the truss member is out of service. Sometimes one or two such bents will do, but this is a risky plan unless the distribution of stresses in the truss under these conditions is carefully investigated, and the overstressed members strengthened. In the reconstruction of the Wabash River bridge on State Road 34 at Covington, traffic was carried on a truss span which was strengthened and supported at the first panel point while an abutment was torn out and a pier built in its place.

In many cases, if live loads are kept off the bridge, a temporary member may be used to permit the removal and replacement or the repair of the member without removing it. This was done in repairing a damaged hanger in the Broad Ripple bridge over White River on State Road 31. In the double intersection truss bridge over the Wabash River on State Road 1 at Bluffton, several compression verticals were buckled. The cost of falsework in this case would have been excessive. These members were straightened in place all at once by specially designed clamps and beams and without the use of falsework. The clamps and straightening beams were left in place, resulting in members stronger than when they were built, though rather clumsy in appearance.

A discussion of this subject would not be complete without reference to one rather common mistake. When a bridge as a whole shows signs of weakness, it is only natural to think of putting an additional support in the middle of the span. In the case of slab, beam, or girder bridges, this is a very effective device for strengthening the structure, but in the case of truss bridges, it may even have the opposite effect. A rather simple stress analysis will show that unless certain members are reinforced or new ones added, under certain conditions a simple Pratt truss with an extra support at the center of the span may actually fail under a concentrated load which it would safely carry without the center pier.

NEW DEVELOPMENTS IN THE MATERIALS FIELD

By H. F. Clemmer, Engineer of Materials,
District of Columbia

Professor Ben H. Petty, in his splendid discussion entitled "Highway Demand Is Turning from Main to Local Roads," as published in the recent highway number of the Engineering News-Record, stated: "The peak has been reached in improvement programs concentrated on main state highways. We are now entering an era of unprecedented low-cost improvement of secondary roads." This fact is very evident. During the past ten years, a network of high-type pavements has become a reality. With this development has come an appreciation of the value of improved roadways, which has created a demand for the improvement of our secondary roads. These latter roads require, in general, only the so-called "low-cost" type of improvement.

With the study as to the best methods of treatment for these roads, and from the study of the service records of our high-type pavements, the importance of obtaining a thorough knowledge of the subgrade foundation conditions as they exist has developed. Soil experts, particularly those connected with the federal bureaus, are putting forth every effort to learn the best methods of treatment for various types of soil to obtain the maximum stability of subgrade.

In some states, where traffic did not warrant a costly road and finances were not available, roadways which have proved entirely adequate for the requirements of the existing conditions have been constructed and maintained at a very low cost. One of the most interesting types has been the sand-clay roads in the South. Where proper care and study have been exercised in the construction of these roads, the surface developed has been satisfactory.

The research engineers of the U. S. Bureau of Public Roads, in co-operation with a number of state highways departments, have recently developed fundamental facts regarding the laws controlling the stability of low-cost road surfaces.

So important has become this problem of soil stabilization and so satisfactorily have the studies referred to above progressed that most of the state highway departments, many of which now include a special soils organization, are applying the principles that have been determined, to obtain the maximum benefit in road construction according to their local conditions.

REQUIREMENTS FOR STABILITY

The basic requirements for stability in low-cast road construction, as suggested by the studies of the Bureau of Public Roads, are a graded granular material and a binder. It is the granular material or mineral aggregate which furnishes the structural strength of the road slab and also the hardness of surface to resist the abrasive action of traffic. The binder consists of two parts: an inert filler and a cohesive cement. The silt particles, which have practically no cohesive properties and are not apt to expand or shrink in appreciable amounts because of moisture changes, and which by themselves have little or no stability in the presence of water, form the filler in soil-road slabs. In this capacity, silt performs the very important function of "packing" in the voids between the larger sand grains and preventing the rocking action or movement of these grains, which is destructive to the stability of the slab. The finer clay particles and the colloids, the very finest material, furnish the cement or "glue" to bind the sand or gravel grains, properly choked by the inert silt particles, into a stable, wear-resisting, untreated soil-road surface.

