built first, generally within a certain period; those to be built next; and finally, a last group that can be economically postponed. Elaborate studies for reconstruction programs in some of the largest and wealthiest States in the United States have recently been based on this method with considerable success.

As a matter of fact, the primary and secondary classification based on relative importance of routes is more or less artificial, and is entirely perfunctory so far as the early construction program is concerned. It is impossible to confine construction to the primary roads until these are completed, because what are important as routes, frequently have unimportant sections which must be delayed.

With the system now planned and base maps prepared, it is possible to decide on types and attempt a first period of construction. The first road to be built should be the most important section existing in the system. It may be five kilometers or 100 kilometers in length, but it demands first construction. This is the simple and universal rule to follow from the point of view of the engineer and economist. However, it is quite common as a matter of political expediency to make a distribution of funds by political subdivisions; and to build for instance the ten roads of greatest importance in each of ten districts, rather than the ten roads of greatest importance in the whole country. The latter method might result in the construction of ten roads all in one region geographically much restricted.

The types to be built will depend largely on traffic in the early years of development of such a national system as any country in Latin America is likely to have. As the systems become perfected other considerations will become of more relative importance.

Unfortunately, engineering data are not yet sufficient to enable a rational choice of types on any exact basis. We must content ourselves with certain broad generalizations based on wide experience and past practice.

In general the following table will serve as a guide in the selections of types.

Table

Proposed Types for Initial Construction Based on  
Average Daily Traffic Count

0 to 100 vehicles	Earth
100 to 300 vehicles	Selected materials, sand-clay, top-soil, etc.
300 to 500 vehicles	Gravel
500 to 1500 vehicles	Surface treated gravel, macadam, bituminous macadam, and other intermediate types
More than 1500 vehicles	Bituminous concrete, brick, Portland cement concrete and other pavement types.

These proposed types of construction may be shown in the working maps for demonstration purposes. They will, however, have to be changed as traffic changes. It is seldom of advantage to plan the actual types much ahead of the financial program. For this reason the method of programming the construction will be considered together with the financial problems in a later paper.

The types as selected for the first period of construction may be entered on the map by appropriate symbols or legends and so far as concerns the general control which is exercised by a national highway system over the construction program our first problem is finished.

EARTH ROAD DESIGN AND CONSTRUCTION.

Seeing that highways are taking their place as an integral and more and more important element in the national transportation system of every country even the design and construction of earth roads, formerly the simplest and crudest work of road building, is no longer to be despised. Highway construction is so costly and the demands of traffic so insistent and so rapidly growing, that highway designers in planning an earth road must at once solve some of the most advanced problems in highway engineering.

When the State of Massachusetts, one of the first in the United States to have a state highway system and a highway commission, undertook systematic highway construction in 1896, the work was done to meet the traffic then existing. The Massachusetts system was inexpensive to construct, when compared with current estimates. A few thousand dollars per mile served to provide adequate roads for that day. As traffic increased, and as it finally changed about 1906 to 1910, Massachusetts and other States, and likewise other nations like England and France, added to their original investment by making betterments and improving surfaces. The capital costs of such roads have been distributed over a generation.

The state or nation that begins to build roads today finds itself confronted with a new and heavier type of traffic, differently propelled, applying different forces to the road surface and requiring conditions of economical operation not at all dissimilar to railways. Then we built along the line of least resistance to original construction. Now we must build along lines that will insure the least maintenance and operating charges.

It is a fact, however, that the countries of Latin America have a better opportunity to distribute their costs over a period of years much longer than may one of the United States, like Arkansas or Montana, that begins in these days systematic road building under state direction. In Latin American there is now, and probably there will be for many years, a considerable portion of steel tired and horse-drawn vehicles among the total traffic. Consequently, there will be some opportunity to build progressively, such as rarely exists in the United States today.

It may not be financially possible nor economically justifiable to construct high type surfaces, such as sheet asphalt, brick, or concrete, when some roads are laid out and graded, and there will be no present or immediate demand for such types. They may be postponed in many sections for a longer or shorter period, depending on the growth and prosperity of the region; but costs today are so high that it is imperative that nothing be constructed along incorrect or unscand lines.

We must keep before us the principle that while the road building may be made progressive, each advance being made to meet increasingly heavy demands, it must be so prosecuted at every step that

all that has gone before shall be salvaged in the new work no matter how long that work may be postponed. A highway may be graded and drained to meet the needs of a small rural traffic; surfaced first as a gravel road; then topped with a course of bituminous macadam; scarified, prepared as a base and surfaced with some type of mixed bituminous concrete; and finally reconditioned as a duplex road with two concrete sections having a bituminous center, or as a heavy pavement with bituminous shoulders. But each step must be so ordered as to make it develop as much as possible of the value remaining in the preceding one. In this way and in this way only can a highway system be economically handled under the tremendous and increasing demand of modern traffic.

Earth road building, therefore, involves much more than mere grading and the installation of needed drainage structures. Every detail of alignment and gradient must be studied and adjusted just as if the surface were to be of the most expensive type. Where the possibility of alternate locations exist both must be investigated to determine the one ultimately the most economical.

The general highway plan already described in a previous article may be assumed to exist and certain sections to be so located and conditioned that it is decided that they are first to be graded and drained. This may be done for two purposes. An earth road may be entirely adequate for the small amount of light agricultural traffic using that particular piece of road. The total number of vehicles may not exceed, for instance, one hundred per day and there may be no heavy trucks or other heavy vehicles likely to use the road except under favorable conditions, as in dry weather. It is to be noted in passing that an earth road in good condition and under favorable weather conditions will carry practically any weight of traffic in small quantities, provided the tire width of vehicle is controlled. On such roads the limiting feature is rather the number of vehicles than their weight. Of course, such a surface will not stand up in wet weather.

Also we may have to construct an earth road where the traffic is so heavy that an earth road will not be adequate, where the daily traffic may be several hundred vehicles including many heavy ones, because the topography may be such as to require considerable deep filling. It would not be good practice to place an expensive surface on such fills, especially if rigid types of surface involving either concrete base or pavement are projected. In such cases it will be necessary to grade and drain and let the earth embankment settle for at least one round of seasons. During this time the road must be opened to accommodate the traffic, and during such time it must be used and maintained essentially as an earth road.

The determination of location is the first problem in earth road construction. The general highway plan will indicate the general route, but there may still exist a choice of alternate locations for actual construction alignment. The study of alternate routes solves this detail and the solution should be one that can stand for all time.

The decision will often be determined by the existence of certain controlling features. There may be several settlements that demand local service, an irrigated area may lie so that it must be served by the proposed improvement. A gap in the hills may decide the question in favor of one route as against the other. These are general considerations and often may be settled by established policies as well as by strictly engineering principles and the law of least resistance.

For instance, we must recognize the principle that the highway is first of all for local service. Because long after the country has reached a high condition of development, local traffic will constitute 75 to 90 per cent of the traffic flowing on the road. It is generally the fact that more than one line can be run and each will be equally satisfactory from the technical point of view though costs may vary. It is a sound policy, when considering existing local settlements, to deviate from a direct line in order to give such points adequate highway service, provided only that distance is the only technical feature involved. We are justified always in the early days of highway planning in accommodating as many local centers as possible, even at added cost. But in all such cases, the location secured should, except in length, be equivalent to the best obtainable. No added curvature or increased gradient, no unfavorable soil conditions, nor excessive unnecessary drainage should be accepted in order to accommodate unimportant small centers of population. For such purpose spur roads should be used. The map of Iowa, U. S. A., published last month in the first article of this series shows a large number of such spur roads built to give small centers contact with the improved highway system.

In actually determining the final line, consideration should be given to the ultimate requirements of the route, so far as they can be foreseen, and not merely to the present traffic conditions. The specifications for the location survey should determine the maximum gradient, minimum radius of curvature, minimum tangents, and any other elements that require decision at this point in the work, just as though the highest type of pavement were under consideration.

The maximum allowable grade is often set at 6, sometimes at 5 per cent. But it is truer economy and better design to adopt a less rigid policy. It is true that for horse-drawn vehicles a 6 per cent grade long had strong support among designers, but the future vehicle is to be motor driven, and as we are now designing for the future as well as for the present we should consider the motor vehicle as controlling and not the horse. Consequently, we can use grades up to 9 per cent, provided they are short and properly placed.

A gradient of 9.0 per cent, not over 1000 feet long, can be climbed by a motor vehicle in second gear without difficulty and the average automobile operating in high gear can travel uninterruptedly on the following grades:

<u>Length of Gradient</u> <u>Feet</u>	<u>Per Cent of Gradient</u>
1,000	5.4
800	5.7
600	6.3
400	7.3
200	11.0

In the above table it is assumed that the approach to the grade is at a speed of 25 miles per hour, and the final speed at the top is not less than 15 miles; and the tractive resistance assumed is that for natural earth in good condition.

In the matter of curvature, our views likewise must be somewhat revised. Curves of 80 to 100 feet radius should not be tolerated as they have been until recently. Not less than 250 feet radius should be constructed, and in flat and easy topography a minimum of 500 feet should be made the regular policy, and 1,000 feet secured where possible.

Our fundamental principle of salvaging old road values must be recalled at this point. We can salvage a partly graded profile, but we can not salvage an abandoned alignment. Consequently, we must resist the tendency to introduce poor alignment, sharp turns and curves and short tangents, when it is impelled only because of proposed low type surfacing. It is just as important to adhere to an alignment of first quality for a graded earth road as it is for an expensive type of pavement.

In selecting curves, therefore, the policy of the engineer should be altogether controlled by the ultimate requirements. It will be desirable ultimately to introduce such refinements as easement curves, widening on curves, and compensation of grades for curvature; and the engineer responsible will be able to determine to what extent these must be introduced in the original work in order to avoid losses in future reconstruction. The decision will depend largely on the width to which the roadway is at first to be graded, and the radius of curvature in each case. It will often be possible to salvage all or nearly all of a grade if simple curves are used originally and easement curves and widening introduced simultaneously at a later date. The difference between the external of simple circular curves and the external of the same curve with an easement spiral introduced is somewhat less than 2.0 feet for extremely sharp curves and less than that for curves of less degree, so that little is lost if simple curves are first built in and later eased. By skillful adjustment of the center line practically all loss of grade can be avoided.

The width of the original grading need not be that of some future high-class improvement. The grade can always be widened without serious loss of work done. The actual width of first construction will depend on the traffic existing and contemplated, but it should be noted that it is generally easier to maintain a two-lane earth road than a one-lane road, because of less concentration of traffic.



Each traffic lane of a hard-surfaced road should be 10 feet wide. The graded width should be made dependent on this figure. The width of shoulders should not be less than four feet, and where safety demands should be wider. Accordingly, if we are contemplating at first a single-lane road, the minimum width in fill should be 18 feet (6 M.) and in cut, 22 feet (7 M.). For a proposed two-lane road these dimensions should be respectively 28 feet (9 M.) and 32 feet (10 M.).

The cross section will vary according to the nature of the topography. In prairie regions, in the level pampas and across deserts, a relatively low grade should be used, but generally the entire road should be in fill. If the rainfall is much above 25 inches per year, the surface of the grade should be about 18 inches above the probable level of water in the ditches. In hilly and mountainous regions, cut and fill sections, similar to railroad work, should be used. It is not economical to adhere to one uniform cross section, and there should be no hesitation on the part of the engineer in changing his cross section design to secure the greatest economy in earthwork. The width between shoulder lines is the detail that alone need be uniform.

On the assumptions made herein we shall often find that the cost of grading alone is excessive, and not justifiable by existing demands of traffic. To meet this condition it is only necessary to lay a new grade line on temporary assumptions as to maximum gradient. We may reduce cuts, and correspondingly reduce fills to bring the quantities moved down to what is a reasonable estimate from the point of view of present funds. Note that in general no variation is to be made in alignment. This is for the reason mentioned above. The partly graded profile is not lost, but the abandoned line is. Later, when a surface is to be placed, and therefore final profile must be used, the cuts can be deepened and widened, the fills raised, and the profile generally adjusted to its final line.

At the same time that a road is graded, it is generally considered economy to install permanent drainage features. This fact applies especially to culverts and bridges which, unless deliberately built as temporary structures, will normally have a life long enough to reach the time when the road will require surfacing and maybe even reconstruction. If long lived structures are to be built, certainly they should be on final line and grade. With respect to culverts, this holds as well as for bridges of larger span and greater cost. But it does not hold with respect to subdrainage. It is not necessary that the so-called French drains, tile drains, blind drains, etc., be installed at the time an earth road is graded. It may be desirable to introduce these features, but like V-drains, Telford base, and other sub-base features nothing is actually lost by postponing these details to a time when a surface is to be laid. They should not, however, be postponed beyond that time.

The ultimate use of subdrainage and sub-bases will depend largely on the kind of natural soil existing in the subgrade. Also the treatment of the finished earth road should depend to no small degree on this same detail. Even if traffic is not in excess of 100 vehi-

cles and nothing better than a common earth road is required, nevertheless, the engineer is often justified in doing something better if it can be done at little or no greater cost. When the grading operations are going on, there will frequently be disclosed certain types of soil, such as disintegrated rock, indurated sand, plain sand, and even loam that are far superior to clays and heavy loams as a surface for traffic. When such materials are found they should be so handled, if at all possible, as to bring them into the top layer of all fills, and if it can be done, cuts should be surfaced with the same selected materials.

This handling of the excavation and the deposition of material in fill to secure the best results will require careful planning and almost constant attention on the part of the engineer in charge. Unfortunately, no general plan can usually be made in advance because the soil conditions below the visible surface are not easily or cheaply ascertainable. But as good material is exposed during the progress of the work, the handling methods should be so planned as to utilize these materials to the best advantage at the surface of the graded road.

The usual simple appliances and general methods of handling ordinary earthwork need not be discussed. Only one point need be emphasized, and that is that grading over long distances should when possible be so balanced, at the time the profile is worked out and quantities computed, that the work of grading may be done with the simplest possible outfit and equipment. The work should be planned to involve generally an economical wagon haul, wheelbarrow, or slip haul, as the case may require. But combinations of such equipment within short distances should be avoided. This adjustment presents a nice problem for the engineer, but it simplifies the equipment needed to do the job, tends to reduce costs, and creates work adapted to the capabilities of small as well as of large contractors.

The usefulness of an earth road is dependent entirely on its adequate maintenance. Its deterioration is so rapid under unfavorable conditions of weather that not only is traffic seriously hampered by neglect of proper maintenance, but loss of investment is rapid because of weathering of the slopes, distortion of the surface by rutting, and washing away of shoulders. The problem of maintaining earth roads, therefore, should be constantly before the engineer responsible.

The simplest, cheapest and best implement for general earth road maintenance is a drag, and a common wooden drag has never been surpassed on narrow roads for quality of results produced. The old fashioned split log drag used in the early days of earth road improvement in the United States was composed essentially of a log split into halves, these turned so that the split surfaces faced the same way, and cross bars introduced to hold the two half logs in the proper relative position. But this primitive implement has given away to larger and heavier equipment more suited to rapid work and adapted to use behind motor trucks. In either case, the action is the same.

The drag is drawn along the road while the surface is damp after rain. In this condition, the ridges and ruts that may have been formed by passing vehicles while the road was wet and soft are smoothed away or filled with crumbled earth. Water lying in depressions on the surface is splashed out over a large area and exposed to more rapid evaporation, and the process at once quickens the drying out of the earth and insures its being smooth and in proper form as it hardens. Dragging should not be done in dry weather or when the road is dusty, as the work tends at such times to aggravate the dusty condition.

