below the surface through scarifier teeth. Emulsions and medium-curing and slow-curing asphalts were used. The travelling plant-mix was not entirely satisfactory because of conditions existing on this project. It is necessary to have the windrow of material quite wet in order to get it through the travelling pug-mill mixer. The project was built late in the fall, and the water did not evaporate from the mixture. In soil-bituminous stabilization, water may be necessary to facilitate mixing, but the resulting mixture is no good until the water has been reduced to the optimum or below. This is a point worth remembering, because it has been responsible for poor results in a number of states. The costs varied from $4,300 per mile for the sub-oiled section and slow-curing oil to $8,900 per mile for the section mixed with a travelling mixer and asphalt emulsion. It seems probable that costs lower than this might be obtained on future projects after the contractors have become more familiar with the process. Recent reports from Kentucky indicate that this type of construction has not been very satisfactory. The cause of the poor performance has not been determined.

All of us would like to know how to build a good low-cost road. That seems to be one of the most difficult problems a highway engineer has to solve. It has often been said that the lower the type of road desired, the higher the grade of engineering required. No doubt this is true. I am sorry that I am not a good enough engineer to tell you definitely how to build a good road cheaply. I hope, however, that some of the things I have suggested will be found useful in constructing a more stable road at a reasonable cost.

ROAD-MIX VS. PLANT-MIX IN BITUMINOUS ROAD CONSTRUCTION

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It must be clearly understood at the beginning of this discussion that it is not my purpose to disparage road-mix bituminous construction and promote plant-mix construction, but to tell you why the Michigan State Highway Department has adopted plant-mix methods for its bituminous road program. From this discussion you may obtain some thoughts that will fit into your own situation.

There are many types and methods of bituminous-surface construction for highways in use throughout this country today. Certain factors or conditions, such as climate, character of traffic, available aggregates, first cost, and maintenance expense, lead different states and localities to select one or more types and methods of bituminous construction. The

Fig. 1. A plant-mix, oil-aggregate surface on M - 66 near Six Lakes.

availability of equipment and experienced organizations are also factors. Any bituminous surface is relatively flexible and requires a well-drained subgrade and a firm base, so that base conditions are not generally a factor in the selection of a bituminous surface.

On major rural trunklines we usually build reinforced concrete surfaces, and on trunklines in municipalties, sheet asphalt or brick on concrete base or reinforced concrete pavement.

On our secondary system we are following stage construction practices by building or rebuilding gravel and some crushed-stone bases, which in the following year or so are given a bituminous surface course. To provide a dustless surface in the interim, and to assist in determining the sufficiency of the foundation, a bituminous surface treatment is generally applied to the newly constructed base.

FACTORS CONSIDERED

The factors and conditions governing the selection of a type and method of bituminous-surface course construction for secondary roads in Michigan are:

1. Climatic Conditions. Because of severe winters and considerable rainfall through parts of the year, an open-graded type of surface would not be suitable; rather, a dense mixture to prevent infiltration of water and disintegration from frost action is desired.

2. Character of Traffic. The predominant type of traffic, even in rural sections, is pneumatic-tired and fast moving. This requires a smooth, dustless, yet non-skid surface, but permits the use of softer bituminous materials and mixtures, which would be affected by a large amount of iron-tired traffic or sharp-shod animals. Since Michigan's large tourist traffic volume is at its peak during the summer months, the importance of selecting a type of construction that will not seriously interfere with traffic flow must be considered.

3. **Available Aggregates.** Michigan has generally available a large supply of sand-gravel aggregates, which can be cheaply prepared for dense-graded mixtures, but would be more costly for open-graded mixtures because of the large amount of sand to waste. Stone deposits in the state, suitable for the production of crushed stone of a hardness and toughness required for some types of bituminous construction, are very limited.

While the supply of sand-gravel aggregates is widespread, its quality is spotty and in many areas contains much soft stone. This condition indicates the use of a soft or self-healing bituminous material, which will enable fast-moving, rubber-tired traffic to heal over pitted surfaces during the warm season. Our limited lower grade crushed stone supply also fits this type of bituminous material.

4. **First Cost.** On account of our large volume of seasonal tourist traffic, touring all over the state in search of recreation, a low-first-cost, durable, dustless surface is required to cover some three thousand miles of gravel trunklines as soon as possible. Therefore, it is important to use our low-cost aggregates with suitable bituminous material to provide a mixture that can be cheaply produced and laid.

