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U. S. DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

PUBLIC ROADS

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RESEARCHES AFFECTING THE DESIGN OF ROADS FOR HEAVY MOTOR TRUCKS

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

THE heavy motor truck which has come upon us within the past few years, and which promises to increase in numbers, imposes an entirely new problem of design and a far more complicated problem than has ever existed before. We no longer need regard the abrasive wear of the higher types of roads with much concern, for by proper maintenance we can take care of abrasion. The development of the design for light, fast-moving, rubber-tired traffic may also be considered as practically completed. But the problem of how to design a road to carry heavy concentrated loads under all conditions, without fear of structural failure, remains unsolved, and this is our most important problem in road design to-day. The governing traffic unit in the present-day design is the heavy motor truck, and when we have built our road to take care of this unit under all conditions we need not fear for the adequacy of the road for any other class of traffic.

FAILURES OF ROAD FROM HEAVY TRUCKS.

Before considering what researches should be undertaken to gain the necessary information to serve as a basis for adequate road design for heavy motor trucks it will be well to stop and review briefly the character of failures that have resulted in some of our roads through use of heavy trucks. General observation of roads that have failed under heavy trucks invariably reveals what has been termed a "structural failure." Such a failure involves not only the road slab but also the subgrade. It is brought about by a combination of exceedingly heavy loads and a very soft condition of the subgrade. Had the poor subgrade condition not existed, complete structural failure would not in general have resulted. Failures of this kind have involved entire stretches of roads or in many cases have occurred in spots, which, coupled with evidences of incipient failure of the road as a whole, have led to the conclusion that a short period of still more unfavorable subgrade conditions would probably cause general failure of the entire road surface. Where exceedingly heavy units of traffic are not in general use and where the subgrade is of good supporting value, complete structural failures are hard to find, but they are numerous where this condition does exist. Minor defects, such as cracks, which might be regarded as incipient failure, are brought about in many cases by the action of heavy traffic. It is recognized, of course, that there are in addition other causes for initial failure of the road. It is recognized, too, that heavy traffic produces other defects in the road surface depending on its type, but such defects are insignificant and can be taken care of by maintenance or comparatively inexpensive resurfacing in the future.

It will not be amiss to review the mechanics involved in the design of roads in so far as this is possible. When we consider the design of any structure built to carry loads we must know with reasonable accuracy what will be the maximum load. The motor truck as it is commonly built at the present time has its weight distributed on four wheels, with as much as 80 per cent of the gross load carried on the two rear wheels. The road surface, then, must support four concentrated loads, the maximum concentration being not uncommonly 12,000 pounds on a single wheel. This is not a quiescent load, for the truck is in motion and the road surface is never perfectly smooth. The sprung and unsprung weights of the vehicle are set into vertical motion, and thus instead of a static force we have a suddenly applied load or even an impact. The concentrated load imposed on the road is distributed to the underlying subgrade. If the wearing surface possesses slab strength, or if it does not possess slab strength but is of comparatively great thickness, the concentrated load is distributed over a considerable area on the subgrade and becomes a load of varying intensity, with highest intensity directly under each wheel and gradually diminishing away from the wheel.

SUBGRADE SUPPORT IS NOT CONSTANT.

Soils composing the subgrades of roads are limited in their bearing value, particularly when they have become soaked with water. It is a matter of common observation that certain soils when water-soaked approach a state of fluidity and will hardly support the lightest load. It will readily be appreciated that heavy concentrated wheel loads may impose pressures on the subgrade of greater magnitude than the bearing value of the soil. Under such conditions the subgrade material naturally deforms and immediately great stress is thrown into the wearing surface through flexure. When the subgrade is of very high bearing value, as it invariably is when dry, it yields practically not at all under light pressures distributed to it by the wearing surface, and under such conditions the flexural stress under the load is likewise small.

Enough investigations have been made thus far to indicate that the support offered by the road subgrade is anything but constant and anything but uniform.

It has been shown very definitely that the subgrade support changes with the varying moisture content and with the effect of frost. In fact, instances have been observed in which the road surface has been left without support over large areas. Under such conditions considerable stress must be produced in a rigid slab under the action of traffic. Such conditions are brought about, however, mainly through inadequate preparation of the subgrade and through inadequate drainage.

From the foregoing brief discussion it would seem that our road-design problem of to-day is very decidedly a problem of structural design, and that it does not stop at the design of the wearing surface alone, but that it involves the proper design of the underlying subgrade. We must adequately support the slab and we must design the slab so that it will not fail under heavy loads.

When one approaches a problem of design of any structure the knowledge required involves, first, knowledge of the forces to be imposed upon that structure; second, knowledge of the manner of distribution of stress throughout the structure; third, knowledge of the behavior of the materials used when subjected to stress. Researches for the adequate design of roads for heavy motor trucks must include, then:

1. Investigations of the forces applied to the road surface by heavy motor trucks.
2. A determination of the distribution of these forces through the wearing surface and subgrade.
3. An investigation of the behavior of the road surface and subgrade materials under the action of these forces and other forces produced by natural causes such as temperature and moisture changes.

In the present discussion it is not the purpose to outline in detail the various investigations which must be made in connection with the three broad general problems just mentioned. It will be well, however, to call attention to a number of these researches in order to indicate in a general way why they are necessary and how they might be carried out.

INVESTIGATION OF THE FORCES ON THE ROAD SURFACE PRODUCED BY HEAVY MOTOR TRUCKS.

It is apparent to anyone who has stood on a road surface during the passage of a fast-moving heavy truck that the surface is being subjected to a considerable force—a force far in excess of the static weight of the vehicle; and this is evidenced by the vibrations produced under the action of the truck. It is apparent that the road is being subjected to a variable force as the truck rolls along and that in many places severe impacts are delivered by the wheels of the trucks. Just why should this be so? It would seem that with road surfaces as smooth as we are able to make them under the present-day methods of finishing, trucks should roll along with practically no vibration; but it is surprising just how much effect a slight inequality will produce in causing the truck wheel to actually leave the surface.

For illustration, it has been observed that the rear wheel of a heavy Army truck moving at 20 miles per hour apparently cleared the road surface by at least 1 inch in passing over a slight inequality due to a small excess of bituminous filler in an expansion joint. But what force exists on the road surface when the truck wheel lands under such conditions, and why should there be any extraordinary force produced? Let it be remembered that when a truck wheel is clear of the road surface there is an enormous force in the truck springs tending to bring it back to the surface. In consequence of the spring compression, when the wheel again comes into contact it has attained high vertical velocity. The truck tire is compressed as soon as again in contact with the road surface, which then exerts an upward force, finally reducing the vertical velocity to zero. In other words, the force existing between the road surface and the tire has decelerated the downward vertical velocity of the portion of the truck beneath the springs.

Now, it is an old law in physics that force is equal to mass times acceleration, and since the mass of the unsprung portion of the truck is brought to rest vertically on the road surface, or decelerated, there must have been required a reaction between the road surface and the tire at least equal to the mass of the unsprung portion times the deceleration of that portion; and in addition to this force there must be added the force due to the compression of the spring. The longer the time required to bring the unsprung portion to rest vertically the smaller becomes the deceleration and consequently the lower the force. This explains why pneumatic tires are apt to prove so much lighter in their destructive effect on the road than solid tires, and likewise explains immediately why steel tires have such a destructive effect.

If in the future we plan to design our roads in a purely rational manner, is it not plain that we must find out all there is to be known of the various forces acting upon the road? The heavy forces of traffic are vitally important. Very complete investigations should be made of the various kinds of motor vehicles when fitted with various kinds of tires, for the tires play an important part in easing the effect of the blow. Such researches[1] have already been carried out extensively by the Bureau of Public Roads and thousands of tests have been made. These tests which have been made under artificial impact conditions should be followed by impact tests made on actual roads in order to obtain an idea of the relative destructive effect of traffic due to varying degrees of smoothness. Such in-

[1] A report of these tests will be printed in the March number of this magazine.

vestigations will shortly be made by the Bureau of Public Roads using an apparatus which permits of drawing a curve from which the vertical acceleration of the sprung and unsprung portions of the motor vehicle may be obtained and thus the forces on the road surface may be calculated. This apparatus is now partially successful, and it is believed it will be possible to make it produce very satisfactory results. It would seem that the results of tests of this kind at some future date might be used in motor-truck legislation, but before this is done tests will be necessary to show the relation between the force to be expected from motor trucks and the destructive effects produced by these forces.

A DETERMINATION OF THE DISTRIBUTION OF FORCES THROUGH THE WEARING SURFACE AND UNDERLYING SUBGRADE.

Having determined what forces are exerted on the road, the next logical step in our efforts at the development of rational design leads us to an effort to find out how the surfacing and subgrade are stressed under these loads. These are research problems for the future and they present many experimental difficulties. At the present time we are able to determine stress distribution under static loads, and we can also determine distribution of pressure on the subgrade, and both of these investigations should be made. It would be well to work toward the development of apparatus for measuring deformation under impact, and also apparatus for measuring subgrade pressure under impact.

An investigation of the behavior of the road surface and subgrade materials under action of forces.—As in any type of structure we must know how stresses are distributed when that structure is subjected to external forces before we can hope rationally to design the structure. When we consider that the road slab is supported by the subgrade in a nonuniform and continually varying manner, and when it is considered that if the slab were subjected to static loads alone the difficulties would still be enormous, how much more difficult must be the problem before us when we attempt to consider impact. However, rational design should be our goal of the future, and an effort should be made to measure the stress distribution in the slab under the various loading conditions to which it is subjected, including not only traffic loads but the loads produced by natural forces. Again, we must not neglect the stress due to impact, and suitable means must be devised for obtaining the stress distribution under the action of suddenly applied forces.

Pressures distributed to the subgrade.—A matter about which there is comparatively little knowledge is that of just how heavy truck loads are distributed to underlying subgrades. It goes without saying that if we ever hope to reach the stage of rational design we must be able to say definitely something of the law of distribution of concentrated loads to the underlying subgrade. Very little actual research has been performed on the distribution of pressures through materials, primarily because of the extreme difficulty of performing investigations of this character. A few results have been obtained, however, showing how concentrated loads are distributed through a concrete slab to the subgrade, and it is felt that we now at least have an apparatus that is satisfactory for that purpose. It would seem that a very important research would be that of determining the distribution of pressure intensity between the subgrade and the road slab under the action of heavy loads on the slab. The slabs should be of sufficient range in thickness and design, and the subgrade should vary in its characteristics. Such an investigation should also be made when the slab is subjected to impact. Unfortunately, however, there is now no available apparatus for determining subgrade pressures under impact, although it should be possible to devise such an apparatus.

THE EFFECT OF FORCES ON THE ROAD STRUCTURE.

We have seen that roads are subjected to impact; then why is it not a logical procedure to subject road surfaces of different design to the heaviest impact that is to be expected from actual motor trucks? That is the plan now being followed in a large series of tests in which a number of variations of designs are being used. The specimens are being subjected to the impact of a special impact machine designed to give the same impact given by the rear wheel of a 5-ton truck. By careful observation the results of impact tests of this character and the relative load-supporting value of various types of pavements is secured, and, moreover, such tests can be made when the road surfaces are supported on subgrades of varying supporting capacity. From the results of the tests thus far completed it has been observed that there are astounding differences in the resistance to impact of slabs of different design. Such experiments should be carried out on a sufficiently wide range of subgrades, and should be followed by experimental stretches of road subjected to actual traffic so as to tie in the results of the impact test with actual traffic conditions. It is planned to accomplish this by subjecting actual roads to impact through the use of an impact machine mounted on a motor truck.

Investigations of the subgrade material.—General observation leads us to the belief that low bearing value in the subgrade greatly decreased the load-carrying capacity of the road structure. The question naturally arises, then, what characteristics do soils possess which render them of high or low bearing value? And, further, what steps must be taken to improve the bearing value of the subgrade? It becomes necessary to make laboratory tests on soils to determine the physical characteristics which cause them to have low bearing value.

The following procedure is being carried out at the present time: Samples of soil are taken from the subgrade in the vicinity of places where the road has failed very badly. Similar samples are also taken from parts of the same road that have not failed under the same traffic. All of the supporting data are obtained in the field, giving complete information as to the topography and drainage. Samples of soil are then analyzed in the laboratory, determinations being made of their physical characteristics, including mechanical analysis, percentage of clay, silt, colloidal content, and bearing value when the soils are saturated and when they are in various stages of saturation. In this way it is hoped to establish what are the physical characteristics of soils making for good or bad support.

The question of how to improve the bearing value of soils should likewise be investigated. No laboratory tests are needed to prove that high water content in soils makes for low bearing value, and it goes without saying that if we could properly eliminate water from the subgrade we would always have adequate support for our roads. Investigations should, therefore, be made on drainage to the end that means will be established for adequately draining subgrades composed of the various kinds of materials and under all conditions of topography.

The field of research to be covered for the rational design of roads to successfully carry heavy traffic under all conditions has many ramifications and can only be treated in a very general way. The following table, however, gives a list of the researches, the information from which should lead to the actual design of our roads:

RESEARCHES LEADING TO THE ADEQUATE DESIGN OF ROADS FOR HEAVY MOTOR TRUCKS.

1. Determination of static forces and impacts of motor trucks on roads, including the effect of—
   - (*a*) Sprung and unsprung weight distribution.
   - (*b*) Tires and cushion wheels.
   - (*c*) Springs.
   - (*d*) Speed.
   - (*e*) Kind and degree of roughness of road.
2. A determination of the distribution of static force and impact through the road surface and subgrade, including effect of—
   - A. Surface:
     - (*a*) Load.
     - (*b*) Variations in materials (bituminous, concrete, brick, etc.).
     - (*c*) Variations in design (rigid slab *v.* non-rigid type).
       (Reinforced *v.* plain concrete.)
     - (*d*) Variations in thickness, etc.
     - (*e*) Variations in subgrade.
   - B. Subgrade:
     - (*a*) Variations in wearing surface.
     - (*b*) Variations in load.
     - (*c*) Variations in physical characteristics.
     - (*d*) Variations in moisture.
3. Investigations of road surface and subgrade materials.

NOTE.—This includes researches of the physical and chemical characteristics of materials and their combinations to determine their suitability and to establish such physical constants as may be needed in design.

The above researches are deemed necessary in order to place the design of roads on a rational basis, and it is only possible to carry out such a program in the shortest possible time through the coordination of all the agencies of the country capable of performing such work.

ACCELERATED TESTS.

In the meantime we are building roads and we want information very badly that will tell not how to arrive at the design of a road rationally but that will tell us with reasonable accuracy whether our road is going to prove adequate for the traffic. We should pursue our long series of tests to establish the fundamentals of road design, but we want approximate information immediately on what to expect of various designs. That is the reason for accelerated tests on actual roads. Such tests are not absolute, but they do give us much needed information quickly, and they point to certain limitations in the various designs. Among such tests may be classed the impact tests of road slabs now being carried out by the Bureau of Public Roads and the accelerated wear tests in which different types of roads are subjected to the same wearing device.

