Shakespeare's statement in *Henry VI*—"Ill blows the wind that profits nobody"—has been particularly true in highway construction during the past few years.

You may ask what good could possibly be derived throughout the past eight or ten years of reduced budgets, diversion of funds, etc. These very factors have forced highway engineers, as a matter of self-preservation, to an appreciation of the possibilities of low-cost road construction. Many of us have been amazed at what can readily be done by the use of local materials and, quite frequently, by the use of road-side soils.

As a result of study and experiment, good hard-surfaced roads have been built at costs never before dreamed of. The mileage of improved secondary roads has increased by leaps and bounds, so that, in some localities, the farmer today has but a few hundred feet to travel, in any direction, before he is on a road that is serviceable the year around. In these localities, the little old country school has practically become a thing of the past. Centralized schools have been built, giving the rural students, through increased facilities, the same advantages in education as those in the villages and cities. Buses are provided to transport the children to and from their homes. Instead of each one carrying two or three cans of milk to a shipping point each day, the farmers are now able to load their milk on large trucks that carry the product.
direct to the larger cities. This condition prevails, not only through a few months in the dry season, but throughout the entire year. As a matter of fact, the farmer residing in the communities that have adopted the low-cost road, or farm-to-market construction, no longer measures the distance from his farm to the village in miles, but in minutes.

The governing bodies of the lower political units which adopted programs of this type of construction are now reaping the benefits of their expenditures, in increased valuation of farm lands due to the reoccupation of abandoned farms. From time to time, we have been advised that one of the cures of the nation's present condition involves a "return to the farm" movement. It is the duty of each township or county so to improve its rural roads that the attractiveness of rural life will be enhanced, and that the small farms, privately owned, will be brought nearer to the cities and villages in transportation time.

DEVELOPMENT OF STABILIZATION

Local materials were used exclusively in road work by our forefathers; but with the advent of the motor vehicle, and the lack of knowledge of the principles of stabilization, they were forced largely to abandon their use and select high-type pavements, the cost of which confined such improvements to the main traffic arteries. Luckily, experiment and research have shown us how we may return to the use of these same local materials. By the aid of certain chemicals, namely, calcium chloride and sodium chloride, we may now bind a properly proportioned mixture of gravel and soil into a solid, compact surface which is practically free from dust, smooth to travel upon, and capable of carrying reasonable loads throughout the year.

As gravel is one of the most commonly used road materials in this type of construction, it would perhaps be advisable to look at it through a microscope, so to speak, in order that we may determine of just what it consists. On close observation, we find that it is composed of various sizes of stone, sand, and, usually, varying amounts of soil, clay, and silt. The stone or pebbles themselves will not bind into a hard stable surface without the use of a binder, either tar, asphalt, loam, or clay. The same is true of the coarse sand. This refusal is due to the spaces between the different particles of stone or sand. We call these "voids," and they actually represent air pockets. We know that there are no binding properties in air. If we were to look through a microscope at the sand, the particles would appear much the same as the coarser stone in the gravel. The voids are just as noticeable, but the proportion of voids is even greater, because the individual particles are more nearly of the same size. If we are to lock these particles of sand and pebbles together, something must be
added to reduce the voids or air spaces. We add finer materials such as loam, clay, and silt to make as dense a mass as possible.

By properly proportioning those finer materials and mixing them together, we can greatly increase the density, but if we again look at the mixture through a more powerful microscope, we still find voids, much smaller, but still there, and before we can get a stable road material, one which will bind together, we must completely fill these or coat them with something; and we find that it can be done with moisture.

The stability of the mixture depends upon this moisture film, which must remain constant and at a minimum, just sufficient to coat the finer particles of the binder. The extent to which any soil can be compacted depends upon the density and moisture content, which varies with different soils. The binding properties of this moisture can best be shown by placing a drop of water between two pieces of glass. The glass plates will break before they will separate. We wish to emphasize the fact that it is the moisture film covering the very small particles of binding material which permits the consolidation of any roadbuilding material.

