11TH SEPTEMBER, 1890.

DANGERS ARISING FROM THE USE OF CERTAIN CLAYS IN EMBANKMENTS, DAMS, ETC.

BY ANGUS MACKAY, F.C.S.

IN complying with the request of the Council of the Engineering Association, that the author should submit a paper upon the changes that occur in certain clays, when used in embankments, dams, etc., and with special reference to the share taken by him in overcoming the dangers that during last year threatened the great reservoir dam at Prospect, it was cause for regret to him that he was unable to prepare and read such a paper at an earlier date. But, there is now available for professional purposes, the very able and exhaustive papers submitted to Parliament by the engineers who had charge of the investigations made at the request of the late Minister for Works, the Honourable John Sutherland, and which includes the evidence given by the author, and also chemical analyses of earths and clays which were the cause of the trouble. That paper is ample, he believed, for professional purposes, yet he willingly complied with the request of your Council to bring the subject still more fully before the Association with the view of getting at details that may be of use—of immense practical usefulness, he has no doubt—to the profession in dealing with clays of the Wianamatta series, as substances in the formation of earthworks, embankments, dams, etc.

That the result of our investigations may reach the points which seem to him of most importance, we must, at the outset, define the character and nature of clays much more closely than is usual in the general acceptance of terms which class clay as that species of earthy matter which is ductile and sticky, in contradistinction to the looser or more sandy earths which are free or comparatively so from the properties mentioned. There are very many characteristics in clays additional to what may be termed "plastic," "sound," "meagre," "pipe," or "brick" clays, "faulty," "spewy," "slurry," "rotten," etc., etc. Clays are, in reality, amongst the most intricate of earths, their qualities are not to be got at by off-hand casual examination. In some most important particulars they differ from the general laws which appear to regulate the behaviour of inorganic and organic substances. Thus, most bodies expand by heat, and contract by cold. The clays we are concerned with reverse this very general law of nature; they contract by heat. Then, they are enormous absorbers of water. Some of them will take up and hold over twice their own weight of water after drying. In the case of some of the clays examined at Prospect, which he was assured were quite dry, they were found to hold over 30 lbs. of water per cubic foot. These clays have the further property of dissolving water, and absorbing the oxygen that it contains, thus bringing about changes which alter their nature, and what is of still more consequence in an embankment or dam, increasing their bulk and lowering their powers of cohesion. By drying a clay in the open air, and observing its behaviour and the changes that occur from contact with the atmosphere and rain, its appearance when rubbed, whether gritty between the teeth and similar tests, a good deal can be learned concerning it. Such investigations may be sufficient when moderate masses of clay matter have to be moved in order to form embankments. But when great masses of material of the kind have to be changed from the beds where they lie in the state of nature, and then placed in position where absolute solidity is required, and the mass has to resist the heavy sudden pressure of loaded trains, or the still more disturbing influences of moving masses of water, it seemed to him a serious responsibility to go on with such work without the more definite examination which is reached only by minute chemical analyses.

It was not his purpose, in this paper, to enter upon any lengthened disquisition concerning either the general formations or the chemical composition of clays. They are very various. Those with which we are immediately concerned—the clays of the Wianamatta shales and the Hawkesbury sandstones series, are dealt with, possibly to a sufficient extent, in the analyses submitted by him concerning the Prospect dam. In addition, he might add that other clays he had examined are composed of alumina (or true clay matter), silica, iron in various forms, water, and sulphuric acid; others contain no iron; and others contain potash, as much as 6 atoms per 100. Pure clay is by no means plentiful. An immense field for investigation is opened by examination and analyses of N. S. Wales clays, some of which are rich in the wonderful metal aluminium, and which might well make us hope for such a discovery, at no distant date, as would bring that immensely valuable metal into general use. But, for the purposes of the investigation with which we are at present concerned, the following report, submitted to the Minister for Works, and which appears at pages 71-2 of the Parliamentary Paper mentioned, may prove ample:

Technical College, Sydney,

31st December, 1888.

Re Prospect Dam.

