SECTION IX

IMPROVEMENTS OF THE MECHANICAL PROPERTIES OF THE SOIL

GENERAL REPORT

G. WILSON (England)

GENERAL

The papers in this section comprise one general paper, seven on mass stabilization by grouting, one on electrical osmosis, nine on the stabilization of subgrades, two on the adaptation and improvement of the consituent materials of earth dams, three on accelerated consolidation by vertical drainage, and thirteen on the compaction of soils, to which should be added the paper by R. R. Proctor in Section VIII.

Winterkorn's excellent survey of the subject forms an appropriate introduction to this section and his statement that soil stabilization is an art as well as a science is an important reminder. One could go further and say. with our forefathers, that the art part of it is an "art and mystery", such is the secretiveness shown by many of the initiates. This is, of course, one reason why, as stated by Winterkorn, certain techniques are periodically lost and re-discovered. The paper might, however, have given more attention to the question of mass-stabilization by grouting or injection.

MASS-STABILIZATION BY GROUTING AND INJECTION

Blatter reports on an interesting laboratory investigation on cement sediments. The questions that appear to arise with regard to the investigation are (i) how did the properties of these cements compare with standard specifications and can the properties investigated by Blatter be correlated with the usual compliance tests?: and (ii) are tests made on appreciable volumes of cement sediment significantly related to the behaviour of cement grout in the fine interstices in the soil?

The paper by Messrs. Sondages Injections Forages quotes tests which show that the addition of up to 50% of clay to cement will be satisfactory, a 55 - 45 cement-clay mixture having a compressive strength of over 2,000 lbs. per sq. in. and has many advantages, not the least of which is an appreciable economy. Poisson reports some laboratory tests on clay slurries for injection into the soil and on the search for appropriate flocculating agents.

C. S. Proctor reports on a cap grouting over a limestone bed-rock. Ischy gives particulars of injections of silica-gel, clay and a ternary mixture of cement, sand and clay used to stabilize a dam which had been seriously eroded due to rapid draw-down. Noblet reports on the successful solidification of a pocket of sandy gravel by means of chemical injections, after injections of marl slurry had failed, as the pores in the sandy gravel were too large to act as a filter. Johnston reports on the grouting of soft-spots in a railroad track: in this connection reference should also be made to papers in Section VIII.

ELECTRICAL OSMOSIS

Poisson reports some small scale tests which appear to show that clay which has been subjected to partial dehydration by electrical osmosis is more compressible than in its natural state. This result does not accord with the work of other investigators in this field.

STABILIZATION OF SUBGRADES

Mehra, Sindzingre and Thuilleaux report on experiences with stable mixtures of granular and cohesive materials in India, Tunisia and Belgium. The term "Clay-concrete" that is proposed by the two latter authors for such mixtures has something to commend it. However, as stated by Sindzingre, the material has much in common with waterbound macadam and it would seem that "claybound-macadam" would be a preferable term.

Thuilleaux tried to make his mixture meet definite gradation requirements: Sindzingre appears to have found that gradation is desirable but not all-important: and Mehra that an excess of fines was required in the case of soft (brick) aggregates.

It is interesting to compare the materials used by Mehra and Thuilleaux with the specification proposed by Sindzingre, which will repay careful study.

Property	Sindzingre	Thuilleaux	Mehra
L.L. of Soil Mortar	25 - 35	39	35 - 40
P.L. of Soil Mortar	5 - 15	11	4 - 12.5

Webb reports on the correlation of the results of standard compression tests on 4 inch cubes with the quality of cement stabilised soils and Armstrong gives particulars of some lengths of road constructed in this material.

McDowell and Moore tell us, in a most interesting paper on stabilisation with hydrated lime, that this material was used for the same purpose by the Romans and they give a number of test results which show the remarkable increase in strength resulting from a small admixture of lime.

Barrett reports on experience with stabilization by means of cut-back asphalts.

American and British experience with resinous agents can be compared in Eustis and Shockley's paper and in Webb's paper referred to above. Two tests to determine water absorption were devised in each case: one a full submersion test and one a capillary rise test, the details of the tests are, however, different. Eustis and Shockley point out that the permanence of the treatment is not known and that it does not prevent dusting in dry weather the latter fact alone would make it impossible to construct a permanent unsurfaced road by this method. Jones reports on microbial attack and some possible antiseptics.

