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The use of stabilised soil as a structural material

Die Anwendung von verfestigter Erde als Baumaterial

Emploi de la terre renforcée comme matériau de construction

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Observation of the behaviour of old brick and stone arch bridges has shown that they have a carrying capacity much in excess of that which theoretical calculation indicates; tests carried out on such bridges, as well as on old cast iron girder bridges, have confirmed that they are capable of supporting very heavy loads in some cases, not only without failure, but with an ample margin of safety.

There is no doubt that the main carrying members of these bridges are greatly assisted by the action of earth filling. This, having been thoroughly compacted by comparatively light traffic for many years, has become a dense mass possessing not only appreciable compressive strength, but also a certain amount of tensile strength. It seems, therefore, that if satisfactory consolidation could be achieved quickly, it would be practicable to use filling material of suitable type as a structural member, with much economy.

The technique of soil stabilisation has been greatly developed in recent years, and the successful construction of roads and airfield runways of stabilised soil has proved that much can be done with what are, from the structural point of view, poor quality materials, to consolidate them to the required density and strength.

Stabilisation can be produced by mechanical means, by the addition of cement, bitumen cut-backs, certain resins and industrial wastes, or by heat treatment of the soil. For structural work, cement stabilisation appears to be the method most likely to give satisfactory results, but stabilisation with cut-back bitumen may be suitable in some cases. While soils possessing a considerable degree of cohesion naturally can be stabilised, those of a coarse-grained, sandy character are most suited for structural work. Whether a particular soil is suitable, and in what proportion the binding agent should be added, must be determined by laboratory experiment, and as soils are very variable, no rigid rules regarding proportions can be stated. In general however, it may be said that the quantity of cement required varies from

5% to 10% of the weight of dry soil, the finer grained soils requiring the greater cement content; the quantity of bitumen ranges from $2^1/_2$% to 10%, the finer grained soils again requiring the greater quantity.

If a particular soil is unsuitable, in its natural state, for stabilisation, it may be practicable to mix granular material with it to produce satisfactory results. In structures, the total amount of soil required is usually fairly small, so that the importation of granular material may not cause costs to rise beyond economic limits. The greatest economy, however, is achieved when it is practicable to use materials found on the site of the works, and to stabilise these with light plant and unskilled labour. There is, in fact, no great difficulty in doing this, and it is not necessary to adopt any elaborate technique.

The strength of stabilised soil is somewhat variable, as might be expected owing to the variation of grain size and grading between different soils. Average results fòr clean granular soils with cement contents varying from 5% to 7% are:

Compressive strength	600 lb/sq. in.	(42,5 kg/sq. cm)
Bending tensile strength	180 lb/sq. in.	(13 kg/sq. cm)
Direct tensile strength	55 lb/sq. in.	(4 kg/sq. cm)

These figures are for tests at 28 days on 6 inch cubes, or on beams 6″x 5″ cross section for the bending tests.

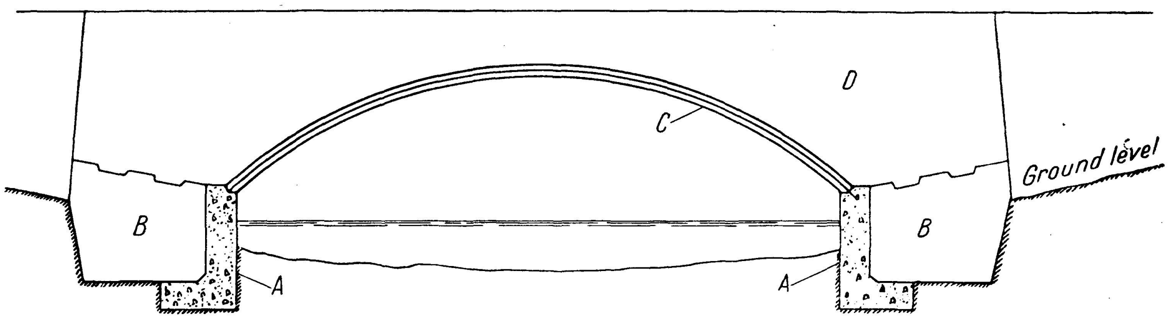
No figures can be given for bitumen stabilised soil, but it is not likely that anything like such strengths could be obtained. It would seem that the main use of bitumen stabilisation is likely to be in providing a mass of stiff soil for retaining wall construction, as described later.

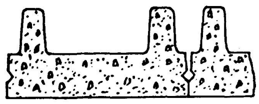
In the application of stabilised soil to structural work, it is important to remember that the problem to be solved is essentially one of soil compaction; one is not dealing with concrete, which, however much the water content may be reduced within practicable limits, is still capable of flowing into position. Instead we have a mass of damp soil which has to be compacted, and for which there is an optimum water content at which the best compaction can be achieved. Determination of this, and the minimum amouns of cement required to give a satisfactory strength, are essential preliminariet to construction.