Dear Sir,

As coming within the scope of investigations I have been making into the soils of the colony, considerable attention has been given to the nature of the clay and soil used for forming the puddle-wall and for making up the sloping embankments of the Prospect Dam; and as I now feel certain of having discovered the cause of the fretting away or weathering of the material used in the earth-work, and the consequent alarms which have arisen concerning the safety of the whole structure, I take the liberty of submitting the following for your consideration.

You will see that the cause of disturbance is more of a chemical than a mechanical nature.

On examination of the stuff used for building up the earth embankment on the reservoir or inside slope of the work, I find it to be made up very largely of a peculiar species of clay, common to the Wianamatta shale formations of the metropolitan district. This clay is largely composed of silicates of iron, and is acted on rapidly and visibly by exposure to air, rain or water. It shrinks in bulk as a first change, it then cracks and oxidizes rapidly, changing to yellowish and reddish clay loam, of a character different essentially from the original clay. These are some of the chemical changes that occur, as I have had frequent and minute occasion for observing in connection with the cultivation, trenching, and draining of the Wianamatta shale soils—the clays especially, for orcharding and other purposes.

The mechanical effect of the chemical changes have become very visible at the Prospect Dam works. As the shrinking and oxidation proceed, the silicious or sandy portion of the clay matter tends downwards, it being very much the heaviest; while the oxidized and loamy portions of the clay earth become so lively, especially when saturated with water, that they float or wash away. This is, in reality, what has been going on at the Prospect Dam, ever since water was brought into contact with the clay soils of the inside slope of the work; and the process must continue to go on until the oxidation and chemical changes are complete, and the soil settles down into regular loamy strata or layers.

The question then is, how can these consequences be met? And this, I have not a doubt, will be found a much less troublesome matter than at first sight appears. It will be seen that if any extra heavy material, such as stone, is placed on top of earth undergoing the chemical changes, and under the conditions mentioned, the result will be to press out the lighter portion of the material—which analyses, in this case, let me say, is nearly one half of the whole—the stone sinking downwards by the displacement. Where the soil is in contact with water, as in the case where slips outwards have occurred at the Prospect Dam, the process is very rapid, the light stuff being literally spewed out upon the water, where it is forming ugly blemishes upon the magnificent proportions of the huge earthwork.

I would suggest that, as the changes going on in the embankment cannot be stopped, the better course would be to meet the alterations as they occur, and so aid in the process towards absolute solidity. This can be done by using water from the reservoir to soak—not to saturate—the soil. This would increase the process of oxidation, the sinkage and shrinkage being met by applying loamy soil, which would be washed into any small cracks or crevices. Large gaps and slips could not occur under this course of treatment. Thus the material of the embankment would solidify gradually downwards upon the solid earth below and against the puddle-wall behind. The said puddle-wall is, to every visible appearance, a most solid and perfect work.

Examination of the whole earth embankment along the inside face of the dam shows that the changes mentioned have occurred most rapidly where the greater proportion of loose clay matter has been deposited, and where the westerly winds have had fullest opportunity for exerting their influences. This is just what might be expected. If all the bank facing the water had been of loamy earth no such rapid changes would have been likely to occur; and it might be worthy of consideration whether, where such masses of material have to be dealt with, it would not be a desirable course to have chemical analyses made, in order to have a knowledge of the changes which must occur when the stuff is moved and placed under different conditions from its natural state. Where clay has to be dealt with, so intricate and obscure is much of it in composition, that investigation of the kind seems to me a very necessary proceeding, to ensure safety.

In order to meet the fretting or weathering action upon the earthwork slope by the water in the reservoirs, when moved into wavelets by the winds, I would suggest that slabs of colonial hardwood—which does not float, being more dense or heavier than water—would answer the purpose of protecting the moving earth below. They could be fastened so as to lie upon, without pressing or shifting, the material under them ; and as the stuff settled down solid the stone cubes could be laid in position, as being the very best material for the purpose.

I have now the pleasure of submitting the foregoing for your attention and consideration in such manner as you may consider most fitting, either in a private, or public sense. I do not intend doing anything more in the matter. My desire has been to try and help to get at the cause of the troubles at Prospect Dam. The leisure of a brief holiday, and the use of the apparatus in the Agricultural Department here, have made the investigations possible and pleasant. I will be glad to give any further information in my power, either to yourself or to any of the professional gentlemen concerned, whom you may entrust with the same. I will be in Sydney during Wednesday, Friday, Saturday, and Sunday, January 2nd, 4th, 5th and 6th. I leave for Port Macquarie, Monday.