Steel drags have been designed to cover practically the entire width of an earth road at one operation and these produce good results if they can be operated at times when the road is practically clear of all traffic. Otherwise, drags covering one-half the road width are most practicable and satisfactory. It is necessary to use two and sometimes three drags in combination to cover a wide road. Most modern drags are adjustable so they can be made to cut little or much, and brush the loosened material toward the center or toward the shoulders of the road as desired. Usually all material should be dragged toward the center. Should this overbalance the natural tendency of the material to drift and wash toward the shoulders and result in increasing the crown of the road excessively, the drag should be reversed in operation so as to brush the loosened material outward toward the shoulders.

Generally speaking, the maintenance of an earth road surface is accomplished by adequate dragging. No other work is required so long as the road is not permitted actually to lose its proper cross section. Some distortion of form will, however, be almost unavoidable, and in such cases, a blade-grading machine is needed in order to cut the surface more deeply and brush the necessary material to one side or the other to reshape the crown and true the cross section. This kind of equipment, like the drags, may be combined so as to cover the entire width of road at one operation by using three blade graders. A single blade grader may be used, however, and equally good results be secured.

Both drags and blade graders may be drawn by animals or by motor trucks. The amount of mileage under maintenance and the organization of the working force will largely influence the type and weight of equipment.

The action of the drags is to smear and to close the more or less plastic earth surface, squeezing out free water and inducing rapid evaporation and hardening of the earth. This must be done soon after rains and when the roads are still moist. Usually the day after the rain stops is a good time to begin dragging unless the rain has been a long one. The best time can easily be determined by inspection. The color of the soil will begin to change and to become slightly lighter. When this change is noticed it is time to drag. To do the work in a single day, enough drags must be provided to cover the total mileage at the rate of 20 to 25 miles to each motor truck outfit, and from 5 to 10 miles to each animal drawn outfit. The smaller drags should be given short hauls and the heavy equipment the longer ones.

In the days when a large mileage of earth road was maintained with small drag equipment, it was successfully done by employing on part time the farmers along the road. The same practice might be successfully worked out in many places. Plantation and ranch owners could be induced to become responsible for the dragging, and their employees could actually do the work.

Earth road work is simple, but it demands persistence to be made effective. There are still in agricultural regions of the United States, where the soil is not much superior in stability to that of the pampas of the Argentine, some roads that are kept in remarkably good condition except during rainfall and immediately afterward. The efficiency with which earth road maintenance is done will do much to influence the attitude of public opinion toward highway improvement and very considerably influence the increase of motor car registration. These in turn may be depended upon to create a demand for a greater mileage of road of a constantly improving type. This cycle of action and reaction is responsible for the great era of road building that every progressive nation faces today..

GRAVEL AND OTHER LIGHT ROAD SURFACES

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It will be found that a large mileage of any highway system requires some form of surface at the time of initial planning. Other sections originally constructed as earth roads will eventually have to be surfaced. Much of this mileage, probably upwards of 60 per cent, will be satisfied with surfaces of gravel, sand-clay, top-soil or variations of these types. In general, all roads carrying an average traffic of from 100 to 500 vehicles per day will come within this group of roads of light surface.

Whether the first construction involves the placing of a surface or not, the details of grading, including all the considerations of alignment, gradient, curvature, etc., will be taken care of as described in the preceding article on earth roads. This paper will review the materials and operations used in the construction and maintenance of the large group of surfaces consisting of gravel and similar materials. If, for reasons of economy, the grading was not entirely completed at the time of original construction as an earth road, the road should be brought to proper profile before surfacing. Otherwise, surfacing placed on such a grade will later have to be discarded if the grade is changed.

Assuming that traffic gradually increases and that each successive betterment of the common earth road can be progressively used for a few years, the first advance that should be made is the treatment of the natural earth with some material that will increase the stability of the soil. All such work certainly will meet our economic requirement that it be subject to salvage as the betterments are successively added.

The best and usually the most available material for the first treatment of an earth road is sand or fine gravel. Suitable material can usually be identified by an engineer without the use of specifications or testing sieves, and specifications need be resorted to only when materials are being purchased from some producing plant, or furnished by a contractor, when it will become necessary to have some measure of quality to protect the buyer. In general, any good clean sand will serve, but the coarser and cleaner the material the better. It is unnecessary at this stage of construction to distinguish between sand and fine gravel. They run into each other. Usually all material may be classified as sand that passes a quarter inch mesh and all material gravel that is retained on that mesh, and a satisfactory material may have not more than 20 per cent retained on a one-quarter inch mesh and all passing a three-quarter inch mesh. The common sources of material are river and stream valleys, where sand and small gravel bars are common. Often the material is dredged from the river and washed in the process of dredging. Sometimes the banks are exposed at stages of low water and the material can be dug and loaded directly into carts or trucks.

There are regions, however, like the northern pampas of the Argentine where material of this kind is scarce and costly, but south of Rio Negro, in Patagonia, it is plentiful and will furnish a satisfactory material for treating an almost unlimited mileage of roads.

The simplest method of treating an earth road that shows evidence of too costly maintenance and unsatisfactory service, is to haul sand and deposit it in a line, called a windrow, along one side of the road. A blade grading machine is used to brush a small quantity of sand over the entire surface, if possible after a period of light rain. The sand will work into the soil and when the road dries the surface will be harder and firmer than natural earth, and in wet weather it will be less absorbent of moisture. An ordinary heavy loam road will require at least two inches of sand and if the nature of the soil is such that the two inches of sand are taken up entirely in a single season or less, additional sand should be dumped into the windrow and spread until the natural soil refuses to retain any more.

Hundreds of miles of earth road are being sanded in this way in the United States and the method is very satisfactory, even on heavy black prairie loams, provided the rainfall does not exceed about 22 inches per year.

This simplest of processes is not so satisfactory where rainfall is excessive nor does it serve where the natural soil is itself composed largely of sand or sandy material. To meet these conditions at a relatively low cost the first step in the betterment of a graded earth road may be the placing of top-soil or sand-clay surface. Sand-clay is either an artificial or a natural mixture of the two materials named, in such proportion that in dry weather it will not crack by shrinkage and in wet weather will not slake, or at least will not slake rapidly. It is a mixture closely approximating that required for ordinary burned building brick, with perhaps slightly more sand.

If the natural earth contains much clay the sand may be spread as described above, or hauled and spread directly from carts or wagons. After spreading about three or four inches of sand, the entire road should be plowed about eight inches deep, harrowed thoroughly, and then shaped to proper cross-section with a blade grading machine. The crown of the road may be reduced slightly below that indicated for a plain earth road, and made approximately three-quarters of an inch per foot.

If the natural soil is sandy and the road is unsatisfactory because of ruts formed in dry weather, or if the material is practically all sand, then the treatment consists in adding clay to complete the sand-clay mixture. The finishing process is the same as in the first case.

When the subgrade contains little or no plastic material like clay and yet is not sandy but is rather a loam or silt, it may become necessary to add both sand and clay to produce the necessary mixture. In such cases the material may be used to advantage when found in its natural state. It occurs generally in two natural forms; in geological strata con-

taining often sufficient iron oxide to make it a very serviceable material, in which case it may usually be identified by its deep red color; and also as top-soil, a mixture of sand and clay in which the highly plastic material has been altered by aeration. It is to be found on the surface where a relatively high state of cultivation of a sandy loam has existed and also occurs naturally where a sandy loam soil has been thoroughly leached and aerated, but remains uncultivated. Natural red sand-clays may be found extensively throughout a large area north of the La Plata in Uruguay and in southern Brazil. Wherever they exist they may be economically used in the early stages of road surfacing.

Some attempts have been made to establish a test for a good sand-clay, but most of them are so elaborate that they are hardly worth while. The best way to test it is to try it out on the road for a short distance. An engineer observing its action in use will soon be able to judge a good material.

The maintenance of a sand-clay or top-soil road, as also of a sanded road, is practically identical with the maintenance of an ordinary earth road. The only essential difference is that the former will sometimes require the addition of sand to keep them in good condition. Under weather and traffic such surfaces lose sand and this must sometimes be replaced if the loss is excessive.

Instead of using sand-clay or top-soil to surface an earth road, it may be advisable to use gravel or some other material of a more durable character. Some of those used are marl; caliche, a soft powdery limestone that sets hard after being wet and compacted; colitic limestone, such as coral formations; bank gravel containing clay binder and sand; river gravel, almost free of clay; chert; novaculite; scoria; low grade iron ore; etc.

The available marls represent a rather wide range of materials. The common shell marl is useful; caliche, which is found in Texas, Arizona, and New Mexico, and is like the tepalcate of the Mexican plateau, is excellent. It is similar to the tosca rock that exists in the pampas in scattered locations. It is a material that should be carefully prospected. If it can be found in sufficiently well distributed deposits on the pampas, it will furnish an excellent traffic source of material for building a road surface that will accommodate traffic for a lengthy period.

Any of these marl-like materials are subject to use in the same way. Care must be taken to keep them unmixed with earth or sand as they act much better in a relatively pure state. The valuable element in all of them is the carbonate of lime that acts as a cementing material. They should be placed on the road so as to produce a compacted thickness of about 8 inches. The cheapest method is to spread the material entirely across the desired width of roadway at the needed depth and then feather or taper the edge to approximately an inch in thickness. This gives some additional width and makes it possible to maintain the surface cheaply with a blade grader.

It is usually worth the cost to roll a road of marl or soft limestone, although it is not necessary. If a roller is used, plenty of water should also be used to sprinkle the surface so that the bonding value of the lime will be developed. A blade grader can be used to shape the surface before, during, and even after rolling, and the surface may be finished to a remarkably true and uniform section. In spite of all care in construction, however, such roads will suffer seriously by abrasion if traffic is relatively heavy and will become intolerably dusty in dry weather. They can, however, be successfully treated for these difficulties by methods to be described in another paper.

All the marl and similar materials are amorphous in character, and readily cement together if moisture is present in sufficient quantity. If the surface is kept smooth and true by frequent use of a blade grading machine, and if material is added wherever local weaknesses develop in the surface, roads of this kind can be kept in satisfactory condition for several years. They cannot be well maintained with light drags and require a heavy grading machine, operated with some degree of skill. They should always be patched when necessary with the same material of which they were built.

Better than the marls are the great varieties of gravel that can be used successfully in surfacing a road. There are almost no limitations as to quality of gravel to be used in such work. Felspathic, granitic, quartz, and calcareous gravels are all good, and as to size, practically any gravel source can be developed and handled so as to produce usable material. The harder and tougher the gravel particles the more durable the surface will be, and the best possible gravel road will require careful control of material with respect to its durability, size, grading, and content of binder. But ideas regarding gravel road construction have changed greatly in recent years, and if gravel is cheap and plentiful it may be used without much regard to the quality of its constituent mineral. The only exception is that generally a shale gravel is to be avoided because it breaks down into clay so rapidly.

Gravel should contain between 15 and 20 per cent of clay as a binder, but no hard and fast rule can be set. Some fine gravels having much less clay are entirely satisfactory. More clay may safely be present also if there is a high per cent of coarse sand. The maximum size of pebble should not be greater than two inches, and generally a smaller maximum gives better results. Some engineers are specifying as low a maximum as one inch. It will be found that in semi-arid or arid regions the smaller the gravel the better it will bond.

When gravel is specified as large as a two-inch maximum it is desirable to insure that it be well graded, and for that reason some control of the intermediate sizes is provided by requiring that not more than 75 nor less than 55 per cent of the material shall pass a 1-1/4 inch mesh, or not more than 60 nor less than 45 per cent shall pass a one inch mesh. The control size is about at the middle range



of the gravel, and should not depart more than ten or fifteen per cent in either direction from a straight line grading. It is sometimes required that not less than 60 or even 75 per cent of the material delivered shall be retained on a one-quarter inch screen. This fraction is then classified as gravel; that part passing the screen is sand.

With the increasing practice of using generally finer material and reducing the maximum size, it becomes less necessary to have intermediate control and more important that the clay content be not excessive. The best test of a satisfactory gravel is that of service, and the refinements of specifications for surfacing gravel are generally for the sole purpose of securing a gravel approximately like some especially successful kind.

Gravel banks are the result of depositions and consequently a satisfactory material can usually be found, but if the bank has too large an amount of stone above two inches in size, it may be desirable to crush it and so use the entire product. In many cases the large pebbles would have to be screened out of the surface course, and if handled this much it adds little to the cost to crush and save the material. If this method is too costly, then a two-course road surface may be laid and the large gravel can be used in the bottom course. This method is much less in favor than it used to be.

Ordinarily the gravel road will be built on the graded earth, or possibly on an old sand-clay or top soil road. A graded earth road should be dragged or bladed until the top is practically flat, with a crown of not over one-quarter inch per foot. A layer of 3 to 6 inches of gravel may be spread evenly over the surface directly from trucks or wagons, or the gravel may be dumped in a windrow along one side and brushed over the surface with a blade grading machine. The thickness of the course of gravel will depend on the kind of material, the condition of the subgrade and the climate. A good sand-clay containing plenty of coarse sand and a relatively high per cent of clay may be spread full 6 inches thick. It will compact with its natural moisture or with a very little rain. On the other hand a sandy gravel, fine and containing little clay can not be advantageously spread deeper than two or three inches at a time. All of the gravel so laid should be spread over the entire width of the earth grade, so that when maintained with a blade grader no earth from the shoulders will be mixed with the gravel.

If the gravel surface is to be built over sand-clay surface, it will be better to place the gravel in a windrow and spread it over the sand-clay only when the latter is wet or softened by rain.

It is seldom economical, and except in case of a two-course gravel road, it is not especially desirable to roll a gravel surface. Traffic can be depended upon to compact the surface provided the material is kept well shaped and true by frequent and timely use of a grading machine. If large sized gravel is to be used, however, and a two-course surface built, the first or bottom course may be rolled with advantage.

In such a design, it is desirable to require trench construction, as it is called, for the lower course. This method of building requires that the shoulders be built up to a thickness about equal to that of the lower course of gravel when spread loosely over the subgrade. Both gravel and shoulders are then rolled at the same time, the first passage of the roller being made so that one rear wheel will lap the junction of the earth shoulder and the gravel base. In this way coarse gravel up to 3 inches in size may be used, but if the climatic conditions are such as to produce much ground frost, it is likely that in course of time the larger pieces of gravel will work upwards and may even come through the top layer of surfacing and give trouble because of their large size.

When the base course has been thoroughly compacted, the top course or wearing surface should be spread over the entire width of the road, including both shoulders and base. For this layer only fine gravel should be used, including particles up to one inch in size. This may or may not be rolled; because here again we have the same conditions as in a one-course surface and traffic may be depended upon to compact it if a blade grader is kept at hand and the surface is maintained in a smooth, uniform condition as it gradually compacts.

From the above it is seen that a gravel road may be constructed more satisfactorily if gradually built than if built as a single operation. The first gravel spread will to some extent be incorporated into the subgrade until the mixture is stabilized, and the amount of clay, loam or other binding material present is just enough to form a mixture that will have a minimum of voids and consequently will be least absorbent of water and least likely to disintegrate in dry weather. When nearly all of the first application of gravel surfacing, whether it be a top course or a single course, has become compacted, additional gravel should be spread so as to produce a layer of loose material about one inch thick over the entire width of the road. This covering of fine loose gravel appears to serve a variety of purposes and is now sought and often provided with much care by the best road builders. It prevents abrasion of the compacted gravel, furnishes an absorbent material for rain, induces a more uniform wear on the road surface, prevents the formation of small holes, and furnishes a constant supply of excess material to fill any ruts, holes or local depressions that may occur, including the characteristic ridges, or washboard effect, produced by heavy traffic.

The method of maintaining a gravel road that is most effective is first to keep the cover material present in correct quantity, viz., about one inch thick. This will be brushed gradually to the sides and center by traffic, leaving bare strips where the wheels customarily pass. It should be maintained by using the grading machine as frequently as needed to respread it, or to add to it by bringing upon the surface more gravel from the side. On heavily traveled gravel roads there should be kept along the sides or at least along one side a windrow of new material. This can in the course of maintenance be worked back and forth across the road, leaving each time as much material as may be necessary to maintain the cover and fill all depressions that form.