Construction of Small Arch Bridges

Figure 1 shows the suggested procedure for the construction of arch bridges for spans up to, say, 10 metres. The first stage is the building of mass concrete abutment walls, A, to form the external facings to abutment blocks, B, formed of cement stabilised soil. The construction of B is the second stage of the work, the upper surfaces of B being trenched as shown. The third operation is the erection of pre-cast reinforced concrete ribs, C, which for very short spans may be single rings, while for longer spans they could be made in half rings jointed at the crown. The units should be interlocked, with grouted joints, as shown in the detailed cross section.

With the ribs, C, in position, mass concrete or masonry spandrel and wing walls are built, the thickness of these being sufficient only to provide an effective protection against the weather for the stabilised soil filling. The last operation is the placing of the stabilised filling, D, which is carried out in layers about 15 cm thick, each layer being thoroughly consolidated by rolling, or by hand ramming where the roller cannot be worked. Satisfactory consolidation and strength has been obtained by the following procedure.





Details of Arch Ribs C. Fig. 1

A layer of soil 15 cm thick is spread over the area required. The predetermined quantity of cement necessary for this amount of soil is then deposited in small heaps of uniform size on the soil layer, the heaps being about 50 cm apart in each direction. A rotary tiller is then worked over the soil until the cement is thoroughly incorporated, about a dozen passes of the tiller being required. A good practical test of the uniformity of mixing may be made by plunging a spade vertically into the soil and tilting it forward; this leaves a vertical section of the soil layer exposed, and if insufficient mixing has been done, bands of cement can be seen in the section and further passes of the tiller are required. Further tests are then made, and mixing continued until the section of the soil appears uniform in colour, with no bands of cement visible.

When mixing is complete, a pre-determined quantity of water is sprayed uniformly over the soil layer, using cans with spray nozzles. The amount of water added will depend on the natural moisture content of the soil and on the amount of water in total required for optimum compaction. It is possible that no addition of water is required. The strength of cement-stabilised soil varies with the water cement ratio something in the same way as does the strength of concrete, and excess quantities of water should be avoided. both from the strength point of view, and for the achievement of full compaction

After the addition of water, the soil layer is compacted with a hand roller weighing about 500 kg, about six passes of the roller being sufficient to complete compaction. Work may then proceed on the next layer of soil; during the mixing of this, the tiller will disturb the upper surface of the already compacted lower layer, but there is no disadvantage in this, as it ensures the bonding of the soil layers together. Care should be taken, however, not to disturb the lower layer deeply, as the roller cannot be expected to correct more than surface disturbance.

When the filling has been completed an application of bitumen or tar emulsion to the upper surface may be advisable in order to seal it against moisture penetration, before the final road surface is constructed. Some form of upper crust is considered to be essential in any case, such as a concrete road slab, or stone pitching with a suitable running surface, as concentrated wheel loads should not be allowed to bear directly on stabilised soil when it is used as a structural material.

For an arch of 10 metres span, 2 metres rise, and having a crown thickness of 1 metre, subjected to the standard live load prescribed by the British Ministry of Transport for Highway Bridges, maximum compressive and tensile stresses are approximately 2,8 kg/sq. cm and 2,10 kg/sq. cm respectively, calculated on the assumption that the arch is rigidly fixed at the vertical planes of the front faces of the abutment walls, and that it behaves as an elastic structure.

It is doubtful whether either of these assumptions is really valid, but in default of precise knowledge of the method of action of a stabilised soil arch, they may serve as a working basis for the proportioning of such structures. Until some reliable method of measuring the internal stresses in arches of this kind is available, what happens under load must remain to some degree a matter of speculation, like so many other structural problems.

It will be seen from the above description of the construction of an arch that no heavy plant is required for the mixing and consolidation of stabilised soil. The "mix-in-place" method is quite satisfactory with soils of a friable nature, but with stiffer soils machine mixing may be required for proper incorporation of the cement. The ordinary concrete mixer is not suitable for the work, but a double paddle mixer will deal successfully with the most cohesive soil which it is possible to use for this work.

Apart from the construction of new arches, stabilised soil can clearly be used to strengthen existing ones. The spandrel filling may be removed from a bridge, and if suitable, it can be put back with the addition of cement binder; or, an imported fill, more suitable for consolidation, may be used. If the abutment walls of such bridges are thin (as they often are), they can be backed with blocks of stabilised soil as necessary. In the construction of new masonry arches, it is suggested that it would be worth while to provide stabilised filling in all cases, making some reduction in the thickness of the arch ring as compared with what it might otherwise be with ordinary filling.

