

in some cases with gravel and clay mixed, a rubble or bush drain being previously laid in from the back to the front. The thickness of this gravel buttress (G) was from 6 feet to 12 feet, according to the size of the slip, and the same circumstance regulated the distance between the buttresses, which were united and mutually supported at the foot, by a retaining wall, or footing of gravel (F) running the whole length of the slip; the top of the slip was pounded tight, and the face trimmed off. This plan has been perfectly effective, at once supporting and draining the slip, while it was a far less expensive method, than removing the slip and trimming back the slope, and avoided the necessity of so many obstructions to the traffic of the railway, which would have occurred in removing the spoil along the main line.

Water in these and most other cases, appeared to be the ultimate cause of all the slips; the drainage, therefore, of the slopes, as recommended by the author, in both cuttings and embankments, is a consideration of the utmost importance, and where, as in the system above-named, it can be united with a means of opposing weight to weight, it may fairly be presumed, that the cure is permanent and complete.

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Mr. Cowper said, that he should be inclined to attribute the slips Mr. E. Cowper. to the expansion of the clay, from the action of water. He had recently examined the retaining walls, on the London and Birmingham Railway, in the cutting near the Euston Square station, and had found they were, in several places, forced forwards, apparently by some action behind them. This action was irregular, for its effects appeared indiscriminately at the top, at the bottom, and in the middle of the retaining walls, which were built of brick, generally about 5 feet 6 inches thick at the bottom, and 2 feet 6 inches at the top, with a curved face. Wherever the wall had been removed, for the purpose of rebuilding it, the face of the clay behind appeared to stand quite straight, without any fissure. He was therefore induced to think, that water descended to various depths, according to the degree of permeability of the clay, and as far as its action extended, expansion took place. If the whole mass had expanded, from having been exposed to the action of air, before the face was covered with brickwork, the entire wall would have been moved forward, which was not the case.

General Pasley said, that from his observation of the usual character of slips, he was induced to think, that the slopes were generally Maj.-Gen. Pasley. too steep; 2 to 1 had been considered sufficient for almost all kinds of earth, although Sir Henry Parnell, in his Treatise on Roads, said, "When it is necessary to make a deep cutting through a hill, the slopes of the banks should never be less, except in passing

through stone, than 2 feet horizontal to 1 foot perpendicular; for although several kinds of earth will stand at steeper inclinations, a slope of 2 to 1 is necessary, for admitting the sun and wind to reach the road.”\* The same authority stated,† “in the London and plastic clay formations, it will not be safe to make the slopes of embankments or cuttings, that exceed 4 feet in height, with a steeper slope than 3 feet horizontal to 1 foot perpendicular. In cuttings in chalk, and chalk marl, the slopes will stand at 1 to 1. In sandstone, if it be solid, hard, and uniform, the slopes will stand at  $\frac{1}{2}$  to 1, or nearly perpendicular.” “There are many instances of slips in sandstone and marl strata alternating (when the line of road is parallel to the line of the bearing of the strata), where the slopes are as much as 4 to 1.”

General Pasley had arrived at the conclusion, that 3 or 4 to 1 ought to be given, in order to insure good work; he had, therefore, authorized the railway companies to take possession of land, to increase the inclination of their slopes.

It was remarkable, that the slips rarely occurred during, or immediately after, the formation of the cuttings; it would appear therefore probable, that the movement was caused by the combined action of the air upon the surface, and that of water, which had percolated through the upper strata, and acting behind it, forced the earth forwards in the line of least resistance.

He believed, that a series of gravel counterforts, with a revetment at the foot, was the most effectual method of preventing slips. On the South Western Railway, hard chalk had been used with good effect, instead of gravel, for that purpose.

The perfect drainage both of the surface of the ground, on either side of the cuttings, and of the slopes themselves, was of the utmost importance. On the Eastern Counties Railway, shafts had been sunk at intervals in the slopes, and filled up with dry rubble; from their bottoms, iron pipes proceeded to the face of the cutting (Fig. 10, p. 162); these had proved effective in draining away the water.

With regard to embankments, he was of opinion, that if more attention was paid to forming them only in propitious weather, placing the material in thinner layers, in a concave form,‡ and draining them well, as the work proceeded, the result would be more satisfactory, and less expensive, not only in the first cost, but in subsequently avoiding slips.