5. **Maintenance Expense.** Low-cost construction is not only low first cost, but must also take into account maintenance and upkeep expense. A type of bituminous surface that can be readily and economically repaired by ordinary workmen and equipment of the Maintenance Division makes possible a low maintenance expense. This again points in the direction of the soft, slow-curing bituminous mixtures that can be stockpiled and handled without heating in warm weather. Owing to this soft bituminous material, the surface can also be reworked in summer months, as was necessary on a few of our projects, because of settlement and break-ups over unsatisfactory subgrade.

These are the reasons why we have selected the oil-aggregate mixture for bituminous surfacing on our secondary system. It is a dense mixture to fit our climatic conditions. It provides a dustless, durable, non-skid surface for our automobile traffic. Our cheap available sand-gravel and stone aggregates are perfectly suitable for this mixture, which requires only about 4 per cent by weight of an inexpensive slow-curing oil—SC6A. The aggregate contains about 50 per cent by weight passing a 10-mesh sieve, but we do also add a small amount of limestone dust as filler. The mixture can be cheaply manufactured in almost all parts of the state, and the use of maintenance stockpiles provides low cost maintenance.

Since the oil-aggregate mixture fits the Michigan picture, the problem of the best and most economical way to mix and lay it presented itself.

ROAD OR PLANT-MIX?

Both road-mix and plant-mix oil-aggregate constructions were first laid by the Michigan State Highway Department in 1935. Some additional road-mix was laid in 1936, but since then the entire oil-aggregate program is confined to plant-mix construction. We have laid so far a total of about 750 miles, and next year's program will involve about 250 miles more.

Many Michigan county highway organizations have successfully laid, and still continue to lay, oil-aggregate, and other types of bituminous surfaces, by road-mix methods with their own equipment and forces. The Michigan State Highway Department, however, believes that the contract system of road construction is the most economical and best suited for all interests and for the general economy.

ROAD-MIX

Road-mix construction has some difficult problems for our conditions and some serious drawbacks under the contract system of construction. In the first place, the oil-aggregate, dense-graded mixture, we believe, requires for durability a uniform gradation of aggregate from coarse to fine, including suitable 200-mesh material, and freedom from moisture—over 2 per cent being harmful and less than 1 per cent being desirable. The frequent rains of spring and fall limit good con-

Fig. 2. A modern portable asphalt plant of one-ton mixer capacity.

struction to the few summer months, if road-mix methods are used. The delay and expense to a contractor, in long-drawn-out manipulation to blend aggregates properly and to free such windrowed aggregates from excessive moisture due to frequent rains, are considerable. With road-mix construction, traffic on state highways must generally be detoured; and additional detour expense and inconvenience to the travelling public because of such delays are a further problem. Since the favorable road-mix construction season is in the comparatively dry summer months, when tourist traffic is at its peak, we were faced with the detour problem and annoyance to the tourist industry, second only to the automobile industry in importance in our state.

Road-mix machines and travelling plants, while capable of more efficient and speedy construction than with ordinary blade machines or patrol graders, are still subject to about the same drawbacks and difficulties in our situation.

PLANT-MIX METHODS

So we have standardized on plant-mix oil aggregate construction for our secondary roads. Almost any standard batch-type asphalt plant is permitted. We thus are securing uniformly graded mixtures, with carefully controlled oil content, by batch-weight proportioning and mixing. The use of driers provides aggregates with less than 1 per cent moisture and permits a much longer working season. In fact, we start oil aggregate construction as soon as the spring breakup is over and have laid as late as Christmas.

Fig. 3. A mechanical spreader for two-layer, part-width spreading of oil aggregate.

Fig. 4. View of mechanical spreader on two-layer, part-width operation.

The gravel road surface is shaped to a crown of 1½ inches to 2 inches for the 20-foot-wide surface and to proper grade to insure good riding quality. This is accomplished with patrol graders or maintainers when the proper moisture condition in the gravel surface is present.

The base is then primed, one-half width at a time, with about one-fourth gallon per square yard of cutback asphalt or tar prime. After the prime has cured, the oil-aggregate mixture is spread one-half width in two layers by means of mechanical, self-propelled spreaders, such as the Adnun, Barber-Greene, or Jaeger machines. Inequalities in the base are greatly reduced by the two-layer method with these types of spreaders, and better compaction is obtained. The compacted thickness is approximately 2½ inches, obtained by using 250 pounds of mixture per square yard. Smooth riding surfaces can, of course, also be obtained with road-mix methods, but capable blade-grader operators are not plentiful. The mechanical method of spreading is generally more foolproof. A tandem roller of five- to eight-ton weight, rolling only once or twice over to close the surface, is required. Traffic assists in providing compaction and is encouraged to use the freshly laid surface after the roller has passed over once.