Construction of Abutments for Beam Bridges

In this class of work the object is to provide a vertical load-carrying member to support the concentrated load of the bridge deck, the necessary mass to withstand the horizontal earth load being provided by blocks of stabilised soil. Figure 2 illustrates the principle of construction. A mass concrete footing slab, A, is formed with a recess in the upper surface, into which the ends of pre-cast concrete units, B, are fitted. These units, which may be similar in cross section to the arch units shown in Figure 1, require to be strutted from the front (or otherwise supported against horizontal load) during the construction of the backing. As the units are placed in position, anchor ties, C, (also of pre-cast concrete) are fitted with them, projecting for a suitable length into the backing space. The tops of the vertical units are enclosed by a reinforced concrete bearing beam; the construction of this before the placing of the backing helps to ensure that the vertical units will not be forced out of line by the compaction of the backing.

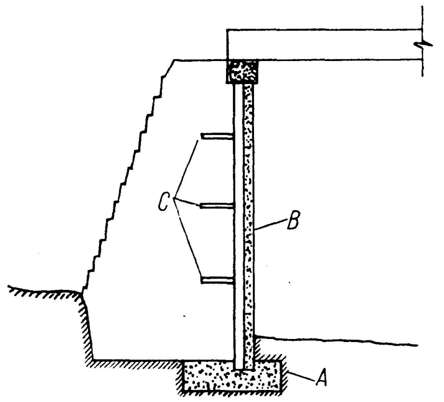


Fig. 2

The backing of stabilised soil may now be constructed, the soil being hand rammed carefully round the anchor ties and consolidated by rolling elsewhere. The supporting struts should be left in place for several days after the completion of the backing, after which they may be removed and the superstructure work may proceed.

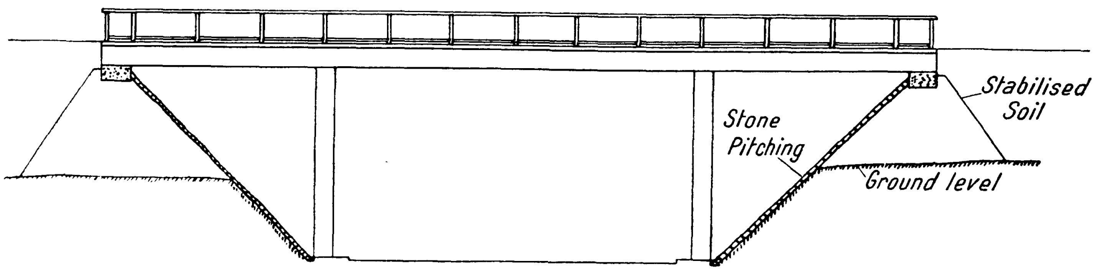


Fig. 3

A further application of stabilised soil for abutment construction is shown in Figure 3. This shows a three span bridge, the outer ends being supported on a reinforced concrete bearing slab constructed on top of a prism of stabilised soil. The exposed slopes of this prism are faced with rough stone pitching, which is set in position as the prism is built up. The joints in the pitching should be formed with cement mortar, and tightly pointed, so that the stabilised soil may be protected from the weather. The ordinary earth filling of the approach embankments of the bridge may be deposited as the prism is constructed, the latter being kept slightly in advance of the former. The back slope of the prism may with advantage be stepped as each layer of stabilised soil is consolidated, and this, together with careful compaction of the approach filling, should reduce the tendency to settlement of the approach road surface due to subsidence of the supporting fill. The same procedure should be followed in the construction of the backing shown in Figure 2.

For the construction of retaining walls which do not support direct vertical loads, any convenient form of outer skin construction may be employed, e.g., brick, stone, pre-cast concrete blocks, concrete crib units, or units similar to those shown in Figure 2, but laid on their edges in lifts of two or three at a time, as the backing is built up. In all cases, the skin should be well tied to the backing by methods appropriate to the form of skin construction adopted, but it would be advisable not to use bare steel or iron ties. It is not necessary to provide a concrete footing for the skin, as the construction of this can be commenced on the bottom layer of stabilised soil. The amount of stabilised backing to be provided may be determined from the usual earth pressure calculations, but in all cases, generous proportions should be adopted so as to avoid high tensile stresses in the material. There is, indeed, little reason to reduce the sections to fine limits, for the whole advantage of this form of construction is that it makes use of material readily available on the site, with only a small proportion of imported binder.