The Indian National Committee report an experience in the stabilisation of soil with pectin, tannin, with certain minor forest products, and with metallic scape. 1% to 2% of stabiliser is found to be effective. It was found that fungi developed in pectin stabilised soil, but that the growth of fungi was inhibited by a mixture of tannin and pectin. Small percentages of such waste products as molasses and lignin have been found to increase the strength and abrasive resistance of earth roads.

IMPROVEMENT OF THE CONSTITUENT MATERIALS OF EARTH DAMS

Philippe presents a thoughtful and thought provoking paper that should be studied carefully by all engineers interested in earth as a material of construction. It is one of the two most outstanding contributions in this section.

Wetter gives an interesting paper on the laboratory tests which have been carried out on the preparation of material for the impervious core of a dam by the addition of very small percentages of bentonite to a sandy gravel.

ACCELERATED CONSOLIDATION BY VERTICAL DRAINAGE

The tremendous development in vertical drainage in America since the time of the first conference is shown by Stanton's paper. This valuable paper standardises practice and presents specifications for the carrying out of the work that will be most valuable to engineers.

Kjellmann gives particulars of a most interesting type of drain that has been developed in Sweden and of an automatic machine for constructing the drains. It is interesting to compare the costs with those given for sand drains by Stanton. Kjellmann estimates that one sand drain is equivalent to 2.5 cardboard wicks The former cost $ 1.00 per foot and the latter 1.50 Swedish crowns per metre. If these figures are correct wick drainage only costs as much per metre of depth as sand-drain drainage costs per foot of depth.

Steuerman suggests a further method, the results of practical experience with which will be awaited with interest.

SOIL COMPACTION

Pride of place amongst the papers on soil compaction is taken most appropriately by the symposium of five papers by R. R. Proctor, the father of compaction. These five papers on laboratory soil compaction methods, on the relationship between compactive effort in laboratory tests and that required to secure similar results with sheepsfoot rollers, on the relationship between compactive effort and soil density, consolidation, and shear strength, and on the preparation of compacted soils as foundations for paving or structures, will repay very careful study.

The principal conclusions from the first four papers may be summarised briefly as follows:

(i) The ratio of the necessary field compactive effort (measured by draw-bar pull) to laboratory compactive effort varies from 100% to 140% .

(ii) "x%" of "standard compaction" does not require as much as "x%" of "standard compactive effort", nor does it produce "x%" of the strength produced by "standard compaction": it would be safer, and often economical, if the minimum compactive effort required were laid down in the specification: as this is often surprisingly low compared with standard: it should, however, not be less than 15,000 - 20,000 ft. lbs. per cubic ft.

(iii) The proportionate compaction to be specified should be determined so that the required minimum indicated saturated penetration resistance is attained: a specified "90%" or "95%" of "standard" may result in a material too weak for its purpose.

These are, however, two points of criticism. Firstly, Proctor's work does not appear to take account of the fact brought out by Mc Lean and Williams, amongst others, that there is a maximum density that can be produced by any given set of field plant, however many coverages are made and that compactive effort exerted after this saturation point is reached is wasted: if further compaction is required, heavier equipment is necessary. Secondly, the values given bij Mr. Proctor for the shear strength and, in particular, for the angle of friction are extremely high for the type of material concerned. It is believed that this is due to the use of the double shear type of test apparatus, which is not considered reliable: it is suggested that the tests should be repeated, using a triaxial apparatus.

Proctor's paper on the preparation of subgrades shows the importance of the use of rubber tyred rollers in the final stages of compaction of earthworks, although the use of the term "consolidation" does not appear desirable in respect of the compaction induced by this type of equipment. Others, notably Lewis (in a paper in Section VIII) and Salazar have pointed out the great advantage of subjecting a subgrade to rubber-tyred traffic before construction of a pavement. Proctor is right in emphasising that the compaction of the upper layers of a fill should be controlled and that the surface layer of a fill compacted by sheepsfoot rollers should be removed. It is, however, possible that pneumatic tyred rollers can compact the whole depth of a fill, in layers of suitable thickness, and that they are preferable to sheepsfoot rollers, except in the special case for which they were developed, the construction of earth dams, where it is important to avoid a laminated structure.