This method of laying the surface interferes very little with traffic flow, as only around the machine and a short distance behind is one-way traffic necessary.

Contractors are able to get good production and are not much delayed by weather. The spreaders can readily handle one hundred tons per hour. Plants having a one-ton mixer box can satisfactorily produce an average of fifty to sixty tons per hour. The mixing time required to coat the aggregate thoroughly is generally ten seconds for the dry mix, and thirty-five seconds for the wet mix. Contractors frequently work two shifts at the plant, stockpiling the mixture during one shift and hauling from both plant and stockpile to supply the spreader during the other shift, thus securing the economical advantage of the spreader's ability to lay more than the one-ton plant can produce. All mixtures are weighed on approved and state-tested platform truck scales to determine pay quantities. The contractor provides the scales and the state, the weighmaster.

We also provide a field laboratory at each plant, with trained inspectors to insure uniform quality.

COSTS

Even though plant-mix construction has decided advantages over the road-mix method, in securing uniformity and better control of the mixture and providing less traffic interference, it still might not be justified if the cost were considerably greater. We have found, however, that the cost of plant-mix construction is very little, if any, more than the road-mix method, when all factors are taken into consideration. By letting oil-aggregate projects in lengths of ten to twenty miles, the unit cost of plant moving and erection is greatly reduced. Many contractors are equipped with highly portable plants that can be transported in sections over highways to otherwise inaccessible locations.

The average bid price for the 1938 program was $3.29 per ton for the oil-aggregate surface laid complete. For the 1,500 tons per mile which we use, this gives a cost of $4,935.00 per mile. In 1939 the bids averaged $3.10 per ton, or $4,650.00 per mile. The highest price in the 1939 program was $3.95 per ton, and the lowest, $2.75 per ton. Cost of aggregate and length of haul were the principal factors causing this variation.

Road-mix aggregate construction during 1935 and 1936 ran from $3,790.00 to $4,240.00 per mile, without taking into account detour cost.

While the State has not built road-mix projects lately, quite a number of county projects have been built under State supervision in connection with the Federal Aid Secondary program. Some of these projects were oil-aggregate and some asphalt or tar retread. The direct contract cost averaged $4,350.00 per mile.

The availability of suitable equipment and experienced organizations must also necessarily be a consideration in the adoption of plant-mix construction. It happens that there are a considerable number of contractors with such equipment and personnel who bid regularly for our work.

It appears to us, therefore, that for our conditions the advantages of plant-mix construction outweigh the small extra cost. In other sections of the country where climatic conditions are more favorable, or aggregates are more costly, the situation may be entirely different.

ROAD-MIX VS. PLANT-MIX IN BITUMINOUS ROAD CONSTRUCTION

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Mr. Schaub's paper indicates the intelligent approach that Michigan has made to its problem of low-cost bituminous construction. I find very little to criticize and nothing to contradict in his considerations. So, for the purposes of this discussion, I propose to apply similar considerations to the Indiana scene.

Indiana's problem is similar in many respects. Our climate is not greatly different; our aggregates are probably better distributed, both in location and quality; traffic conditions and maintenance problems are quite similar. However, most of our secondary state highway system has been developed through the various stages of traffic-bound, dust palliative, oil mat, and successive surface treatments, and many have developed to higher types. Most of this development was accomplished by "road-mix" methods, during the "twenties," when little other equipment was available. In fact, many of the so-called "road-mix" methods were originated during this period by Indiana highway engineers. However, there is probably a place even now for "plant-mix" methods on our secondary system.

We also have a related problem that is being met with similar considerations. Many of the old grades and alignments have to be improved to meet modern traffic demands. This means abandonment of the old base and quick development of new base and surface. A similar problem is involved on much of the mileage constructed for the counties in the F.A.S. programs.

Indiana has made various attempts to solve this base and surface problem. It is my opinion that there is still much to be desired in our development of quick, adequate, and cheap bases. But I do believe that Indiana's bituminous stabilized surface is the best answer to date to the surface problem. In many respects it is similar to Michigan's "oiled aggregate," though both road-mix and plant-mix methods are permitted in Indiana.