DISCUSSION OF MR. GOLDBECK'S PAPER.

WM. D. UHLER, Chief Engineer, Pennsylvania.

IT would be hard to question any of the writer's conclusions on the design of road slabs, inasmuch as he has covered in detail the effect which heavy, fast-moving traffic would produce on road slabs and surfaces—namely, (1) the induction of shear, (2) of bending (thus causing very considerable stresses due to bending moment), (3) abrasive action, and finally (4) such stresses as may be occasioned by vibratory action set up in the slab. We all know that as a rule heavy shearing stresses induce incipient surface cracking or rutting, heavy bending stresses ultimately result in unduly wavy pavements, abrasive action ruptures the top surface, and vibratory action causes general rupture of the slab throughout its entirety, the last named being perhaps the most dangerous in very thin slabs, even though the subgrade conditions are ideal.

We should not lose sight of the fact, however, that there are many other features which should be given

as much consideration as the purely theoretical factors of structural design. It is possible that we may not be justified, economically, in working toward an ideal pavement slab or section under all conditions. I mean that it may be quite apparent, under given conditions, that inferior materials may be used to form a base for a road surface in which the stresses might be indeterminate.

It would seem, primarily, that the design of the road slab or section should be based upon the subgrade conditions. Thus it follows that the subgrade should be subjected to certain tests, which will in the future become standardized, just prior to the placing of the slab. Such tests presuppose the protection of the subgrade from weakening influences such as saturation, which would ultimately lead to failure, due either to flow of the subgrade or frost action.

It would naturally follow that future practice will lead to what we might term the design of the subgrade in the field and to a refusal to accept it until it passes the tests which the engineer feels will warrant him in concluding that the slab which is to be used will be capable of so distributing the pressure that the coefficient of elasticity of the slab will not be exceeded.

PREPARING SUITABLE SUBGRADE CONDITIONS.

In order to carry this out, the engineer must become thoroughly conversant with the methods which may be used in arriving at suitable subgrade conditions, viz:

(1) The design of the proper type of drainage system. This may consist of tile underdrains, stone underdrains (the underdrains being of either longitudinal or lateral types); the selection of a proper open-ditch design, or the selection of a paved ditch which will readily handle surface waters and keep the subgrade dry, or, finally, gravel or broken stone sub-bases.

(2) Some treatment of soils which will reduce their capillarity. It is realized that up to this time no economical method has been developed to remedy this condition.

(3) A study of the proper compaction of deep fills to lessen the possibilities of slab failures.

(4) Treatment of variable subgrades, such as old road surfaces, by plowing, harrowing, etc., so that when rerolled they will have the same relative coefficient of elasticity over their entire surface.

My reason for discussing these features is to bring out the fact that it is relatively just as important to design the subgrade as it is to design the pavement, and I feel that to the lack of a subgrade design may be laid the major portion of such failures as have occurred in the past, and, further, that it is not practical to attempt to design an economic slab until a subgrade is formed which will provide a suitable foundation.

TESTS ARE NOT YET CONCLUSIVE.

It would seem that it is particularly undesirable at this time to accept any tests or conclusions which might point to an accepted or recommended practice in the design of slabs, because such tests as have been carried out do not furnish substantial evidence which might reasonably point to an economic design. In this connection it is pertinent and germane to question the desirability of accepting as conclusive at this time any tabulation, prepared for the guidance of engineers and highway officials, which shows the relative suitability of the many types of pavement surfaces now in use in this country for heavy-truck traffic. In a recent tabulation it was stated that vitrified brick on concrete is considered the highest or best type of pavement for heavy motor-truck traffic. This conclusion was undoubtedly arrived at through laboratory tests. Actual field experience shows that this type of pavement must be considered among the most unsatisfactory pavements for heavy motor-truck traffic. The wearing surface on this type of pavement is not under the direct control of the engineer in the field. Due to irregularities of surface, brought about either by poor details of construction or by nonuniformity of the brick units forming the surface, exceptionally heavy impact stresses are created.

It is unfortunate that many of the tests which have been conducted have been premised upon sections which, from an economic standpoint, are not comparable; for instance, it is shown that the relative resisting qualities of a grouted brick surface on a 6-inch concrete base closely approximate those of a grouted brick on a 4-inch concrete base, placed under practically the same working conditions. Extreme care should be taken, therefore, in attempting to interpret these tests, and we should always keep in mind not only the relative resisting qualities of the types but their relative costs in dollars and cents. We should not forget that the laboratory test is but one means of attempting to solve the problem, and we should not lose sight of the fact that the test of actual experience with roads which are carrying heavy traffic is probably at this time the most consistent and conservative way of judging of the permanence of any particular type of pavement.

Pennsylvania, at this time, has a yearly registration of over 570,000 motor vehicles. Our roads are subjected to an exceedingly heavy punishment, particularly from excessive truck loading, and the conclusions arrived at above are based on actual engineering observations and studies in the field.

NEED OF CONSERVATIVE INTERPRETATION.

It would seem desirable at this time to call attention to the need of a conservative interpretation of tests. A pamphlet issued not long ago entitled "Clouds on the Transportation Horizon" endeavors to create the impression that it is not the heaviest type of truck which causes failures of our road surfaces, but, rather, that it is the light, fast-moving truck traffic. It would seem particularly unwise at this time to endeavor to reach this conclusion. These conditions might hold for one

season of the year, but are inapplicable to other seasons: for instance, a heavy, slow-moving load will undoubtedly result in failures of road surfaces during the early spring months when our road surfaces are, as it were, held in unstable equilibrium. Having in mind the various points which have been raised, I might state that our studies in Pennsylvania have led us toward the preparation of more uniform subgrades, and that our new specifications will eliminate the storage of all construction materials on the subgrade or require their storage in piles which shall at all times be at least 1,000 feet in advance of the actual placing of the surfacing materials. It might be of further interest to state that we have at this time six different schemes for drainage which are being used on all construction work, the particular system adopted being premised on actual investigation in the field.

In conclusion, I wish to congratulate Mr. Goldbeck on the able presentation he has made of the necessity for detailed researches in connection with this most vital and interesting topic, and it is to be hoped that the States will cooperate with the Bureau of Public Roads in the fullest measure, in its endeavors to carry out further researches along broad, practical, economical lines in the field; for it is by these methods only that we can arrive at a definite conclusion.

DISCUSSION OF MR. GOLDBECK'S PAPER.

By CLIFFORD OLDER, Chief Highway Engineer, Illinois.

It is a matter of common observation that as rapidly as paved roads are built the traffic using such roads increases enormously and almost invariably changes in character. When roads are built through agricultural or industrial territory it soon becomes evident that truck traffic is the chief destructive element, and as the most insistent demand for paved roads comes largely from such territory it is evident that rural pavements, except in unusual cases, must be designed for truck traffic.

It seems evident from even a casual observation of well-constructed rural pavements of rigid type that wear is no longer an important factor. As an example, Milwaukee Avenue, leading northwesterly from Chicago and just north of the city limits, carries from 2,500 to 3,000 mixed vehicles on week days and from 10,000 to 15,000 passenger cars on Sundays. This section was paved with concrete in 1915. It is not difficult to distinguish in places the original hand float marks, and it is altogether probable that practically all of the slight wear to be observed occurred during the first year or two of its use before steel-tired wagons were replaced by rubber-tired trucks and automobiles. Very careful measurements have been made during the past six months and no measureable wear can be detected.

EXPANSION AND CONTRACTION.

Expansion of the pavement due to any cause may be provided for either by inserting transverse joints of a yielding material or may practically be neglected if the pavement is sufficiently strong safely to resist the compressive forces induced by expansion. Expansion joints have been omitted in Illinois practice for five years. The few "blow-ups" that have occurred were repaired at much less expense than the interest on the money saved by the omission of the joints.

It would seem that no economical means have yet been devised to prevent transverse cracking due to the contraction of the pavement slab, except by the construction of artificial joints. Longitudinal cracks, due perhaps largely to frost action, seem still to be with us, although such cracks can probably be largely controlled by substituting longitudinal dividing planes.

The only visible evidence that our well-constructed rigid pavements may have a limited life is found in the appearance and widening of cracks, the occurrence of "blow-ups," and the occurrence of breaks due to excessive loads.

Apparently, transverse cracks or joints and possibly longitudinal cracks or joints also will always be a factor to be considered. Observation of brick and so-called soft-top pavements laid on concrete bases show that at least the bases of such pavements are no more free from cracks or joints than are concrete pavements. In such pavements, however, the cracks are not as conspicuous and may not require the same class of maintenance. It may safely be stated that cracks and joints, if properly cared for, affect the life of a rigid slab only as they may affect its strength or load-carrying capacity.

CORNERS ARE CRITICAL POINTS.

It is not necessary to apply mathematical calculations to develop the fact that a load applied near the center of a comparatively large unbroken pavement slab would produce much lower stresses therein than would be produced were the same load applied at or near the edge of the same slab. Further, it is evident that a load applied at the edge of an unbroken slab would not produce stresses comparable with those produced by the same load placed at a corner formed by cracks or joints. It is obvious that these are bending stresses and the resisting moment of the slab, especially as regards tensile stresses, is of vital importance. This theory was advanced in an article by the writer published in Engineering News-Record, May 18, 1919.

Regardless of the supporting capacity of the subgrade, it is the corners formed by the intersection of cracks and joints with each other and with the edges

of the pavement that constitute the weak points of rigid slab pavements. On the Illinois roads which carry truck traffic many broken corners have been observed in all types of rigid pavements, and only in a single instance has a traffic break been observed that was not readily traceable to the piecemeal breaking down of corners or narrow strips formed by longitudinal cracks making acute angles with the edge of the slab.

The exception was an asphalt-top pavement on a 1:3:5 concrete base, 4 inches thick at the sides and 5 inches thick at the center, which broke into small pieces under excessive truck loads. An examination of the base showed that the transverse strength of the base had been exceeded, not merely at the corners but also at the edges and near the center of large slabs. No concrete slab or base 6 inches or more in thickness has broken except at the corners.

Until we are able to control completely the cracking of rigid slabs it seems obvious that we must design the entire slab to carry the imposed loads at the weak points—the corners.

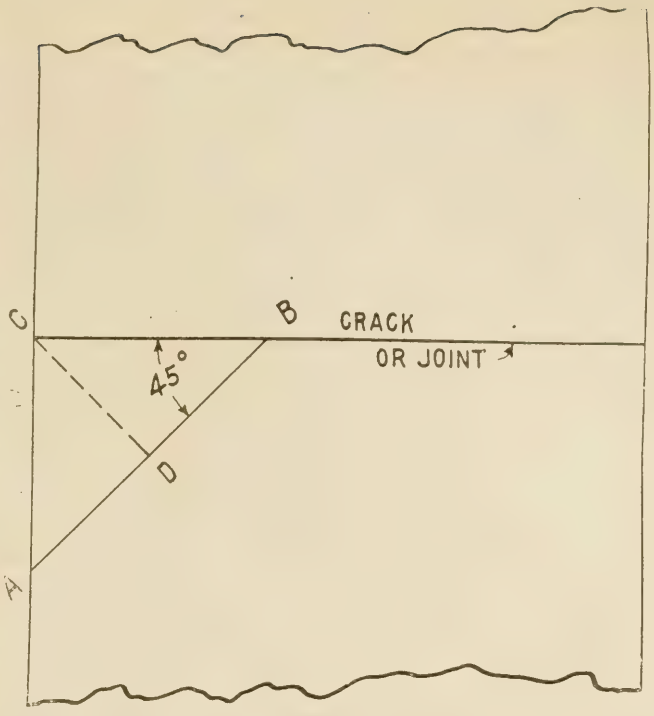

Fig. 1.

SUBGRADE SUPPORT OF CORNERS.

Preliminary investigations by the Illinois highway department confirm the findings of the Bureau of Public Roads as to the greatly reduced supporting capacity of clay soils as the percentage of moisture increases.

Further investigations have developed the following data:

Illinois corn-belt clay soil rapidly absorbs sufficient moisture to render its supporting capacity near the surface almost nil.

Under the center of an 18-foot concrete slab one month old, laid on a subgrade on which no rain had fallen for 6 weeks, the subgrade soil was found to contain about 17 per cent moisture after a 2-days drizzling rain.

The subgrade under pavements laid on both cut and fill sections with 6-foot earth shoulders, but without tile drains, appeared practically saturated when investigated 3 or more days after the beginning of a rainy period.

A very narrow crack will permit the passage of large volumes of water to the subgrade. The practical saturation of the subgrade soil for several feet each side of a narrow crack is but a matter of a few hours' time during a period of continuous rain or melting snow.

The repeated passage of heavy wheel loads over corners, even when such corners are supported by comparatively dry, clay subgrades, causes, within certain limits, a progressive depression of the soil under the corner.

These investigations, although not as yet extended enough to be conclusive, indicate strongly that it may be difficult, if not economically impracticable, by any system of drainage, combined possibly with a waterproofing of the subgrade, to maintain a clay subgrade dry enough to afford any reliable support to the corners.

In the following tentative method of design it is proposed that subgrade support be neglected as a definite factor.

TENTATIVE METHOD OF DESIGN.

Assumptions:

As corners are obviously weaker than other portions of the slab, only the corners may be considered.

Until erratic cracking can be controlled it is necessary to build all portions of the slab on the basis of corner strength.

Considerations of economy prohibit the use of reinforcing steel as a strength factor.

Until conclusive observations of the dependable supporting capacity of subgrade soils can be made, taking into account the possible control of the moisture content, support of corners by the subgrade should be practically neglected.

When bituminous-filled expansion joints are omitted, and frequent dividing planes with dowel pins or tongue-and-groove joints are used so that erratic transverse cracks may not be expected to open materially, a wheel load placed on one side of a joint or crack near a corner may be considered as divided equally between the adjacent corners or slabs. (It is suggested that contraction joints be formed by galvanized or painted corrugated sheet metal or metal sheets so bent as to provide tongue-and-groove joints.)

When bituminous-filled expansion joints are used, or when frequent contraction joints are not used, thus increasing the probability of the wide separation of occasional cracks, the entire maximum wheel load should be considered as supported by one corner.

The effect of impact on a rigid slab constructed strictly in accordance with strict specifications as to

surface smoothness may be considered as offset by subgrade support. The improbability of the maximum wheel load ever being applied at a point causing maximum moment provides an additional factor of safety.

Observation of the pointer of an Ames dial set to measure the deflection of corners failed to show visible vibration during the close passage of moving truck wheels. These tests were made on a Federal-aid section of concrete road constructed by contract, with no attempt to secure unusual smoothness. It is possible, although not probable, that impact vibration, too rapid to be detected by ordinary means, may have been present.

In the design it is only necessary to consider tensile fiber stress.

Referring to the sketch, figure 1, W=maximum wheel load, one-half of which is to be considered as applied at C.

x=CD=distance from load to critical section= moment arm.

AB=$2x$, since the critical section is located on a line making an angle of 45° with the edges of the slab.