The function of the sand particles and the silt filter is the same regardless of the type of cementing agent and is well understood by the road-building fraternity. The manner in which the soil "glue" functions, however, may not be so generally understood, because it is the moisture films between the minute soil particles and not the particles themselves which comprise the true binder. Instead, therefore, of the soil "glue" having a distinct degree of cohesion as is our general conception of a glue or cement, it may be enormously high or practically zero, depending upon the extent to which the soil is filled with moisture.

As suggested by C. A. Hogentogler in his reports presented to the Highway Research Board, the cohesive force of water, which is generally referred to as surface tension, may reach unbelievable values. These forces may be understood when it is considered that moisture in trees will rise to 300 to 400 feet in height. The force needed to hold this column of water is furnished by the surface tension and would amount to as much as 170 pounds/square inch. A further illustration is the automobile racing course at Daytona Beach, which accommodates speeds requiring the highest stability and abrasive resistance. This course consists of perfectly cohesionless fine-grained particles cemented together temporarily by surface tension furnished by an interstitial sea-water film.

From the foregoing discussion, the importance of maintaining moisture in the soil may be realized. Should the clay or binding medium be allowed to dry out, the surface tension between the individual particles is destroyed. However, if material such as calcium chloride, possessing deliquescent properties, is properly incorporated with the binder, it will serve to supply sufficient moisture to maintain this cohesive ability of the binder and thus aid in maintaining a road of maximum stability.

Investigations are being made of both physical and chemical admixtures and the manipulation required to change clay, silt, or sand subgrade into semi-solid constant-volume road slabs, capable of accommodating heavy traffic when surface-treated or covered with relatively thin flexible wearing courses. The problem is to create a subgrade which will not soften up in the presence of moisture; that is, one that will not readily absorb moisture.

RECENT INVESTIGATIONS

Two years ago the Highway Research Board of the National Research Council, realizing the importance of this problem and interested in the value of calcium chloride in the treatment of gravel roads, established a committee of engineers to study the use of this material for highway construction and maintenance.

Two research projects were started under the direction of this organization in the summer of 1931—one project in South Carolina on a sand-clay road, and another in Missouri on a gravel road.

The results of experiments conducted on these projects show that the calcium-chloride-treated sand-clay soils did not lose moisture at as rapid a rate as the untreated soils of the same character. The time required for a treated sample to become thoroughly dry when subjected to temperatures of 80-100° F. was twenty-seven days, while the time required for an untreated sample to dry was three days. The calcium chloride content of the treated sample was 1.25 pounds per square yard. The untreated sample dried in a much shorter period of time because of the fact that the contained moisture had a relatively high vapor-pressure compared with that of the solution of calcium chloride formed at the surface of the treated sample, which had a low vapor-pressure. All the moisture in the soil had to pass through this surface solution of low vapor-pressure in order to be evaporated. This action is similar to that of calcium chloride applied to a road surface following a rain. The solution formed on the surface of the road retards the evaporation of the moisture which entered into the road bed before the application of the calcium chloride.

A check made in the Missouri investigation to determine the loss of road material by comparing the dust collected on treated and untreated sections indicated that 50 per cent less dust and fine material was collected from sections treated with calcium chloride.

Study during the past year, 1932, was continued on these projects as well as on a new project in Nebraska. In order to determine the best method of using calcium chloride, attention was given to the study to determine what reactions took place when calcium chloride was used for maintenance, and what chemical reactions the calcium chloride might have with the soil, as well as the effect of rainfall and the effect of maintenance manipulation.

It was found that the loss of calcium chloride due to chemical reaction with the soil, or base-exchange, is dependent on the chemical composition and the degree of acidity of the soil. The fact is established that an exchange of bases may take place when a soil is treated with calcium-chloride solution; that is, part of the calcium is absorbed by the soil and is replaced by an equal amount of some other base. This chemical exchange, however, is the least influential of the three factors studied, but it is mentioned because in some soils it may influence the structural texture in such a manner as to make its effect of particular importance. It does offer the best method for determining the effects of calcium chloride on different soils. At present, it appears that this action is usually offset by certain inherent structural characteristics of the soil, which play a more important role in the retention of calcium chloride. This soil reaction makes subsequent applications of more value and likewise reduces the amount of calcium chloride necessary to produce maximum results, inasmuch as it is believed the base-exchange action reaches equilibrium, and the dissipation of calcium chloride from this cause is minimized.