If a gravel surface because of insufficient or improper care, becomes rough and irregular so that the use of the blading machine will not quickly correct its condition, it is advisable to scarify the entire surface, except the extreme shoulders, to a depth of about 2 inches, move all the loose material to one side, and then gradually respread it again so that traffic may again compact it as in the case of original construction.

Finally, gravel roads may be maintained with bituminous surface treatments, and this method will be described in a later paper in connection with similar treatments on waterbound macadam.

## WATER BOUND MACADAM AND BROKEN STONE ROADS

The water bound macadam introduces us for the first time to a type of surface that is the result of a conscious effort to find a solution for a specific difficulty in road building. It was the beginning of the modern road. MacAdams' problem was to prevent a surface composed of rock fragments from disintegrating. He discovered the effect of the cementing value of stone dust, and reasoned that sufficiently heavy traffic would provide enough such dust as the effect of abrasion to keep a broken stone road constantly supplied with its necessary bonding material. MacAdam was right; but traffic has changed in many places, and we are confronted with the limitations of the water bound macadam type, and must use means of converting it into something more suitable for motor traffic.

In some countries it will be many years before horse-drawn traffic will dwindle to the low place it holds in the United States. In France the macadam type is still an adequate surface for a great part of the national road system. In Spain and Portugal no other type has ever been built until very recently. But where motor traffic does exist in considerable quantity water bound macadam no longer serves as an economical surface and must be modified to meet the new conditions.

It will be useful, however, to follow through the construction of water bound macadam and a simpler form of crushed rock surface, and use them as an introduction to bituminous surfaces. This is the historical and logical order.

A water bound macadam surface is composed of crushed rock, and depends for its stability as a surface on the interlocking of the stone particles and the weakly cementitious properties of rock powders. It is a type that can probably be used for many years in large parts of Latin America because of the abundant supply of rock and the large proportion of animal drawn vehicles. It will be a valuable type where gravel is not available, and the possibilities of salvaging it are so good that it may well be resorted to for many years as the principal type of pavement for general use in most of the South American Republics. The limit of its economical use will depend on motor traffic. In 1910 the automobile registration in Massachusetts was 31,360. By that time there were approximately 37 cars per mile of state road in the State, and the proportion of horse-drawn to motor propelled vehicles was 62 to 38. By that date the seriously destructive effect of motor driven traffic had become clearly recognized on Massachusetts roads, which had been constructed largely of water bound macadam. The same general limits may be assumed as applying in South America.

The first valuable tests devised for road materials had reference to macadam, and of these the tests for hardness and cementing value are the most important. It is a fact that in the United States we today give less weight to resistance to abrasion and more to cementing value. This is so because practically all

water bound macadam there is soon altered to some simple form of bituminous surface. This same course may no doubt be followed to some extent in Latin America, especially in the vicinity of large cities.

Where, then, it is still advisable to build a macadam road any sound stone may be used but it should preferably be a stone of considerable toughness, and have a cementing value as determined by the Page Impact Test of not less than 50. The toughness as tested in the Page Impact machine should if possible be from 8 to 10, and the French coefficient of wear about 7, but in Florida, U. S. A., successful macadam roads for light traffic have been constructed of soft limestone having a French coefficient as low as 2.5. When motor traffic increases those surfaces had to be protected but they served for many years.

The rock should preferably be a trap rock or limestone. These unquestionably give the best results for water bound macadam. The rock should be quarried and crushed to small particles, and screened into 3 or 4 sizes. Three sizes will ordinarily serve. The maximum size of stone for use in the bottom course of macadam depends on its toughness. A soft stone, easily broken, should start with larger fragments than a hard, tough rock. The second or wearing course should be of smaller size and finally there should be a third separation consisting of all stone chips and dust combined. These may be separated and considered as third and fourth sizes. The following table expresses the grading that is usually sought and indicates the extremes for a hard trap and a soft limestone.

Table I.

Sizes of Crushed Stone for Water Bound Macadam

	: Stone for Base :	Stone for Top Course :	: Screenings (large) :	: Screenings (small) :
Product of Soft Rock	: 2-1/2 to 3-1/2 : : Inches :	: 1-1/4 to 2-1/2 : : Inches :	: 0 to 3/4 : : Inches :	: 0 to 1/4 : : Inches :
Product of Hard Rock	: 1-1/4 to 2-1/2 : : Inches :	: 1-1/4 to 2-1/2 : : Inches :	:	: 0 to 1/4 : : Inches :

The construction of water bound macadam requires the use of

heavy power rollers and sprinkling carts. The subgrade whether it be an old sand-clay, top-soil, gravel, or earth road should be brought to a reasonably true section, and the shoulders should be built up to the depth of the loose stone for the base course with earth or other material. The stone is then spread in the broad flat trench thus formed by the raised shoulders, and to insure even distribution and true edges it is desirable to place boards along the sides to mark the separation of stone and shoulder material. Care should be taken to spread the stone evenly and to move all the pile that is dumped on the subgrade. Long pronged rakes are excellent implements for spreading and forks are necessary for rapid work. When the stone has been spread the boards along the sides should be removed and the rolling should be started at the edges, with the first passage of the rear wheel leaping the junction of shoulder and stone. The rolling should be continued until the center of the road is reached. It should then be started at the other side and progress to the center. The base stone should be thoroughly locked and wedged until a man walking on the compacted layer does not disturb the separate stones.

The shoulders should then be raised again, if necessary to the height of the top course of stone and this should be spread, using the side boards again as a guide. Ordinarily it is good practice to dump this size of stone on a large sheet of metal, called a dumping board, and to spread it by hand from this point. It can be spread by specially constructed dump wagons or trucks, but these are hardly economical unless a large mileage of stone road is to be built.

This course of stone should be rolled in the same manner as the base stone and when well locked, the stone chips, if these have been screened out separately, should be spread lightly over the surface and then swept in with stable brooms. These chips fall into the interstices between the stones and gradually fill them. The course should then be rolled again and if necessary to secure a tightly wedged surface more stone chips should be spread and swept across the surface.

The surface should then be sprinkled, the stone dust should be spread, more water should be applied and the final rolling begun. This work should not be hurried. It should in fact consume several days. Each day the roller should be run back over two days' work and correct any defects or irregularities that develop. Dust and water should be added until the mixture flows before the roller, and care should be taken to emphasize the rolling at the edges so that the crown and true cross section will be maintained.

Finally, a thin layer of screenings and dust should be spread over the surface and for several days after the road has been opened to traffic it should be sprinkled enough to keep it always wet.

Macadam road construction must be conducted with considerable care and requires a good foreman who can vary the time of rolling,

adjust the sprinkling, both as to quantity and time, and above all so handle the rolling as to prevent a soft stone from becoming rounded, because after that it can be wedged together only with greatest difficulty, if at all.

In place of macadam construction there has been developed a form of crushed stone surface which can be maintained more easily than water bound macadam, but which does not lend itself so readily to the subsequent use of bituminous material. It requires much less care in construction and its results are so nearly as good as macadam under light motor traffic that it is now generally preferred.

The entire product of the crusher is separated into two sizes, everything above one inch going into one bin and everything through one inch into the other. The large stone is spread and over the surface is scattered sandy loam or sandy clay as a binder. The road is then rolled, using a small amount of water to moisten the binder, and the next size material is spread in one heavy blanket over the entire surface, much as fine gravel is spread in a gravel road, and traffic is allowed at once to use the road.

As the surface course is compacted, the fine material acts much like gravel and must be worked back and forth, and all ruts kept filled by use of a blade grader. If binder is not sufficient a small amount of sand-clay or even loam may be added. The surface is really made of artificial gravel and it is just about as good as that type of surface.

The maintenance of water bound macadam where most of the traffic is on steel tires is not difficult. A supply of the top course stone and of chips and dust should be kept in storage piles along the roadside and stone covered with the screenings should be put into all holes that form. If the new material can be watered and rolled it will always give much better results. But this method of repair is practically impossible where there is much motor traffic, for the passing cars scatter the new and loose material and effectively prevent its forming a bond with the old stone. It was this difficulty, together with the disintegration of the macadam surface and the intolerable dust that resulted from the loosened material, that early demonstrated the inadequacy of this type under automobile traffic and led to its practical abandonment in the United States. The crushed stone road on the other hand is maintained just as a gravel road is, by use of a blade grader. This type does not depend on the cementing properties of rock powders to hold the stone in place. Clay or loam binders are used, and the surface has a covering of loose small stone and screenings that is maintained in regular section by the grading machine.

The difficulty of maintaining water bound macadam under heavy motor traffic and to a much less degree of gravel roads, at once introduce the subject of surface treatments with bituminous

materials. Today in the United States practically all roads listed as macadam are in fact surface-treated macadams, and their surfaces are being maintained with oils or tars and stone chips, sand, or fine gravel. A variety of bituminous materials are available for this work of surface treating stone and gravel roads. Some are applied hot, some cold. They range in consistency all the way from crude oils to heavy materials equal to those used for penetration macadam or heavier. Engineers do not agree on any one that is best. In fact, some are best for one form of application and others for different treatments. What is entirely successful for use in treating a water bound macadam will not serve at all on gravel. Practice in surface treating varies with the engineer and his experience, and there are two prevailing ideas among engineers relative to the finish of surface treatments. One group prefers a leathery or rubbery mat having enough stone to give it support, but essentially a bituminous protection to the underlying macadam. The other prefers a mosaic finish as full of stone as possible. The tendency in practice is toward a mosaic finish and the writer has always preferred it during a long experience.

A typical method of surface treating a macadam with a hot oil, using stone chips for covering material, may be described as follows:

The water bound macadam road should be kept under traffic long enough after completed to compact it thoroughly. Spots which ravel in the meantime should be constantly repaired by covering the places with stone chips and stone dust and freely watering and rolling. When the surface treatment is to be applied, all accumulated dust should be swept to the sides by means of a rotary street broom or with hand brooms. To the surface thus cleaned the bituminous material should be applied at the rate of about one half gallon per square yard. The bituminous material is applied by hand or by a distributing wagon or truck. Besides hand-pouring pots there is a large variety of efficient equipment for this work: tank wagons for distributing hot or cold material under pressure or by gravity, sand and stone spreaders, brooms, and vacuum road cleaners. But it should be kept in mind that such heavy expensive equipment is seldom economical unless it can be kept in service and operation most of the time. The type of equipment to be used, therefore, and whether hand or machine methods shall be employed will depend on the location and quantity of work of this kind to be done. When the mileage of surface-treated road in any region becomes large, then machine equipment can be introduced with the economies that may be expected from such methods.

A variety of bituminous materials may be used and sometimes used in combination of two oils, two tars, or a tar and an oil. The total application rarely exceeds 0.5 gallon per square yard of surface whether made in one or more applications.



After the bituminous material has been spread the entire surface should be covered with a thin layer of stone chips, pea-sized gravel, or coarse sand, depending on the quality of bituminous material used. The stone chips should be clean and all should pass a half-inch mesh. Gravel, if used, should likewise be free from clay or other dirt, but may contain some sand, and should all pass a 3/8-inch screen. The amount of such cover material used will vary with the quantity and quality of bitumen and with the judgment of the engineer.

Accordingly the amount of stone chips or gravel that should be used varies from as little as 18 pounds to as much as 60 pounds per square yard. It may be expressed conveniently in square yards per cubic yard of cover material, when it will range from 160 superficial yards to 50 superficial yards per cubic yard of covering. The scant application of cover material produces a leathery mat; the heavy application, a mosaic mat. In the latter case it will be found that bitumen will not at first hold all the covering applied. Much of it will be brushed toward the sides of the road by traffic. It should be broomed back over the road two or three times as the sun softens the surface and causes the bitumen to "bleed" or come up through the covering material. Gradually the bleeding will stop, indicating that the bitumen has bonded all the stone it can hold to the road surface. If sand is used with a heavy bitumen a leathery effect will be produced. The larger the material used to cover the bitumen the more the surface will be like a mosaic.

In all cases, except when sand is used, it is better but not necessary to use a roller to fix the cover material firmly and uniformly in place. The larger the stone the greater the benefit of rolling. This method of surface treating a macadam road is the simplest of several methods in common practice.

Bituminous materials, suitable for cold and hot applications with their characteristics, as determined by the tests of the American Society for Testing Materials, or of the U. S. Bureau of Public Roads, are listed in the following tabulation. The quantity of bitumen to be applied per square yard and the amount and kind of cover material are also indicated.

TABLE II

	: Specific Gravity: : 25° / 25 ° C.:	: Flash Point :	: Specific Viscosity: :
Oil for thin cold Application	: 0.935 - 0.970	: Not more : than 50° C.:	: At 25° C. 80 -120
Oil for hot Application	: Not less than : 0.980	: Not less : than 80° C.:	: At 100° C. : not more than 60
Tar for Single cold Application	: 1.100 - 1.140		: At 40° C. 25 - 35
Tar for hot Application	: Not less than : 1.130		

TABLE II

	Float Test	Loss at 163° C. in 5 Hours	Float Test of Residue
Oil for thin Cold Application		Not more than 30 per cent	Not less than 90 Sec. at 50° C.
Oil for hot Application	At 32° C. not less than 60 sec.	Not more than 15 per cent	Not less than 110 Sec. at 50° C.
Tar for Single cold Application			
Tar for hot Application	At 32° C. 60-150 Sec.		

TABLE II

	:Total Bitumen :Soluble in Car- :bon Disulphide	:Per Cent of Bitu- :men Insoluble in :66° B Naptha	:Total Distillate : by Weight
Oil for thin cold Application	:Not less than : 99.5 per cent	:Not less than : 6 per cent	
Oil for hot Application	: Same	: Same	
Tar for Single cold Application	: 95 - 100 : per cent		:To 170° C. : not more than 2% :To 270° C. : not more than 25% :To 300° C. : not more than 35%
Tar for hot Application	: Not less than : 85 per cent		:To 170° C. : not more than 1% :To 270° C. : not more than 15% :To 300° C. : not more than 25%

TABLE II

	Temperature when Applied	Quantity per Sq. Yard	Cover Material to Use	Quantity of Cover Material per Sq. Yard
Oil for thin cold Application	Air temper- ature 60 F.	1/3 to 1/2 gallon	Sand 3/8" gravel or 1 1/2" stone	28 - 35 lbs.
Oil for hot Application	200° - 250° F.	1/3 to 1/2 gallon	1/2" grav- el 1/2" - 3/4" stone	30 - 40 lbs.
Tar for Single cold Application	Air temper- ature at least 50° F.	1/3 gallon	Sand	25 - 30 lbs.
Tar for hot Application	200° - 250° F.	1/3 to 1/2 gallon	1/2" grav- el 1/2" - 3/4" stone	30 - 40 lbs.

Surface treatments will last under normal traffic for that type of work for periods ranging from eight months to several years. Generally the heavier treatments are now employed because of their longer life. The surface will not always remain intact, owing to local weak spots. These will break away from the macadam below and form annoying holes, small in size, but deep and with abrupt sides. To maintain such a surface requires a supply of the same bituminous material as used for the general treatment and cover material. If the break in the surface is only through the treatment and not into the macadam, a small amount of bituminous material should be brushed well into the hole, and covered with stone chips or gravel. Stone chips, because of their angularity, will always be found better than gravel for such repairs, even where gravel was used originally for the general treatment. This cover material should be lightly tamped by hand to set it well in place.

If the break is into the underlying macadam, as well as through the surface treatment, a different process should be used in repairing the break. A quantity of stone passing an inch mesh should be available. This should be coated with the bituminous material, preferably by placing it in a fine wire basket and dipping it into the bitumen supply, or by pouring the bitumen through it from one bucket or container to another. It should be allowed to drain thoroughly so that no excess of bitumen except that necessary to coat the stone is left. This coated stone should be put into the hole in the surface, until it is filled a little above the surface level, and should then be covered plentifully with clean stone chips and thoroughly tamped.