Johnson and Maxwell confirm Proctor's experience that a heavy sheepsfoot roller is effective in increasing the density of a soil to a depth of as much as 4 feet, 2'6" below the bottom of the feet in their case, and they found that a heavy pneumatic tyred roller was effective to a depth of two feet: they also found the most effective compaction was secured by the use of a sheepsfoot roller followed by a pneumatic tyred roller.

Du Bose found that standard "Proctor" compaction on a M L material was closely reproduced in the field by the use of a sheepsfoot roller with a working pressure of 300 lbs. per square inch. It would be an advantage if a figure could be given for the field compactive effort. The permeability, the consolidation characteristics, and the behaviour under stress of the laboratory and field compacted material was closely similar. It is interesting to note that the modulus of elasticity of unconfined compression specimens varied from 400 to 600 lbs. per square inch, whereas that of specimens subjected to a minor principal, stress of 30 lbs. per square inch varied from 4,000 to 6,000 lbs. per square inch.

W. J. Turnbull and McFadden give results of tests to show the effect of varying the pressure intensity of sheepsfoot rollers and the total weight of rubber tyred rollers: they found the effect was very small. It is interesting to note that they did not find the deep compaction effect reported by Proctor and by Johnson and Maxwell. The shift of the peak of the the compaction curve towards the zero air voids curve found by these Authors in the case of M.L material is also at variance with the experience of others and certainly merits further investigation.

Salazar, in an interesting paper on experience in the Argentine, gives some valuable data on the permanence of compaction and stresses the importance of compaction by traffic. It has been found by this Author that the "toughness index" of the soil is significant - this subject may repay study elsewhere.

McLean and Williams show that it is unsound to estimate the compaction characteristic of a soil containing large aggregate from those of the matrix by assuming that the stones act only as displacers and they have found that standard compaction test equipment gives satisfactory results with material up to 3/4 inch size. Their suggestion that this size should be made the limit, instead of 3/16", could well be adopted. The data given in this paper, again lead one to wonder whether sheepsfoot rollers have any advantage, except in the special case of earth dams.

These Authors, with Heiselman, give data which proves that there is a definite limit to the amount of compaction that can be produced with any given set of field equipment, however many passes are made.

McNeil Turnbull reports on a relationship between the optimum moisture content and a new classification proposed by him in another paper presented to the conference. It is possible that the proposed soil classification may be useful for this particular purpose, but it is nowadays generally accepted that a soil classification connot be based on grain size distribution alone. The statement, in the second paper, that the particle size distribution curve of every soil consists of a straight line from 0.001 mm. downwards is scarcely acceptable.

Lane proposes a vibrated density test for cohesionless soils, in the case of which the normal compaction test is not satisfactory.

The Indian National Committee report on the "Abbott" compaction test apparatus, which is said to produce results agreeing closely with the standard Proctor test and to have certain advantages for field use.

-o-o-o-o-o-o-

SUB-SECTION IX b

MECHANICAL METHODS

IX b 18

DISCUSSION

S.J. BUCHANAN (U.S.A.)

As chairman of the subcommittee of the U.S. National Committee that was concerned with the subject of compaction of the subgrade it is desired to clarify several points made in the summary, and to briefly outline the current trend of thought prevailing in the U.S.A. on compaction. In regard to the summary of the two papers - one prepared by Messrs Maxwell and Johnson and the second by Messrs Turnbull and Mac Fadden - it is desired to make the following comment:

1. The observation of compaction reported by Maxwell and Johnson deals entirely with compaction from the surface as produced by pneumatic tired rollers weighing 40.000 lbs and a sheepsfoot roller exerting 1100 psi, while the observations reported by Turnbull and Mac Fadden are concerned with layered compaction produced by pneumatic rollers of 10, 20 and 40.000 lbs and sheepsfoot rollers exerting 250, 500 and 750 psi also for layer compaction. A high density is produced initially, consequently the effect of compaction with respect to depth, as noted by Maxwell and Johnson, would not be expected to occur.