So we see that the density of the aggregate depends upon the reduction of the void content, and, therefore, on the reduction of the capillary area. We are all familiar with the action of clay containing various amounts of water. Some clays expand more than others with an increase in moisture content. All clay contracts as the moisture is withdrawn. If the moisture is kept constant, the volume of the clay remains constant; and, therefore, the voids or capillaries, being filled with a uniform volume of moisture, provide the bond neces-
sary to hold the whole mass together. The moisture contained in the capillaries tends to repel the absorption of any additional water, either from the surface or from the subgrade. If we can retain this moisture content through the dry periods of the year, it will prevent the clay binder from contracting, with the consequential loss of binding properties of the clay.

CHEMICAL AGENTS

Calcium chloride and sodium chloride are the agents which, because of their hygroscopic nature, retain within the road mixtures the necessary moisture to prolong their life under traffic and seasonal climatic changes. The loss of this moisture will cause the road to fail by disintegration or ravelling and the loss of the binding soil as dust. These same two materials, through their ability to retain the moisture in a thoroughly compacted road, tend to exclude any other moisture from penetrating into the surface or up from the subgrade. The presence of too much moisture would cause the destruction of the road by turning the fines or binder into a semifluid.

While this moisture film is of extreme importance, the gradation of the road metal, in order to obtain the best results, must not, by any means, be overlooked. Frequently, bank-run gravel can be obtained which meets all the requirements of a stable material, but any deficiency encountered should be supplied by the addition of stone, sand, soil binder, clay, or silt as needed to obtain the proper density and to meet the requirements of a stable mixture.

METHODS OF CONSTRUCTION

When the necessary quantities of stone, sand, and clay are known, there are three different methods of preparing the desired mixture for the road surface, namely, plant mix, road mix, and stage construction (cut-and-try method).

The plant mix provides for the drying and pulverizing of the binder, the accurate measuring of the various aggregates in their proper proportions, and their thorough mixing. The mixture is then hauled to the job, dumped, spread, wetted down, and shaped. This is one of the most expensive methods, but precludes the chances of failure due to variations in quantities, and eliminates much of the guess work involved in other methods. The calcium chloride or sodium chloride is added either at the mixing plant or when the mixture is spread on the subgrade.

In the second method of construction, the different types of materials are spread directly upon the subgrade, in the proper proportions, including the calcium chloride or the salt, and the whole mass is thoroughly bladed and mixed by means of disk harrows, spike-tooth harrows, power or horse-drawn
graders, or multiple-blade maintainers. When thoroughly mixed, the proper amount of moisture is added, and the mixture is spread out and compacted in layers, gradually bringing the roadway to the proper crown.

This cut-and-try method is used extensively in the so-called stage construction and traffic-bound roads. It does not require technical determination, but its success depends upon the experience of the superintendent in securing the proper gradation of the aggregate to furnish stability. It requires the addition to the road surface of various aggregates to supply the deficiencies which show up under traffic as the road metal is being compacted.

Fig. 3. Button Road, constructed in 1932. The stabilization process made this gravel road so hard that the center line could easily be marked with white paint.

Mr. C. A. Hogentogler, Senior Engineer of the U. S. Bureau of Public Roads, has recommended the following experiment to determine a mixture of soil which has the desired properties and gradation.

Take a sample of material which has been moistened and squeeze it in the hand, and the following will be noted: (a) the soil is extremely gritty; (b) it can be formed into definite shapes which retain their forms, even when dried; (c) if the clay alone adheres to the hands, it will be only enough to discolor them slightly; (d) if more than enough soil to discolor the hands adheres to them, it will consist of both sand and clay, instead of clay alone; (e) when the wetted sample is patted into the palm of one hand, it will compact into a dense cake which cannot be penetrated readily with a stick the size of a lead pencil. These characteristics indicate well-graded material. The grittiness of the sample indicates the presence of sufficient granular material. Development of some strength on drying indicates a sufficient amount of binder soil. Resistance to the penetration of the pencil or stick, even when the sample is thoroughly wetted, indicates a desirable inter-
locking of the grains and the presence of a sufficient amount of capillary force.

Too much sand would cause the sample to fall apart when dried. Too much clay would leave the hand muddy after the wet sample was squeezed, and would cause the wet sample, after being patted, to offer little resistance to the penetration of the stick.