M=moment of force applied to one corner=$\frac{1}{2}Wx$.

S=allowable tensile stress of the material forming the upper surface of the transverse strength element of the slab.

d=depth of slab.

c=distance from neutral axis to outer fibre=$\frac{1}{2}d$.

I=Moment of inertia of the cross section of the slab at the critical section=$\frac{2xd^3}{12}$.

Substituting these values in the formula $S=\frac{Mc}{I}$, this formula reduces to $S=\frac{1.5W}{d^2}$, or $d=\sqrt{\frac{1.5W}{S}}$

Assuming the whole load carried by one corner only, this formula would become $S=\frac{3W}{d^2}$ or $d=\sqrt{\frac{3W}{S}}$

It is to be noted that at right-angle corners the critical sections may be at any distance from the loaded point. In practice the subgrade under the corners of a slab carrying a double line of heavy traffic will be depressed more than elsewhere leaving subgrade support some distance back.

Perhaps it would be safer to consider the entire wheel load as carried by one corner, although the few experiments so far made in Illinois show equal deflections of adjacent corners when such corners are formed by narrow cracks or doweled dividing planes, the load being imposed upon one corner only.

If one corner only is considered as carrying the whole load, then the above formula is undoubtedly on the safe side if the pavement is built with a sufficiently smooth surface to reduce impact to a negligible quantity.

We have had under observation a concrete road, 6 inches thick at the sides and 8 inches thick at the center, constructed with a 1:2:3½ wet mix, roller, and belt finish. No expansion joints were used in the construction. Header boards provided dividing planes at the end of each day's work. The breaks were all at corners formed by rather wide cracks, and were definitely known to have been caused by certain trucks hauling crushed stone. The load on each of the rear wheels of these trucks was computed to be 9,000 pounds.

In accordance with the above formula and assuming no subgrade support or mutual support of adjacent corners, a wheel load of 9,000 pounds applied at the corner would produce, in a 6-inch slab, a fiber stress of about 750 pounds per square inch.

The actual stress developed at the right-angle corners was no doubt less than this, as it would have been impossible for the entire wheel load to come upon the extreme corner.

Only 12 corners have been broken, out of several hundred which existed in the length of road used by the trucks. The modulus of rupture of the concrete is not known, but probably it is between 500 and 600 pounds per square inch.

The fact that all corners were not broken was probably due to partial subgrade support, partial mutual support of adjacent corners, but largely to the fact that the loaded trucks traveled close to the edge of the 18-foot slab only when passing empty trucks going in the opposite direction. There was no traffic on the road aside from the stone trucks. The loading of the corners, therefore, occurred only at infrequent intervals when trucks passed at cracks or joints. A total of about 1,500 loads were hauled. This instance would seem to afford a rough check on the formula.

FURTHER INVESTIGATION UNDER WAY.

The further investigation of slab deflections and stresses, the effect of mix, type of wearing surface, etc., on modulus of rupture, the supporting capacity of soils with varying moisture content, the variation of the moisture content and supporting capacity of such soils under pavement slabs at different seasons and with different types of drainage systems, the compression of soils under repeated loads, the possibility of largely controlling the location of longitudinal and transverse cracks by sheet-metal divisions, the mutual support of adjacent slabs afforded by friction on the rough surface of cracks, the mutual support of adjacent slabs which may be secured by artificial means at dividing planes, and other items affecting the transverse supporting capacity of pavement slabs is being carried on in connection with a 2-mile test road which is being constructed by the Illinois highway department, and at favorable points on old pavements.

The test road was designed to determine as far as possible the load-supporting capacity of various types of pavements, laid on a uniform subgrade, as affected

by thickness and other elements governing transverse strength.

Great care was used in selecting the site in order that uniform subgrade, alignment, and grade conditions might prevail. The road will be closed to public traffic until the test is complete. Upon completion and curing of the pavement the road will be subjected to an artificial truck traffic, gradually increasing in weight until the legal load limit as established in Illinois has been exceeded by about 50 per cent.

Four principal types of pavement are being used—macadam base with brick and bituminous concrete wearing surface; concrete base with bituminous top; concrete base with monolithic and soft filled brick top; and one-course concrete.

In the main each test section is 200 feet long. The series of sections for each type begins with a thickness roughly estimated as equivalent to 4 inches of concrete and increases to the approximate equivalent of 9 inches of concrete.

The behavior of the subgrade before and during loading will be observed by means of pressure cells secured from the United States Bureau of Public Roads, and by means of special observation devices consisting essentially of sections of iron pipe set in the slab, protected at the top oy removable plugs, and containing a loose brass disk in contact with the subgrade. By means of an inner pipe this disk is forced down when the pavement deflects under load and remains in contact with the subgrade as the slab recovers. Thus a means is provided to observe with an Ames dial the permanent or temporary depression of the subgrade.

The supporting capacity of the subgrade may also be observed at any time by loading the disk and by removing the disk moisture samples may be obtained.

A descriptive bulletin is being prepared which will give in detail the design of the various sections, methods and control of construction, description and use of special apparatus, observations under way and contemplated, plan of loading, etc. It is expected that the loading will be started in July or August, 1921.

It is hoped that when completed the above briefly described investigations may aid materially in determining a rational method for the design of rigid slabs. In the meantime the foregoing provisional method of design is suggested for use.

Load Limitations for Primary and Secondary Roads

C. J. BENNETT, State Highway Commissioner, Connecticut.

THE topic under discussion is directly connected with the consideration of the efficiency of highway transportation, a subject which heretofore has not been very seriously studied by the majority of highway engineers.

Preliminary to discussion of this topic it may be said that most of us are faced in a greater or less degree with an abnormally heavy highway traffic which, from various causes, has been placed upon our highways regardless of their suitability or strength. We know that we shall be required to carry tremendous loads over the highways. We do not know the magnitude of these loads, nor have we any assurance of a limit, either to the weight of the units or to the total volume of traffic to which our highways will be subjected.

It seems evident that before we can intelligently design highways, bridges, or other structures, we must know the character, amount, weight, and speed of vehicles which we are expected to accommodate. It would also seem axiomatic that it is not fair to ask for the development of highway systems everywhere to carry the extreme loads which are now being borne by motor trucks. This would mean the expenditure of vast sums of money for the accommodation of a limited number of units. Hence, we develop a need for a separation of highways into classes. For purposes of discussion we shall assume that highways may be divided in two classes as outlined in the subject of this article.

CLASSIFICATION OF HIGHWAYS.

In order to indicate more clearly the scope of the problem, we must define the terms which we are using. In other words, we must answer the question, What are primary and what secondary highways. For purposes of discussion and not determination, let us roughly define primary highways as those highways connecting centers of industry, whether manufacturing or agricultural, over which must be carried commercial products in large quantities continuously at all seasons of the year. Secondary highways may be said to include all other highways than those classified as primary, or perhaps those roads which are required to carry traffic of a secondary importance, whether passenger cars or light commercial vehicles. These highways are those which eventually must serve all parts of the community and aid in the progress and development of the Nation.

Roughly speaking, the routes thus classified should be so correlated and so designed as to provide for the most efficient use of the motor vehicle for commercial purposes without infringing upon the field of other methods of transportation, such as rail or water. Pro-

vision must be made in design that the primary highway systems may be expanded as the need arises without undue loss in original investment. Here we have a very large field for investigation. It is not herein intended to give an absolute solution of the problem nor to cover all of this investigation. We have suggested the need for limitation of load, and the impossibility of improving all highways to the maximum requirement has been superficially indicated.

LIMITATIONS SHOULD BE NATIONAL.

The restriction of loads under these suggested limitations should be further considered. In the first place, the subject must be approached not as one concerning any particular State or group of States, or any small unit of government. It must be studied as affecting the administration of all highway departments throughout the United States. In other words, any limitations which are placed upon loads should be universal and apply to all motor vehicles whether operated in Maine or California. This, of course, implies the passage of National or uniform State laws. It can easily be seen from this statement that the problem is not easy of solution. It requires broader study and stronger cooperation than we have yet been able to accomplish. It demands a knowledge of motor-truck operation that is not yet available. It suggests numerous lines of thought which can be followed by conclusions which, when reached, can be collected together and used as information to impose restrictions as to weight and as data for design. The subject is not alone one of load limitation, but should be enlarged to cover any limitations which may be placed upon the operation of motors and loads such as speed, width, height, length, number of units in a train, design of mechanism, and myriads of other things that will develop as we pursue our way.

These are, of course, generalities. We must have a starting point. We must have some specific suggestions as to the limits of the loads which may be operated on routes designated as primary and on those defined as secondary. Of course, for the purpose of securing a definite point of beginning, we must go into what has already been done along these lines.

LIMITATIONS DECIDED UPON AT CHICAGO.

Referring to a discussion held in 1918 in Chicago, at which both the highway officials and the motor-truck manufacturers were represented, certain limitations of motor vehicles were decided. So far as the writer is concerned, nothing has developed since that time which would modify the conclusions there reached. These conclusions have to do with the maximum weights, widths, and heights of motor vehicles, and are consequently applicable only to the primary routes which we have defined above as those which may be considered as the main media of highway transportation. The limitations thus set were a maximum gross weight of 28,000 pounds, or 800 pounds per inch width of solid rubber tire. The width of the load was to be 108 inches, and the maximum height 12 feet. These restrictions would allow the use of a 5-ton truck as now built, loaded to capacity, and it would seem that this is the maximum weight of truck which may be efficient for primary highways. We must realize that this limitation is not for to-day alone but for the future as well, and should last for the life of the road.

Until, however, we have finally completed our primary highway systems, we must modify these restrictions somewhat. In other words, we must provide for the operation of these units only at such times as they will subject the road surface to the minimum wear. We must provide some method of still further restricting these loads at seasons of the year when the maximum damage to highway surfaces occurs. This power, again, should be universal and in the hands of those intrusted with the care and upkeep of highways. Means must be provided whereby the maximum loads will be operated only on the primary systems.

REGULATIONS FOR SECONDARY HIGHWAYS.

Considering further the question of secondary highways, here we have a still larger subject, for we must provide a standard of construction and maintenance for all other highways than primary routes in order to carry a specified load. This portion of the problem is much more complicated and harder of solution than the former portion, for we must realize that we are dealing with the far larger amount of traffic over the secondary routes than over the primary routes. In other words, as we increase the restrictions on loads or amount of load, we are approaching closely to the maximum number of motor vehicles operated.

For illustration, taking a certain 20,000 commercial motor vehicles licensed, only 750 of these vehicles are in excess of 4 tons capacity, while upward of 16,000 are less than 2 tons capacity, so that our restrictions for a secondary system of highways must be such that we shall secure the maximum efficient operation of the larger number of commercial motor vehicles. For this reason it is suggested that the maximum allowable total load for secondary highways shall be 12,000 pounds unless the load is carried on pneumatic tires, when it may be increased to 15,000 pounds. We may inquire why this increase may be made. Roughly, it is thought, and experiment tends to prove, that the pneumatic tire, properly inflated, does less damage to the highway surface than the solid tire, especially when the solid tire is partly worn. It is hoped that these assumptions may be checked in the future and more formulæ developed which will be exact rather than empirical. None of the limitations suggested have taken into consideration the passenger car, as either

system properly designed should properly accommodate the passenger car when load alone is considered.

In general consideration of the subject as a whole we must therefore conclude that limitations are necessary whatever they may be, but that the information at hand is not sufficiently definite to say what the effect of certain loads may be. A future study of this topic is imperative and is being made.

NECESSITY TO ENFORCE LIMITATIONS.

Again, as a general conclusion to this discussion, we must admit that if any limitation of loads is determined upon it must be enforced. There is no use or reason in attempting to establish restrictions on traffic with no intention or means of enforcement. A study of this subject would not be complete, or even partially so, without a suggestion of the methods to be followed in seeing that the rules laid down are carried out. The writer has knowledge of many instances where laws restricting weights are written without attempt to enforce. It is evident that such a practice is almost of no use.

In order that the universal rules suggested above may be properly carried out, there will be need for cooperation between the different States in the enforcement of their licensing rules and in checking up the vehicles registered. Consequently, it appears that any highway system should be developed in cooperation with the motor-vehicle department, and a proper policing department provided whereby it may be thoroughly established that the laws regarding the use of the highway by loads are absolutely carried out. These departments should all be built up on a standard scheme of organization.

As outlined above, this is not an attempt to solve once and for all a problem which has been presented to us. This is impossible. There are many steps ahead of us in the proper solution of this difficulty. We have only begun to realize the magnitude of the traffic which we must accommodate. Repeating again for emphasis, the problem is large and broad in its scope; its factors are unknown. We have a long, tedious course of study before us until we can set down the actual facts to prove our contentions regarding the limitation of loads. To this we must add a sincere effort to prove to the different agencies interested in highway transportation the need of some sensible and reasonable restrictions to be enforced.

DISCUSSION OF MR BENNETT'S PAPER.

Thomas Maddock, State highway engineer, Arizona: If no load limitation is provided we shall inevitably have a lot of valuable paving destroyed by heavy loads on the one hand, and on the other some paving will be built heavier than is needed to carry those loads which are finally agreed upon as being proper.

If enough States limit truck loading, the manufacturers will build accordingly, as it is obvious that they can not manufacture a few large trucks economically. Apparently there is no possibility of trucks competing with railroads in carrying heavy loads long distances. Trucks can not compete economically even with narrow-gauge railroads, where quantity tonnage is concerned, even with their tracks, i. e. the highways, built and maintained by the public. Unrestrained by any law, except the law of supply and demand and the carrying capacity of rubber, the great majority of trucks now built are of not over 5-ton capacity. In other words, existing conditions have already restricted maximum truck capacity.

There is a limit to the labor and capital which the public can devote to road building. Such expenditure of the limited funds as will procure the greatest good for the greatest number is certainly the only course it is practicable to take at this time. This will mean the construction of large mileage of a rational type of road rather than the building of an indestructible but decreased mileage of highways capable of carrying the occasional giant vehicle.

FOR SINGLE ROAD LIMIT.

I do not agree with the suggestion that different load limits be adopted for primary and secondary roads. It is nearly impossible to build a good secondary road without thereby creating a primary road. I believe the primary thoroughfares should be broader than the secondary roads; but the difference in width of primary and secondary roads is not under discussion. In ability to carry load I believe the two classes of roads should measure up to the same standard. The difference in the cost of the small drainage structures capable of carrying say, a 28,000-pound load as against a 15,000-pound load, is negligible in permanent construction. Large bridges are so expensive under any circumstances as to be relatively few in number. This concentrates traffic on them which makes them become part of primary roads. The surface of pavements is probably worn more by the number of vehicles than by the few extra heavy loads which use the road.

The elimination of the bridges and the width and surface of paving leaves the strength of the paving slab as the controlling feature in load limitations. The strength of these slabs increases with the depth of paving much faster than the cost, and I should prefer

to invest the State's money in the greater depth required to paying the salaries of three 8-hour shifts of policemen to stand at the innumerable intersections of primary and secondary roads and weigh every vehicle which some one desires to drive on to the latter. If our secondary roads are built strong enough, they can be widened at any time and easily become primary roads. On roads already built the load limitation should be determined by each road's carrying capacity rather than by some general classification as primary and secondary.