\* “A Treatise on Roads, by Sir H. Parnell, Bart.” 2nd Edition, 1838, page 83.

† Ibid., page 87.

‡ Vide “Description of the Formation of the Embankments of the Bann Reservoirs, by J. F. Bateman.” Minutes of Proceedings, 1841, p. 169.

He thought, that in situations of difficulty, advantage would arise from the employment of wooden stages, like those which had been used by Mr. John Braithwaite at the Colchester embankment; the traffic of the railway was there carried on, over the wooden viaduct, until the subsidence of the earth had ceased, when the timber work was either cut off, or drawn out, as the contractor found least expensive.

Mr. Bruff remarked, that the timber viaduct at the Colchester em- Mr. Bruff.  
bankment, was only adopted in consequence of the extreme subsidence of the material, which had assumed a slope of 6 to 1; he had seen the same material, which was plastic clay, stand well at a slope of 2 to 1. If an embankment was formed with that material in a wet state, it would inevitably spread at the foot.

The cuttings of the Eastern Counties Railway had remained open for 2½ years, but owing to the nature of the soil, the water would not drain from them.

Mr. Phipps corroborated the statement, relative to the use of the Mr. Phipps.  
timber viaduct on the Eastern Counties Railway; it was only an expedient to enable the railway to be opened, at an earlier period than it could otherwise have been, in consequence of the subsidence of the embankment, which however now stood very well.

He approved of the formation of embankments, by depositing the material in thin layers, and by several lifts; the embankment was, by that means, rendered sounder, and less liable to slip.

Dry shafts and gravel counterforts had prevented many slips, but he thought, that sufficient time had not elapsed since their adoption, to enable an unqualified approval of them to be given. The pipes which had been inserted into the clay slopes, did not appear at present to draw away much water.

Mr. Braithwaite said, it should be remembered, that the soil at Mr. F. Braithwaite.  
Brentwood Hill, was very different from that on the Croydon Railway. The Brentwood sand was so full of water, that when it was opened, it appeared semifluid, like a quicksand; the gravel counterforts, which had been effectual in stopping the movement of the London clay, would have but little effect in sand of such a quality as he had described.

He had seen much of the London clay, in sinking wells, and it was notorious to well-sinkers, that even in the absence of moisture, if the London clay was left exposed to the air for a few hours, expansion took place, and the surface of the cutting began to fall away; by this expansion, the walls of wells were frequently fractured, unless allowance was made for it.

He could not agree with Mr. Cowper, as to the cause he had

assigned for the partial action upon the walls of the Euston Square cutting. The London clay was impervious to water, therefore it could not arrive at the different parts of the wall, unless the line of junction, between that clay and the pervious superstrata, was very irregular in its course, as compared with the inclination of the railway.

**Maj.-Gen. Pasley.** General Pasley coincided in the opinion, of the difficulty of working a material like the Brentwood sand, which was mixed with silt and quicksand, and demanded more than ordinary care: he thought, that such ground should not be worked upon at all in wet seasons.

He believed, that in many cases, slips had occurred, in consequence of the too great proximity of side cuttings, by which the ground between them and the foot of the embankment, was too much weakened. He had in some cases recommended, that the side cuttings should be filled up, in order to consolidate the embankment.

**Mr. C. H. Gregory.** Mr. Gregory believed, that the expansion of the clay, was in some degree (but not entirely), the cause of slips. The blue clay was impervious to water; the yellow clay permitted the water to traverse it freely, by the natural joints and fissures in it, and also by those which were formed, by the drying action of the air upon its surface. When the face of the bed of the blue clay was softened by the action of water, and its surface became lubricated, there was not any longer sufficient friction between the strata, to retain the weight of the superposed yellow clay, the mass of which, on the slightest impetus being given by expansion, travelled forward down the inclined strata, which in the case of the New Cross cutting, was towards the railway.

He had tried the insertion of pipes into the sides of cuttings, and almost every other kind of drainage, without effect, and he was of opinion, that the general saturation of the mass, was the cause of the slip in the New Cross cutting.

**Mr. Hoof.** Mr. Hoof said, he had executed the greatest portion of the works on the Croydon Railway; his experience induced him to agree with Mr. Gregory in the statements contained in the paper, and in the reasons he had assigned for the causes of the New Cross slip.