The loss due to the washing-out effect of rains depends on the type of rains and the permeability and texture of the soil. The maximum loss from this cause would occur when a heavy rain immediately follows the application of the calcium chloride.

The loss due to continued daily maintenance was, however, the most important factor considered. It was found that sections maintained only immediately after a heavy rain or when absolutely necessary, remained in better condition, with less dust, than sections receiving daily maintenance, carrying comparative amounts of traffic. These results show that more value is derived from the use of calcium chloride when regular maintenance is carried on *only* during or immediately following rains.

An explanation of the action of calcium chloride, when used in the treatment of gravel roads during and following rains, is of interest (Fig. 1). During prolonged dry spells,

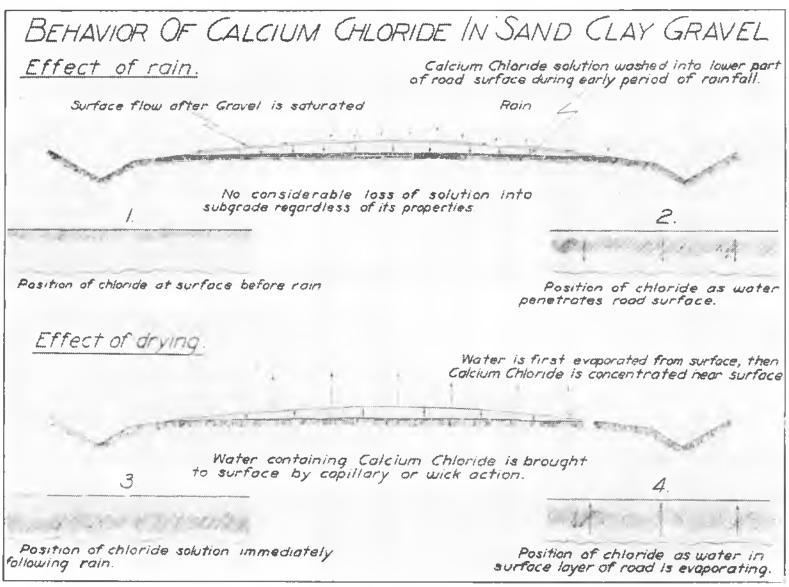

Fig. 1. Illustration of action of calcium chloride during and after rainfall on a gravel road.

the solution of calcium chloride present in the soil from previous application is drawn to the surface. When a rain occurs, the first water absorbed serves to carry this solution below the surface. When the surface material becomes saturated, subsequent rainfall is shed into the ditches. Following the rainfall, evaporation of the surface water takes place. As the moisture in the top layer of the road evaporates, it is replaced by the solution of calcium chloride, which has been stored below the surface during the rain. This solution is brought to the top by the capillary action of the soil. Evaporation takes place until a concentration is reached at which the calcium chloride solution will no longer lose moisture under the existing humidity and temperature conditions.

From this discussion, it can be seen that if maintenance manipulation is carried on while calcium chloride solution is near the surface, the material is dissipated; however, if manipulation is carried on during or immediately after a rain, when the calcium chloride solution is some depth below the surface, the road surface may be put in best possible condition without the loss of calcium chloride.

TANGIBLE RESULTS OBTAINED

Tests as to the value of calcium chloride for maintenance have also been in progress in several Canadian provinces, particularly in Nova Scotia. During 1929, the total mileage of gravel roads in this province treated by this method was 1,521 miles.

Professor Eno of Ohio University has recently reported on "Experimental Treatment of Subgrades for Traffic Bound Roadways" in Ohio. The aggregate used in most cases, when chemical admixtures were added to the soil, was slag, inasmuch as this material was readily available.

