Paper No. 5170.

"Engineering Problems Associated with Clay, with Special Reference to Clay Slips." †

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Mr. J. M. Lacey observed that one of the chief causes of slips in cuttings and erosion of cliffs was the surface-water at the back of the cutting or cliff. In that connexion he would like to draw attention to two Papers published by The Institution *.

Mr. A. R. Pollard thought that there seemed to be some doubt about the actual form assumed by the surface of a clay slip, and that further information on the matter was desirable.

Some years ago he had presented to The Institution a Paper entitled " Profiles of Earth Dams when Clay is partly or wholly used in the Embankment " ‡. In that Paper an attempt had been made to determine the changes of slope needed to ensure the stability of a high clay bank. That changing slope was referred to by Mr. Seaton (p. 497 §) and by Dr. Herbert Chatley (p. 487 §). According to the conclusions reached in Mr. Pollard's Paper ‡, a slope of 1 in 3 would be stable for a bank or cutting from 40 to 50 feet high where the clay was firm, as it would be in a well-drained bank or cutting. With wet clay the height would be 20 feet or even less.

Dr. Chatley, on p. 487 §, mentioned that the sliding surface was assumed to be circular, cycloidal or a logarithmic spiral. In his own Paper ‡ Mr. Pollard had calculated a curve of rupture, the shape being such that the horizontal thrust was a maximum, with the coefficient of friction decreasing as the height of the bank increased.

† Journal Inst. C.E., vol. 8 (1937–38), p. 457 (April 1938).

* R. B. Stanton, " The Great Land-Slides on the Canadian Pacific Railway in British Columbia." Minutes of Proceedings Inst. C.E., vol. cxxxii (1897–98, Part 2), p. 1.

* J. M. Lacey, " Littoral Drift along the North-East Coast of Kent, and the Erosion of the Beltinge Cliffs near Herne Bay." Inst. C.E. Selected Engineering Paper No. 72. (1929.)

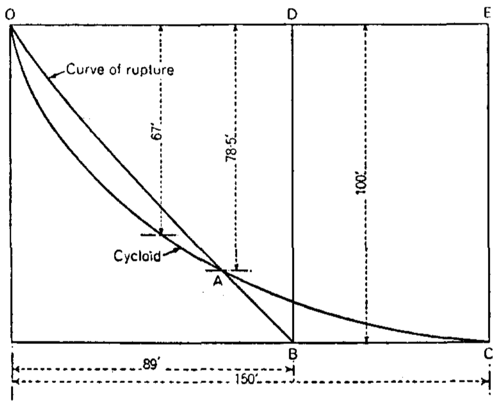
‡ Paper No. 4603. *Abstract published in* Sessional Notices Inst C.E., Session 1926–27, p. 98 (May 1927). [The MS. and illustrations may be seen in the Institution Library.—SEC. INST. C.E.]

§ Page numbers so marked refer to the Paper. (Footnote (†), above.)—SEC. INST. C E.

The curve of rupture and a cycloid were shown in *Fig. 15* for a bank 100 feet high made of clay that would not, by itself, stand at a greater height. The tops of the sliding surfaces at Folkestone Warren in 1915 and 1937 (*Figs. 13* and *14*, facing p. 477 §) seemed to resemble the curve of rupture much more closely than a cycloid.

The pressure against the surfaces DB and EC (*Fig. 15*) at various heights would be calculated by the methods used in his Paper ‡. The calculations showed that for heights up to about 19 feet the horizontal thrust from the cycloid was slightly in excess of that from the curve of rupture. Between heights of 19 and 67 feet the curve of rupture gave the greater horizontal thrust, but thereafter the pressure from the cycloid

Fig. 15.



was greater, which might be expected since, at the greater heights, the mass enclosed between the cycloid and the vertical line against which the pressure was calculated was much larger than the corresponding mass for the curve of rupture.

So far as calculations were concerned, the curve of rupture was much easier to work with than the cycloid, and could be safely used in preference to the latter when the height of the bank or the depth of the cutting did not exceed two-thirds of the limiting height of the clay.

Mr. E. F. Sykes, of Bundi, Rajputana, observed that, while working on the headworks of a Panjab canal, he had been concerned with hydraulic mortars; among other substances, he had made briquettes of clay. By " clay " was meant the alluvium thrown down by the rivers on the inside of their bends or in spill channels, and called in its early stages *Dal-dal* or " quicksand "; it was probably finely-ground rock from the ice in the back hills. Like Mr. Harold Berridge, he had found a remarkable

§ *Ibid.*
‡ *Loc. cit.*

strength in those briquettes, which like Mr. Berridge's, had sloughed when put in water. When, however, slaked lime had been mixed with the clay in varying proportions, the result had been very different. After a short period in damp sand, the briquettes could be cured in water in the usual way, with continually increasing strength. He had, in fact, made a hydraulic mortar. That suggested an entirely fresh approach to the problems with which the Paper dealt; namely, no longer to put up with the inconvenient properties of the material, but to convert the material into something else; that was to say, to convert clay into hydraulic mortar, which did not have the inconvenient properties of clay.

The appropriate method could only be determined by experiment, which, whether in the laboratory or the field, was extremely inexpensive. As a beginning he would suggest that in, say, a new bank or cutting, the formation-surface should have the lime puddled into it, in the shape of a turtle-back, and the surface of the slopes should be dealt with in a similar manner. If a cut-off were required, a trench might be back-filled with clay puddled with slaked lime.

The slaked lime used in his experiments was the nearly pure calcium hydrate that used to be known as "Miani lime."

