

quate drainage. During 1916 about 75% of these weaker areas was repaired and 238 miles of thin pavement was resurfaced. It may have still more force when I tell you that in New York State in 1917, 48 miles of improved highways, out of a total of 2,090 miles, broke up in the spring of the year, of which 18% was attributable to inadequate drainage.

"The percentages given as attributable to inadequate drainage were reported by the men having charge of each section and the personal equation enters largely into the cause to which each break-up was made attributable. They are, however, the most accurate percentages that could be obtained of the inadequacies of our drainage systems. These roads were not built by guess but under careful calculation by some of the best road engineers in the country. They installed upon them drainage systems such as they thought ample, but they had not taken into account the large increase in traffic and wheel loading that we have to-day. The roads failed because they disregarded the pumping action caused by the excessive pounding of that traffic, which draws the water and fine material up to and through the crust of the pavement until the crust is broken and the road shattered.

"I shall not attempt to suggest any scheme for the solution of the drainage problem, because each condition requires different treatment. Broadly speaking, however, drainage can be divided into two classes; surface drainage, and subsurface drainage. Surface drainage is cared for by the crown of the road and side ditches with proper run-off to carry the water away from the road at frequent intervals, so that it will not trouble us again as subsurface drainage. Every roadway should have ditches."

No better evidence of the importance of drainage, at least in climates like that of New York State, with severe winters, is needed.

It is unnecessary to go into detail here in regard to systems of drainage for ordinary conditions, since these are described in all their various forms and for different types of pavements and of road construction in text-books, in discussions of the subject before societies, in publications of the United States Office of Public Roads and State Highway Departments and in the engineering press. It is, however, necessary to insist upon the fact that in clay or heavy subsoils, especially in northern climates, if drainage is inadequate no amount of thoroughness in the construction of the foundations and surface of both pavements and roads will result in a satisfactory return for the money expended, even where the traffic is of the most moderate description. Adequate drainage for heavy clay subsoils, in the coldest climates, can rarely be satisfactorily accomplished, and the only method of meeting such conditions is the excavation of the clay to a considerable depth and its replacement with material which can be drained, or which is not as liable to displacement by frost. In general, it may be said that drainage is a local problem and its satisfactory solution is more dependent on a study of local and individual conditions than upon fixed standards.

Foundations

The first essential in the construction of pavements and road surfaces of durable character having been shown to be a dry, that is to say a well-drained and firm, sub-soil, as the result of either natural or artificial provision therefor, upon which to build and maintain a durable surface, another and equally essential factor in the successful construction of both pavements and highways is a suitable foundation. Its character will depend upon the conditions to be met. Practice, which might be excellent in one locality, may fail in another. A concrete foundation will, of course, be more costly than one of broken stone, but a foundation of this type 4 ins. in thickness will be stronger than a loose one of 2½ ins. broken stone of 6 ins., and the difference in cost will not be a serious consideration since the much smaller amount of stone used in the 4-in. foundation will largely make up for the cost of the cement and sand in the concrete. In a concrete foundation, when once laid, we have an asset which can be counted upon for all time, while a broken stone foundation is necessarily of a more or less temporary nature, owing

to its displacement under travel, and disappearance, in some cases, into the soil which should support it.

Concrete Foundations

There seems to be every reason why, in the building of our highways, an effort should be made, at least in the case of those which are to carry heavy travel, to construct them with a concrete foundation, which will last for all time, and on which a wearing surface can be constructed, at such intervals as may be necessary, something which can be easily and economically done, and the life of which depends on the rigidity of the support afforded it. It is evident that as we are now constructing surfaces for many of our main arteries of heavy travel, we are throwing away large quantities of money by lack of adequate support of them. The result is much the same as if expensive buildings were erected without suitable foundations. This question of adequate foundations is one which should receive the careful attention to-day, and one which, if neglected, will do more than anything else to hamper the development of good roads, since great disappointment must arise when, within the course of a few years, it is discovered that the wearing surfaces which are now being constructed are so inadequately supported that they have given no reasonable return for the cost incurred in building them.

An adequate return, therefore, for the money expended on any type of pavement or road surface is dependent, after the provision of a dry support, on the rigidity of its foundation. The necessity for strong foundations is emphasized at the present time by the fact that our street pavements and main arteries of communication are called upon to carry a heavy burden and a very large traffic, owing to the advent of the motor vehicle, more especially the motor bus and motor truck, the latter rapidly increasing in capacity to such an extent that it is recognized that means for regulating it must be considered.

Foundations may be differentiated, primarily, as those depending on the soil alone as a support, known as natural or subsoil foundations, and those provided artificially which are of many types.

Foundations, like drainage, are a local problem. To meet it satisfactorily involves a careful consideration of the environment of the road and the uses to which it is to be put. A foundation of a thickness of only 4½ ins., which appears to be satisfactory in the climate of southern California, would be useless in northern New York. A different thickness may be called for on a hillside and on a level and in low as compared to high ground. The nature of the subsoil or manner in which the road is supported from below will also have a decided influence, a weak support calling for a heavier foundation. Again, if the drainage is not entirely adequate, a heavier foundation will be demanded. Its character will also be influenced by the materials which are available for its construction. If these are of the best, the thickness may be less than would be desirable with inferior materials. Last of all, the character of the travel to be carried must be given due consideration. If heavy motor trucks form part of it, proper provision, greater thickness and stability must be made for their support.

Thickness of Foundations

In any case the foundation must be perfectly rigid and free from vibration, that is to say, it must have complete stability under the conditions it is called upon to meet and the loads which it will carry. No rule can be laid down for a thickness suitable for all conditions. In some instances, as on city streets, from 8 to 12 ins. or more of concrete may be necessary under the heaviest travel, while, as has been said, in California, 4½ ins. in that climate seem satisfactory for the main country highways.

According to the London "Times" of Feb. 13, 1913, the following depths of foundations have been used in London and in the neighborhood:—

"In Bermondsey, for instance, while concrete 6 in. deep was formerly sufficient, the depth is now being made 9 ins. or even 12 ins. In Hackney, foundations which were sufficient a few years ago, are now found quite inadequate, and in new