This method of occasional repair of isolated weaknesses will serve to keep a surface-treated macadam road in good condition until the treatment has been worn down practically to the original macadam. As stated, this will result in from 8 months to 3 or 4 years, according to the weight of topping and type of bitumen used. It will then be necessary to retreat the surface according to the original method except that a smaller quantity of bitumen and a correspondingly smaller quantity of cover material should be used. Using the lightest bituminous material, as little as one-tenth of a gallon per square yard may serve for retreatments; frequently as little as two-tenths is used for practically any of the other materials up to the heaviest commonly employed in this kind of work. Two-tenths are as little as a mechanical distributor will spread. Less than this, if desired, must ordinarily be spread and broomed by hand.

The type of construction described in this paper will generally give good service under traffic up to 1,000 vehicles a day. It commonly fails by shoving and develops folds or waves, making the surface irregular and rough. This condition is difficult to combat or correct once it occurs. It is best prevented by adopting a consistent practice of filling the surface as full of stone or gravel as possible, securing always a surface having a mosaic appearance; and by avoiding entirely the leathery or rubbery type of work.

Each retreatment should be postponed until the existing treatment is well worn down to the original macadam and the retreatments should be as scant as will serve to restore a good wearing mat. Every effort should be made to prevent the accumulation of a mat so thick that it will iron out under traffic and form waves. When this wavy condition finally prevails, as it will if traffic increases and necessitates more and more frequent retreatments, it can not be cheaply or easily corrected, and it is an indication that this type of surface is no longer adequate. Heavier bituminous work of another type must be resorted to and this will be described in a succeeding paper.

## BITUMINOUS SURFACES OF MODERATE COST

In previous articles we have described those types of surfaces that are a heritage of the days before the automobile. The first and simplest method of treating the older types with bitumen to meet the new conditions was described under water bound macadam.

We have now to consider a variety of surfaces that have been devised to meet the new traffic. These types probably would never have existed, certainly not outside of cities, but for the motor propelled vehicle. They are what we include in the term modern types of pavement and most of them are indeed very modern.

The principal distinction between earlier and modern surfaces is that in the latter we use prepared or artificial binders and no longer depend on the natural cementing value of rock powder, or the efficacy of clay to hold stone particles in place. Instead we use a tar, an oil, or a native asphalt of suitable quality, or we resort to an artificial Portland cement. All of the bituminous types may be used in designs which contemplate the salvaging of other low type surfaces such as gravel, water bound macadam, and crushed stone. It is possible to use them to a certain extent also in reconstruction over sand-clay and top-soil.

The simplest and least expensive bituminous surface used is the single surface treatment already described. It was soon found that traffic rapidly wore such thin mats to a point where they broke away from the underlying course, and a heavier type of treatment was developed, known as a double surface treatment, or sometimes as inverted penetration. The significance of the latter name will be plain later. These heavy surface treatments are used to salvage water bound macadam, first-class gravel roads, and occasionally--almost experimentally still--sand-clay and top-soil roads.

In addition to the single and double surface treatments, and inverted penetration, there are bituminous macadam, a type widely used and of much value; a variety of thin surfaces or mats laid in place on the road; and a type of sand-asphalt that is a premixed surface approaching the standard sheet asphalt; but adaptable for light or modern traffic only. Three of these surfaces will be fully described, and the others briefly covered by reference to their essential variations from the more general types.

The simplest is the double surface treatment, for use on old or new water bound macadam, and on gravel roads of the best sort which are reasonably free from clay binder. The water bound macadam should be in excellent condition, thoroughly compacted, smooth and regular before the double treatment is attempted, and in the case of gravel



roads, only the best of this type should be made the base for such treatment.

It is a sound principle that as we advance our types of surfaces we should also advance the quality of our bases, because we expect the better types of surface to carry more traffic, of course, and we must pay more for such surfaces. So we must protect our investment and insure greater endurance by providing bases for traffic heavier both in respect of quality and also of the weight of separate units.

The preparation of the surface is the same as that described for surface treating a water bound macadam, and consists of sweeping from the old road all loose dust, and exposing thereby the well bonded stone. On this the first application of bitumen is made, preferably by means of a pressure distributor, at the rate of 0.3 to 0.4 of a gallon per square yard. At once the surface is covered with a layer of 3/4 inch to 1 1/4 inches stone at the rate of one cubic yard loose measurement to 40 square yards of surface and lightly rolled. A second application of bitumen is applied at the rate of about 0.4 to 0.5 of a gallon per square yard and the surface is covered with a layer of 1/4 to 3/4 inch stone, clean and free from dust, at the rate of one cubic yard loose measurement to 75 or 80 square yards of surface. The surface is then finished with a power roller, care being taken to direct the rolling so that the surface is not distorted or the stone displaced, but so that it is maintained in a true, regular cross section. The process of rolling the second application of stone compacts and wedges the entire mass, and to some extent the first application of bitumen is forced upward by the squeezing process and penetrates from the bottom. This accounts for the name sometimes given to this type. The resulting surface mat is about 1-1/4 to 1-1/2 inches thick and represents the best surface that has so far been developed by the method of surface applications.

A number of different grades of bituminous material have been used, but practice is becoming rapidly standardized for this type of work and the following specification may be depended upon to provide a satisfactory material:

#### Asphaltic Oil for Double Surface Treatments.

1. The Asphaltic oil shall be homogeneous, free from water, and shall not foam when heated to 175 degrees C.
2. Specific Gravity 25° C., not less than 1.000.
3. Flash point, not less than 175° C.
4. Melting point 38° C. to 66° C.
5. Penetration at 25° C. 100 grams, 5 seconds, 120 to 150.
6. Loss at 163° C., 5 hours, not more than 2 per cent.  
Penetration of residue at 25° C., 100 grams, 5 seconds, after heating at 163° C., as compared with penetration of asphaltic cement before heating, not less than 60 per cent.
7. Total bitumen soluble in carbon tetrachloride, not less than 99 per cent.

8. Ductility at 25° C., not less than 50.

The stone used may be any grade of material suitable for water bound macadam, and in addition any other hard rock, even though it has a low cementing value. This characteristic is obviously of little significance where an artificial binder is being used.

In some cases a third application of bitumen and stone is made simply as a sealing coat, but this variation of method is unusual.

Resembling the surface treatments, but differing in the method of applying, are the mats mixed in place. These have been developed for use where the underlying macadam or gravel road is not first class, or is even loosened and ravelled. A variety of light oils, even fuel oil, may be used. These are applied first to the swept road surface; over the oil a thin layer of loose material including the sweepings is brushed with a grading machine. A second application of oil is made, more loose material brought over the surface, and the whole loose surface worked backward and forward across the road enough times to mix the oil and stone or gravel thoroughly. The surface is then shaped and allowed to compact under traffic, or may be rolled to expedite the consolidation of the mat. If traffic is depended upon, a grading machine must be kept available to maintain the cross section true while the consolidation is going on.

These mixed mats are useful in arid or semi-arid regions where there is not enough rain to carry off the oils used. The results are somewhat better than single surface treatments on well consolidated macadam, but not so good as double surface treatments.

The most important of the moderately priced bituminous surface is the standard bituminous macadam built by the penetration method. This is the best known and most widely used medium type pavement, and its use is constantly increasing. In some states it has been developed for use under heavy traffic in designs having unusually heavy bases and thick wearing courses. Such construction, however, removes it from the moderately priced class and places it with the pavement class of surfaces.

The lightest design for bituminous pavement is a base 6 inches thick and a wearing course of 2 inches. The base course may be increased by using double courses of 4, 5, or 6 inches each; and the wearing course may be increased to 2-1/2 or 3 inches. The commonest cross section design in the United States is 6 or 8 inches base and a 2-1/2 inch wearing course.

The base is laid exactly as the base for water bound macadam, except that a wider variety of stone and sizes may be used and the stone is not so completely bonded with water and stone dust. It is common to employ a base stone graded from 1-1/2 to 3 inches in size.

By thickening the base a wide range in quality of stone is permissible.

The base course or courses are thoroughly rolled and compacted and the finished base is made true and uniform, the voids being filled by brooming chips or sand over the surface and rolling either dry or with a moderate amount of water.

Upon this base course enough stone graded from 1-1/2 to 2-1/2 inches is spread to give when compacted a wearing course of the depth required. For a 2-1/2 inch top, the stone should be spread at the rate of one cubic yard to approximately 12 square yards; and for a 3-inch course, one cubic yard to 10 square yards, all by loose measurement. The spreading of this course of stone must be carefully done and the surface must be left very true and even. The stone is then rolled sufficiently to make the surface firm and to disclose irregularities or low spots. These are filled and the rolling continued until a true, firm but not closed surface is obtained. When a softer stone is used, less rolling must suffice else the stone will break and the surface will be too much closed.

When the top course of stone has been adequately rolled and low places filled with additional stone where necessary, the first application of the bituminous binder is made. This process calls for great care and much of the success of the work will depend on the attention paid to this detail. The total rate of application should be about one gallon per square yard for each inch depth of stone. This rule holds for surfaces of 2 and 2-1/2 inches in thickness, but should not be used with 3 inch tops as it provides excess bitumen. As a part of this material must be withheld for a second application or seal coat, it is customary practice to hold one-half or three-quarters of a gallon per square yard for the seal coat and the balance of the total amount is poured as binder into the wearing course.

The application may be made by hand or by distributors of the gravity or pressure types. Excellent equipment has been developed for both methods. If the mileage to be constructed is large and the time limited, especially if hand labor is costly, mechanical equipment should be used. The pressure type of motor distributor is the best as it drives the material heavily against the stone particles and into the voids. If dust remains on the stone this process somewhat counteracts the presence of such dust and insures a better contact. On the other hand, the distributor may be so heavy and the weight so balanced over the rear axle as to cause excessive rutting of the stone and considerable distortion of the surface. Heavy and exceedingly skilful rolling is then necessary to bring the surface back to proper cross-section. It is sometimes difficult to start and stop the flow from the nozzles of a distributor so that entire control of the quantity applied is had at the starting and stopping lines of the several trips. Specifications require sometimes that building paper or other covering shall be spread over the stone at the start so that full rate of discharge shall be made just as the

equipment reaches the exposed stone, and that the flow shall be cut off as soon as it begins to diminish as the tank becomes empty. Paper may be slipped under the dripping nozzles at the end of the run to prevent the formation of "fat" spots, that is, places having excessive bitumen. Similarly, protective covering is spread to prevent lapping the distribution at the junction of two successive runs of the distributor. These details may appear to be meticulous and even unnecessary, but bituminous macadam is sometimes referred to as the "least fool-proof" type of bituminous surface built, and this reputation results from the fact that disregard of these careful details produces an unevenly bonded road, "lean" in some places, "fat" in others, that is, having too little or too much bitumen; and once this condition is produced it cannot be corrected except by removing the stone and starting over again. This work of correction is so costly that it is not done and in consequence we have many miles of poor bituminous macadam that might with proper care and skill just as well have been first class.

If the amount of work to be done is relatively small and the program gives ample time, especially where hand labor is cheap and susceptible of being adequately trained for the work, hand pouring is to be recommended. Some engineers actually prefer this method, and believe that superior results can more certainly be secured. They adopt mechanical methods for the sake of speed and economy where labor is costly.

Hand pouring is done with pouring pots of metal, having wide flat nozzles. The pots hold usually 3 to 5 gallons and have a strainer across the top so that foreign materials, blown by the wind, will not get in and clog the spout. The pots are filled with the hot bituminous material at the heating kettle or from the discharge valve of a tank mounted on wheels and supplied from a central supply and heating station. The temperature of the material should be between 135° C. and 177° C.

The men chosen to pour should be provided with heavy gloves, trousers, and shoes because the temperature of the bitumen is sufficient otherwise to take the skin off exposed parts of the body by the end of a day's work. Before pouring is begun and as it proceeds, the foreman should lay out a definite length of road surface to be covered by a single pot of binder. If the pots have 8-inch nozzles and the application is to be at the rate of 1.5 gallons a square yard, the length of a single strip covered by the contents of a 3-gallon pot will be 27 feet; or if the man is to walk forward and back, pouring two adjacent strips, the length will be 13.5 feet. The pouring may be done crossways of the road and if the width is 15 feet, two passes across and back, will be enough to empty the pot. In any case the area to be covered should be carefully marked by a stake or other handy means and the pourer trained to walk and pour at a speed adjusted to exhaust the contents of the pot in exactly the right distance. With a little practice men will become very proficient in doing this and once trained these same men

should be kept at this part of the work. Often it is required that the pouring be done in lines at an angle of 45 degrees with the center line. This is an advantage in reducing the tendency, often experienced in hand poured work, toward an uneven or ridged finish.

As soon as the first application is made, intermediate stone graded from  $3/4$  to  $1-1/4$  inches is spread over the bitumen coated coarse stone until it is so entirely covered that the roller wheels will not pick up the stone. The intermediate stone should be broomed lightly across the surface so that the voids are well filled and excess stone brushed to the sides. Rolling should then be started at the sides in the manner customary for water bound macadam and the surface should be thoroughly compacted by wedging the small stone tightly into the voids. Great care should be taken not to distort the surface, especially not to destroy the low crown used in designs of this type. The final appearance and the smooth riding qualities of the road depend largely on the rolling and it requires a roller man of great skill and patience to get a really good finish.

When the stone has been thoroughly compacted and locked, the seal coat is added, consisting of the remaining one-half or three-quarter gallon of binder and an additional layer of fine stone, graded from  $1/4$  to  $3/4$  inch. The surface is again rolled and brought to final finished shape. It may be opened to traffic as soon as the bituminous binder has thoroughly chilled.

A variation of this type is sometimes built using two sizes of stone. This is possible when the wearing course is designed 2 inches thick. In such case the first stone laid on the base is 1 to  $1-1/2$  inches in size. After rolling as described, the binder is applied and the stone used to wedge the surface is graded from  $1/4$  to  $3/4$  inch. This size is used also in the seal coat. The process of construction is otherwise the same as described.

Obviously, any stone suitable for use in water bound macadam is satisfactory for bituminous macadam, and in addition many rocks may be used that have a low cementing value. Slag from blast furnaces and steel mills makes excellent aggregate provided only that it is not of the highly acid or glassy kind. Soft limestones, even oolitic limestone and coral rock have been successfully employed. Just how severe the requirements should be for quality of stone depends upon the density of traffic and probable weight of individual traffic units. A French coefficient of 6 or 7 is quite sufficient for first-class construction of this type.

The bituminous binder, if an asphalt, should have a standard penetration of 80 to 120 and if a tar, should give a float test of 150 to 180 seconds. A general specification is given herewith.

Asphalt

The bituminous material, which shall be oil asphalt, or fluxed Bermudez asphalt, shall meet the following requirements:

1. Specific Gravity at 25° C., for oil asphalt, not less than	1.000
for fluxed Bermudez, not less than	1.040
2. Flash point, not less than	175° C.
3. Penetration at 25° C., 100 grams, 5 seconds	100 to 120
4. Ductility at 25° C., not less than	30
5. Per cent of total bitumen soluble in carbon tetrachloride, not less than	99
6. Per cent loss at 163° C., 50 grams, 5 hours, for oil asphalt, not more than	1
for fluxed Bermudez, not more than	3
Penetration of residue at 25° C., 100 grams, 5 sec. as per cent of original penetration, for oil asphalt, not less than	60
for fluxed Bermudez, not less than	50
7. Total Bitumen percentage, soluble in carbon disulphide, for oil asphalt, not less than	99.5
for fluxed Bermudez, not less than	94.0

A well-built bituminous macadam will satisfactorily carry a traffic up to 1500 vehicles per day including 50 to 60 trucks up to 3-1/2 ton capacity. It actually will carry a great deal heavier traffic than this, but it will become more or less distorted, begin to shove, and form corrugations or shallow waves in the surface. These can not be eliminated successfully by any maintenance methods that are inexpensive and consequently it is always well to consider carefully the limiting traffic. Beyond 1500 vehicles per day the cost of maintenance rises sharply.