"The amount of crushed slag applied was about 3.5 inches in depth of loose material. This was bladed across the road, leaving about two inches to be beaten in by traffic, with the surplus stored in windrows on either side." *

Inspection of Project 13, Route 265, in Guernsey County, was made after the experimental sections had been in service approximately ten months. The results observed as to the condition of the road rated the calcium-chloride-treated sections in the highest classification in all divisions.

The State of Michigan (Fig. 2) has used calcium chloride for maintenance extensively. It has reported the following, regarding its use on gravel roads:

"The ability of a gravel road to resist wear is governed to a marked extent by its moisture content. An excess of moisture impairs the cohesive quality of the binder, and holes and ruts form easily. The absence of capillary moisture is con-

* Highway Research Proceedings, December 10-11, 1931.

Fig. 2. View showing junction of stabilized and loose gravel sections on Michigan State Trunkline Road No. 20.

ducive to disintegration, resulting in a cover of loose pebbles which serves as an effective abrasive to accelerate further breaking up of the compacted surface. While this is going on, a heavy loss of material is being sustained, with damage to equipment, growing crops, orchards and fields adjacent to the highways. Proper drainage will reduce excessive amounts of moisture and the use of a deliquescent material will mitigate the difficulties encountered in dry weather.

"Due to its relatively low cost, the ease and speed with which it can be handled by unskilled labor without special equipment, the ease with which it can be stored in any place that provides shelter from rain, and from the results obtained, calcium chloride meets the requirements of an effective dust palliative and stores sufficient moisture in the gravel surface to reduce to a minimum the effect of the disintegrating forces heretofore mentioned."

It has been stated by the Bureau of Public Roads that the annual wear on gravel roads is equivalent to ½"-1" of surfacing material, which in the case of an 18-foot surface would be 150 to 300 cubic yards per mile. Where calcium chloride is used, the loss of road material is reduced to a minimum. The cost of using calcium chloride is approximately equal to the cost of the replacement of gravel required where calcium chloride is not used; however, the application of calcium chloride insures the alleviation of dust, while a replacement of gravel offers no such assurance. As stated by a representative of one of the states using large quantities of calcium chloride for maintenance, "It costs nothing to use calcium chloride—if we don't use it we pay an equal amount in replacing the gravel."

The use of calcium chloride for the treatment of gravel roads has often been with only the thought of alleviating the dust nuisance, and the engineer has not realized the many other important factors resulting from its application. Investigators interested in this problem are now studying the many beneficial effects of calcium chloride towards improvement of the condition of the soil for a satisfactory road surface, and they consider the alleviation of the dust nuisance, which is in reality a dangerous factor, only as one of the added benefits.

One value of calcium chloride is its ability to flocculate soil, that is, to cause small particles to group together into larger ones to produce a more permeable soil. This effect is important in reducing the destructive frost action. The open or permeable soil does not hold the moisture which, when freezing, creates expansive forces.

Maintenance engineers regularly using calcium chloride do not believe that it should be applied at any specific rate, but rather depending upon the amount of traffic carried by the road. The following table shows typical practice under general conditions:

100 to 200 vehicles per day...	1 lb. /sq. yd.
200 to 500 vehicles per day...	1½ lbs./sq. yd.
500 to 1,000 vehicles per day...	2 lbs./sq. yd.
1,000 and up vehicles per day...	2½ lbs./sq. yd.

The best practice of applying calcium chloride is to make several applications. For example, should the road require 1½ pounds per square yard, it would be advisable to make one application of 1 pound per square yard and follow with a second application of ½ pound at an interval of approximately six weeks, depending upon the prevailing weather conditions.

PROPER USE OF CALCIUM CHLORIDE

A summary recently offered by the Maintenance Committee of the American Road Builders' Association* presents the following outline for the proper use of calcium chloride on a gravel road:

1. Remove oversized material.
2. Add to the gravel the constituents it lacks, either sand or clay.
3. Scarify the surface and thoroughly mix all material added.
4. Maintain not more than ½ inch to the foot of crown.
5. Remove all cover and apply calcium chloride.
6. Blade carefully after each rain and at such other times as the surface of the roadway demands it.