When you once know how to recognize the desirable mixture, samples can be taken of other gravels, and the approximate additions of sand or clay necessary to produce a stable mixture can be determined. If the gravel shows a lack of fines to fill the voids properly, usually roadside soil is added. If the surface then shows a slippery or muddy condition in wet weather, a sharp, granular material should be worked into the surface. Or, if the gravel or soil being used remains loose and fails to bind down under traffic, a small quantity of clay must be worked into the surface. When sand or any granular material is added to correct an excess clay condition, as much as 80% of the resulting mixture may be of a granular nature. In binding a loose gravel or sand, seldom should more than 15% of clay be added.

When the surface begins to compact or show indications that the proper mixture is being approached, the calcium chloride may then be spread upon the surface. The ability of this material to draw its own moisture from the soil or atmosphere will usually furnish sufficient water for the final compaction. If sodium chloride is to be used, the surface must be broken up, and the top two or three inches impregnated with salt. This may be done with a salt brine; but if rock salt is used sufficient moisture must be applied to dissolve the salt, so as to insure its thorough distribution throughout the stabilized mixture before reshaping and consolidation.

You will notice that all the methods of mixing depend upon the application of the proper quantity of moisture to bind and to consolidate the roadway properly, or upon the ability of the chloride to furnish sufficient moisture. The success of the road will depend upon the retention of this moisture without any appreciable increase or decrease during the various climatic changes. The density of the mixture will tend toward the elimination by absorption of excessive quantities of water, and the salts will help to retain the proper moisture content during the dry periods.

As to the quantities of the calcium chloride to be used, we have found that, for a six-inch depth of road metal, one and one-half pounds per square yard is required, but when there is little, if any, moisture in the mixture, and under particularly dry atmospheric conditions, this quantity should be stepped up to about two pounds per square yard.

Regarding the use of sodium chloride, the Highway Research Board advises that two pounds is necessary per square
yard for a 3-inch depth. Some states, however, require \(\frac{3}{4}\)-pound per square yard per inch of depth, regardless of the thickness of the road constructed. The Highway Research Board recommends the use of salt as follows:

Principally rock salt has been used, but any commercial type of salt or salt brine is satisfactory. The coarser grades of rock salt are well adapted for stabilization, as they remain free flowing and can be more uniformly spread than the finer gradations which will absorb moisture and cake when stocked along the road. Chemically there should not be less than 98 percent pure sodium chloride.

When sodium chloride is applied in the form of brine, any of the gradations of the salt may be used, since the condition of the salt before it is dissolved is unimportant. The stabilized mixture will remain plastic longer if all of the salt has been dissolved, thus permitting rolling and compacting to be continued over a longer period of time, with the possibility of attaining greater compaction at the time of construction. There should be enough water to moisten the soil somewhat beyond the plastic limit.

In Indiana it was found that from \(\frac{3}{4}\) to \(1\frac{1}{4}\) gallon of water per square yard per inch thickness was needed to moisten the mix satisfactorily. This was slightly more than 20 per cent by weight of the soil fines. In some cases, it was possible to arrange the work so that rain supplied the moisture for finishing the roads. If there is an over-wetting of the surface mixture, there is danger of vehicles cutting through the surface and mixing it into the subgrade.

Water is usually added by means of pressure distributors, sprinkler wagons, or gravity tank trucks. It is preferable to make several short trips over the course, sprinkling lightly on each trip. This gives the moisture a chance to penetrate the entire course and does not result in a sloppy condition on the surface.

