

other hand, the need for economy is equally rapidly growing greater, and if, as the old definition has it, "the engineer is a man who can do with one dollar what any fool can do with two," the demands of economy—i.e., true economy in the long run, must be recognized and sought by him.

The decision in this matter at present must be made largely on the basis of judgment founded on general knowledge and experience. There is little scientific data recorded to guide one in the matter though there is some. It is admitted that the stresses from the load on the surface of the pavement passing down through the body of the pavement itself are distributed over a larger area of the foundation. The supporting powers of various kinds of earth have been approximately determined. If, now, some conclusions can be reached as to the distributing effect of the stresses through the surface of the pavement, a fairly accurate determination of the questions concerning the use of the natural material or the substitution of other material for the foundation of the pavement surfacing may often be had.

Summing up in regard to natural foundations for roadways, it may be said that the highway authorities should be sure that the supporting power of the material is and will be continuously sufficient for the purpose, and that sufficient protection against injury to its supporting power is provided, that the foundation shall be stable in place and sufficient protection against displacement of it shall be provided; that the natural foundation shall be homogeneous and uniform in character; and that these results shall be obtained at the minimum cost. Possibilities of failure in any of these respects should generally warrant the authority in prescribing reinforcement by foreign material or the substitution of other material for the natural foundation, or in prescribing the use of an artificial foundation.

**Artificial Foundations.**—Under the head of artificial foundations will be included for convenience all layers of foreign material not naturally found in place and specifically provided for the purpose of interposing a layer of some sort between the natural material and the pavement surfacing. Consequently, under this head will come layers of sand, gravel or similar material, macadam (old or new), paving (old or new), as well as the more common exposition of the term—i.e., the concrete slab.

A layer of sand or gravel as an artificial foundation for the pavement is sometimes used to good advantage on subgrades whose supporting power is relatively weak, under such conditions as may be expected to prevail around it, and largely for the purpose of distributing, through the medium of a cheaply installed layer, the stresses coming down through this layer from the pavement, so that the strains on the foundation will be within what might be called the "elastic limits" of the latter. Sometimes, the further advantages of such a layer are that they assist in providing drainage and in increasing the stability of the sub-grade in places. For instance, such a layer may be valuable in preventing the serious effects of frost action otherwise taking place in the spring. Again, with sub-grades of clayey material, such a layer of sand or similar fine material, will prevent the working of the sub-grade material up into the somewhat porous bottom layer of the macadam to the detriment of the latter. Again, economy may dictate the use of a layer of considerable thickness, say, two feet of sand for the foundation of a pavement where traffic conditions will be relatively light and yet an insufficient natural sub-grade exists locally.

Properly graded gravel with sufficient sand in it to reduce the voids to a minimum will prove an even stronger artificial foundation than the sand layer above referred to,

as there will be less tendency toward displacement under traffic. In the same way, macadam may be superior to the gravel layer and a thinner foundation of macadam may equal or be superior to a much thicker layer of the best available gravel. Well-compacted macadam is high in its supporting powers and in its stability in place. The difficulties of using it as an artificial foundation are those always found with materials containing a large percentage of coarse particles—i.e., it is difficult to get its surface sufficiently even so that the surfacing shall be sufficiently smooth, and at the same time have the requisite degree of uniformity in thickness. Without going too much into the question of surfacing, the writer wishes to point out the necessity, for the sake of evenness in wear, of uniformity in thickness for the surfacing layer of a pavement, whether the latter be sheet asphalt, wood block, brick or stone block. It is true that the blocks are now generally made with a reasonable degree of uniformity in this respect, but if the bedding material on which they are placed be, as is frequently the case, sand, it must be considered as a part of the surfacing layer. The necessity for this bedding layer to be of reasonable uniformity in thickness is now generally recognized and a general demand exists rationally for a high degree of smoothness and evenness in the surface of the foundation. This demand will exist and even become more severe so long as a layer of material quite different from either the foundation or the surfacing material itself shall continue to be placed between the two.

Many brick pavements have been laid using the old macadam surfacing as a foundation. The failures of most of them have been directly connected with the unevenness of the sand layer required for the purpose of evening up the surface of the macadam and furnishing a bed in which to set the brick. Where newly laid macadam was attempted, to provide for a foundation for such pavements, some of the failures have been attributed to insufficient consolidation of the macadam prior to the brick laying and to subsequent shifting of the sand layer between the macadam and the brick, which shifting was caused or intensified by the passage of the sand into the interstices of the insufficiently compacted macadam foundation, as well as to the lack of evenness for the surface of the macadam and lack of uniformity in the thickness of the sand layer.

Old pavements have frequently been used as foundations for new pavements and in some cases, an artificial foundation in the shape of a stone pavement has been provided for the new pavement. Such foundations are of considerable antiquity. The Telford pavement as a base for a macadam surfacing is a well-known instance. There are many cases in cities of this country where the streets were originally paved more or less roughly with stone blocks, or so-called cobble stones, and these old pavements used, with or without relaying, as foundations for different kinds of pavement surfacings. Various degrees of satisfaction have resulted. Properly laid, the supporting power and stability of such foundations is relatively high and in many cases under the local conditions, their use has been economical. On the other hand, in some cases, the development of traffic conditions has resulted in such severe strains on these foundations that they have failed, and have had to be replaced by the more substantial concrete slab. Probably most of the failures of these pavements as foundations have come through the lack of evenness of surface obtainable on them, and a consequent lack of uniformity in the thickness of the pavement surfacing.

Apparently the highest type of artificial foundation is the concrete slab. The power of such a foundation to

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