The prestige of the Bureau of Public Roads should be sufficient to secure the passage of a uniform load law in each State upon request. If not, the Government's interest in the investment of Federal funds warrants the bureau in demanding that the Government's equity be protected by restricting the use of roads to properly loaded vehicles.

I think the load limitation suggested by Mr. Bennett—that is, 28,000 pounds for primary roads—while probably somewhat higher than is absolutely needed at present, provides well for the future and should be adopted. To my mind, however, it is not a question of adopting this load limitation, but of deciding upon some load limitation. There are too many unknowns in the road equation. This one can and should be eliminated.

MASSACHUSETTS RAISES TRUCK FEES.

James W. Synan, commissioner, Massachusetts: No doubt the Eastern States find themselves bothered more by the great truck problem than many of the Western States. Our commission has charge of the motor-vehicle department as well as the road-building department, so, like Commissioner Bennett, we have had our eyes opened to a realization of the troubles that are coming. Massachusetts is attempting to meet the problem by charging a license fee somewhat proportionate to the damage done by the truck to the road. We have reached the point where we do not believe that the ordinary individual should be taxed to take care of the comparatively few people who are benefited, in a broad sense, by these tremendous vehicles. We find that every road in our State built previous to five or six years ago will have to be rebuilt to accommodate the comparatively few people who insist upon operating trucks with loads weighing 12 to 15 tons or more.

For many years, in Massachusetts, trucks paid a fee of $5, no matter how big they were or how much weight they carried. After some agitation the fee was increased, but we could only get it increased to $8 for a 2-ton truck, $11 for a 3-ton, $14 for the 4-ton, and $17 for the 5-ton truck. Two or three years ago the fees were again increased to $10 for the first ton and $10 for each additional ton, making $50 for 5-ton trucks. The board, of which I happen to be a member, has submitted a bill to the legislature for passage at its coming session, levying $20 for the first ton, $50 for vehicles carrying between 1 ton and 2 tons, $100 for the 3-ton size, and $150 for the 5-ton truck. Even these fees are not comparable to the damage these trucks do. I told a man in my community who asked to have certain roads improved that a proper fee for his truck would be $1,000 a year, and that even then he would be a burden to the Commonwealth in running that truck. He carried about a 15-ton load every day in the year for the paltry sum of $17 a year.

We might as well meet this problem face to face. I question very much whether we could justify our present low scale of fees if we were called upon. We do not believe that the ordinary individual who comprises the great 99 per cent of the population of our State is called upon to submit to taxation for the benefit of the few. We believe in taxing the motor truck somewhat proportionately to the damage it does, and we feel that until we do we shall be unduly and unfairly laying the burden of these loads on the ordinary individual.

Andrew Marvick, commissioner, South Dakota: I subscribe to the spirit of the remarks of the gentleman from Massachusetts, but in fitting action to the thought I should be inclined to go a little further. I do not think the tax proposed will begin to pay for the damage done by the trucks. In my judgment the tax should be about $50 for the first ton, and it should be greatly increased for every additional ton. We all agree that the heavier loads are the ones that damage the roads. Why not, then, make them pay proportionately, say, at the rate of $100 for a 2-ton truck, $200 for 3 tons, $400 for 4 tons, $800 for 5 tons, and $1,600 for a 6-ton truck. If they build them any larger, we can go up with them. That would be the best solution of the problem.

MARYLAND ELIMINATING OVERLOADING.

J. N. Mackall, chairman, State roads commission, Maryland: We started out with a tax of $25 on a 1-ton truck, $150 on $5 tons, and $500 on a 7-ton truck. Two years ago we found that $500 would not carry a 7-ton truck, nor would $5,000 carry it, so the last legislature provided that no trucks of greater than 5 tons capacity would be licensed.

Then we started out to clear the highways of undesirable overloaded trucks. We could not tax them out of existence, so we decided to legislate them out. One large company was operating a fleet of 107 trucks to Boston from a point beyond our western border. They came in over the national pike to Cumberland, carrying 14,000 pounds net, and the trucks weighed about 6 tons. We fined them $50 for overloading and made them take off the load, put it on the railroad train, and ship it to Boston by rail. They kept on coming. We got $50 a trip, and they kept on coming. That wasn't what we wanted. We established a weighing station

over in the mountains, where the road enters the State. When we caught a truck carrying a gross load of more than 10,000 pounds we made the driver unload and pile his merchandise on the side of the road until another truck could be brought in to put it on. We only had to unload two trucks to convince them we were in earnest. They could afford to pay $50, but when they had to send another truck 17 miles over the mountains to pick up the load and carry it to Boston they quit.

As a result of our experience we consider it is a simple matter to eliminate overloaded traffic. We thought three months ago that it might be very difficult. On our main lines we erected permanent scales, where we can weigh 20 tons. On the other highways we use the loadometer. We have found it very satisfactory except that when they come thick and fast it is difficult to weigh them without a great deal of protest on the part of the truck drivers. During the first week of the campaign, which was the first week in September, we caught 60 trucks on the Washington road. We found the owners guilty of overloading and fined them from $10 to $100. The next week on the Belair road we got 70 trucks; at the end of five weeks we got three trucks in a week; the sixth week we got only one truck. We have not averaged more than one a day for the last three or four months, and it begins to look like we have practically eliminated overloading.

For the purposes of the campaign we have erected two sets of permanent scales—one on the Baltimore-Philadelphia road and one on the Washington Boulevard. We use these one day a week, and supplement them by the use of the loadometer on the other roads where we have knowledge that trucks are operating. When we have no definite knowledge of violations of the law, we simply select a road at random. The uncertainty as to where we are going to be does away with the necessity for constant patrol. The patrolmen all have the power of arrest and do actually arrest, but they also see that the truck is unloaded immediately, and this, we believe, is the salutary part of the treatment.

We believe we have hit upon the solution of the problem. Certainly it is not sufficient merely to increase the license fee, because that does not make it possible to maintain the existing roads. Nor is it enough to arrest the violators of the law and fine them—they are perfectly willing to pay for the privilege of carrying the overload. The only measure which seems to be effective is to unload the trucks.

COOPERATE WITH MANUFACTURERS.

J. N. Cole, commissioner of public works, Massachusetts: There seems to be a very definite purpose in the minds of most of those in control of the operation and construction of highways to force the trucks off the roads or make them pay a fee which will adequately compensate for the damage they do to the highways. I think it will be wise to think twice before accepting the first proposal. It would be wrong to adopt the theory that these roads are sacred for a single individual or for a group of individuals. The theory that should guide us is that roads are for service, and beyond that it seems to me that we are charged to-day with the construction of highways in order that motor trucks may operate over them with a service to the community comparable with and even perhaps more important than the service of the railroads and the waterways. If we overlook that we shall fail to make of the highways the agency to industry, to commercial life, to transportation in its broad relation to world activities, that it must become in order to justify, in the end, the big expenditures we make. The way to solve the problem is to cooperate with the manufacturer of trucks, working along little by little until we reach the point where he knows he can not afford to destroy highways any more than the railroad man can afford to run a 40-ton locomotive on a 40-pound rail. When you reach that point you will have no difficulty.

UNIFORM TRAFFIC LAW WILL HELP.

Clifford Older, chief engineer, Illinois: I think there can be no doubt that load limitations should strike a balance of economy between motor-truck operation and the maintenance of the road surface. Whether we know just what the load limitation may be to strike that balance at the present time is a matter of some doubt. However, all of us here are so intensely interested and have such a knowledge of the damage done by excessive loads that it seems to me that some load limitation at the present time is almost essential. A uniform traffic law might be a possibility. I believe that it is, and as an illustration I would say that the Mississippi Valley Association of State Highway Departments decided a few years ago upon certain load limitations which were thought to be fair for the Mississippi Valley States. Such a uniform law was drafted or the governing provisions of such a law were agreed upon, and a number of our States have followed with the passage of such traffic laws. The Illinois law may be cited as illustrating the general provisions agreed upon. It provides for an 8-ton axle load as a maximum with 800 pounds per inch width of tire in contact with the road surface. We believe that it is better to specify the axle load than the gross load, inasmuch as an investigation of figures submitted by truck manufacturers shows a variation of load on the rear axle of from 57 to 93 per cent.

Modification of Contracts To Meet Present Conditions.

W. R. NEEL, State Highway Engineer of Georgia.

IN presenting for consideration a new form of contract I wish to remove from the minds of everyone any suggestion or thought that I have devised a form of "cost plus" under a new name. However, the "cost-plus" contract when originally drawn embodied two fundamental principles, which were based on fairness to everyone: First, that the owner or beneficiary should pay the cost of the improvement; second, that the contractor effecting the improvement should be fairly compensated for his efforts. Recognizing these two principles, we have had as a result several forms of contracts based on these fundamentals. The plan which provides for the payment of cost with a percentage of whatever that cost might be to cover the compensation, commonly known as the "cost-plus plan," is in bad repute, and certainly the results of the use of this method during the late war have given everyone just cause for prejudice against it. In an effort to remove the incentive to an unscrupulous contractor to increase the cost, thereby increasing his profit, the cost plus a fixed fee was tried out and proved more satisfactory to the owner and also the conscientious contractor.

GEORGIA'S FORM B CONTRACT.

My principal criticism of the "cost-plus fixed-fee plan" is that there is no incentive for the contractor to keep down the cost of the work other than a desire to secure a reputation for economical and efficient work. In public work where it is necessary to advertise and receive bids, thereby removing to a great extent the discretionary powers of the public official in selecting the contractor, something more than is provided in these two forms of contract is needed. In attempting to embody the two fundamental principles recognized by everyone as a basis for any contract, and at the same time perfect a contract more adapted to the execution of public work, the Georgia Form "B" contract was written.

The original draft was submitted to a large number of experienced engineers and contractors and to legal talent and changed to meet the suggestions we thought worthy of consideration. Since initiating work under this form of contract other changes have been made to perfect its weak points, and in submitting it I am cognizant of the fact that it will probably be changed from time to time as experience in its use directs.

In approaching the demand for a new form of contract in Georgia I was confronted with a constantly ascending scale of unit prices, each succeeding set of bids being a little higher than those preceding, until it was a question of either suspending the letting of new contracts or of devising a means of decreasing the cost of the work. I do not wish to place all the blame for the excessively high bidding upon the contractors. They in turn were under the fear and actual conditions of constantly ascending prices for material and labor, together with the uncertainty of freight rates, until no one knew where he stood nor how to bid. It was a gamble, as the old form of contract always has been, with the odds heavily against the contractor, and, as a consequence, there was high bidding. Furthermore, everyone was affected by the many uncertainties, and the bonding companies, realizing the greater risk, demanded of the contractor higher bidding. On several occasions contractors have informed me after the bids had been rejected that they were willing to submit a lower bid but could not secure a bond if they did so.

It therefore appeared to me that in order to meet this situation it would be necessary for the State of Georgia to carry a large part of the risk, and, briefly, the actual use of the present form of contract immediately produced the desired results in decreasing the cost of the work to the State.

HOW THE CONTRACT WORKS.

The use of this form of contract does not eliminate competition. The contractor in submitting his bid divides it into two parts—the estimated cost and the desired compensation. In order to have an incentive to keep down the cost the contractor is allowed 25 per cent of any saving on the estimated cost, provided it does not exceed 50 per cent of the total compensation in the proposal, and should the cost exceed the estimate 50 per cent of this excess is deducted from the compensation, with the provision that the compensation must not be reduced more than 75 per cent. Therefore the contractor is assured of at least 25 per cent of the compensation, as shown in his bid, for which he must furnish at his expense a superintendent and any overhead expense, such as the maintenance of his general office. It is calculated that the 25 per cent will allow the contractor to break even, with no loss other than that of his time. The contract also provides for a machinery and equipment rental, a form being provided which must be filled out and which forms a part of the contract cost of work. However, the rental schedule is fixed, and only the interest on the value of the equipment is allowed, plus a fair compensation for depreciation, insurance, and estimated repairs. In this way no profit can be made other than that shown as compensation, and this amount varies with the skill and zeal used in the prosecution of the work. Thus the minimum compensation obtainable by the contractor will be 25 per cent of the compensation shown in the bid, and the maximum will be the compensation shown

in the bid plus an additional 50 per cent of this amount. If the contractor should be so fortunate as to receive the maximum, the State should not begrudge him this additional compensation, as any additional compensation means a saving of three times as much to the State.

The cost of the work is paid by the State, which is required to pay promptly all bills in order to take advantage of any cash discounts. A bonded accountant in the employ of the State makes up pay rolls and supervises the paying of all labor, etc. All materials are purchased by the purchasing agent of the State highway department, and the prices for all materials, f. o. b. railroad siding, are included in the proposal. In this way the only financing required by the contractor is in purchasing of equipment pertaining to the job and in paying the salary of his superintendent. This has resulted in the immediate delivery of all necessary materials for the vigorous prosecution of the work as soon as practicable after the awarding of the contract.

REDUCED COMPENSATION DEMANDED.

The contractor is called upon to furnish the necessary equipment and a skilled organization properly directed by an experienced and efficient superintendent. The elimination from the requirements of the contractors of practically all financing results in a considerable reduction in the compensation demanded by them, so that this is practically net profit to the State under this form of contract.

At first thought it might appear that the compensation of a contractor could be saved by an organization operated by the highway department, but analysis makes it evident that the item of compensation of a contractor, if conservative, would closely correspond to the operating expenses of an organization owned by the highway department, and, while it should not be the case, I am afraid in actual practice it would be hard to get supervision for a State contract in an organization working on salary that would exert the same effort in construction as would a contractor, under the Form B contract, where incentive in dollars and cents would be to keep the construction cost under the estimate. At the same time the estimate must be conservative in order to meet the competitive feature.

In addition to this objection to a State construction organization there would be the enormous investment in equipment which could only be used on State highway work, whereas a contractor has for a field not only State highways within the State but in other States, as well as municipal, railroad work, etc.

GIVES OPPORTUNITY TO SMALL CONTRACTORS.

One of the first advantages in this new form of contract is that it permits honest contractors of small means to show their ability on a larger scale than would be possible under the old form, under which a surety bond is required for the full amount of the contract, which many contractors of small means are unable to make. At the same time the facilities for financing this Form B contract open a field for intelligent, honest bidders who would otherwise be unable to participate in a project of very great magnitude, except as subcontractors, although their ability might be ample to handle the project.

A striking example of this is a recently completed concrete paving project. The successful bidders could not have financed a project of this extent under the old form of contract, and yet they have had charge of the construction of more miles of concrete pavement within the State than any other contractor. The result has been that 5½ miles of 18-foot concrete pavement were laid in 3¼ months at a 15 per cent net saving on the contract as awarded. The contractors not only earned the compensation set forth in their bid, but an additional 50 per cent, the maximum amount permissible. The advertisement for the letting of this contract, as is our custom, called for bids under both forms of contract. The successful bid was on Form B, and was 24 per cent less than the next lowest bid, which was on the old form contract, and it therefore resulted in an actual net saving of practically 30 per cent under the Form B as against the standard form of contract.