I have, etc.,

ANGUS MACKAY, F.C.S.,

Inst. Agriculture, B.T.E.

The author wishes it to be clearly understood that in all the steps taken by him in connection with the Prospect Dam investigations, he was careful that no reflections should be cast upon any of the professional gentlemen who had been or were engaged in the work ; and this for the simple reason that neither at that time, nor since then, did he consider that blame was attachable to those who had carried out the operations. The changes that were taking place, and the changes especially in the earthwork embankment facing the waters of the reservoir, had all the characteristics of novelty. No such huge masses of Wianamatta clay shales had been moved previously into one work. The alterations going on, therefore, were unforeseen, as part of embankment-forming experiences. His own acquaintance with the clays and other soils of similar formation had been made from quite another direction—that is from the processes of minute examination and analyses of the agricultural chemist, whose labours lead him into more intimate relations with the nature, composition, and changes in soils, clays, etc., than is considered necessary for the purposes of the railroad or hydraulic engineer. When the alarm concerning the movements in the dam earthworks at Prospect was at its height, the idea caught him that possibly the changes going on were similar in character to those under his observation at that time upon clay soils from near Hornsby, and another part of the same Wianamatta series. So, on his own responsibility, he spent several days about the Prospect works, and being assured that he had got at the cause of the trouble, it became a duty to communicate with the chief of the Department concerned. Hence the foregoing report.

After consultation with his advisers of the engineering branch, the Minister called on the author to give evidence for the experts called in from the other colonies. That request was complied with. The evidence goes over much the same ground as the foregoing report, and appears in full at page 52 of the Parliamentary paper. Then came a further request that he should examine, analyse, and report upon the soils and clays at Prospect in the most exhaustive manner possible. That final report solved the difficulty, he believes, and as it gives the most definite information yet worked out concerning these clays, he offers it in full, from pages 84-5-6, of the Parliamentary paper:

Technical College, Sydney,
28th February, 1889.

Sir,

In response to request conveyed in your communication of January 9th, I proceeded to the Prospect Reservoir in order to get specimens of the clay and other material of which the dam is constructed.

The Engineer in Charge, Mr. Ryan, promptly placed the necessary facilities at my disposal, and by means of auger rods (bores having been put down in parts of the work where the process of disintegration is going on, and again where the stuff has "slipped" or moved forward by gravitation from its original position in the bank) I got the material dealt with in the analyses as Nos. 2 and 3.

The No. 1 material is the raw unworked clay taken from the bed of the watershed, from which, as I am informed, was got the bulk of the clay for forming the puddle-wall, and a large proportion of the stuff used in the protecting embankment which faces the Reservoir, and which is now in contact with the water.

The No. 4 is the loamy earth which covers and faces the Prospect Quarry, and is of the type of which is formed that portion of the embankment facing the water which has given the least, if any trouble. This latter material is of volcanic origin, it is true; thoroughly oxidized earth that is not likely to move or separate were it placed in masses of any conceivable size. It affords all the properties which should make perfect reliable material for an earth embankment formed on correct lines, and which has to resist disturbing atmospheric effects, or from being in contact with, or possibly saturated with water. This latter material does not alter—in a mechanical sense—on exposure to the weather, air, or water, and is thus the very opposite of the clay material of No. 1.

Plate X. shows from where Nos. 1, 2, and 3 were taken:—

In order to get at the real character of the substances, they have been tested by mechanical and chemical analyses, by microscopic examination, by weight, and specific gravity, with the following result:—

No. 1 Mechanical analysis of clay matter from the Wianamatta shale series—already described in a former report—yellowish-white in appearance, as taken from the natural bed, where it lies unaltered by air exposure. It weighs 165lb. per cubic foot; when dry, 143¾lb. per cubic foot. It yields 31 per cent. of very fine sandy matter which, under the microscope, appears as rounded grains of quartz sand, white in colour, and which weighs 170lb. per cubic foot. 69 per cent. of the whole is very fine silicate of alumina, plastic, and which, for ordinary purposes, is true clay matter of very fine quality. For making puddle it is not easy to find anything better.