The method of constructing bituminous macadam may be varied by first coating the large stone with bitumen by mixing the material at the rate of 18 gallons to each cubic foot of stone. The coated stone is then laid, the intermediate stone is spread over the surface to key and wedge the larger stone, and rolled as in the method already explained. This variation of the process requires dry stone, and even heated stone is desirable. It adds to the cost and undoubtedly produces a somewhat better result.

A final surface to be described among the types now under consideration is the so-called sand asphalt. This much resembles standard sheet asphalt and its durability increases the more nearly it approaches the standard type, but it is generally built as a cheaper form, by utilizing a natural sand, without admixture with other sands or any other treatment to produce an artificial, scientific grading of the fine aggregate. It is a useful type in desert regions, or wherever the natural soil is notably sandy. It has been used with success on Cape Cod, Massachusetts, U. S. A., and along the coastal plain from the Virginia line to southern Florida. It may be constructed as a combination base and top or as a top where a suitable base of other material is available. It should make an excellent, relatively inexpensive type for use in the southern Argentine, Patagonia, the Atacama desert and the entire northern arid region of Chile.

When built as a combination base and top, the total depth should be at least 5 inches, of which 2 inches is top or wearing course.

The sandy subgrade should be carefully leveled and compacted as thoroughly as possible. If water is available thoroughly wetting the sand as it is rolled will greatly facilitate consolidation. In places where water is not available the sand may be stabilized by spreading upon it and harrowing in a layer of one or two inches of clay. Rolling will then be much more effective than on dry sand.

The mixture for the bottom course is prepared hot and is composed of 91 to 94 per cent of sand and 6 to 9 per cent of asphaltic cement. The sand is heated prior to mixing to a temperature of 225 to 350 degrees Fahrenheit, and the work must be so handled that the mixture may be placed and rolling started with the temperature of the material not under 265 degrees and not over 325 degrees F. The composition of the sand is not controlled

beyond requiring that it shall all pass a 1/4-inch sieve and be graded from coarse to fine. Almost any natural sand deposit will furnish adequate material.

On account of the character of subgrade on which this type is usually built, it is impracticable to use a roller heavier than a 6- or 8-tone tandem weighing about 200 pounds to the inch of width. Care must be taken to roll the edges well before progressing toward the center. To support the edges of the mixture and furnish a guide for the spreaders and rakers, timber forms of suitable depth must be used. Two by eight inch-timbers set on edge with the shoulders banked high against them on the outside may be employed. These should preferably be left in place when the surface is completed, but this is not imperative.

After the base has been rolled it should be allowed to chill thoroughly before the second or top course is laid.

The base course should be kept clean; no traffic should be allowed upon it, and before placing the surface mixture a paint coat of one gallon of bituminous binder to 16 square yards of surface is applied to the base course.

The surface mixture may be the same as the base mixture, but the work will be much improved by more closely approximating a standard sheet asphalt grading. The following is suggested, and experience shows that a combination of not more than two natural sands, and often a single sand, will suffice to give the desired result.

	<u>Per cent</u>
Passing 10 mesh and retained on 40	14 to 50
" 40 " " " " 80	30 to 60
" 80 " " " " 200	16 to 40
" 200	0 to 5

The sand is heated as for base course before mixing and mineral filler is added to raise the percentage of material passing a 200-mesh sieve in the finally prepared material up to 10 to 15 per cent. The total fine aggregate and filler should be 88 to 90.5 per cent, and the bituminous cement 9.5 to 12 per cent.

The top course is handled and laid at the same temperatures as the base course and rolled in the same manner. As this course is final, the raking must be done with great care and the rolling must be skillfully managed so that the surface as finished shall be true and regular. It is possible, and often required, that this type of work be finished so that under a straight edge 10 feet long laid parallel to the center line, there shall be no



depressions greater than 1/16 inch for each foot in distance to the nearest resting point of the straight edge. Very careful work is demanded to secure such close conformity to a true surface.

Where there are available some of the lighter materials already discussed in describing gravel roads, such as marl, caliche, sand-clay, top-soil, etc., the base may be constructed of any of these and the mixed base may then be omitted. In such case the base course of light natural material must be thicker than 3 inches. Usually not less than 6 or better 8 inches should be used. The mixed top course is laid on the base as already described.

Sand-asphalt is a relatively new development. Until ten years ago only two or three sections, and all of these very short, had been laid. None of them carried more than very light traffic. But within the last five years this method has developed qualities indicating that it is satisfactory for a traffic of 800 to 1000 vehicles, and it is dustless and susceptible of construction where water is almost non-existent and no other natural material available than the desert sands.

## HIGHER TYPE PAVEMENTS

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The present article will cover in a necessarily brief manner the first introduction into a highway system of the more costly and durable types of surfaces usually referred to as pavements. Were we building a national highway system pari passu with the development of the country from pioneer conditions until traffic becomes as dense as it is today in some advanced countries, we should find the types to be described as the ones finally constructed, in point of time. The course of road building could economically follow closely the series of steps outlined in these papers. But in fact we are never able to pursue such a course, because our highways are behind our traffic in development. Some construction, therefore, even on a highway system being newly planned must consist of the higher types that represent the final forms of surface that the highway engineer knows.

Where traffic is denser than 1500 vehicles per day, including 100 or more trucks of 3 1/2 to 5 tons capacity, it is found that some form of pavement is justified. In the list from which the designing highway engineer may choose are several forms of bituminous concrete, Portland cement concrete, brick, or some other block pavement, and with the exception of the Portland cement concrete pavement these may be constructed on a variety of bases. Consequently, there are on the whole a large number of designs available; and in addition to the standard types there are numerous patented pavements which are variations of one or other of the standard types.

The original studies for laying out a national highway system will disclose some locations at once requiring a higher type of construction; or subsequent traffic increase will demand the reconstruction of an existing lighter type, the salvaging of as much as possible of the existing surface and the building of some form of modern pavement. The first condition permits a free selection of types to suit existing requirements. The latter condition frequently limits the choice or even determines it if the greatest advantage and most economical service is to be obtained. The three general classes of pavement are bituminous concrete, concrete, and block. In the large building program of the United States Government under the Federal Highway Act the mileage of these several classes which have been built may serve as an indication of the judgment of a large number of engineers who have worked under the greatest possible variety of conditions. Under that program the pavements built are distributed as follows:

Pavements Built on Federal Aid System

To September 30, 1927

Bituminous Concrete	1,751 miles
Brick	778 "
Portland Cement Concrete	14,408 "

It should not be assumed that this same order would prevail in any other country. It does not in France, nor in England. In both of the countries mentioned, pavements on the rural highways represent only a relatively small mileage, and in both cases bituminous or block types have been favored over concrete. In a continent like South America where coal is not available and oil is abundant and may be in much greater abundance in the future, it is likely that economy may determine the prevailing type of high-class construction with a different result from that appearing in the United States. In any case, the dictates of economy should prevail, and it should be borne in mind that equally serviceable pavements may be designed and constructed in any of the three classes mentioned. The engineer must study his local conditions and make careful estimates to determine what type to build.

Bituminous concrete differs physically from bituminous macadam in that the aggregate, composed of sand or stone or both, is very carefully graded according to size and is mixed with the asphaltic cement before being laid upon the base prepared for the surfacing course.

Bituminous macadam, as previously described, has the asphaltic material added after the stone is spread, by what is known sometimes as the penetration method, and the combination of aggregate is not graded except as necessary to secure a certain degree of mechanical bond.

The bituminous concrete pavements may be subdivided into three groups according to whether a fine aggregate, passing a sieve having 10 meshes to the linear inch, is used; or a graded aggregate containing particles passing a 1/2-inch screen and retained on a 1/4-inch screen, in addition to sand such as that confined to the first group; or finally a graded stone and sand aggregate ranging from 1 1/2 inches to dust.

An example of the first group is the ordinary and common standard sheet asphalt used on city streets in great quantity, and several other patented types designed in an effort to reduce the cost of the standard type. The second group is represented by the pavements built under Topeka specifications in which approximately 25 per cent of the aggregate consists of stone ranging from 1/2 to 1/4 inches and sand which is itself graded approximately as for a sheet asphalt. Also included in this group is the District of

Columbia specifications, Amiasite, Bessonite and some gravel mixtures of similar compositions. A variety of crushed gravel or stone mixture is now being extensively tried in some of the western states of the United States and should this type develop satisfactory qualities it may take its place in this group, although it presents some radically different elements in its preparation and construction. Finally there are the large aggregate mixtures containing stone as large as 1 1/2 inches and having both stone and sand carefully graded. There is in use today no standard type of this group, which is unquestionably best represented by the patented pavement laid under the name of Warrenite-Bitzolithic.

All bituminous concrete mixtures are designed and depend on the principle of internal stability. That is, the material composing the aggregate is separated into sizes and the voids existing in the largest size are filled with the next smaller size so far as possible. The voids in this combination are filled with the next smaller size and so on until finally all voids are theoretically full. Bituminous material is added in sufficient quantity to coat all particles and prevent them from moving on one another. In practice the complete filling of all voids is impossible at any reasonable cost, and in the various mixtures made some omit the large stone and some the fine. Some rely on a stiffer grade of asphaltic cement to fill a certain amount of remaining voids as well as to hold the particles in position. The standard example of this type is undoubtedly sheet asphalt. This mixture is composed entirely of sand passing a 10-mesh sieve, mineral filler passing a 200-mesh sieve and asphaltic cement. The theoretical specific gravity of a voidless mixture may be 2.26, and in actual practice a specific gravity of 2.20 should be secured, indicating voids in the final product, as left by the roller, amounting to 2.6 per cent.

Volumes have been written on the theory of designing these mixtures, and our knowledge is by no means complete today. A full description is impossible in an article like this and the reader is directed for a further study to some of the standard texts on the subject.

The bituminous concrete type of pavement is laid on some adequate base, as it has little or no beam strength and must be continuously supported. Bases used are of two common kinds, the rigid and non-rigid. The former is usually a Portland cement concrete base, but it may consist of an old Portland cement concrete pavement that is being salvaged or an old brick or block pavement similarly treated. The base if new should be at least 6 inches thick, and if soil conditions are not favorable this depth should be increased. Non-rigid bases may be of water bound macadam; rolled stone suitably filled and compacted but not necessarily water-bonded; gravel bases of considerable variety; other light materials such as caliche, tepitane, green (i. e. new) shell or old shell from bank deposits; good grades of marl; or in fact of

any non-slacking material, reasonably impervious to water and capable of being thoroughly compacted. These materials, like the marls, shell, and soft lime rocks, may be light and friable when dry and very non-resistant to abrasion, but because they are entirely covered and protected from the traffic by the bituminous concrete wearing surface, they will nevertheless serve adequately as bases for such types. The thickness of such bases should be at least eight inches compacted. The bituminous concrete surfaces are expensive, and no chances should be taken of losing them by having inadequate support. Such surfaces under modern motor traffic are exceedingly durable and more often fail because of insufficient support than from wearing out. It is, therefore, false economy to reduce a non-rigid, or any base design for such pavements to the point where full life of such pavements cannot be secured. Another form of non-rigid base widely used is known commonly as "black base," because it too is a bituminous concrete mixture, designed on the same principle as an asphaltic concrete wearing course, but usually with less care and attention to the theory. Such black bases should be at least 4 inches thick under favorable conditions of soil and climate, and are much improved by having a subbase of gravel or stone 4 to 6 inches thick. Then the black base may be reduced to a 3-inch thickness.

When sheet asphalt or an Amiesite mixture is used it is almost universal practice to introduce a binder course between the base and the wearing surface. This binder course is almost identical with a black base in composition and serves to provide an even surface on which to place the wearing course, reduces the needed thickness of that course, which is a more expensive mixture, and binds it firmly to the base. Where a bituminous concrete contains larger stone particles than a sheet asphalt or Amiesite it is not customary to introduce a binder course, because such tops may be laid thicker than the fine mixtures and thus a single course can be made sufficiently stable to resist movement under the effects of traffic.

Typical designs with dimensions are shown herewith, but these types lend themselves freely to combination in a variety of ways to accomplish the salvaging of former surfaces and the complete possibilities of design can only be suggested. Typical formulae for a number of mixtures are also given. These are subject to some adjustment to meet the characteristics of local stone and sand supplies.

Bituminous concrete must be prepared and laid with great care. The ingredients of the mixture must be proportioned by weight and thoroughly mixed after drying and heating. The temperature at which it is laid varies somewhat, but in most cases should be from 200° to 325° F. on the road. The spreading and rolling must be done with great care, and the fullest possible compression should be obtained.

The construction of bituminous concrete has developed a great variety of equipment consisting of large stationary plants, portable plants, spreading devices, rollers, and miscellaneous hand tools. This class of surfaces is susceptible to repair, and other machinery is required for such work, among which the surface heater or "turtle back" heater is today almost indispensable where a large amount of repair work is to be done.

The use of bituminous concrete is especially to be recommended in a continuous series of construction and salvaging operations, as the last or final surface. It is always possible to use an old base, or old road surface as a base for this kind of work, provided the old material is of sufficient depth, thoroughly compacted and stable. By means of "black base" or binder course, irregularities in the old surface can be removed, either by local patching or by laying a full course. On this a wearing surface of bituminous concrete can be laid. Practically all old road surfaces, even if badly worn and irregular, may be salvaged as part of a new design for a bituminous concrete, and this pavement in turn has a long life and is susceptible of extensive repairs when necessary, so that it is a satisfactory type to use as a final wearing surface regardless of what may have preceded it.

Before leaving the list of bituminous concrete types, reference should be made to the combinations of rock and native bitumen which occur in nature and are commonly known as rock-asphalts. These consist of a sandstone or limestone impregnated with asphalt and found in ledges sometimes of considerable thickness. The per cent of bitumen existing in the combination varies from amounts inadequate to act alone as binder, to a quantity so large as to make the use of the material impossible until additional stone is added. These materials are usually characterized by the exceedingly intimate mingling of the asphalt with the particles of stone. In the sandstone type every grain appears to be completely covered; in the limestone type the very rock appears to be impregnated with the bituminous material. No doubt this condition is the result of great pressure at the time of the geological formation of the deposit.

The rock asphalts can ordinarily be used either hot or cold depending upon the amount of bitumen present, the additional fluxing bitumen that may have been added, and the thickness to which the material is spread and rolled. They can be handled and adapted to cross section designs, either in original construction or in salvaging processes such as bituminous concretes are used. They are especially valuable in salvaging operations. Should deposits of rock asphalt be discovered in any Spanish-American country, care should be taken to develop the supply for road building purposes.

Portland cement concrete pavements are no doubt at the present time receiving more favor for rural highway construction

than any other type. In spite of certain defects that appear to be inherent and which certainly have not yet been overcome, this type appeals strongly to the engineer because of its homogeneous character and the consequent fact that it can be handled in design with greater precision than any other pavement material. It is consequently on this type of pavement that most studies have been made relating to the effects of impact, of passing loads, of strain distribution and of the effects of subgrade conditions. As a result this pavement has been set up, not so much as a standard, but as a unit with which other pavements are compared to determine their relative ability to carry certain given loads.