One contract for concrete pavement is showing a saving of 11.3 per cent on first estimate. Federal-aid project No. 162, a grading job, shows a saving of 13.2 per cent, and the work has been under way for more than three months.

The contracts now under way in Georgia under the Form B plan amount to over $1,500,000, and a saving of a little over $20,000 has been effected in bond premiums alone, as a minimum bond is required under this form of contract.

The supervision that is required under the Form B contract by the State requires a very high-class man, preferably one with experience as an inspector on the old form contract, and also experience as a contractor, or superintendent for a contractor. His duties are to watch for violations of the contract and to catch the leakage on the job. The former duty should be performed subconsciously, but most of his thoughts should be centered on methods to reduce the cost. The cost sheet tells him a very true story and should be kept up to date, so that he can see at a glance where he should put most of his attention.

In my judgment this form of contract requires a more intelligent insight into construction details and a more thorough knowledge and analysis of costs by the engineer than the old form.

DISCUSSION OF MR. NEEL'S PAPER.

Frederick S. Greene, State highway commissioner, New York: I can not conceive of any better way to encourage contractors to enter the highway field than by this cost-plus-fee arrangement. Highway contracting seems to be about as big a gamble as there is in the contracting field, and, furthermore, highway contracting as it has been conducted in the past is not a business which the large concerns care to go into. In 1919 several large companies that I know of started into the highway contracting business. I have since talked with officials of three of them with a view to letting large contracts and having two or three plants on the job, and they have told me that they have had enough of it; that they can not compete with the smaller contractor who does not have the overhead that a large concern must necessarily have.

Many States would probably find that legal difficulties stand in the way of putting the plan into effect. Such would be the case at the present time in New York, but in my opinion any State in which the law will permit would benefit by using this form of contract.

PROTECTIVE FEATURES SUGGESTED.

One weakness which occurs to me is the possibility of contractors entering into combination to raise the estimated cost of the job in order to profit on the apparent saving which would be attributed to the efficiency of the contractor. To prevent this the engineer's estimate should be published and it should be understood that no bid would be received which overruns that estimate. It would be well, also, to have the engineer estimate the cost of a suitable plant, so that the contractor could not load down the job with surplus equipment. If, then, the engineer were to fix a reasonable time for the completion of the work and it were understood that plant rental would be paid only for the estimated reasonable period, there would be an added incentive for the contractor to expedite the work.

With these changes made, the only stumbling block I can see lies in the question as to what is to be done when the work overruns the estimated quantities. According to the terms of the contract "any changes in quantities, whether increases or decreases, shall be computed and certified by the engineer at the unit prices quoted therein and the fixed compensation and rental of equipment increased or decreased in proportion." That reads very simply, but I am afraid there would be difficulty in applying it. Take the case of rock excavation, for example; in our State—and I presume in other States as well—we do not go to the expense of making borings to actually locate the rock. To do that would run the cost of surveys up to an enormous price. Really our estimate is merely a careful guess. Of course, it is a guess based upon the experience of men who are familiar with the general lay of the rock. But, in spite of that, rock excavation frequently overruns or underruns, and in that case there is a question in my mind as to how to adjust the item of rock excavation to the general fixed fee. It would seem to me to be a rather difficult proposition. That is the only question that I think is yet unsolved by this form of contract. I would prefer to have the contract written so that the contractor would share equally with the State in any saving he makes; but that, of course, is a matter of personal preference.

PROPOSED FORM WOULD DEVELOP DISPUTES.

W. F. Cocke, assistant commissioner, Virginia: Though I fully realize the difficulties under which contractors have been working for the last three years, and would be glad to see the development of a form of contract which would minimize the unfair risk which contractors are now required to take, yet, at the same time, I think this proposed form of contract may develop a great many indeterminate items, which, under certain conditions, would lead almost inevitably to the courts. Taking care of the percentage of increase and decrease of rock excavation would of itself be a very intricate problem. I have had a good many years' experience on railroad work in the mountains and I have never seen two engineers who could agree as to percentage of solid rock. Another difficulty, which I believe we would encounter in my own State, lies in the fact that this form of contract would afford an opportunity for a great many inexperienced road builders to grasp the opportunity to go into business without a great amount of risk to themselves. I suppose the same condition exists in other States, but we have hundreds of men who have been inspired from their early youth to tell everybody how to build roads, and a great many would flock to the construction game if they could go into it with the element of risk to a large extent removed. If we exhaust the supply of experienced contractors and fall back on this class I fear the public would suffer materially.

WOULD ENCOURAGE SMALL CONTRACTOR.

A. R. Hirst, State highway engineer, Wisconsin: We in Wisconsin have been very much interested in this form of contract which has been proposed by Georgia. One thing in the situation which would deter us somewhat from adopting it is that the contractors have been contending for three years with a rising market. They are now getting the benefit of a falling market, and I know that the moment Wisconsin proposed to change to this form of contract they would accuse us of taking away their chances of recovery.

But I can not agree with the objection which has been raised on the ground that the new form of contract would give encouragement to inexperienced contractors. It is highly essential that we develop contractors, and the only way we can develop them is by

encouraging them. They must be educated and the public will have to pay the bill. The only alternative is the development of large day-labor organizations, which I do not believe we should undertake.

I am heartily in favor of encouraging the small contractor. I believe, as a general proposition, that the States that are going ahead on the basis that highway work requires large organization are making a mistake. An experience of very many years in highway work of all classes indicates that highway work, after all, is a small unit operation, and that a multiplication of those units in one place does not necessarily mean lower costs or increased efficiency.

Frank F. Rogers, State highway commissioner, Michigan: We have had some small experience in this way, but not just exactly in the manner provided for by the proposed contract form. In some cases where we have been unable to get satisfactory bids we have made arrangements with a contractor in whose business ability we had confidence, agreeing with him on an estimated cost of the work and agreeing to pay him cost regardless of whether it ran over or under the estimate. We have further agreed that he should have 50 per cent and the State 50 per cent of all that could be saved on the estimate. Up to date we have made a saving in every case.

Organization of a State Road Maintenance Department.

J. N. MACKALL, Chairman, Maryland State Roads Commission.

THE State highway department of Maryland is probably the only one in the country which does not maintain a maintenance department. Yet it is the belief of the writer that Maryland has at this time one of the most efficiently and satisfactorily maintained systems of highways in the country, and this is accomplished without a maintenance department. In any event, the department is rendering a "road service," which, dollar for dollar, is undoubtedly the cheapest in the country. This economical "road service" is possible partly because the State roads were built when materials and labor were very cheap, and partly because, regardless of how weak the road was in the first instance, it has been and is being maintained to-day in a highly satisfactory state of repair.

WHY A MAINTENANCE DEPARTMENT?

The first question to arise, therefore, is, "Why a maintenance department?" Is there not a tendency to-day toward overorganization rather than underorganization, and is not a State highway department a department of the State government, and is not this carrying departments far enough?

The principal argument which the writer has heard for a maintenance department as separated from the construction department is that, usually, good maintenance men are poor construction men, and vice versa. To his mind no greater fallacy ever existed than this. What makes a man a good construction, maintenance, designing, financing, or even propaganda engineer? Is it not in the final analysis just plain "horse sense," plus experience, and will not the same "horse sense," plus experience, which makes a good maintenance engineer, also make a good combined maintenance and construction engineer? If he exercises good judgment as a construction or as a maintenance engineer, you may be assured that he will use the same good judgment in the combined positions.

Another argument often used is that if maintenance is separated from construction the time, efforts, and enthusiasm are concentrated and not divided. Enthusiasm is, of course, necessary, but actually does not the man immediately in charge of any piece of work supply most of this, so it is not necessary that the head of department or even the subhead have it. The writer's idea is that the judgment should come from the top, the enthusiasm from the bottom.

One of the greatest assets, if not the greatest, which any highway department has is the confidence of the public, and no highway department can continue longer than the public believes it is reasonably efficient and thoroughly honest, and, certainly, willing to listen to reason. If this is true—and we look for the greatest source of danger from this point—where do we find it? In the lack of cooperation, lack of understanding, and lack of appreciation on the part of one or the other of the subdepartments as to what is proper construction and proper maintenance. It is impossible to keep the knowledge of these conditions from getting to the public, and filtering through the public back to the department, and the writer believes that too often this does not come to the department until it comes through the public. Is it not a fact that soon the public comes to believe that both the construction and maintenance departments are right—right in their criticism of the other? Stop criticism in the department and you will stop criticism of the department. On the other hand, if maintenance is going to follow construction immediately and consistently in the hands of the same man he will not say, nor permit anyone else to say, that the construction is not the best; that the alignments, grades, and details of finish are not the best that could be obtained; and any defects which do exist will be corrected as rapidly and as satisfactorily as possible without criticism for their existence. In other words, the defects will be corrected, not criticized.

NOT JUSTIFIED ON ECONOMIC GROUNDS.

There can be no economical lines of demarcation between construction and maintenance; so why have any? Who will say that things are not done in construction which do not return 10 cents on the dollar, when the cost of doing similar work in the form of maintenance is considered? Consider, for instance, the one question of shaping shoulders, sloping banks, etc. This work, done by the contractor, usually by hand, at a tremendous expense, is obliterated after the first rain. After this it is done with a road machine at probably less than 10 per cent of the cost of the contractor's handwork; yet who has ever seen a construction engineer willing to accept from a contractor a piece of road unless the shoulders and slopes from beginning to end were in perfect state of repair on the day of acceptance, regardless of whether or not this would last for one day or one week after the road is actually accepted? The writer does not want to be understood as unfavorable to reasonably well-shaped shoulders and slopes, but they should not be done better than they can be maintained. Make no mistake, the ultimate consumer, the public, pays all the contractor's bills and a profit on them. How, then, are many of the economic problems involving construction and maintenance going to be solved except from an intimate knowledge of both, and how is this to be had when the two departments are kept separate? It can not be done. What is to be done as construction or left undone to be taken up as maintenance can only be determined by an intimate correlation of the two.

If it is remembered that the money, whether used for construction or maintenance, is the public's money, and that the public is interested not at all in whether the work for which its money is spent is named construction or maintenance, but only in seeing that it receives 100 cents for each dollar expended, the separate construction and maintenance departments will disappear. This seems to the writer, generally, a reason for not maintaining a maintenance department separate from the construction department, and up to this point nothing tangible and definite in the line of saving of money has been touched upon.

SAVING OVERHEAD AND TRAVELING EXPENSE.

The writer believes, moreover, that a large proportion of the overhead and traveling expenses can be eliminated by combining the construction and maintenance departments, and that much duplication must and does exist where these departments are separate. The State of Maryland, for example, has constructed probably as many of its main through roads as any State in the Union. It has connected by an improved road every county seat in the State, and, in addition, every town of more than 1,000 people is connected with every other town of similar or larger size by an improved road maintained in almost perfect condition. Certainly, then, it would have less duplication of overhead and traveling expense than the States which have not completed their main line system, yet, even in Maryland, construction and maintenance go together so closely that it is impossible to inspect and supervise construction without at the same time going over maintenance and vice versa. In States where the main line systems are not completed, and where construction sections immediately adjoin maintenance sections, it is evident that expense can be saved by combining the departments, but it is equally true where the main lines are completed, because new construction on the branch lines immediately joins the main-line maintenance. The writer has reference only to connected systems and it is assumed that all departments are organized with hope and expectation of eventually having a connected system, if not now. Certainly, then, separate construction and maintenance departments make for duplication of effort which can only mean duplication of expense.

AS TO RECONSTRUCTION WORK.

Probably one of the most potent factors in arriving at the combined construction and maintenance department is the feature of reconstruction. "Reconstruction" is a word which probably should never have had a place in highway work. The work called reconstruction is really maintenance, and the cost of it should be charged against current receipts. Under a system of separate maintenance and construction organizations how is this reconstruction to be handled? By reconstruction the speaker means extensive reconstruction, essentially new construction, done by contract. For instance, why should the building of a sheet-asphalt top on an old macadam or concrete base be under the maintenance department and another section in the immediate vicinity, built on the identical specifications but on a new base, be under the construction department?

To pursue the contrast further, take as an illustration the work Maryland has just done on a 50-mile section from Washington to Baltimore and on to Belair on the road to Philadelphia. This consisted in a few cases of replacing the 14-foot macadam with 20 feet of concrete. But in most cases it consisted of the construction of a strip of concrete 3 feet wide on each side of the macadam, as was fully described in the September issue of Public Roads, which, no doubt, some of you have read. Under Maryland's system of financing, then, the work done on the 14-foot width of macadam was charged to maintenance and the additional width of 6 feet to construction. With separate construction and maintenance organizations would all this work be done by the construction or the maintenance department, or would each one have done its portion of the work? This may be an extreme case, but it demonstrates conclusively that maintenance and construction are inseparable in execution. So why maintain separate organizations?

Having advanced the reasons leading up to the organization of construction and maintenance work along similar lines, and having referred to the saving in overhead in connection therewith, the writer will perhaps be pardoned for citing the organization he is now maintaining as an example of the kind of organization which in his judgment will give the best results in both construction and maintenance.

THE MARYLAND ORGANIZATION.

The State roads commission of Maryland as at present constituted consists of three members, of whom one is the chairman, and the law provides for a chief engineer and assistants. The commission, in organizing, selected the chairman as chief engineer, so that the authority and responsibility is concentrated at the top as much as possible. Under the chief engineer is an assistant chief engineer, who has such duties as are specifically entrusted to him by the chief pertaining to all phases of the work, including surveys, plans, construction, maintenance, and costs. In all his dealings he acts for the chief engineer and in his stead, so that all reports to him have the force of reports to the chief engineer. Next in line of authority is the district engineer, there being seven of these in charge of the work in Baltimore city and 23 counties of the State, averaging a little more than 3 counties to a district. The district engineer, therefore, is really the first subdivision lower than the chief engineer, there being neither construction nor maintenance engineers in the department, and the district engineer, therefore, handles and is responsible for both construction and maintenance in his district.

The maintenance work is further divided, approximately by counties, with a superintendent for each county. The maintenance superintendents and construction inspectors are interchangeable, so that it is possible to fill the position of district engineer from within the ranks of the organization. The purchasing agent, working directly under the chief engineer, is responsible for the purchase and delivery of all materials. The materials as required by the district engineer are requisitioned from the purchasing agent with specifications as to quality, time, and point of delivery. Centralized purchasing has always been desirable in that it stops competition for price and delivery within the department, but the difficulties in obtaining materials and in their transportation during the last few years have demonstrated the absolute necessity for it.

All requisitions are forwarded by the district engineer to the chief engineer for approval and order of delivery, and then transmitted to the purchasing agent, who places the order and effects delivery to the point of destination on the railroad or water, from which point the responsibility for ultimate delivery is with the district engineer.