Chemical analysis shows:—

	Per cent.
Moisture of combination and organic matter (the latter fractional)	9·7
Sandy and dry matter, insoluble in strong acid	86·755
Alumina and iron	2·37
Sulphuric Acid	0·11
Lime	0·22
Magnesia	0·12
Undetermined matter (alkaline)	0·725
	100·000

This material, owing to its close density, the weight of other clays over it, and the enormous proportion of fine clay matter present in its composition, would remain unaltered for all time in its natural bed; but, when moved and exposed to the air and the changes of contraction and expansion, arising from drying winds and wet weather, it alters in a remarkable manner, as we see from the next analysis of the stuff (No. 2.) taken from the inner face of the embankment where the "slip" had occurred, and from below the water level in the reservoir.

No. 2 plastic clay-like material, showing reddish veins and streaks. Weight, 172lb. per cubic foot; when dry, 151lb. Masses of particles of hard oxide of iron are visible under the microscope. Oxidation, or separation of the sandy from the fine clay matter is going on rapidly in this material. 14 per cent. of sandy matter separates freely; the remainder, 86 per cent., is coarse clay, coloured by the oxodized iron, and is still undergoing separation.

Chemical analysis shows:—

	Per cent.
Moisture of combination and organic matter	9·31
Sandy and clay matter, insoluble in strong acid	83·257
Alumina and iron (peroxide)	5·857
Sulphuric acid	0·11
Lime	0·23
Magnesia	0·095
Undetermined matter (alkaline mostly) ...	1·151
	100·000

That a great change has taken place in this material, in comparison with the raw stuff from the undisturbed bed below, is very evident. The increase of weight and presence of nearly 6 per cent. of alumina and oxidized iron, show what has been going on and what must go on till the oxidation is complete.

No. 3. Matter got from below the level of the water in the reservoir, and outside of the original slope of the embankment. It is, in reality, part of the stuff that has "slipped," or moved forward, because of the chemical changes brought about by contact with the water in the reservoir, which movement is increased by the pressure of heavy material above.

As taken from the boring tool, it weighs 120lb. per cubic foot; when dry, 96lb.

Further separation gave 47 per cent. of very fine clay matter, weighing 70lb. per cubic foot—which is but slightly heavier than water. This stuff really floats in water for several days before it settles.

It seems very likely that if further tests are applied, and the matter that has moved furthest into the water can be reached, it will be found to be still lighter; indeed, that the mass there is but very little heavier than water, and therefore, most difficult stuff to retain in position in the presence of water in a state of movement—as the case is in the reservoir at Prospect. Under the microscope, it is seen to be a mass of very fine aluminous matter, with but little sandy or silicious stuff.

Chemical analysis shows :—

	Per cent.
Moisture of combination and organic matter	14·50
Clay and sandy matter, insoluble in strong acid	75·10
Alumina and iron	10·00
Traces only of sulphuric acid and magnesia.	
The lime has all disappeared	......
Undetermined matter	0·40
	100·00

No. 4. Earth from the surface embankment of bluestone quarry, from which broken metal and cubes are got for facing the inside embankment of the reservoir. This is very decided volcanic material, and which shows the process of oxidation still going on very rapidly in the rock. In the soil the change is practically completed, and hence, that part of the embankment made up largely of stuff of this kind, is not influenced by the weather changes or contact with the water. Mechanical analysis gives 48 per cent. of very fine silicious matter, which the microscope discovers to be coated with oxidised iron. The remainder is fine aluminous earth. As gathered during a dry day, the earth weighs 119lb. per cubic foot. By drying at an even temperature of 212°, 25lb. of water per cubic foot of soil is evaporated.