Cement concrete pavements have passed through a somewhat remarkable change in design within the last six years. Formerly constructed with a center thicker than the edges, they are now very generally built with a thickened edge. This change has resulted from the mathematical analysis of Westergaard of the Bureau of Public Roads and from the experimental roads tests made at Bates, Illinois and Pittsburg, California. The Bates experimental studies produced the formula proposed by Mr. Older of the Illinois State Highway Commission for designing a concrete pavement cross-section. The formula for the edge thickness is:

$$d = \sqrt{\frac{3w}{S}} \quad \text{and for center thickness,}$$

$$d_c = 0.7 d$$

where  $w$  = the wheel load, and

$S$  =  $1/2$  the modulus of rupture

$d_c$  = center thickness in inches

$d$  = the edge thickness in inches

These formulae produce designs usually referred to as 9-6-9, 9-7-9, 10-8-10, etc., and are typically shown in the cross-section reproduced herewith. It is quite possible to design a concrete mixture according to the water-cement ratio theory and thus, having determined the strength of concrete that will result, the assumption of strength can be made accordingly in the Older formula and the pavement designed. No other type of pavement can be controlled to any such degree.

The continuous and fruitful studies that have been made of concrete mixtures during many years indicate that good concrete can not be produced by careless methods. There is a pronounced movement current to change from the method of proportioning by volume to that of proportioning by weight, and this change, which was recently recommended by the Committee on Standards of the American Association of State Highway Officials marks a distinct advance in the control of concrete work of all kinds.

Heretofore the prevailing mixes used for concrete pavement construction have been 1-2-4, 1-2-3, or 1-1-1/2-3. The new methods now coming into use, which recognize the bulking of damp sand, the shrinkage of coarse aggregate, and the effect of the water-cement ratio, do not permit using a constant mix for all conditions even on a single job. The engineer must study the materials used and design a mix to produce the desired result. As in the case of bituminous concrete mixtures, a full discussion of this development of theory and practice in connection with concrete would carry us far beyond the limits of this paper, and the reader should seek such information in the technical reports which are available.

When first built, concrete pavements were considered really monolithic, but it soon became clear that a concrete slab will crack in spite of any means we have so far been able to devise. In view of this inherent characteristic we now usually build a road as a series of slabs, which are formed by inserting joints. Good practice indicates that a center joint shall be built in if the pavement is 18 feet or more in width, and it is now recommended that in 3 and 4 lane pavements the longitudinal joints shall be 10 feet apart, separating each pair of traffic lanes. Dowell bars or other suitable mechanical means should be used to prevent such joints from slipping.

When a concrete pavement is built of plain concrete, and no attempt is made to reinforce with steel, transverse joints except for construction purposes may be omitted. But if the pavement is reinforced with steel mesh or bars, these should be discontinuous in 60 foot lengths and definite provision made for transverse joints at 60 foot intervals. The longitudinal steel should be carried across the joint, or Dowell bars provided for that purpose, and such steel should be tight on one side of the joint and slip in the other to permit of a certain amount of contraction. From 40 to 60 pounds of steel per square yard are commonly used to reinforce the slabs which are, in a 20 foot pavement, 10 to 60 feet in size.

As already indicated, the concrete pavement is not the final pavement because at present it is not adaptable to convenient repair with concrete. Fortunately it does not, or at least should not require much repair, if properly built and in the future no doubt it will have a longer life than the average heretofore attained. But when the pavement is in need of minor repairs, these can best be made with bituminous materials. The use of alumnite and other quick setting cements may furnish better methods in time. When a concrete pavement, for any reason, becomes badly broken up it may be salvaged by



placing upon it a bituminous concrete top or wearing course. In some instances a second course of concrete has been laid upon the first. The joint is waterproofed with a heavy paint coat of hot tar well broomed on, and the new top is laid about 4 inches thick and reinforced. Relatively little of this latter work has been done.

Concrete does not adapt itself to the salvaging of other pre-existing surfaces to any great extent. It is rarely if ever economical to recover gravel or stone in the existing road for use as concrete aggregate; usually the most that can be done with such material is to grade it out flat and roll it down to strengthen and improve the subgrade, or to brush it aside with a grading machine after thoroughly scarifying it, and use it as material with which to build shoulders against the concrete pavement. The maintenance of the shoulders immediately adjacent to a concrete surface is generally difficult, and the use of old gravel or stone that may be available as salvaged material for constructing heavy shoulders is thoroughly worth while.

Before passing to a consideration of brick and block pavements, attention should be given to some of the designs into which bituminous concrete and Portland cement concrete are worked in connection with reconstruction or with the advancing in type of certain classes of lighter roads.

One of the most serviceable uses to which concrete may be put is to the construction of curbs of three general designs in connection with the widening of old gravel, water bound macadam, bituminous macadam, or bituminous concrete surfaces. The line and grade of the new surface must, of course, be adjusted to develop as much of the old as possible. The curbs are then constructed in proper position. They may take the form of a marginal curb to be flush with the top of the new pavement, they may be two or three feet wide and flush with the top of the new work, or they may be of varying width, according to the widening done and be at such an elevation as to unite with the old base to form a wider base, over which a complete new wearing surface is laid. These forms of reconstruction are best shown by illustrations. After the curbs or edgings are laid the old surface is repaired, new base laid if necessary between the old base and the curb and all the old and new base between curbs is then covered with bituminous concrete. The elevation of the new curbs is usually one inch below the proposed elevation of the new center, and by this adjustment it is possible to reduce and re-shape the crown of the new road to conform to modern practice regardless of what crown previously existed. A variation of this reconstruction produces a duplex road, usually a three lane road, having two outside lanes of concrete and the center of what remains of the old surface, treated with bitumen in some form. An illustration of such a road and a sketch of the cross-section are shown.

The third general type of pavements to be considered is brick or block. The principles of construction are the same whether brick, granite block, setts, durax, or other form of block is used. In every case the block should be considered as a surfacing material, and an adequate base must be prepared. Portland cement concrete or other forms of base construction are used. The base can rarely be finished so smooth as to receive the blocks directly and if it could be the slight variations of the blocks themselves would require that some provision be made to take up such irregularities. Accordingly on the base a sand cushion is spread averaging one inch thick. This cushion has varied considerably in brick designs from time to time. A mixture of sand and Portland cement, plain coarse sand, stone chips, slag chips, and a mixture of sand and bituminous material have been used.

At one time the proponents of brick pavement advocated what was known as monolithic construction, in which a sand-cement cushion was used and the brick after being placed and rolled, were heavily sprinkled with water and the joints between the blocks were then carefully grouted with a rich creamy grout of fine sand and cement. This type of brick construction was never entirely satisfactory and under motor traffic which does not wear brick appreciably the block was not subject to any salvage. It has been found if the brick are so laid that they can be removed, that their salvage value is high if for any reason the pavement becomes distorted, or has to be widened or rebuilt.

The block are, therefore, according to present day practice, laid directly on a sand or sand-mastic cushion, rolled and culled and then filled with a specially prepared filler of bituminous material. This serves to seal the pavement water tight and hold the block in place.

Where an old road furnishes an adequate base, brick may be used as a new surface and it thus provides a satisfactory step in the series of stages through which many miles of a well planned highway system may pass. But brick should not be placed on any non-rigid base less than 8 inches thick, and in general any base for brick should be equivalent to 6 inches of Portland cement concrete.

The only other block pavement that need be considered here is granite block, sometimes called Belgian block, from the country where they were first used. Granite block is perhaps the most costly of all pavements, and for that reason is rarely used in the United States on rural highways. It must be considered as a surfacing material, and should be laid so as to be susceptible of salvage. Many miles of old block have been taken up, recut and relaid in American cities. The general

design resembles that of a brick pavement having a concrete or other suitable base, a sand cushion usually one inch deep for recut blocks, and the blocks laid with a bituminous filler. Occasionally they are still laid as of old with tar and pebble filler, and sometimes with a cement grout. The latter practice prevents any future salvage of the blocks.

Any form of block pavement may serve as a base for a bituminous concrete when the blocks become so worn as to be no longer satisfactory as a surface.

In concluding this series of papers on laying out and constructing a national highway system it may be well to emphasize the point of view taken throughout.

No country can begin such an undertaking in these days without carefully considering traffic demands. Present traffic in some localities prohibits the economical use of some types of road that were in general use before the advent of the motor vehicle. Every piece of construction should be planned with an eye to the future and to the possibility, indeed to the probability that a betterment of type will be required. The advantages of permanent line and grade should be developed always, even on the first and cheapest work. Local material supplies should be studied and designs made to utilize such materials. Roads should be built only to the extent, and of such types as will pay for themselves. Sound economic, financial, and technical principles should prevail over the exigencies of transitory political conditions.

ANALYSIS I

SHEET ASPHALT

Binder Course.

Passing 1 inch and retained on $\frac{1}{2}$ inch screen	15-65%
" $\frac{1}{2}$ " " " " " 10 mesh sieve	20-50
" 10 mesh sieve	15-35

Sand for wearing surface

Total passing 10 mesh sieve	100%
" " 10 " retained on 40 mesh	12-50
Passing 10 mesh, retained on 20 mesh	2-15
" 20 " , " " 30 "	5-15
" 30 " , " " 40 "	5-25
" 40 " , " " 50 "	5-30
" 50 " , " " 80 "	5-40
Total passing 80 mesh, retained on 200 mesh	20-40
Passing 80 mesh, retained on 100 mesh	6-20
" 100 " , " " 200 "	10-25
Total "200 "	0-5
Mineral filler	6-20
Asphaltic cement	$9\frac{1}{2}$ - $13\frac{1}{2}$

ANALYSIS 2

COARSE GRADED AGGREGATE BITUMINOUS  
CONCRETE

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Coarse Aggregate	
Passing 1 inch screen, not less than	95%
Total passing $\frac{3}{4}$ inch screen	25 to 75
Retained on $\frac{1}{4}$ inch screen, not less than	85
Chips for Seal Coat	.
Passing $\frac{1}{2}$ inch screen, not less than	95
Retained on $\frac{1}{4}$ inch screen, not less than	85
Fine Aggregate	
Passing $\frac{1}{2}$ inch screen	100%
Total passing 40 - mesh sieve	30 to 70
Retained on 200 - mesh sieve, not less than	90
Penetration of Bituminous Material	60 to 80
Composition of mixture	
Coarse aggregate	45 to 60
Fine aggregate	25 to 40
Mineral Filler	3 to 5
Asphaltic Cement	6 to 8

ANALYSIS 3

FINE GRADED AGGREGATE (TOPEKA TYPE)  
BITUMINOUS CONCRETE

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Coarse aggregate	
Passing $\frac{1}{2}$ inch screen, not less than	95%
Retained on $\frac{1}{4}$ inch screen, not less than	85
Fine aggregate	
Passing $\frac{1}{4}$ inch screen	100%
Retained on 200 mesh sieve, not less than	90
Composition of mixture	
Passing $\frac{1}{2}$ inch and retained on $\frac{1}{4}$ inch screen	5-10%
" $\frac{1}{4}$ " " " " " 10 - mesh sieve	11-25
" 10 -mesh " " " 40 " "	7-25
" 40 " " " " 80 " "	11-36
" 80 " " " " 200 " "	10-25
" 200 " sieve	5-11
Asphaltic cement	7-11

ANALYSIS 4

TYPICAL WARRENITE BITULITHIC

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Passing $1\frac{1}{4}$ inch, retained on $\frac{1}{2}$ inch screen	30-60%
" $\frac{3}{4}$ " " " " 4 mesh screen	15-25
" 4 mesh " "10 " "	5-15
" 10 " " " " "	20-35

That part passing the 10 mesh sieve when tested separately shall have the following grading:

Passing 10 mesh, retained on 40 mesh sieve	15-40%
" 40 " " " 80 " "	22-53
" 80 " " "200 " "	15-40
" 200 " " " " "	10-15
Asphaltic Cement	8-12%

COST REPORTS FOR FIELD ENGINEERING

In the execution of engineering work it is usually necessary to delegate certain authority to field engineers. These men work under instructions given them by superiors who have planned the undertaking, and designed the details. The degree of authority that the field engineer has varies with his position and his duties. In the building of highways the field man may be in charge of surveys or construction. He may be making reconnaissances, running location surveys or bench mark levels, setting grade stakes, or he may be a resident engineer in charge of construction. In any case he is working under certain general instructions that insure that so far as his particular activities go they shall produce results in harmony with the proposed plans.

It is not always possible for the engineer in chief to follow the work in detail each day, and that official has in all probability several operations going at the same time as well as office duties that demand his attention in connection with other projects that are in the formative stage or are being designed. To maintain that close contact with the various field operations that successful and economical work demands is always a problem that requires a certain amount of attention. This contact must be maintained by occasional visits to the field and inspection of work, but these visits can at best be made at irregular and infrequent intervals and at other times the chief must rely on some method of field reporting by his subordinates that will give him constant and consecutive information of what is going on. The progress of the work and its cost are the elements by which the competent chief judges of the adequacy of his subordinates to accomplish the details assigned, and the occasional inspections determine the degree of precision and technical skill with which the work is accomplished.

To secure the necessary reports of field operations some simple, clear, flexible and at the same time sufficiently comprehensive method should be used. The reports must be as nearly as possible uniform and adapted to rapid analysis in the head office. They must be suitable for reporting a considerable variety of operations and furnish satisfactory information for determining unit costs if a system of cost accounting is in use.

Many such systems have been devised and are in use today. In fact, the differences of opinion among engineers with respect to the items and form of cost accounts have doubtless made any fixed practice difficult to establish. Each engineer thinks his method is the best, and no doubt it does suit his particular needs well enough to make him resist any change of system. Frequently the laws governing the fiscal operations of the state or province require certain forms of accounts and any method of reporting field expenditures must be adapted to showing the necessary information for such records. After all, these matters are details of analysis and should be considered quite apart from the actual field reports. If these show what is done, where and when it is done, and who was engaged in doing it, the analysis of costs in the head office can then take any form that is desired.



A system of field reports used on a large variety of highway work with entire success and satisfaction is described briefly in this paper. The field report consists of a single form for all surveying and construction, and another single form for all subsequent maintenance operations. The first form, on any single piece of work, is naturally discarded when the time comes to use the second.

The two forms are shown herewith in Figures 1 and 2. The first form, it should be noted, is always used by a man competent to keep records and set down facts intelligently. The second is for use by workmen who frequently can do little more than write, but who know how to do certain necessary work in the way of road repairs and maintenance.

Figure 1 is for use by surveymen, chiefs of party, resident engineers, inspectors and engineering subordinates, and provides for a daily record of all operations. A concrete case will explain its use.

At the end of each day's work the chief of party or other field man in charge of certain details, makes a report of all operations conducted by him that day. He may have a bench mark party of two setting permanent or temporary benches; a locating party of eight including two axemen; a level party of three; and a cross-section party of three. He should use a separate form for each separate party, filling in the several forms so that all work done shall be covered, all expenses accounted for, and the personnel employed shown. His own time, spent as front rodman of the locating party, may be charged entirely to the location survey or distributed as his judgment dictates. Sample forms made out for the locating party and the cross-section party are shown in Figures 3 and 4. In all, four forms should be used for that day's work and the total cost should check the total of the four cards. If the survey party operates from a camp, which is maintained with cook and helper, a separate card should be made out for camp charges or the cook and his assistant may be distributed among the several parties. Similarly, if transportation has to be used, the items for this may be separately reported or distributed among the parties. The manner of reporting camp and transportation costs should be covered in the instructions to the field man in charge; and these instructions will depend on the desired analysis of survey expenses. It is well to note that if the items are separately reported, the field man does not have the bother of prorating such costs against the several parties operating and also that the head office is then free to make any distribution it finds necessary. In making out the report the chief of party may enter the time only of each employee, leaving the head office to enter the rates of pay and the total day's charge. Or the field man may enter the entire record assuming he has been furnished with the necessary information regarding the rates of pay of all employees, and bring down the total cost. Usually in such parties some men are employed directly by the chief of party and laborers like axemen may be frequently changed. So that in some cases no one but the field engineer knows what the rate of pay is.