MAINTENANCE BY PATROL SYSTEM.

Maintenance, other than extensive reconstruction done by contract, is effected by the patrol system, supplemented by the gang system. The backbone of the maintenance system, however, is the patrolman, the man with the pick and shovel. It is the writer's opinion that no road can be properly maintained without the patrol system, regardless of whatever else may be used. Properly maintained, as it is interpreted in Maryland, is perfectly maintained, so far as the surface is concerned. No hole of the smallest size is permitted to remain in any highway. By this system the department is rendering a most satisfactory road service on very low types of construction, and at a most reasonable figure when interest and maintenance charges are considered. It is, of course, necessary at times during the year, especially in the spring, to supplement the patrolman with a gang, which does small sections of resurfacing, cleaning of ditches and culverts, dragging shoulders, etc.; but the gang does not relieve the patrolman; it only supplements him. The gangs are under the direct supervision of the foreman in charge, but report to the maintenance superintendent in the district and he, in turn, to the district engineer. The gang is entirely independent of the patrolman, though the latter is at times employed in the gang.

On numerous occasions it has been attempted to dispense with the services of the patrolman, but invariably it is found to be impossible properly to maintain the roads. One of the greatest difficulties with patrol maintenance is that the patrolman frequently works inefficiently. We have found it expedient to overlook a certain amount of loafing, which we recognize as inevitable, because we hold firmly to the belief that the patrol system, in spite of the inefficiency of individual patrolmen, is a necessary adjunct to perfect maintenance. Whenever the services of the patrolman have been dispensed with, public-spirited citizens, true friends of the road movement in Maryland, have noticed that this has been done, and have noticed that the roads were not being maintained in their usual first-class condition.

The speaker believes that there is as little loafing and unintelligent work done by the patrolmen in Maryland as any State in the Union. This, he believes, is largely due to the fact that whenever inspections are made, either of construction or maintenance work, the patrolman comes under the eye of the inspecting officer, who is in authority on maintenance work.

SINGLE DEPARTMENT MOST EFFICIENT.

In conclusion, the organization of a combined construction and maintenance department prevents the dodging of responsibility. It concentrates in the hands of the district engineer undivided authority and undi-

vided responsibility for the building of good roads, and maintaining them in perfect condition. It stops criticisms of bad construction, of bad maintenance, of things done and things left undone. It makes for a coherent absolutely loyal organization, free from the faultfinding and backbiting which results chiefly from the conflict of separate construction and maintenance organizations.

Efficiency is certainly the keystone in any organization. Combined construction and maintenance organization makes for efficiency of funds in that a dollar does a dollar's worth of work; efficiency of men, in that one man does what two would do otherwise; efficiency of results as reflected in Maryland's 1,600 miles of roads maintained in perfect condition in 1920 for an average of $600 per mile.

DISCUSSION OF MR. MACKALL'S PAPER.

J. H. Mullen, chief engineer, Minnesota: I can not agree with the argument that there should be no State highway maintenance department. It is undoubtedly true that in a small State, having only 1,600 miles of arterial roads, of which practically all have been surfaced, the maintenance and construction work can be handled efficiently without separation. But these conditions do not prevail in many of the States, and for the reason that we do have such various governing conditions in the several States, it would be very difficult, if not entirely impractical, to set forth a standard method of organization applicable to all.

The organization of a State highway maintenance department is one of several highway problems which must be studied and worked out largely with reference to local conditions. Take, for instance, the organization in Maryland, which is described as being ideal, and upon analysis it would appear that this State highway department is really in effect a maintenance organization, and the small amount of construction necessary under the stated conditions could properly be considered as incidental work, the same as grade separations, material surveys, or other subactivities are considered as being incidental to the maintenance and construction departments in other States.

I do not wish to be understood as criticizing the Maryland organization. On the contrary, I have no doubt that it is the most effective that could be worked out to handle the local problem, which appears to be largely maintenance. But if that State should enter upon an extensive construction program I think it might be found advantageous to provide for a construction department within the organization.

ONE DEPARTMENT, SEPARATE DIVISIONS.

Having departments of construction and maintenance does not mean complete separate organizations. They are both integral parts of the highway department but are each in charge of men specializing in the particular branches of the work. I have received the greatest help in conducting the work in our department by having as principal assistants three experts, one in charge of road construction, one bridge construction, and one maintenance. These men sit in conference with me on all questions of specifications, engineering policy, or methods of work, acting really as an engineering council, and bringing out the best ideas with regard to all phases of the work. Under this plan there is no danger of domination by one branch of the work to the detriment of another, as might be when there is no separation. I have not found that this method leads to any dodging of responsibility or "backbiting," as described, for the engineers in charge of the three different branches are interested and feel a sense of responsibility for all of the work. However, if such a condition as mentioned should arise, it would be the duty of the chief engineer to institute a house cleaning.

EFFICIENCY BY SPECIALIZING.

The great advantage of having a maintenance department is in the efficiency brought about by specializing, a point which needs no elaboration in this meeting. This, however, has been demonstrated by experience in the Middle West, where for the last 5 or 10 years the States have been engaged in the construction of from 500 to 2,000 miles of new work each year, and also the maintenance of from 400 to 12,000 miles of all kinds of roads, ranging from common bladed dirt roads to the highest types of pavement. This is particularly true in Minnesota, the first State in the Mississippi Valley to consider maintenance as a State activity.

I believe considerable credit for starting this work should be given to Mr. George W. Cooley, former State engineer of Minnesota, whom most of you know as a fine gentleman and a good roads pioneer. Twelve years ago the State highway commission, of which Mr C. M. Babcock was then chairman, ordered Mr. Cooley to investigate road conditions in Europe, with a view to applying the results of the investigation to construction of roads in Minnesota. Mr. Cooley spent a year in this investigation and upon his return made a report to the commission that the desirable road conditions generally prevailing in Europe at that time were not due to construction methods but rather to an intensive system of patrol maintenance. Consequently there was established under Mr. Cooley's direction a patrol system of maintenance in Minnesota which has continued since that time quite successfully under various methods of supervision, and, I am pleased to say, has been adopted in several of our neighboring States.

The management of the work has been conducted in various ways since the State took charge. First, it was considered as a county proposition, then as a part of the miscellaneous work of the department, and during

the last four years as a separate subdivision of the work. And now, in the light of our experience, we are satisfied that the latter method is most productive of results. As stated before, this does not mean complete separation but only a division within the highway department.

RESPONSIBILITY DEFINITELY PLACED.

It seems to me that responsibility for each general branch of work should be definitely placed in a subdivision of the highway department charged with responsibility for doing that particular work and given the authority to carry it on. Minnesota has just passed a constitutional amendment selecting from the 12,000-mile State road system a trunk highway system 7,000 miles in extent. The trunk highways will be maintained directly by the State and the remaining State roads will be maintained by the counties under direction of the State with State aid. Under this plan our work will be in charge of a maintenance engineer reporting directly to the chief engineer and working in conference with the construction and bridge engineers. His department will also have in charge such matters as grade-crossing separations, rights of way, traffic census, etc.

The State is divided into eight divisions, each having a division engineer who has control of all work in his territory and who will have as his principal assistant an engineer known as the road superintendent, whose duty it is to give personal direct supervision to the maintenance of the trunk highways. The construction work will be handled as before by resident engineers reporting directly to the division engineer. The road superintendent will have authority to employ such men and equipment as may be required to carry on the work and will have use of the excess war trucks and tractors now being employed for this purpose to very good advantage. We have made it a policy not to purchase any considerable quantity of small tools, but to engage individuals at a stated rate including the use of tools, teams, wagons, etc. Heavier equipment, such as graders, tractors, tarring equipment, etc., is, of course, furnished by the State, excepting where the equipment of a county is employed on a daily rental basis.

MAINTENANCE IS DAY-LABOR WORK.

An outstanding difference in the construction and maintenance organizations is that the first is a contract organization, for we believe in contracting for all construction which can be figured on a unit basis, while the maintenance organization is almost entirely a hired force and does all miscellaneous day-labor work.

The maintenance work in our State amounts to a great deal more than the name implies. We do not consider that maintenance is successful unless it brings about a substantial betterment of the road, and we class as maintenance all those minor improvements, such as shoulder surfacing, light regraveling, reshaping of roadway on earth roads, and even grading with blade graders to natural contour those connecting roads which do not for the time being require construction. It is also the duty of the maintenance department to mark the trunk highways and to mark and maintain suitable detours around construction work. In short, it is the duty of the maintenance department to see to it that traffic is maintained continuously over the highways in the most satisfactory, efficient, and economical way, which, in my judgment, requires direction by men who are specialists in that work and are not likely to become sidetracked on account of other activities.

Report of Committee on Use and Care of Federal Equipment.

IN developing a report on this subject the committee agreed—first, that the report should quite properly go beyond the limits imposed by its title and include reference to the receipt or acceptance of Federal equipment; and, second, that the report would be prepared and submitted without recourse to a second questionnaire.

The data compiled as of February 1, 1919, are perhaps of questionable value to-day. In each of those States represented by members of this committee, for instance, the year's experience has indicated many weaknesses of policies previously tentatively adopted; has impressed certain fundamentals that will be herein referred to, but has notwithstanding failed to eliminate all uncertainty as to the best method of disposing of this question. The older departments were able to meet the situation brought about by the allotment of Federal equipment with somewhat less confusion than were many of the newer organizations; but it is significant that even among the established organizations no uniform policy obtains. The first conclusion of this committee, therefore, is this: The acceptance, use, and care of Federal equipment is a matter primarily of local concern; the problem is one not susceptible of a single, uniform solution throughout the several States.

ACCEPTANCE OF FEDERAL EQUIPMENT.

This committee believes that too few of the States have asked seriously the question, Shall Federal equipment be accepted, and if so, for what use or distribution? The exigencies of the occasion seemed to justify the haste with which allotments and shipments were handled by the bureau. But the enthusiasm of the moment engendered by the altogether human desire to get something for nothing has, in some instances, we

believe, obscured the economics of the transaction. The result seems to be:

(*a*) Some States now have a surplus of one or more kinds of equipment or materials, both desirable and usable, and a deficiency of other kinds;

(*b*) Some States have a supply of equipment and material wholly unsuited to their needs and requirements, although in itself valuable and serviceable;

(*c*) Many States have on hand material and equipment supplies that, because of its unfit condition or the lack of adequate funds for repair, or both, are altogether valueless to the States.

The transfer of equipment between States might appear to offer a solution of this difficulty, and did at first so appear to this committee. But such transfer is subject to the limitation of distance and is contingent upon agreement between the parties as to reimbursement for amounts invested. This committee believes that the transfer plan is not possible of broad application as long as the State seeking the equipment feels that it may be obtained direct from the bureau at a cost considerably less than that involved in transfer expense plus reimbursement to the State transferring. The points here suggested are:

(*a*) The acceptance of miscellaneous equipment has placed a heavy financial burden upon many States; and

(*b*) Amounts paid out (in freight, etc.) for unusable or undistributable equipment are likely to represent an actual and serious loss to the States.

This committee, therefore, suggests the following:

(1) That each State that has not already done so undertake an immediate determination of its present and future equipment requirements. Such determination involves a decision as to (*a*) ability and plan to finance the handling, and (*b*) plan of use or redistribution.

(2) That each State that has not done so inventory its present stock, segregating the desirable and usable from the undesirable or unfit.

(3) That the bureau endeavor to ascertain and announce the kind, quantity, condition, and value of surplus materials yet to be allotted.

(4) That initial or additional shipments be accepted by the States only when the units can be put to economical use, in accordance with the principles herein noted, within a reasonable time.

(5) That all undesirable or unfit units or supplies be disposed of by the States in whatever legal manner offers the greatest possibility of reimbursement.

(6) That the bureau recognize the reasonableness of the plan of ultimate disposal by the States, as "unserviceable materials," of such units or supplies as may for any reason be unusable or unsuited for the purposes of the State and not possible of redistribution within or without the State. Decision as to the "unserviceability" of units may be reached by agreement between representatives of the State and bureau.

USE OF THE EQUIPMENT.

Acceptance of Federal equipment should be in conformity with a definite policy as to use. If there is no present or immediate future use for the unit its acceptance undoubtedly represents unnecessary expense. This principle apparently has not been recognized by all the States. The possibilities as to use include:

(*a*) Use by the State on day-labor construction or maintenance.

(*b*) Use by contractors engaged in State or other highway work.

(*c*) Use by counties or other civil subdivisions of the State on construction or maintenance.

This committee suggests that—

(1) Wherever possible, the use of Federal equipment should be confined to State forces; and that when so used a proper charge should be made for depreciation so as to perpetuate the life of the unit.

(2) Use of Federal equipment by counties or other civil subdivisions of the State is less likely to lead to friction and disagreement when such use is on a basis of perpetual lease for which a lump-sum payment is made upon receipt of the unit by the lessee. The payment mentioned should very properly be sufficient to cover: Initial cost, if any; freight; loading, unloading, and reloading; hoist, body, and other accessories; overhauling and repair, including supplies furnished; plus a charge to cover overhead and unanticipated Federal claims. The perpetuation of equipment leased to counties and cities is believed to be desirable but generally impossible.

(3) Use by contractors should be confined to those engaged in State work unless distribution to other contractors is advantageous to the State in recovering funds. The use of trucks, tractors, and similar equipment by contractors should generally be on a monthly rental basis, determined so as to provide a depreciation fund, insure repair and maintenance, and protect the State against loss. The use of certain types of equipment or supplies not in general demand may be by perpetual lease under the terms of which the State receives a lump-sum payment in whatever amount is agreed upon, or at the price submitted by the high bidder following a request for "proposals for use."

CARE OF THE EQUIPMENT.

"Care" includes handling, storage, housing, maintenance, and supervision. This committee suggests that—

(1) Adequate provision should be made for housing all units found to be usable, pending use or distribution by the State.

(2) If justified by the kind and number of units, permanent repair quarters should be established and maintained with sufficient floor and storage space and sufficient shop equipment to care for the anticipated number of units. This involves policy as to (*a*) returning units to a central depot for repair, or (*b*) repairing at the location of use. Since, however, it is presumed that a central receiving depot will be necessary, it appears desirable to maintain a permanent shop at such location.

(3) Spare parts, small accessories, and supplies should be inventoried and stocked in bins or other convenient containers, listed and readily accessible.

(4) Equipment under "perpetual lease" should be subject to only such supervision by the State as may be agreed to, giving due consideration to cost and expediency.

(5) Equipment rented to contractors on a monthly basis should be subject to supervision by the State,

and all repairs should be made by or under the supervision of the State.

(6) Replacement of parts from State stock should be at prevailing market price for such parts.

(7) Accurate records of distribution and of handling and operating costs should be maintained.

(8) Whenever the volume of equipment business justifies such policy, a separate mechanical division should be established, with appropriate responsibility for use and care.

(9) All agreements or understandings as to use and care of equipment rented or leased should be in writing.

CONCLUSION.