* Convention Proceedings, 1930, page 705.

7. Patch any holes with the same material as used in the entire surface.

8. Use heavy equipment for spring work.

Conditions demanding heavier application of calcium chloride are long dry spells, heavy traffic, low clay content, recent heavy resurfacing, no shaded portions, heavy wearing cushion, and dead material. Conditions favorable for lighter applications are frequent rains, light traffic, heavy clay content, and shade.

Item No. 2, "Add to the gravel the constituents it lacks, either sand or clay" is one of the most important of the requirements in the outline and is being given consideration in studies of stabilization of soils. To develop a hard durable surface, the amount and type of cementing medium which will produce maximum stability must be used. The research work carried on by the Bureau of Public Roads has developed tests which will offer practical information as to the best treatment of soils to obtain maximum stability.

Stability of a soil is dependent on both the cohesion and the internal friction which the particles exhibit. In general, clay and colloidal material supply the cohesion necessary for stability, while the internal friction is furnished by the sand grains.

The amount of binder required to furnish stable mixtures depends upon the expansive properties of the binder. Binders which are only slightly expansive may be used in an amount sufficient to fill the pores of the sand almost completely. As the expansive properties of the binder increase, the amount used without danger of unseating the sand grains must of necessity become less. Of two soils whose tendency to shrink or expand is equal, the one having the greater amount of cohesion should be the better binder; of two soils having equal cohesion, that having the less tendency to shrink or expand should be the better binder, since a greater amount of it can be used than of a more expansive soil.

With a satisfactory gradation of sand and gravel particles to form mechanical interlocking, and with enough clay to bind the particles together but not sufficient to separate the particles so as to admit of excessive moisture which would make the clay a lubricant rather than a binding medium, an entirely stable combination may be obtained. It is necessary that the clay be moist at all times so as to be expanded sufficiently to press the particles in place and bind them solidly together. This moisture is maintained by the addition of the proper amount of calcium chloride. As stated, the Bureau of Public Roads has developed tests which are simple of performance and offer valuable information as to what treatment a soil requires to obtain maximum stability.

Apparatus which measures directly the drainage and capillary properties of a soil has been described by C. A. Hogentogler of the Bureau of Public Roads at the recent meeting of the Highway Research Board. At the present time apparatus of a similar type, which also includes a method for measuring stability, is being developed for field use. Such an apparatus will prove of particular value, as it will eliminate the extended programs of study or research which have heretofore been necessary.

When due consideration is given the results which may be obtained by proper construction and the saving in maintenance which will result from proper manipulation of the road surface, the study of the more satisfactory maintenance of roads is justified; rather than the method of following the common practice of using any available material regardless of existing conditions and, by the application of a deliquescent product, endeavoring to keep the road material from being dissipated by the wind and traffic. In other words, investigate the available coarse and fine material and combine them so as to secure in fact a "concrete" road, but one in which the cementing medium is clay or some other binding material in place of portland cement.

Calcium chloride will save enough in material replacement to pay for its use; and though the proper study and combination of materials will incur some original expenditure, the saving in maintenance brought about by this consideration will more than pay this cost and the public will be provided with a smooth and dustless road surface.

HIGHWAY TRANSPORT SURVEY IN INDIANA

By Ralph E. Simpson, Assistant Director, Indiana State Highway Commission

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When history records events of the last ten or fifteen years, I believe this period will be known as "The Era of the Development of Automotive Transportation." This development has truly been phenomenal. In the ten years between 1920 and 1930, automobile registration in Indiana increased 300 per cent, and the number of trucks was increased more than four times. These tremendous increases in numbers were accompanied by a similar increase in the diversity of uses of automotive transport until our highway traffic problem has become of such a magnitude and variety that it is impossible for any individual, no matter how experienced, to comprehend all its details without the assistance of facts obtained from careful studies. We of the state highway department have realized this for some time.