Remedial Works

One form of remedial work — the replacement of defective spandrel filling of arches — has already been mentioned. Clearly, stabilised soil can be used in a number of cases of retaining wall or abutment failure, so long as the original structures have not failed seriously and are still able to function if relieved of some or all of the horizontal component of earth pressure. The description of one such case, may be of interest, and it is illustrated in Figure 4.

A new bridge was being constructed over a railway; the structure had been completed, and earth filling was placed behind the abutments. Almost immediately the latter began to tilt forward, the friction between the bridge deck and the abutment tops having been overcome. The abutments were partially relieved of earth load by excavating some of the filling, and after a time there was no further movement. The amount of tilt was not large, and it did not seem likely that further movement would develop due to the vertical load from the bridge deck. It was decided, therefore, to allow the abutments to perform their function of supporting the vertical loads, but to relieve them of horizontal earth loading. Figure 4 shows how blocks of stabilised soil have been constructed behind each abutment, completely separated from the vertical walls of the latter, but bearing on the foundation slabs.

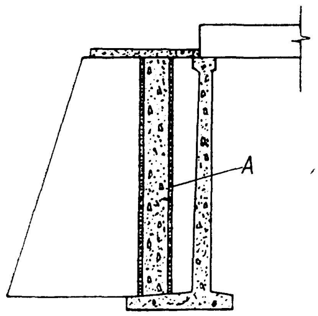


Fig. 4

The first operation was to build a rough wall, A, against which the stabilised filling could be compacted. A small concrete block making machine was obtained and a quantity of rough blocks were made at little cost, to form shuttering for A. The space within the blocks was filled with stabilised soil mixed in a paddle mixer, and the stabilised backing was then constructed, using the mix-in-place method described previously. The approach filling was brought up with the stabilised filling, and the space between the latter and the original abutment was bridged by a reinforced concrete slab.

It is clear that the work just described is representative of many cases in which the remedy for trouble lies in providing a massive block of stiff filling to resist horizontal earth loading. It may not be necessary in all cases to excavate behind the wall right down to its base; in some cases also, the whole length of the wall may not need to be treated continuously, ''counterforts'' of stabilised soil being constructed in trenches sufficiently close together to reduce the total horizontal load on the wall to safe proportions.

Conclusion

It is not suggested that there is any new principle of construction involved in the various illustrations given in this paper. For hundreds of years the practice of building masonry structures with a face of good stone and a backing of inferior material has been followed. It is suggested, however, that the form of construction here described is economical, and, with the aid of modern soil stabilisation technique, it can be applied successfully. It is hoped that delegates to this Congress will find it of interest and worthy of discussion.

The author wishes to refer to his paper on "The Design of Small Bridges for Modern Roads" delivered to the Institution of Civil Engineers in April 1945, and to thank the Institution for permission to refer to that section of the paper dealing with the construction of stabilised soil arches.

Reference is also made to two articles by Mr. G. G. Meyerhof on the subject of the calculation of the stresses in solid spandrel arches, published in "Concrete and Constructional Engineering", in April and June, 1947.

Summary

The stabilisation of natural soils has proved very successful in the construction of roads. Soils of suitable grain size can be stabilised by the addition of cement to form a consolidated mass having a fair degree of compressive and even tensile strength. The paper suggests methods of using cement stabilised soil for the construction of small arch bridges, retaining walls, abutments for bridges, and for remedial works. Construction methods which have been used successfully are described in detail.

Zusammenfassung

Die Verfestigung von natürlichen Böden hat sich im Straßenbau als sehr erfolgreich erwiesen. Böden mit passender Verteilung der Korngrößen können durch Hinzufügen von Zement verfestigt werden, sodaß sie eine konsolidierte Masse bilden, die eine beträchtliche Druck- und sogar eine gewisse Zugfestigkeit besitzt.

Der Beitrag schlägt Anwendungsmethoden von durch Zementzusatz verfestigten Erden für die Konstruktion von kleinen Bogenbrücken, Stützmauern, Brückenwiderlagern und Ausbesserungsarbeiten vor. Konstruktionsmethoden, die sich in der Praxis bewährt haben, werden eingehend beschrieben.

Résumé

Le renforcement des terres naturelles a pu être appliqué avec succès à la construction routière. Des sols accusant une composition granulométrique convenable peuvent être renforcés par addition de ciment dans des conditions telles qu'ils constituent ainsi une masse consolidée présentant une résistance élevée à la compression et même une certaine résistance à la traction.

L'auteur propose différentes méthodes de mise en oeuvre des terres renforcées par addition de ciment, pour la construction de petits ponts arqués, de murs de soutènement, de culées, ainsi que pour divers travaux de réparation. Il expose d'une manière détaillée des méthodes de construction qui ont fait leurs preuves dans la pratique.