**DIFFERENCE BETWEEN CHEMICALS**

The principal difference between the two chemicals is in the appearance of the road surface when completed. When calcium chloride is used, the road surface remains damp, and unless the surface is disturbed by too frequent manipulation by blades, or by excessive traffic, it will remain in this condition. Rainstorms have but little effect upon it, except that the chemical is driven down into the surface of the road. As the road dries out, it again returns to the surface after a few hours. We have never found evidence, even along the shoulders, that the calcium chloride has been washed off the surface, except when the application has been followed immediately by a rainstorm before the chemical has had time to pass into solution. There is no evidence of the grass, weeds, or trees having been affected by its use.
When salt is used as an aid to stabilization, different results are obtained. Shortly after a salt road has been opened in dry weather, the chemical returns to its crystalized form by evaporation, and the road becomes very dry and hard. If examined closely, you may see evidence of the crystals on the surface. Under an excessive amount of traffic, a fine dust will appear, not in any great quantities, however. The road surface is so hard that it is practically impossible to blade it with ordinary equipment. This part of the maintenance must be withheld until a rainstorm occurs. At this time, the surface softens up enough to permit its manipulation. There is some loss of the chemical after rainfall of any duration. This is proved by the salt which recrystallizes in the gutters. Owing to the hardness of the surface, salt roads probably could be better maintained by a light application of calcium chloride occasionally to help retain the moisture on the surface and to prevent loss of fines so essential to the riding qualities of the road.

Regardless of which chemical is used, we have found that the maintenance of a suitable crown is necessary to guarantee the success of the low-cost roads of this nature. On a twenty-foot roadbed, we require a six-inch parabolic crown when the road is completed and opened to traffic. We endeavor to maintain this crown through maintenance, and it seldom gets to be less than four inches. It is the easiest method of eliminating potholes that I know of. Practically the only places where potting occurs are over culverts which are too close to the road surface by necessity of construction, at intersections, etc., where it is impossible to maintain a crown of at least one-half inch to the foot.

**BRIEF HISTORY**

During the past six years we have built nearly 500 miles of this low-cost type of construction, employing a chemical as an aid to stabilization. It is true that we have used calcium chloride exclusively, although sodium chloride is produced also in our county. The aggregate which we used almost exclusively was gravel, although occasionally where gravel has not been obtainable, crushed stone has been used. We prefer a larger-sized aggregate than is commonly recommended. Stone, up to one-third the depth of the course being applied, is permissible in our work, and our center depth is nine inches loose measurement. In localities where neither stone nor gravel is obtainable, the use of roadside materials should be undertaken. As a matter of fact, we completed a road of this latter type this past season, using portland cement as a stabilizer. All of our construction has been done by the cut-and-try method previously described, with the exception of the project in which portland cement was used.

We have tried to keep our work within the meaning of the low-cost construction clause and have not attempted to build,
with local material, high-priced surfaces on main thorough­
fares, or on roads which could not be classed as farm-to-
market roads within our interpretation of the term. We have,
however, built stabilized gravel roads as a foundation to future
construction work where we knew a concrete pavement was to
be built within the next two or three years. We were able to
save enough in our final construction more than to pay for the
initial investment in gravel through the reduction of thickness
of concrete.

Perhaps, in closing, it would not be amiss to quote the
words of caution expressed in an editorial appearing in the
*Engineering News Record* on December 8, last, directed to
those who expect too much of this type of construction or to
those who specify the use of elaborate construction methods:

Equally evident in the Research Board meeting was the promi­
nence of earth-road problems. Soil stablization appears to be a
word to conjure with, for the time being, and the many unanswered
questions that lie in this type of construction give assurance that
future technical meetings will also find much of their time occupied
by earth-road discussions. Some developments suggest, however,
that the original term "low-cost roads" no longer can be applied,
generally, to modern earth roads, for some of the construction proce­
dures used in building stabilized soil roads are fully as complex and
costly as those required to lay a concrete slab pavement. This de­
velopment compels thought, because it departs so far from the
important low-cost objective which brought about the current in­
terest in earth roads. Ingenuity and study should be invoked to
show a way back to the low-cost concept, or else we will be in the
absurd position of combining high construction cost with high main­
tenance cost. The situation forecasts extensive further growth of
investigation and practice in the application of local materials, from
the shale rock roadbeds of Pennsylvania to the soil concretes of
the North, and topsoil surfaces of the South.

**ROAD STABILIZATION WITH PORTLAND CEMENT**

**Bert Myers,**
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Among the more interesting of the recent developments in
highway engineering are the methods that have been devised
for the use of large proportions of soil in the construction of
road surfaces and base courses. These methods for the use of
soil have been designated by the term "stabilization." One of
the most interesting methods of soil stabilization is the one in
which portland cement is used as the stabilizing agent.

The methods that have been used for determining the
proper proportions of soil, cement, and water to be used, and