The daily report forms may be post cards already addressed to the Chief Engineer at the head office, or they may be made up in booklets so that they can be torn out. In any case they are all mailed to the head office daily and are there entered on a summary form like Figure 5. This summary may be made to carry a week's or month's record and it should check with the entire cost of the field work for the period. It can be used as a check against the pay rolls, and can be taken by the bookkeeper for use in making up any desired set of unit cost accounts that the head office is in the habit of keeping. It is unfortunately the headings for these office cost records that are in disagreement among engineers. Some common examples of details over which there is notable disagreement are interesting:

In new highway work it is often necessary to run trial lines before the final satisfactory location is fixed. The topography may require this, or it may result from difficulties over rights-of-way. Shall all the cost of trial lines and final line be charged against the final location survey, or shall only the cost of the final line be charged? Shall bench levels, which if accurately run are a part of the general control of the area for many engineering and survey purposes, be charged against the cost of survey for the highway or not, or shall a part be so charged, and if so, what part? Nobody knows; there is no fixed custom and each chief engineer must determine for himself what he will do. Sometimes the laws direct him what to do and he must compile his cost accounts accordingly.

This form of field report may be used for all succeeding work of surveying and construction. The final construction survey, setting slope stakes, measuring quantities, cross-sectioning borrow pits, taking check levels may all be reported just as the several operations connected with the original location surveys. When construction is started the resident engineers and inspectors can use the same form of report with such headings as may be designated by the chief engineer to cover the operations of building a road. Clearing and grubbing, grading, pipe culvert construction, concrete structures, laying base course, laying top or surface course are suggested as typical heads under which the work may be classified. The chief engineer will select the headings adapted to the work being done. Sample forms are shown in Figures 6 and 7 for grading and bridge construction.

The classification of operations in this manner has only one relation to cost accounting and to unit cost accounts it furnishes the information of field operations of all kinds in such detail that any reasonable accounts can be built up from the field record. But it is to be noted that this method of field reporting does not fix or decide what forms cost accounting shall take. There exists the greatest possible variety among such accounts as they have been developed and are in use today. In the United States where highway building has advanced with great rapidity within the last ten years there can hardly be said to be yet any standard practice with regard to such accounts. The matter is at present, however, under the closest scrutiny and some standardized system will doubtless be adopted in the near future.

When construction has been completed and the highway has been placed under maintenance a somewhat different condition exists, and the form represented by Figure 2 is thereafter used in reporting all maintenance operations.

Maintenance will be under the general supervision of some engineer official and there may be district or division engineers in charge of large geographical areas. But the actual work of maintenance will be done by patrolmen or by laborers working in gangs under a boss and either the patrolman will make his own daily individual report, or the boss will report daily for the gang. In either case, the clerical work must be reduced to a minimum and it must be of the simplest sort.

These men never should have authority to hire or discharge laborers; all such duties should be reserved to the engineer in charge of the district. Consequently, it is never necessary that the salaries or costs of materials be known to the field maintenance laborers. It is necessary only that the amount of labor in hours and the quantities of materials used measured in customary and familiar units, shall be reported. The values in money can be added in the head office, where rates of pay of all labor and costs of all materials are known.

A patrolman, therefore, reporting only for himself, indicates by numbers in the proper column the hours he worked at the indicated operations. Such a report card is shown in Figure 8. The total hours must check with the full work day. If rain prevents work the hours so lost should be indicated and the word "rain" entered as shown.

If the boss of a gang reports for his men and himself he uses the same form and gives the total hours of work devoted to each item. The total should check the product of the men times the full work day. Materials used in maintenance operations are also to be reported as indicated in Figures 8 and 9, and to accomplish this easily each patrolman or gang must be furnished with a pouring pot of known capacity, if bituminous materials are used, and with a cubical wooden box for measuring small quantities of gravel or crushed stone used in making minor repairs. If carts or trucks are used by the gangs these should be measured by the engineer and marks set at different levels inside so that the boss may easily determine the larger quantities of these materials that may be hauled and devoted to maintenance work.

The daily reports from the patrolmen and bosses are summarized on record forms in the district engineer's office and the costs assigned. The daily cards will determine the location of the work and the summary sheets can be made to cover a considerable mileage of road, thus preventing a large or bulky set of records. Especially where maintenance is performed by gangs of laborers working together the sections assigned to a capatez and his gang may be 10 to 15 kilometers in length. Several such sec-

tions may be summarized on a single sheet. A patrolman can care for 1 to 5 kilometers depending on the type of surface and the rainfall. His reports can be similarly grouped.

In all the summary sheets only the total cost figures for each item of work are entered. All the detail is omitted but will show on the daily reports which may be preserved as long as considered desirable. Sample summary sheet for maintenance is shown in Figure 10.

The forms and methods of field reporting herein described have been in satisfactory use many years in a large variety of road work and have been tested in hard service. They have served their purpose well. In one instance very careful and accurate records of costs on experimental roads were needed and this system of field reports was used continuously for two years and a half while the research work was under way. The results were satisfactory in all respects.

In using the reports the chief engineer must himself determine what information is to be compiled from them and see that the supplementary office data are available. One such detail, for instance, concerns the unit prices to be charged for materials reported used by the patrolmen and gangs. On a surface treated macadam or bituminous macadam road, bitumen and small crushed stone or clean gravel will be required for routine patching. These materials will be purchased and delivered along the highway at convenient intervals. The cost of such materials thus delivered will be known to the district engineer or other official in authority. This rate will be charged for the material as it is used and eventually the total, less certain waste or loss will be accounted for. But before all this stock is gone a new supply will have to be purchased and delivered. The cost of this material will be different in all probability from the cost of the first lot. No attempt should be made to distinguish between the two lots stocked along the road, and the patrolmen should not be confused by any instructions to report their use separately. The head office or district office simply adjusts a new unit price for each material based on the value of the old material on hand combined with the new material delivered. For instance, 6,000 gallons of bituminous cold patching material may have been delivered in barrels along a piece of highway at 20 cents a gallon. This is the price used at the head office in making up the summary sheets showing costs of materials employed in maintaining the road. When there are still 1,000 gallons on hand along the road, a second supply of 4,000 gallons is ordered and delivered at a total cost of 21 cents a gallon. The total cost of bituminous material on hand will be 1,000 gallons at 20 cents, or \$200.00, and 4,000 gallons at 21 cents, or \$840.00, a total of 5,000 gallons costing \$1,040.00, or 20.8 cents a gallon. This new unit price is then used until a new stock requires a further adjustment of price.

Exactly this same method is used in setting up the unit prices at which each other material shall be charged as it enters into the maintenance work. From time to time the remaining materials should be measured up and checked with the record to see whether the wastage has been excessive or not and to ascertain to a degree whether the patrolmen are carefully reporting. This check ordinarily should be made twice a year for expensive materials and once a year for cheap materials.

A chief engineer faced with the responsibility of spending annually a considerable sum, through the labor of a scattered force, and the use of large quantities of materials in small units and equally scattered can only discharge that duty intelligently and properly when he knows within a reasonable administrative margin where and how the labor and materials are employed. Some simple but definite method must be resorted to to secure the information, and the method must include to some extent checks that will serve to control its accurate working. The method described and the forms shown are submitted as a practical example of what can be done. The experience of the engineer wanting some such device will suggest to him variations to meet his peculiar needs if such exist.

FINANCING A NATIONAL HIGHWAY SYSTEM

The financing of a National Highway System should be treated fundamentally as a matter of taxation. Unless roads and bridges are built as toll structures, in which case the proceeds from their use are applied to interest, maintenance and retirement of the original cost, the total cost must in the end be derived from public taxes. We are not concerned at this time with toll structures and are to confine our consideration of the financing to a system of free roads and bridges built for the general use of the people.

No comprehensive study of taxation for highway purposes has been made by any authority recently enough to cover the most important developments of the past two decades in highway construction. It is not possible within the scope of this paper to do more than discuss briefly the present trend of public practice and suggest the general principles indicated by it with some reasons for considering these indicated principles as sound or unsound.

We have found the motor vehicle to be the determining consideration in discussing a general highway program and the details of road design. Similarly, we find that the motor vehicle has become the principal recognized source of public income to finance the highways demanded by its own use. But this is not the only source. Road taxes are obtained also from:

- (1) Direct real property tax.
  - (a) General tax.
  - (b) Special assessments.
- (2) Direct personal property tax.
- (3) Wheel tax (occupational tax).
- (4) Miscellaneous taxes which reach the highway fund by transfers from general state or national funds.

The real problem in highway taxation is not so much to discover adequate producing sources of revenue, but rather to establish the proportion which each of these sources should properly and equitably contribute toward the total highway budget. The problem is an involved one, many details are indeterminate, and no expansive study has ever been made to solve it on a sound economic basis; but the general trend of administrative and legislative action in a large number of individual cases serves to indicate some grouping of the sources of taxation that appears reasonable, just, financially sound, and usually successful beyond anticipation. The principal question involved is to establish what part of highway costs shall be carried by real property, how far the motor vehicle and gasoline taxes should be devoted to construction, to what extent these should be confined to maintenance, and what relation if any should be maintained among these and other possible sources as elements in the highway fund of the nation.

For our purpose it is perhaps unfortunate that we have as the most productive field of example the United States, where motor registration is at present so large, and where an unusually well distributed purchasing power and a rapidly advancing highway program have caused a notable development of this source of revenue. Unquestionably, no such rapid increase in actual number of motor vehicles can be expected in South American and Central American countries. There the number of motor vehicles is not now large relative to that in the United States, and extension of the registration probably depends on a development of a wider purchasing power than now exists, but this condition is only a temporary one and will be corrected in time. How fast the relative increase will be remains to be seen.

Assuming the possibility of a responsive and flexible highway building program, it is undoubtedly true that automobile registration is limited only by population and the ability of the purchasing public to buy. The rate of increase of registration is a function of highway improvement, each one reacting directly on the other. Neither highway construction nor the automobile industry is the cause of the other. The demand for easier and cheaper communication in the common cause. But there is a reciprocal reaction that is going on all the time, if we are to accept the experience of the United States, which is the outstanding example of large registration and a big program of modern road construction. The automobile was made practicable and used on existing city pavements. Attempted uses of the country roads at once developed an intolerable dust nuisance and accelerated wear. The dust was laid and the road surfaces protected. More automobiles began to use these improved roads adjacent to the large towns and cities. Their use and radius of operation increased, more mileage was improved, until this cycle reached enormous proportions, involving an increased registration in one year of 2,852,000 motor vehicles and the construction of at least 21,850 miles of surfaced road.

Today in the United States this cycle can be seen in different phases of its development. There are states with a large completed and connected mileage; there are states with no transstate routes yet entirely improved. There is one state at least whose capital city could not be entered over a paved road in 1926. But in that state the local improvements, the extension of the improved mileage in and immediately adjacent to the half dozen cities of the state and the numerous large towns, have been accompanied by a notable increase in the use of motor vehicles.

It is reasonable, therefore, to cite a parallel between present Latin American conditions, and conditions as they existed in the United States in the earlier years of the automobile. Subsequent extension may be slow or rapid in the South American field, but experiences may be expected to run closely parallel with those of the United States in the direction of economic effects. The present

registration there is already sufficient to create a demand for road improvement, the improvements made will react on the registration, raising it as rapidly as purchasing ability and population growth permits. This latter will follow the general prosperity of the countries, and road-building has a sustained history of always promoting prosperity by improving communication.

We find that revenues for road building are obtained from several sources, the commonest of which are direct real property taxation, and direct taxes on the motor vehicle and on the fuel used. We shall accept as generally established that these forms are the commonest, the most productive, and have become, through a certain experience, the most acceptable under an admittedly rapid and extensive highway development, like that in the United States. Errors have been made in the method of application and in the details of distributing the tax. Improper proportions of the cost of road building have been assigned to one or the other of these commonest sources of revenue, but the taxes so levied have been generally adequate, easily and economically collected, difficult to avoid, flexible in application, and acceptable to the general motor operating public. When the revenues produced have not sufficed for such an extended or rapid program of construction as desired, increase of the rates has been accepted and in some cases even demanded in connection with definite plans for increased building activity.

We are concerned in determining what are the principles behind the drift of current practice as displayed in the large financing operations current in the United States.

Any developed area must inherently be economically capable of providing for its own immediate transportation demands. The only possible exception to this would be an area absolutely self-contained and requiring no communications. A single field on a plantation must carry needed fencing charges, as well as cultivation charges, or it can not be operated economically and hence can not be developed. In exactly the same way it must carry its own transportation charges, to the stage of road improvement satisfactory for the transportation demands of farm land. These may involve nothing better than a simple dirt wagon road from the field to the plantation entrance, or to the adjacent public highway. A group of plantations must similarly be able to carry their own needs for transportation and lines of communication. An agricultural or other developed area, be it city, town, suburb, or country side, must carry the same costs as a direct charge against the operations of developed business in that area. On the other hand, such areas can not properly be called upon to do more. A single plantation may be served adequately by a dirt road, well graded and drained. A fertile valley with a large number of prosperous ranches may require nothing more than a gravel road. A city will require its pavements, curbs, and gutters. Each should carry the charge for what it individually needs. It is not sound to burden local development with a heavier charge for transportation than this minimum which is indispensable.



The local traffic which sets a satisfactory minimum of adequate improvement is not, however, the only traffic that exists. For each area produces not only local traffic, which is necessary to and remains identified with the localized business operations of the region, but it produces a certain amount of traffic that flows beyond the boundaries of the more or less clearly defined local area. Each region, therefore, not only has a local traffic, but it produces for some contiguous region a foreign traffic, and in turn receives from contiguous regions a traffic foreign to its own requirements. This traffic, which is here referred to as foreign in a purely relative sense, has little relation to the development of the local areas other than that one in which it originates. Cities send a heavy traffic into and across some poorly developed country side. The distant rural sections send little or no traffic into the cities. Some cross roads carry practically none but a very limited local traffic, others carry little more than the accumulation of local traffic in larger but still limited and well defined areas. Still other highways clearly fill a dual purpose in providing a local road and an artery for distant communication.

The existence of this so-called foreign traffic has come about because the radius of highway transportation has been lengthened by the new type of vehicle in use. During the time when horse-drawn traffic prevailed, at least during the railroad era, the foreign traffic as here understood never existed as an economic factor in the system of communications. Business creates it, but does not account for all of it. Pleasure and convenience are responsible for a large part.

A further indication that real property, especially in agricultural sections, should not be called upon to finance a better type of construction than demanded by the traffic having local origin is found in the experience of some states that have tried it. The creation of so-called improvement districts in Arkansas, U. S. A., comprising fractional parts of one or more counties, was for some years a favorite method of financing highways on the state system. Generally the type of improvement was better than sufficient to meet local needs. The real property of the district was taxed to provide interest and sinking fund, bonds being issued for construction. This practice was continued until over \$60,000,000 of local improvement bonds had been sold. The burden was more than the land could carry. Local opposition to the taxes necessary developed within a few years; in some cases interest remained unpaid, and several districts went into the hands of receivers. Finally, the State through legislative action

provided for motor vehicle and gas taxes, assigned the revenue to the counties to be used according to a sliding scale to meet the charges against improvement districts within the counties. The rich counties applied none of those revenues to bond charges and the poorer counties applied from 25 to 100 per cent of such revenues to that end. In all cases the proceeds had to be used either to carrying the highway bonds or in the construction and maintenance of roads. In the other states where improvement district laws are in force the experience has not been so severe, but tends in the same direction if resort to those means becomes excessive. In other cases the taxation of land for over-developed roads had led to such heavy burdens as to affect the market value of rural land unfavorably.

It is clear, therefore, that there must be some other source for highway income than the real property under development unless we impose an undue burden on that property. Better highway facilities than those required by the mere local needs are demanded. It is equally obvious that this demand flows wholly from the so-called foreign traffic, with its added facilities for business, possibilities of saving in costs, and sources of pleasure and convenience. This traffic should be made to carry the charges incident to its operation. On this basis we may turn to motor vehicle revenues as a logical, probably adequate source for a highway fund to provide the cost of construction to meet the additional demands arising from foreign traffic.