Obviously the details involved in this subject are so numerous as to permit of endless discussion and the preparation of a most voluminous report. One State is interested in the matter of housing, storage, and repair in all the possible subdivisions of the subject. Another is concerned with the organization of a mechanical department, and still another with a determination of rental rates. This committee recognizes the futility of attempting a discussion of and recommendations regarding the many phases of the matter. It may be safely assumed that individual departments are able to develop detailed plans for the conduct of this activity. This committee, then, offers in conclusion the following brief summary of principles and recommendations, the observance of which it is believed will lead more readily to workable details of operations:

(1) Acceptance of initial or additional shipments of Federal equipment should be contingent upon a predetermined policy of financing and upon known requirements of State use or possibilities of redistribution. Acceptance of equipment for other than State use should be, preferably, by previous requisition of proposed user. Uncertainty as to ultimate disposal of units and recovery of funds invested should be eliminated in so far as thoughtful planning can effect such elimination. The amounts charged for rental or lease are purely of local determination. "Perpetual lease" agreements may properly consider matters of altogether local expediency.

(2) Unusable equipment on hand should be promptly disposed of to the best advantage.

(3) The use of Federal equipment by other than the State is very likely to lead to friction and loss. When use is by civil subdivisions of the State the "perpetual lease" plan appears to be most satisfactory; but annual or other deferred payment plans are of questionable value. All rental and lease agreements must be definite as to terms and provisions regulating, to whatever extent is agreed upon, the use and care.

(4) Responsibility for the care of Federal equipment must generally be assumed by the State, except in cases of perpetual lease, when the agreed extent of responsibility may be assumed by the lessee. Efforts to perpetuate the life of leased equipment represent commendable recognition of accepted business conduct, but may lead to friction and embarrassment. Such a policy must be weighed against local conditions and possibilities.

(5) The management of this division of work should follow usual good management procedure, with definite policies, plans, supervision, and records.

(6) The bureau should exercise only such supervision of equipment allotted as is required by law.

Respectfully submitted.

JOHN N. EDY,
ROLLEN J. WINDROW,
For Committee on Use and Care of Federal Equipment.

WASHINGTON, D. C.,
December 13, 1920.

DISCUSSION OF THE REPORT.

R. J. Windrow, State highway engineer, Texas: The report was prepared by the chairman after some correspondence with the other members of the committee. There is only one point I wish to stress, and that is that we must evolve some plan for disposing of the equipment that has been received by the States which is either in unserviceable condition or unsuited for the particular needs of the States. It seems that no definite policy has been evolved for handling that problem. We have discussed it by correspondence, and it seems the law is not entirely clear, but in my opinion we have enough leeway under the present law to dispose of that equipment so we can reimburse the States for the expense to which they have been put in securing it. In Texas we have received quite a large amount of equipment that, from the description we had in advance, appeared to us would be serviceable. Some of it was found upon receipt to be entirely unserviceable for our particular needs. Some of it was received in unserviceable condition. We have a large amount of such equipment on hand for which we have paid freight, loading, and storage charges, and it is necessary for us to be reimbursed for that expense in some way.

DISPOSAL OF THE EQUIPMENT.

Thos. H. MacDonald, chief, Bureau of Public Roads: We have had frequent inquiries from the States as to the policy of the bureau with reference to disposal of this equipment. The only policy that can be enunciated is that of following the law providing for the distribution of this material, which makes it very clear that no material in serviceable condition can be sold. The disposal of the material can not be authorized by the bureau, but should be carried out under the State laws governing the disposal of public property of any other kind. The title of the equipment after it has been delivered rests in the States, not in the Federal bureau.

There is, of course, the question of good faith. The War Department has insisted, in turning over this equipment, that it should be used for road-building purposes. Representations have been made to the committees of Congress which passed the legislation that it would be so used. The only question which has been raised by the bureau with any State, so far as I know, has been to ask for information where the disposal of

equipment has been brought to our attention, either through the agencies of the War Department or through the Department of Justice. Such inquiries have probably been initiated by manufacturers of the equipment or manufacturers of similar equipment who had expected to make sales that were not made because of the disposal of such equipment by the States. In order that we may be able to answer such questions intelligently and honestly, we have requested that complete records of all property disposals be kept by the States.

In general we have taken the position that the title to the property distributed rests in the States; that disposal of it should be made under the State laws governing the disposal of any other State property, and that a clear statement should appear on the records of the commission or the department as to the procedure followed in making the sale or declaring the equipment unserviceable. So long as we adhere to this policy and keep faith with the Congress which made available this equipment; so long as the equipment we dispose of is actually unserviceable I can seen no reason why there should be any question raised; but if any bad faith is manifested, there might be considerable criticism.

As a guide in determining whether a particular piece of equipment may be regarded as unserviceable, I may add that the War Department defines as "unserviceable" any equipment upon which it would be necessary to expend more than 30 per cent of the cost price to put it in operating condition. The Solicitor of the Department of Agriculture has broadened this definition, in his interpretation, to include as "unserviceable" equipment which is unsuited to the road-building requirements of the State departments.

M. L. Shade, commissioner, South Dakota: I have been informed by those in a position to know that there is a large number of trucks and tractors yet to be declared surplus and probably a large amount of other machinery. As a word of caution, it occurs to me, therefore, that if we proceed to dispose of the equipment which is not useful or serviceable to us and the manufacturers make a concerted complaint about it, we might be prevented from receiving any additional equipment that is available or that will be available in the next few months, and thereby lose more than we would by accepting the unserviceable equipment.

A. R. Hirst, State highway engineer, Wisconsin: We are finding in Wisconsin that another word of caution is necessary. We were entitled to receive about 500 trucks. We intended to save 200 of them for our own use with the idea that we would charge enough for their use by contractors on our own work to cover the depreciation and repairs, so that at the end of their use we would be able to buy 200 additional trucks. We have been operating under such a plan for a year and a half, and as a result we found about a month ago that we have not only not collected enough rental to cover the depreciation, but that we actually have not enough to place the trucks in condition for next year's use. And we find ourselves in this condition despite the fact that our rentals have been as high as any State would charge. As a matter of fact, we have reached the stage where our mechanical man says he will not furnish trucks to the contractors and the contractors say they will not have them.

Especially in the Northern States, where work is closed down four or five or six months of the year, I doubt whether the trucks can be rented for enough to really depreciate them, and I am just interjecting this as a word of caution to the States that are planning to rent the trucks.

TRUCKS HAVE PROVED VALUABLE.

Clifford Older, chief highway engineer, Illinois: Our experience has been somewhat at variance with that of Wisconsin. We have received a large supply of equipment, and in the main it has been serviceable and has been kept in useful service by the State. Up to the present time the value received from the use of the trucks and other equipment has not only provided sufficient funds to keep the equipment in repair but to yield some surplus, not sufficient to depreciate the material entirely, but sufficient to keep it in service. I feel that although the equipment may not be put to such service as to provide a revenue sufficient to maintain an equal amount of equipment for an indefinite period, yet we are serving a very useful purpose in getting as much value out of it as possible, considering the character of the equipment. To state that this is not possible with the trucks is equivalent to stating that a truck is not a useful piece of machinery on the highway, or that it is impossible for us to administer the use of the equipment in a useful manner. We have succeeded, as I have said, in actually renting these trucks for enough, which is either paid in cash to our department or in the way of deductions from contract prices, to pay for the freight, unloading, and handling of all the equipment received, and in addition to put up our building, which, of course, should not be charged entirely to the rentals received to date, and still we have a surplus.

As to the adaptation of the equipment that is received in serviceable mechanical condition, but is not useful in the work of the particular State by which it is received, it seems to me we should give a thorough trial to the plan of exchange before deciding to dispose of the equipment by sale, and thus possibly raise some question with the War Department. We have received some equipment that we would perhaps have refused as unserviceable if we had had a complete description of it. However, all such equipment that we have listed with the Bureau of Public Roads for exchange has been exchanged. We now have some additional equipment that we do not believe we can use, but we are in correspondence with the bureau and believe that can be exchanged for an equal value of equipment that is not in service in the State where first received, but which we can use to good advantage. I believe we can go a long way toward the disposal of that class of equipment through the bureau as a clearing house.

FEDERAL AID ALLOWANCES.

PROJECT STATEMENTS APPROVED IN DECEMBER, 1920.

State.	Project No.	County.	Length in miles.	Type of construction.	Project statement approved.	Estimated cost.	Federal aid.
Ala.	20	Clay	14.700	Gravel	Dec. 13	[1] $342,070.71	[1] $171,035.35
	71	Dallas	[2] .056	Asphaltic concrete.	Dec. 7	[1] 108,340.82	[1] 54,170.41
	94	Wilcox	12.380	Gravel	Dec. 4	284,698.57	142,349.28
	95	Tuscaloosa	25.220	do	Dec. 13	545,545.88	272,772.94
	96	Escambia	20.520	do	do	359,706.87	179,853.43
Ariz.	22	Navajo	2.700	do	do	15,958.80	7,979.40
Ark.	23	Jackson	3.190	do	Dec. 16	[1] 36,107.10	[1] 20,000.00
	55	Prairie	1.740	Gravel, surface treated.	Dec. 24	[1] 25,184.73	[1] 16,000.00
	116	Pulaski	2.330	Bituminous.	Dec. 17	48,274.49	21,000.00
	124	Craighead	7.690	Macadam	Dec. 16	75,622.40	25,000.00
Colo.	87	Boulder	1.334	Concrete	Dec. 13	57,587.38	26,680.00
	185	Garfield	1.270	Earth	Dec. 16	64,965.72	25,400.00
Fla.	31	Hamilton	11.861	Bituminous macadam.	Dec. 22	458,129.11	229,064.55
Ga.	187	Rabun		Bridge	Dec. 4	95,531.42	28,659.42
	205	Effingham	4.218	Sand-clay	do	31,213.60	10,000.00
	208	Terrell	8.000	do	Dec. 13	55,037.62	22,500.00
Kans.	74	Chase	8.620	Earth	Dec. 16	68,687.03	25,860.00
	75	Dickinson	.500	Concrete	Dec. 18	23,399.20	7,500.00
Md.	41	Garrett	1.990	Earth	Dec. 24	44,137.50	22,068.75
	43	Prince George.	.500	Asphalt	Dec. 4	22,068.75	10,000.00
	44	Kent	.950	Concrete	Dec. 24	39,138.00	19,000.00
	45	Baltimore	2.040	Earth	do	30,030.00	15,015.00
	46	Somerset	.710	do	do	21,037.50	10,518.75
	47	St. Mary's	4.440	Gravel	do	86,850.50	43,425.25
Mich.	55	Berrien	2.847	Concrete	Dec. 13	125,756.67	56,940.00
	50	Monroe	13.034	do	Dec. 22	688,719.35	260,680.00
Minn.	173	Dodge	3.980	Gravel	Dec. 13	44,326.70	5,000.00
	177	Ramsey	2.500	Bituminous concrete.	Dec. 31	159,544.71	50,000.00
Miss.	90	Benton	27.700	Earth	Dec. 22	258,898.75	120,000.00
Mo.	166	Vernon		Bridge	Dec. 7	22,000.00	11,000.00
	167	Bates	14.200	Chat	Dec. 16	280,066.60	140,033.30
	168	Jasper	6.000	Gravel	Dec. 22	31,200.00	15,600.00
	169	do	7.000	do	Dec. 22	29,400.00	14,700.00
	176	Pulaski		Bridge	Dec. 13	34,375.00	17,187.50
N. Mex.	60	San Miguel.	21.700	Gravel	Dec. 7	108,055.20	54,027.60
N. Y.	91	Hamilton	8.000	Bituminous macadam.	Dec. 13	320,000.00	160,000.00
	93	Genesee	4.900	Concrete	Dec. 8	279,300.00	97,755.00
	95	Hamilton	27.600	Bituminous	Dec. 13	1,104,000.00	522,000.00
	96	Genesee	9.300	Reinforced concrete.	Dec. 6	530,100.00	185,535.00
	98	Steuben	8.500	do	do	484,500.00	169,575.00
	100	Chautauqua.	3.100	Concrete	Dec. 13	124,000.00	62,000.00
	101	Schuyler	3.400	Reinforced concrete.	Dec. 22	193,800.00	67,830.00
N. Y.	102	Chemung and Tioga.	7.800	Reinforced concrete.	Dec. 22	$444,600.00	$155,610.00
	104	Tompkins and Cayuga.	11.100	do	do	444,000.00	222,000.00
	105	Wyoming	9.500	Concrete	Dec. 13	541,500.00	189,525.00
N. Dak.	111	Bottineau		Bridge	Dec. 16	16,500.00	8,250.00
	113	La Moure	8.000	Earth	Dec. 13	36,960.00	18,480.00
	118	Mountrail	11.000	do	do	50,820.00	25,410.00
	122	Ransom	10.000	do	do	44,990.00	22,495.00
	132	Mountrail	6.000	do	Dec. 31	37,950.00	18,975.00
	133	do	12.000	do	do	55,440.00	27,720.00
	134	Williams	2.500	do	Dec. 22	18,425.00	9,212.50
Ohio	107	Warren	[3] 6.865	Bituminous macadam.	Dec. 28	[3] 187,000.00	[3] 93,500.00
	111	Delaware	[3] 7.420	Concrete	Dec. 16	[3] 312,000.00	[3] 60,000.00
	143	Logan	[3] 5.600	do	do	[3] 248,000.00	[3] 85,000.00
	152	Coshocton	[3] 4.043	do	do	[3] 192,000.00	[3] 57,000.00
	190	Madison	9.994	Kentucky rock asphalt.	Dec. 22	328,500.00	150,000.00
Okla.	39	Carter	16.000	Gravel, surface treated.	Dec. 20	340,000.00	170,000.00
Oreg.	48	Harney	10.460	Macadam	Dec. 16	171,192.34	75,596.17
Pa.	88	Indiana	2.688	Concrete	do	241,760.13	53,760.00
S. C.	91	Kershaw	8.875	Sand-clay	Dec. 22	76,145.86	38,072.93
S. Dak.	67	Clay	13.040	Earth	Dec. 24	87,725.00	43,862.50
	68	Charles Mix.	4.300	Gravel	do	39,792.50	19,896.25
Tex.	121	Grayson	7.370	do	Dec. 16	101,938.06	33,333.34
	122	Hill	9.900	do	Dec. 24	138,015.08	30,000.00
	178	Hays	16.790	do	do	101,534.60	30,000.00
	219	Valverde	5.250	do	Dec. 16	203,398.14	101,699.07
	222	Milam	18.860	do	Dec. 13	124,564.00	62,282.00
	225	Trinity	17.800	do	Dec. 16	200,915.55	50,000.00
	226	Jeff Davis	7.216	Earth	Dec. 4	23,981.93	11,990.82
	228	Johnson	12.000	Gravel, bituminous surface.	do	333,953.18	100,000.00
	229	Tom Green	4.000	Bituminous surface.	do	112,697.86	56,348.93
Utah	15	Iron		Gravel	Dec. 22	[4] 147,853.20	[4] 73,926.60
	17	Juab and Millard.		do		[4] 110,880.00	[4] 55,440.00
Wash.	81	Skamania and Klickitat.	.170	Earth	Dec. 18	47,520.00	3,190.00
	82	Kittitas	1.280	do	Dec. 24	63,187.38	27,600.00
W. Va.	105	Jackson	.990	Concrete	Dec. 11	28,700.00	11,350.00

[1] Revised statement. Amounts given are increases over those in the original statement.
[2] Revised statement. Amounts given are decreases from those in the original statement.
[3] Withdrawn.
[4] Decrease in mileage.