2. The observations reported by Turnbull and Mac Fadden pertain only to two specific soils, consequently no generalization of the effectiveness of light as compared to heavy rollers can be made. Experience of many Engineers of the U.S.A. has shown superior performance in some instances, of heavy rollers. It has been my observation, as initially reported in a paper this subject presented in 1939, that a fixed standard or yardstick of compaction should not be rigidly adhered to in all instances, but rather that the specification for compaction should be adjusted or designed to fit the situation with which one is concerned. For example in the instance of the Missisippi river (low level) dam and earth embankments (medium level) and airfield subgrades (high level).

Further, as pointed out by Messrs Turnbull and Mac Fadden, the tools for producing compaction should be selected to accomplish the results by the wellknown method of least work. In addition we should correlate the compaction produced in laboratories with that produced in the field so as to make certain that the condition of the material tested for design purposes correctly represents the condition in the ultimate structure. An initial step in this direction is reported by Mr. Du Bose. These facts and other observations and data show the definite need for more information on types of rollers, the effectiveness of various rollers for various soils and the design of compaction for the specific situation.

-o-o-o-o-o-o-o-

IX b 19

DISCUSSION

S.R. MEHRA (India)

In connection with the report presented by the General Reporter under subhead "Stabilization of Subgrades" there are a couple of points of practical value that I wish to amplify in connection with my paper in section IX. The need for modyfying the conventional method of gravel road construction arose out of the fact that gravel is scarce in many parts of India. The only alternative materials available are soft aggregates of little brick ballast, kankar, moorum etc. Used as such for road construction, these materials would readily crush under traffic vibration, within the body of the road crust and cause the breaking up of the interlock, resulting in pavement failure.

To prevent this, the percentage of soil fines in the mixture is so increased that a thin layer of soil surrounds every particle of granular material and, in addition to holding these particles together, acts as an elastic protective cushion between adjoining particles. It is also worth noting that whereas in a conventional gravel road the grading of the gravel is most important, it is the grading of the soil fines that is of paramount importance in the method described.

The method is applicable to all those countries where only soft granular is available at reasonable cost. I would also like to draw your attention to the use of stabilized soil in a large scale house-construction project, comprising the construction of 4000 houses. The subject is described in an additional paper: "Use of rammed cement soil in large scale house construction in East-Punjab". We should be grateful to know about the experience of other countries in this direction.

-o-o-o-o-o-o-

IX b 20

DISCUSSION ON THE USE OF SAND DRAINS

O.J. PORTER (U.S.A.)

First I might state that the sand drains have been used for 40 years in California without a single failure. They have been used on 14 to 16 highway projects and navy installations during the war, and also in several States of U.S.A., in Washington, Connecticut and in test installations in other places. They are now intensively used in stabilizing very bad conditions of parkways leading to La Guardia airfield. The tests at La Guardia airfield were succesful. When the drains had been used they contained columns of sand, mixed with various other matters and they had 80 cm diameter, and in one or two other cases there was a gauge with a diameter of 1 meter. It is possible that the drain goes to 150 feet in depth. The spacing of the drains has varied from 8 feet, for rapid consolidation under emergency conditions during the war, to 25 feet.

The drains are used for two purposes. First in case of airfields and highways, to obtain all the settlement during the construction period. And in the second place to increase shear strength. The spacing can be much greater as there is no objection in building the embarkment higher. The costs are twenty five dollar cents a foot to a dollar a foot. Four different methods have been used, but owing to lack of time I am not able to explain them to you today, After the methods have been developed better the cost will be reduced. Up till now the cost has more than paid for the profits of the installation of the drains.

-o-o-o-o-o-o-

IX b 21

WRITTEN DISCUSSION ON PAPER IXb 17

W.J. TURNBULL (U.S.A.)