If properly levied and used there is no tax that bears any more direct relation between source and object than the motor license fee and the gasoline tax. The increase in rates on motor vehicles and the rapid introduction of the gasoline tax indicates a wide acceptance of this method of raising revenue.

If we now examine the change in the source of highway revenues we shall find an interesting condition. In 1904 local bond issues for highways in the United States totalled 21,000,000, and the carrying charges were met generally from property taxes. In 1909 the total was approximately \$100,000,000, and in 1914 it was \$286,557,073. In 1921 there was a total of \$1,166,124,700 highway bonds outstanding in the United States. At that time the state highway bonds outstanding were \$289,386,500, leaving a total of \$876,738,200 in local issues. Here we have a continually increasing local indebtedness for highways. But by 1922 the state bonds had mounted to \$367,687,100. In 1925 the total reached \$626,832,350, and in 1926 the accumulated total issues were \$820,780,100. In that year the total state and local bonded highway debt was approximately \$1,800,000,000, leaving about \$979,200,000 to represent the local issues.

Now, it is a fact that in some states the counties or other local subdivisions have been expected to contribute a portion of the cost of state roads in the local jurisdiction. But this has been a decreasing rather than an increasing practice, at least since 1916 when the Federal Aid Act was passed by the Congress and a requirement was made that all funds spent on the Federal Aid System should be made under the control of the states.

We find that in 1920 the proportion of property tax funds devoted to state road construction amounted to 29.2 per cent. In 1925 it was 25.4 per cent. In 1926 it had dropped below 20 per cent.

Whether this proportion will decrease still further can not be foreseen. Certainly it can not continue very much farther in view of the very effect of motor traffic on the development of large suburban areas with heavy increase in land values. The increased proportion of high priced land will certainly offset the past tendency toward a continually decreasing contribution of the property tax to the road fund. A similar effect will flow to a less degree from rural lands whose values are increased substantially by being devoted to the production of higher priced, perishable crops for urban consumption.

However future conditions may alter present tendencies, these are now clear. The construction of state roads has been getting more costly, the roadway wider and the surfaces more generally of higher types, and the share of the cost carried by the local subdivisions has been decreasing and at the same time local highway bonds have increased steadily.

This outline of conditions indicates definite tendencies:

- (1) The local units do not hesitate to increase taxes on property for road purposes.
- (2) The roads built with such proceeds are generally local and the practice of confining such funds to local roads is increasing.
- (3) The participation of local funds in the construction of the state roads is becoming not only proportionately less but absolutely less, due to provision of larger sums for state-wide highway construction.

The experiences represented are those of forty-eight separate government units. These separate agencies are constantly observing the various solutions of current problems found by each other, and they confer and exchange ideas through a large number of semi-official and civic channels. Each state closely watches the success or failure achieved by all the others and a cross section of the combined experience discloses a view of

the greatest significance. The aim has unquestionably been to find a source of ample revenue for highway purposes, one that can be easily drawn upon by methods not easily evaded, one that is not greatly resisted, that operates without great cost, and most of all one that produces on the public mind an impression of fairness and equity. The constant increase of motor vehicle license charges and the introduction and subsequent increase of the gasoline tax demonstrate that both the form of the impost and its operation are satisfactory to an enormously large public. Space is not available to do more than tabulate the existing fees and tax rates prevailing and to add that in 1919 the first gasoline tax of one cent was laid.

Table No. 1

Gasline Tax Rates, by States,  
as of August 1, 1927.

Rate :	States
Cents :	
5 :	5 - Arkansas, Florida, Kentucky, New Mexico, South Carolina.
4½ :	1 - Virginia.
4 :	8 - Alabama, Idaho, Maryland, Mississippi, Nevada, North Carolina, South Dakota, West Virginia.
3½ :	2 - Georgia, Utah.
3 :	18 - Arizona, California, Colorado, Delaware, Indiana, Iowa, Michigan, Maine, Montana, New Hampshire, Ohio, Oklahoma, Oregon, Pennsylvania, Tennessee, Texas, Vermont, Wyoming.
2 :	12 - Connecticut, Illinois, Kansas, Louisiana, Minnesota, Missouri, Nebraska, New Jersey, North Dakota, Rhode Island, Washington, Wisconsin.
No Tax:	2 - Massachusetts, New York.

Table No. 2

Automobile Fees and Taxes  
(Based on minimum rate for touring car)  
as of January, 1927.

Rate	:	States
To \$ 5.00	:	7 - Arizona, California, Colorado, Indiana, North Dakota, Ohio, Utah.
\$ 5.01 to \$10.00	:	27 - Delaware, Florida, Idaho, Illinois, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, Pennsyl- vania, Rhode Island, South Carolina, Tennessee, Washington, Wisconsin, Wyoming.
\$10.01 to \$15.00	:	14 - Alabama, Arkansas, Connecticut, Georgia, Kentucky, Louisiana, North Carolina, Oklahoma, Oregon, South Dakota, Texas, Vermont, Virginia, West Virginia.

After such a review of actual, successful practice in raising funds for the greatest single highway program the world has ever seen we may venture to state certain principles indicated by the course of this experience.

(1) Direct real property taxes should be used to finance only local roads, and only that proportion of the cost of the main roads on the national system which represents the demand of traffic having a local origin.

(2) Motor vehicle license fees and the gasoline tax should supplement the property tax in financing the national road system, and should provide so far as possible for all the construction requirements incident to the traffic that is not of local origin.

In this second principle we recognize that the very element that creates the demand for long, connected, continuously improved roads and heavy, high type construction is made the source of the additional revenue required to meet the demand, and therefore we should logically add a third principle.

(3) Motor vehicle revenues of all kinds should be devoted only to the construction, betterment and maintenance of the national highway system.

To these we must add a final statement because there are other taxes that may be levied to augment the general highway fund.

(4) Special taxes such as a crude oil production tax, a mineral tax, or a wheel tax--none of which are direct levies on real property--may be used to produce emergency revenue funds for the national highway system.

To determine the proportion of cost of the national highway system that should equitably be born by local property taxation is difficult. It might be possible to do so by means of an elaborate traffic census; but this has never been done, and the cost and time consumed in such a study would hardly be warranted. Because a simple adjustment would not continue to be exact as motor registration increased and uses of the motor vehicle became more general and more diverse. Moreover local traffic is subject to sudden and unforeseen changes due to the introduction of new industry, discovery of a raw natural product, unexpected success of some agricultural or developmental production, to colonization in mass and to other large changes of the same sort.

Then, too, the idea of local traffic is relative and the practical determination of what is local and what is foreign traffic in the sense used herein depends entirely on the unit of area considered, which is generally a political subdivision created without consideration of economic or traffic conditions.

For instance, if we consider the state or the province as the unit of area we might find, as we do in the United States, the

foreign traffic as little as 10 per cent of the total. In the central part of Pennsylvania the foreign traffic, that is traffic from without the State, amounted to 10 per cent as shown in a general study of the highway traffic. In Connecticut a similar study of the highway traffic disclosed 10.9 per cent of foreign traffic near the central portion of the State. In Ohio, near the State boundaries, the foreign traffic is approximately 50 per cent of the total, and on all parts of principal through routes across the State it was high, averaging on one main route as much as 23.6 per cent. In the central part of Nebraska on a single main route the foreign traffic is 16 per cent and in Vermont it is as high as 36.6 per cent during the summer tourist season. But in general the average foreign traffic on the state highway systems of several states that have been carefully investigated amounts to approximately 10 per cent.

On the other hand, if the county is considered the local unit we get an entirely different relation between local and foreign traffic, especially if we consider as the county that area outside of the incorporated municipalities. We find in Ohio that on the state roads within a county the foreign traffic amounts to 87.6 per cent, and the local rural county traffic -- the distinctly local traffic -- to only 12.4 per cent. In Vermont and New Hampshire the local traffic on the same basis is only 10.1 per cent and 6.1 per cent, respectively. In Connecticut it is 21.1 per cent, and in Pennsylvania, 7.1 per cent.

In the United States the county is the principal rural taxing administrative unit and it might appear, therefore, that the property taxes devoted to the state highways in the county should not exceed 15 per cent of the total cost. If we are to adjust the proportion on this basis, however, we should consider tonnage and not only source but destination of the traffic, because much of it unquestionably would flow into the cities where it would pay no part whatever of the cost of streets. As a matter of fact, we find the property tax flowing to state road construction amounts now to about 20 per cent and as a part of this comes from incorporated areas, which generally also pay a county tax, the excess above the relation indicated by a simple traffic count is not at great variance with the actual proportion gradually approached by the contribution of the property tax toward state highway construction.

Space forbids discussing in greater detail the proportions of the highway budget to be assigned to the other sources of taxation. The appended Table 3 shows the per cent of total state highway revenue derived from its several sources. Transfers, state appropriations and state direct taxes may all derive from a direct property tax. They probably do not, but it is conservative to assume it. Then all securities sold may be (but are not actually) carried by direct property taxes. If the interest on such issues is 6 per cent the total possible property tax represented in the tabular analysis is 18.5 per cent.

Table No. 1

Composition of the Consolidated Highway Fund for State Highway  
Systems in the United States

For State Fiscal Years ending in 1926

	Per cent
From Motor Vehicle fees and licenses-----	33
" Tax on motor fuel-----	20
" Securities sold-----	15
" Federal Aid-----	11.7
" Transfers from County and town funds-----	10.4
" Direct appropriations by states-----	4.4
" Proceeds of state road taxes levied on real property-----	2.8
" Miscellaneous sources-----	2.7
	100.0

Motor vehicle fees and gasoline revenues are divided between construction and maintenance. The proportions devoted to each are difficult to fix, and in themselves are interesting subjects for investigation.

Fundamentally the financing of a national highway system is a problem in taxation, but the practical operations extend to the detailed methods of handling the highway funds so as to produce the best results.

In general there are but two quite obvious methods. The first is called for want of a better name the pay-as-you-go method; the second is the capitalizing of annual taxation by issuing bonds and obligating thereby the future annual revenues. Each of these methods has had a wide and successful application. The use of one or the other depends on a number of conditions internal to the state or nation choosing between them. The rapidity of increase of motor vehicle registration, the popularity of travel by motor, the financial condition and stability of the state and its ability to secure credit in the money market have their effect in determining the decisions made in the past.

The pay-as-you-go method imposes no financial obligations to be met in the future except that of protecting the investment in roads by adequate maintenance. The building program accommodates itself to changes in the economic status of the nation, and



may be curtailed or extended at will with reasonable flexibility. It involves the creation and protection of no sinking funds, and the direct construction and engineering costs represent the whole cost of the roads built. The program moves along slowly and may, by a careful budgeting of new construction and maintenance, be continued logically and successfully to an indefinite extent. It may be altered to meet changes in development by extending it to supply transportation routes previously undisclosed by the original studies to determine the national highway system.

The use of bonds requires a definite program of construction in advance, covering what might otherwise consume many years to construct. It may involve the accumulation, investment, and protection of sinking funds. It furnishes a means of more rapidly meeting the popular and economic demand for roads, and this aspect has no doubt been the deciding feature in favor of a great many bond issues. It permits construction programs large enough to secure the advantage of big contracts and low prices. But to realize this advantage it may require going beyond the immediate locality, even outside of the state, to find contractors equipped to perform the large contracts. It discounts the future and can not be adjusted, within the life of the securities, to meet temporarily financial or economic depression. It makes the building program more rigid and removes it to that extent from the easy manipulation of local politicians. It involves interest payments, and the safeguarding of a sinking or retirement fund.

A decision to adopt the pay-as-you-go method or the bond issue to finance highway construction should unquestionably depend to a considerable extent on the status of the highway system. If the system is small and incomplete, if the automobile registration is increasing rapidly, if the public is demanding more roads, the bond issue should be resorted to. This response to the popular demand for better and more lines of communication will start the series of reactions that result so favorably on the industries and the economic life of the country. The roads will provide an impulse to greater motor vehicle development and use. This will create a demand for more roads. Together these processes will bring into the industrial life of the nation a new industry and will enliven and revivify others. Lands will be placed potentially in better relation to the centers of population; social life, education, and the entire life of the people will in time feel a strong influence due to the greater mobility, freer intercourse, and closer relations of the public life of the nation.

The pay-as-you-go method should be adopted where and when the national highway system is more advanced, and should alone be used when the system is approaching completion. It may always be used if annual revenues are plentiful and should be used in any cases where the bonded indebtedness is so heavy as to have affected adversely the public credit.

There will be an intermediate period and condition when a combination of bond funds and current revenues should be used. This must occur in any case as a transition period and includes that time when the first construction on modest lines is being salvaged into higher types and at the same time new construction is still proceeding. The new construction extends the system to meet a wider public demand which is entitled to prompt satisfaction, and the reconstruction and betterments represent a concentration of demand incident to increases in traffic. This latter obviously can be met more easily by a gradual program of widening, grade reduction, heavy paving, amelioration of curves, or any of the details that such a program involves. The existing traffic may be put to inconvenience but it is not totally denied by such procedure. The extension of new roads is the first service and if delayed means the denial to some of what has been extended to others.

In considering the issuance of bonds there are further considerations because a choice is presented in the form of bond to be used. In general there are three kinds of bonds: term, serial, and annuity. These have some minor variations such as the deferred serial, annual serial, periodic serial, etc. Term bonds are those which mature after a definite period. Serial bonds are retired annually or at other periods, a fixed portion of the issue being retired at each maturity date. The annuity bond is similar to the serial type, but the retirements plus interest are maintained at a constant figure. A regular serial bond requires the same principal retirements and a decreasing interest charge, whereas the annuity bonds are retired slowly at first, and the principal retirements increase as the interest charge decreases, so that the total payment is practically a fixed amount.

The relation of these forms of bond issues is indicated in the following table. The total cost of the serial bond, interest, and principal is seen to be the cheapest.

Table No. 4

Total cost of a loan of \$100,000 for 20 years,  
interest compounded annually.

Annual Interest on bonds.	Sinking fund compounded annually at -			Annuity	Serial
	3 per cent	3 1/2 per cent	4 per cent		
4	\$ 154,431	\$ 150,722	\$ 147,163	\$ 147,163	\$ 142,000
4 1/2	164,431	160,722	157,163	153,752	147,250
5	174,431	170,722	167,163	160,485	152,500
5 1/2	184,431	180,722	177,163	167,359	157,750
6	194,431	190,722	187,163	174,369	163,000

In issuing bonds it is an excellent practice to arrange to sell the securities no faster than the program of construction can proceed without dislocating the local materials and labor market. Too big a program is not sound. A gradual increase in the annual or biennial sales provides for a gradually increasing building program, which will react on motor registration, which will support the increasing issues of bonds. Prices of materials and labor will be least affected and the economies in construction will be greatest under a procedure of this kind.

One detail must be pointed out that is essential in determining a choice between the pay-as-you-go method and a bond issue. The total cost of the same road varies according to the method of financing adopted. For instance, if \$100,000 are to be spent in building ten miles of highway, the cost is \$10,000 per mile if the funds are produced from annual revenues. But the total cost of a \$100,000 bond issue, serial type, may be \$142,000 and the total cost of a mile of road paid for by this method would then be \$14,200.

This additional cost is compensated by earlier use of the road than could be had without bonds. If this earlier use accommodates enough traffic to earn the difference in cost it is always justified.

Finally, it must be clear from a reading of the fundamentals incident to the laying out of a national highway system, discussed in the first paper of this series, that any highway expenditure to be justified must be earned by the road in the form of cheaper transportation. This means that there must be enough traffic, and the type of improvement shall be such that the actual saving in cost of transportation shall at least equal the cost of the improvement. This alone justifies the cost of highway construction. During its life a highway must pay for itself; otherwise it will be a luxury, whereas our entire discussion of the creation, design, construction, maintenance, and financing of a national highway system has been from the point of view that highways are fundamental requirements in a healthy, progressing, prosperous, and ambitious nation.

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