PROJECT AGREEMENTS EXECUTED IN DECEMBER, 1920.

State.	Project No.	County.	Length in miles.	Type of construction.	Project agreement signed.	Estimated cost.	Federal aid.
Ariz.	23	Pinal		Gravel	Nov. 20	[1] $20,916.55	[1] $10,458.28
Ark.	17	Craighead		Water-bound macadam.	Nov. 30	[1] 12,822.15	[1] 8,000.00
	20	Franklin	23.520	Gravel	Dec. 14	222,133.83	107,000.00
	27	Columbia		do	Dec. 21	[1] 35,957.43	[1] 17,000.00
	28	St. Francis		do	Dec. 11		[1] 20,000.00
	43	Lincoln and Desha.		Gravel macadam.	Nov. 30		[1] 3,500.00
	50	Phillips	7.940	Bituminous concrete on concrete base.	Dec. 30	224,565.00	36,800.00
	66	Little River.	34.140	Gravel	Dec. 11	121,222.48	65,000.00
	67	Dallas	19.030	do	Dec. 20	103,007.85	30,000.00
	75	do		Gravel macadam.	Dec. 11		[1] 10,000.00
	87	Pope	8.140	Bituminous macadam.	do	111,180.01	50,000.00
	109	Baxter	6.820	Water-bound macadam.	Dec. 31	54,506.85	20,000.00
	114	Lonoke	2,840	Gravel	Dec. 11	22 249.37	7,800.00
Colo.	112	Park	.758	do	Dec. 24	28,197.84	14,098.92
	120	Jefferson	1.273	Concrete	do	59,564.42	25,460.00
Fla.	3	Jackson and Gadsden.		Bridge	Dec. 2	[1] $212,316.39	[1] $106,158.20
	31	Dade	[2] 5.475	Chert	Dec. 3	[1] 10,788.27	
	131	Jackson	7.074	Sand-clay	Dec. 4	95,511.83	47,755.61
Idaho	24A	Twin Falls	7.000	Concrete	Dec. 30	301,442.75	140,000.00
	27	Payette	16.720	Gravel	Dec. 20	193,931.38	96,965.69
	30A	Power	14.196	do	Dec. 18	116,240.96	58,120.48
	40	Washington.	18.596	Sand-clay	do	187,354.54	93,677.27
Ind.	16A	Lawrence	11.191	Concrete	Dec. 6	448,799.17	223,280.00
Kans.	33C	Bourbon	3.160	Bituminous macadam.	Dec. 10	32,619.46	9,480.00
	40A-F	Crawford	9.085	Earth and brick or concrete.	Dec. 3	304,923.17	58,285.00
	39A, 39B	do	5.033	Earth	do	96,056.99	25,165.00
	60A, 60B	Anderson	7.597	Gravel	Dec. 10	242,417.72	75,500.00
	66A, 66B, 66C, 66D	Crawford	11.269	Earth	Dec. 3	167,966.16	56,345.00

[1] Modified agreements. Amounts given are increases over those in the original agreement.
[2] Decrease in mileage.

PROJECT AGREEMENTS EXECUTED IN DECEMBER, 1920—Continued.

State.	Project No.	County.	Length in miles.	Type of construction.	Project agreement signed.	Estimated cost.	Federal aid.
Ky.	11	Trigg	17.674	Gravel	Dec. 8	$336,660.84	$168,330.42
	21	Meade	13.566	Earth	Dec. 10	149,308.92	74,654.46
La.	12B	Ascension	.950	Gravel	Dec. 8	11,382.80	5,691.40
	19	St. Landry	11.310	Sand-clay	Dec. 1	187,344.77	93,372.38
	27A	Rapides	8.000	Gravel	Dec. 2	122,452.26	61,226.13
	60	Lafourche and Terrebonne.	4.760	do	Dec. 27	99,334.71	49,667.35
	68	Caddo	9.500	Bituminous concrete on stone base.	Dec. 8	371,102.72	185,551.36
	78	St. Martin	5.600	Gravel	Dec. 8	81,013.93	40,506.96
	23	Lafayette	1.130	do	Dec. 27	[1] 15,455.87	[1] 7,727.94
Me.	4	Penobscot		do	Dec. 22	[1] 6,760.21	[1] 3,380.10
	9	Cumberland.		Concrete	do	[3] 28,582.21	[1] 1,494.35
	15	Penobscot	7.440	Bituminous macadam.	do	277,630.46	138,815.23
	16	do	4.080	do	do	168,751.73	81,600.00
	28	Sagadahoc	1.310	do	do	44,338.41	22,169.20
Md.	7C		.551	Concrete	Dec. 9	[1] 20,481.64	[1] 11,020.00
	9A	Frederick	[2] 1.200	do	do	[1] 7,548.75	[1] 3,774.38
	12C	Carroll		do	Dec. 2	[1] 22,127.60	[1] 7,260.39
	26B	Baltimore	2.400	do	Dec. 9	81,123.79	40,561.89
Mass.	36C	Barnstable	8.043	Bituminous concrete.	Dec. 7	172,261.03	86,130.51
Mich.	33A B	Alcona	12.866	Gravel and concrete.	Dec. 8	199,144.60	98,143.69
	41	Oakland	10.047	Concrete	Dec. 10	556,923.29	200,940.00
Minn.	58	Nobles		do	Dec. 4		[1] 6,000.00
	90	Rock	7.020	Gravel	Dec. 10	68,269.43	25,000.00
	94	Polk		do	do		[1] 16,000.00
	136	Beltrami	2.970	do	Dec. 20	18,520.86	9,000.00
	170	Mille Lacs	17.639	do	Dec. 8	254,522.60	127,261.30
	176	Itasca	7.430	do	Dec. 10	45,729.24	10,000.00
	185	Jackson		do	do		[1] 7,635.51
	186	Hennepin	3.800	Earth	Dec. 4	51,215.17	15,293.20
	191	do	1.420	do	Dec. 10	10,072.30	4,900.00
	197	Dakota	.910	Bitulithic	Dec. 24	47,251.35	18,200.00
Miss.	31	Alcorn	3.194	Gravel	Dec. 7	43,832.74	21,916.37
	40	Monroe		do	Dec. 3	[1] 3,182.58	[1] 1,591.29
Mont.	95B	Hill	10.320	do	Dec. 16	89,413.54	44,706.77
Nebr.	11	Gosper		Earth	Dec. 22	[1] 4,500.36	[1] 2,250.23
	25	Gage and Jefferson.		do	do	[1] 19,344.85	[1] 9,672.43
	35A	Douglas		Earth	Dec. 21	[1] 2,906.47	[1] 1,453.24
	60A	Howard		Earth and sand-clay.	do	[1] 751.68	[1] 375.84
	64	Pierce		Earth	do	[1] 3,115.93	[1] 1,557.96
	146A	Kieth	13.636	Sand-clay	do	75,656.26	37,828.13
N. H.	42	Shafford	[2] .400	Gravel	Dec. 8	[3] 19.75	[3] 9.88
	93	Belknap	.650	Stone macadam.	do	12,010.46	6,005.23
	99	Coos	[2] .170	Gravel	do	[1] 327.10	[1] 163.55
	107	Merrimack	.800	do	do	14,829.18	7,414.59
	118	Grafton	.310	do	do	10,031.56	5,015.78
	121	Sullivan	1.060	do	do	20,000.83	10,000.41
	126	Rockingham.	.580	Gravel, surface treated.	do	9,926.97	4,963.48
	128	Merrimack	.620	Gravel	do	17,889.19	8,944.59
	130	Grafton	.480	do	do	8,245.31	4,122.65
N. Mex.	4	Valencia		Earth	Dec. 10	[4] 33,175.19	[4] 16,587.59
	12	Chaves		Gravel	do	[4] 1,088.39	[4] 544.20
	14	Santa Fe		do	do	[1] 1,551.03	[1] 775.51
	36	Sandaval	5.871	do	do	43,848.31	21,924.15
	49	Otero	11.572	Caliche	do	47,246.77	23,623.38
	45	Luna	5.599	Gravel	Dec. 14	43,780.69	21,890.34
	34B	Rio Arriba	11.968	do	Dec. 23	105,590.70	52,795.35
	42	Socorro	17.157	do	Dec. 14	55,778.03	27,889.01
S. C.	7	Horry	[1] .277	Sand-clay	Dec. 18	[1] 27,069.16	[1] 13,534.58
	40	Allendale	10.165	do	Dec. 1	94,115.64	47,057.82
	64	Lexington	4.948	Topsoil	Dec. 18	43,833.80	15,000.00
	61	Darlington	19.676	Sand-clay	do	144,052.89	67,541.70
	65	Newberry	4.231	Topsoil	Dec. 10	39,011.76	19,505.88
	78A	York	5.031	do	Dec. 18	24,909.15	12,000.00
	83	Union	1.435	do	do	14,358.22	5,395.89
	98	Greenville	2.121	Concrete	do	124,590.22	42,420.00
Tenn.	20	Fentress	14.320	Water-bound macadam.	do	344,163.06	172,081.53
	43	Shelby		Bituminous macadam.	do	[1] 89,137.91	[1] 44,568.95
Tex.	39	Dallas		Concrete	Dec. 23		[1] $17,124.38
	89	Wood	9.830	Gravel	do	$64,394.24	22,000.00
	46B	Gillespie	9.990	do	do	92,137.91	32,320.00
	53C	Jefferson	[1] 1.920	Sheet asphalt.	do	69,213.27	34,606.63
	92	Hood		Earth	do		[1] 20,066.03
	109	Schleicher		Gravel	Dec. 20	[1] 47,032.68	[1] 30,366.52
	128B	Montague	11.767	do	do	112,907.50	56,453.75
	145	Tom Green		Water-bound macadam, surface treated.	Dec. 23	[3] 46,258.26	[1] 10,208.16
	153	Rains		Gravel	do		[1] 11,500.00
	159	Shelby		do	do	[1] 38,287.98	[1] 30,385.42
	135	Schleicher		do	do	[1] 28,456.94	[1] 14,228.47
	162	Potter	14.730	Gravel, surface treated.	do	542,182.08	200,000.00
	169	Dickens	7.560	Gravel	Dec. 20	38,236.94	19,118.47
	173	Travis	6.040	Gravel, surface treated.	Dec. 23	100,650.04	46,299.02
	184	Falls	.770	Gravel	Dec. 20	12,056.02	6,028.01
	187	Bastrop	8.730	do	do	78,939.27	34,496.34
	191A	Milam	5.720	do	Dec. 23	57,879.07	28,939.53
	193	Bexar	6.200	Gravel, surface treated.	do	124,609.07	58,168.43
	195	Falls	6.780	Gravel, bituminous.	Dec. 20	160,599.91	80,000.00
Utah.	5	Boxelder		Bituminous concrete.	Nov. 30	[1] 54,822.48	[1] 27,411.24
	14	do	.412	do	Dec. 31	19,283.47	8,080.00
Va.	32	Fairfax	1.726	Bituminous macadam.	do	[1] 94,597.52	[1] 47,298.76
	43	Albemarle	7.300	Water-bound macadam.	Sept. 25	214,475.86	107,237.93
	61A	Augusta	2.225	Bituminous macadam.	Dec. 28	68,114.80	34,057.40
Wash.	26	Grays Harbor.		Concrete	Nov. 4	[1] 19,800.00	[1] 9,900.00
	33	Clarke		do	Dec. 4	[1] 23,724.63	[1] 11,797.50
	32	Cowlitz		Gravel	do	[5] 20,501.63	[5] 10,250.79
	35	Whitman		do	do	[1] 36,257.84	[1] 17,050.40
	36	Clarke		Concrete	Dec. 9	[1] 9,000.47	[1] 4,500.24
	46	Garfield		Crushed rock.	do	[1] 21,816.52	[1] 10,798.64
	47	Columbia		Gravel	Dec. 4	[1] 7,748.40	[1] 3,848.68
	61	Lewis		do	do	[1] 6,831.77	[1] 2,426.72
	65	Okanogan	1.990	do	do	35,670.91	17,800.00
	71	Columbia and Garfield.	8.640	Crushed rock.	do	40,374.40	20,000.00
	72	Grays Harbor.	1.710	Concrete	do	71,681.83	34,200.00
W. Va.	4	Marion		Concrete		[1] 39,542.33	[1] 18,560.00
	58A	Pleasants	2.800	Earth	Dec. 8	50,000.00	25,000.00
	85	Roane	3.000	Concrete	Dec. 17	64,768.00	27,200.00
	82A	Gilmer	5.000	Earth	Dec. 24	67,400.00	33,700.00
	77	Greenbrier	16.160	do	do	146,712.70	67,271.40
	95	Ohio	1.000	Reinforced concrete.	Dec. 21	42,357.60	13,290.00
	97	Marshall	3.000	Concrete	do	136,643.00	16,843.00
	98	Randolph	4.510	Bituminous macadam.	Dec. 17	80,613.20	39,040.00
	99	Webster	3.343	Earth	do	93,940.00	46,970.00
	100	Tucker	1.900	Concrete	Dec. 21	78,000.00	24,640.00
	101	Raleigh	4.410	Earth	Dec. 29	64,640.00	32,320.00
	102	Boone	3.120	do	Dec. 17	73,000.00	30,080.00
Wyo.	30	Natrona	4.078	Concrete	Dec. 15	368,597.17	103,787.15
	27A	Weston	3.333	Gravel	do	37,577.14	18,788.57
	43	Platte	[1] 1.182	Earth	do	[1] 15,583.70	[1] 7,791.85
	69	Johnson		Gravel	do	[1] 6,582.65	[1] 3,291.33
	77	Fremont		Bridge	do	20,577.15	10,288.57
	87	do		do	do	59,711.01	29,855.50
	82	Laramie and Goshen.	23.437	Gravel	do	193,677.63	96,838.81
	91	Platte	15.088	do	do	191,063.49	95,931.74
	94	Park		Bridge	do	16,199.70	8,099.85
	97	Sweetwater.	1.808	Earth	do	16,315.02	8,157.51
	98	Carbon	4.155	Gravel	do	35,484.61	17,742.30

[1] Modified agreements. Amounts given are increases over those in the original agreement.
[2] Decrease in mileage.
[3] Modified agreements. Amounts given are decreases from those in the original agreement.
[4] Modified agreements. Third revision, Increase.
[5] Modified agreements. Second revision. Increase.

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Report of the Chief of the Bureau of Public Roads for 1919.
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* Department supply exhausted.