Chemical analysis shows :—

	Per cent.
Organic matter and combined water ...	22·50
Sandy matter and loss	28·65
Alumina and iron	47·00
Lime	·60
Magnesia	Traces
Chlorine = Salt	·90
Potash	·20
Sulphates and Phosphates	·15
	100·00

Several minute tests were applied to this soil, as also to the others, in order to get at any changes likely to occur by saturation with water. The only observable change in No. 4 was that it gave off distinct traces of chloride = sodium (salt), and magnesia, which affected the water and made it sweetish.

The violent changes observable in connection with Nos. 1, 2, and 3, and which are referred to fully in the former report I had the honour of submitting to your Department, do not affect this earth (No. 4). Hence my reasons for recommending it and other earths in which oxidation has been completed for the formation of such works as those at Prospect, where in process of time the earth facing the water must become saturated.

It will be seen that, when tested closely, the driest of the clays (No. 2), and which in general observation is supposed to be dry, actually contains 21lb. of water per cubic foot.

I think it will be seen by the foregoing analyses that the cause of disturbance in the embankment is due to the character of, and the consequent oxidation of the large masses of clay matter (No. 1) lodged there. When saturated, the heavier portions of the mass separate rapidly and gravitate downward. In the face of any movement in the mass, which may arise from wind, storms and agitation of the water of the reservoir, the movement must be very rapid, and where there is pressure above the mass, either of stone, earth, or lodgments of rain-water, the change will be accelerated, and accounts in full, as it appears to me, for the changes that are going on in the work referred to, and which may have the effect of loosening the puddle-wall behind, by the removal of its supports.

The state of No. 3 proves further that the lighter portions of the material have been pressed, or floated, outward in large masses, thus tending to still further remove the support the embankment was erected to give.

I can but reiterate the suggestion made after the first investigations, and submitted in the former report, that, as oxidation of this huge mass of matter cannot now be prevented, the better course is to humour it, and to encourage the whole mass to settle in natural strata or layers. Oxidation of the character and dimensions mentioned may be controlled, it cannot be stopped. No human agency can do it; but much mischief may be done by attempting to force this natural manifestation of nature.

In conclusion, I would again suggest the desirability of having chemical examination and analyses made of clay and other materials that have to be moved in masses, in order to make those in charge of the works acquainted with the changes which must take place when such matter is moved and exposed to the influences of the weather under conditions which differ essentially from that of their natural state.

I have, etc.,

ANGUS MACKAY, F.C.S.

In the existing conditions of human affairs, embankment and dam working, the ethics of engineering, chemical analyses, etc., included, it is scarcely to be expected that all of us can agree upon such a very simple discovery as that made by the author concerning the changes that aroused so much alarm for the safety of the Prospect Dam. Personally, he never had a doubt of the safety of the work. It is a magnificent outcome of engineering skill, and a credit to New South Wales; he would be of the very last to detract from the good work done there. It is no ordinary pleasure to add that the efforts made by him were accepted in the spirit they were offered—that was to help rather than embarass during a time of serious public excitement. Of course, in summing up all that had been done, those who drew up the report dissented from some of the conclusions he had arrived at. That was all right, of course, and was expected; but the data was acted on all the same. And there have been no alarms since. The long continued wet weather has been immensely beneficial in aiding the changes going on, and in consolidating the work; and he quite agrees with Mr. Mesteyer, who says, at p. 22 of the report:

"The mechanical action of the water has, I believe, been the principal cause of the movements that have taken place, but the evidence given by Mr. Mackay goes to indicate that this action has probably been much intensified by the chemical decomposition of some portions of the material, notably the clays, which under the influence of moisture rapidly oxidise, and in so doing increase considerably in bulk. My own observations on the behaviour of these materials when exposed to the influence of water and air entirely confirm this, and the expansion of the clays, due to their chemical decomposition, would call into action a force tending to move the bank bodily towards the water, even if the angle of repose were more than has been provided for. If the movement is due to this action alone it will soon cease, and when that occurs the bank will rapidly consolidate."

In conclusion, the author has not a doubt that the work should stand for generations—a lasting monument of engineering skill in New South Wales. But seeing how little is the trouble and expense attached to chemical analyses, he might add that in future that safeguard should be applied before risking the movements of masses of clay matter heaped up in embankments, dams, and similar works, where alterations in, or shifting of the material may lead to very serious consequences.