Laboratory compaction has been expressed in terms of energy in several previous publications, but the measurement of field compaction energy and the comparison of laboratory and field compaction on the basis of energy is believed to be new. The procedure appears to have much merit and should be thoroughly investigated. The field compactive energy as proposed by the author is measured by drawbar pull. There are appreciable differences in the design features of various makes of sheepsfoot rollers and it appears reasonable to assume that all rollers do not compact with the same efficiency. It also seems that not all of the energy based on drawbar pull, would be consumed in compacting the soil but that some energy would be required to overcome bearing friction, the braking action of the cleaning teeth, sliding of the roller, and possibly, other factors. Hence, it is believed that the drawbar pull must be modified somewhat by factors yet to be determined before an accurate determination can be made of the energy consumed in field compaction.

It is believed that the author is in error in assuming that engineers believe that a linear relationship exists between the density and strength of a soil. It has been shown many times that this relationship is not linear.

In the Manual Method of compaction, preferred by the author, the soil is struck a blow with the compaction hammer rather than allowing the hammer to drop through a measured distance. It is difficult to understand how the personal element is eliminated in the Manual Method and consistent results obtained, although the author states that no difficulties have been encountered in seventeen years use of the method.

The data presented in Table 1 show that a definite relationship exists between compaction energy, density, indicated saturated penetration resistance, and shear strength. Based on these data there is no doubt that a reasonably accurate measurement of the shear strength can be obtained from the indicated saturated penetration resistance. The method of determining the indicated saturated penetration resistance (ISPR) is considered empirical, which is not objectionable in itself,but it is believed that the ISPR, determined on unsaturated specimens does not give a true picture of the strength of the soil when actually saturated. The data shown in the paper are consistent, but it must be noted that in all cases data are shown for specimens having water contents greater than optimum. In ordinary construction practice much soil is placed at or dry of optimum, and the applicability of the ISPR has not been shown for these cases.

Whether or not the ISPR actually indicates saturated strength need not prevent its being a valuable tool in compaction control, for the ISPR appears to plot in just as consistent a pattern as does the CBR or shear strength, and certainly is an easily determined value.

-o-o-o-o-o-o-

SUB-SECTION IX c

PHYSICO-CHEMICAL METHODS

IX c 17

DISCUSSION

A. MAYER (France)

We did not bring up the matter of consolidation of alluvial soil by grouting in Rotterdam because it had been discussed exhaustively in Stockholm. I would only like to give some information I was asked here about our work in Genissiat.

The problem there was to make an impervious screen under the dam in Genissiat, through the 30 m alluvial deposits which fill the Rhone valley. This was done with clay and waterglass grouts.

The clay used came from a cement factory where it was dried and ground. That clay was fine enough to pass through the voids on the alluvial material. The granulometric curves of this material and of the clay are in my report for the Stockholm meeting. The clay was treated chemically so as to remain in suspension in water. The grout was pumped into the drilled holes, 3" in diameter. In few cases only it was necessary to insert 2" pipes before raising the outer ones. No special difficulty occured except in one very porous area where the liquid flew into the soil without pressure. In spite of this high permeability we succeeded in making this zône watertight too, starting with a gravel clay cement mixture, to end with clay and waterglass.

The technical result of the work was excellent as the upstream cofferdam, which had been grouted, did not require constant pumping, where as this was necessary downstream, where sheet piles were used. Even the flooding of the site, during the war, and the pumping which took place afterwards did no harm to the screen.

What price conditions are concerned it may be said that the grouted screen did not cost more than the sheet piles. If something, the difference was in favor of the grouting method.

-o-o-o-o-o-o-

CLOSING REMARKS

G. WILSON (England)

I am greatly obliged to Mr. O.J. Porter and Mr. Spencer Buchanan for their remarks on compaction, and I am glad to accept Mr. Spencer Buchanan's correction regarding my comparison of the work of Johnson and Maxwell with that of Turnbull and McFadden.

Mr. McFeeters appears to have misunderstood the emphasis of my written report which was on the basic similarities between different methods of design and not on theoretical considerations.

I must apologise to Mr. McLeod for appearing to confuse his method of pavement design with that proposed by Professor Housel. What I had in mind was the similarity of Mr. McLeod's methods to those advocated by Professor Housel for the calculation of the bearing capacity of soil, and which I must confess I have never been able to understand.

-o-o-o-o-o-o-