Mr. F. L. D. Wooltorton, of Shwebo, Burma, thought that it was a great pity that the Author of the first Paper read before The Instituion for a considerable time having any bearing on soil-mechanics did not present his Paper in a more modern form. If the Author had adopted a more modern engineering definition for clay soils, his introductory remarks would not only have been more accurate, more interesting and their sequence more logical, but he would have found that his subject was far more extensive than he apparently imagined. There were many very troublesome clays which did not fall within his definitions.

The Author's general definition of clay was, if anything, misleading. There were, he felt sure, many clays in which plasticity was not of primary importance, and some in which plasticity was negligible, even for abnormal moisture-contents. The clays the Author designated as "laterite" would probably, in general, be non-plastic over very wide variations of moisture-content.

Plasticity as a predominant characteristic was associated with clay under one or two main conditions: (*a*) richness in inorganic material, and (*b*) having a clay fraction of a siliceous nature. Clays rich in sesquioxides showed little plasticity.

In dealing with the clay materials the Author did not appear to have differentiated between a clay soil and the clay fraction; between the primary non-colloidal clay-forming minerals such as felspar and pyroxenes, for example, and the secondary or fundamental colloidal crystalline minerals of the clay fraction, such as bentonite and halloysite.

Modern research as demonstrated by Messrs. Kelley, Dore and Brown, and C. E. Marshall indicated that the Author was incorrect in describing those colloidal minerals as amorphous. The modern view was that they were crystalline minerals, usually in the form of a gel, having a definite crystalline lattice structure.

The modern view further stated that, although those colloidal minerals were often present together and in varying proportions, yet a clay in any soil group subjected to a definite and geologically-prolonged weathering-process would show a predominance of, or entirely, a single colloidal mineral as the end product of that system of weathering. The production of kaolin was merely a particular case.

He doubted if it were correct to describe laterite and loess as clays without further qualifications. Laterite was certainly not a clay, though lateritic soil was. One was the end product of silica weathering, producing a rock-hard conglomerate material; the other was a very early stage which might never end in the formation of laterite, as exemplified by some red soils classified as terra rosa. Loess in semi-arid regions was often of a sand texture, although prolonged weathering to a chernozem would produce a clay.

The statement that if an unstable clay were allowed to dry out it would again become stable (p. 461 §) should be accepted with considerable caution. Such a condition would depend upon a number of circumstances. In engineering, to permit a foundation to dry out was to court trouble. Examples were on record where foundations were artificially kept moist.

Dr. Stradling raised a very pertinent question regarding the obtaining of information about soil-mechanics. Early in 1937, whilst on leave, Mr. Wooltorton had discussed that question with a member of the Imperial Bureau of Soil Science. Later in the year he understood that the Bureau were undertaking the compilation of a bibliography for the subject. Unfortunately most of the available information was in a foreign language or had been published in America. In either case he knew from experience that it was extremely difficult to obtain any written information from sources available in England.

The Author, in reply, observed that Mr. Sykes recalled an experience in which he mixed lime with clay obtained from the bed of a river in India, and found that he could make briquettes from the mixture which, when cured in water, had greater strength than briquettes made from the clay alone: further, briquettes made from the mixture were able to withstand the action of water without sloughing; Mr. Sykes pointed out that the mixture of clay and slaked lime functioned as a hydraulic mortar. Based on that experience, he suggested a method of hardening the surface of banks or cuttings in clay by puddling in lime, and thereby rendering the banks impervious to the washing and disintegrating effect of drainage water. Such a proposal, if successful, would offer an attractive means of

§ *Ibid.*

hardening a freshly-cut surface in a clay bank, but the Author considered it doubtful whether conditions in actual practice were similar to those applying in the experimental work carried out by Mr. Sykes, and on which he based his proposal. It would be recognized that in the preparation of those briquettes from the lime-clay mixture the curing and ageing took place under water, and therefore in the absence of carbon dioxide, which would be present if the mixture were exposed to the air; the carbonation of the lime would be prevented, and the interaction between the lime, silica and alumina to form silicates and silico-aluminates, which presumably was the chemical action causing the formation of the strong mortar, could proceed without interference.

In conditions applying in the field, however, the slaked lime would be subjected to carbonation by the carbon dioxide in the air at a rate which would probably be faster than that of the combination of the base and acids to form a hard mortar. It seemed also probable that the fine intermixing of lime and clay necessary to form a compact, homogeneous strong bed would not be secured. It might be that the tropical conditions under which Mr. Sykes' experiment had been conducted were a factor, but his suggestion was extremely interesting and might be worth investigating on a small scale under the cooler climatic conditions that applied in Great Britain.

Mr. Wooltorton dealt with an aspect of the Paper which had already been dealt with in the Author's reply to the Discussion (pp. 495 § *et seq.*), but he would reiterate that his Paper did not deal with the subject of soil-mechanics and that what was stated with regard to the material was intended only to be but a brief statement regarding its structure and characteristics, and as such was generally correct. The Author suggested that Mr. Wooltorton, in the penultimate paragraph of his observations, somewhat improperly took part of a statement which, shorn of its context, was not strictly true. It was, however, made quite clear in the Paper that the drying-out referred only to the surface and not to the whole mass of the clay. Methods were also suggested for rendering the surface stable. The Author noted with interest the last paragraph of Mr. Wooltorton's observations, and he hoped that the Building Research Station would supply the deficiency.

He was particularly gratified with the interest his Paper had created in the subject, and one of his objects would have been served if it resulted in more research work being undertaken in Great Britain in connexion with soil-mechanics, and also in the direction of assembling all the available knowledge of the subject for the guidance of the Civil Engineer.

§ *Ibid.*