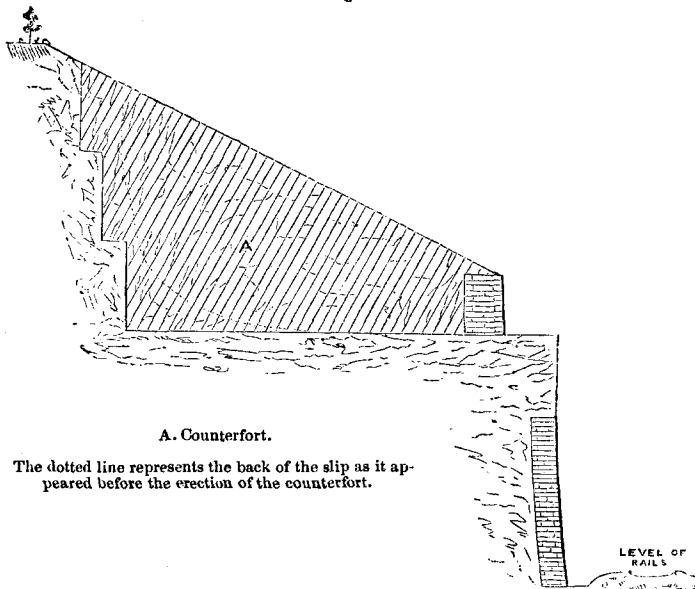
**Mr. J. B. Dockray.** Mr. Dockray doubted the advantage of the benches in the face of the slopes; he thought, that they not only caught and absorbed all the rain, but also a great portion of the water, from the drains of the upper part of the cuttings; a well-drained slope, at a regular angle from the top to the bottom, would, in his opinion, act better.

He had observed, that the slips on the London and Birmingham Railway, generally commenced, either in the line of the fence ditch, or in that of a catch-water drain, or at some natural or artificial

obstruction, which prevented the free passage of the water, over the surface of the slope, into the ballast drains. He considered it of great importance, that the surface water should be carried off as rapidly as possible, and that it should not be permitted to lodge on the slopes, or in the drains; from whence it could only escape, either by evaporation, or by absorption into the ground: it was to the gradual operation of this latter cause, that he attributed most of the slips in clay cuttings.

In repairing such slips Mr. Robert Stephenson had used a plan, (Fig. 5,) which had hitherto proved very successful. He regarded

Fig. 5.



A. Counterfort.

The dotted line represents the back of the slip as it appeared before the erection of the counterfort.

Section of the Slope in the Blisworth Cutting, London and Birmingham Railway.

the slip, simply as a mass, moving down an inclined plane, by its gravity, and he proposed to counteract that tendency by friction. This was effected, by dividing the slipping mass into vertical sections, by excavating perpendicular chases, 5 feet wide, and passing completely through the slip, down into the solid clay below; these chases were 15 feet apart, and were filled up with rubble masonry, or with chalk or gravel, well rammed down, so as to form a solid immovable mass. Thus the slip was divided into a number of isolated portions, of comparatively small dimensions, each side of which, came in contact with the side of a counterfort, and the friction between the masses,

had, in every case, proved sufficient to retain the slip from further movement.

This mode of repair, was first adopted about 5 years ago, and had since been extensively used, in repairing the numerous slips, in the slopes of the cuttings, of the London and Birmingham Railway.

Mr. C. H.  
Gregory.

Mr. Gregory stated, that similar counterforts, with a revetment of gravel along the foot, (Figs. 3 and 4)\* had been tried with good effect, on the Croydon Railway. He had understood, from military engineers, that thin revetments with long deep counterforts, bore a heavy fire better than thick revetments without them. He was well aware, that slips were frequently occasioned by catch-water drains on the face, or at the top of slopes; on that account, his attention was constantly directed, to uninterruptedly keeping up the surface drainage of the earth-works under his charge.

Mr. J.  
Taylor.

Mr. Taylor believed, that the mechanical action of water, produced many of the effects which had been mentioned, but the chemical action upon clays, and even upon solid rocks, must not be overlooked. He would instance, particularly, the well-known action of the air upon shale, which although so tough and hard under ground, as to require the agency of gunpowder for its excavation, became, after a few weeks' exposure to the air, thoroughly decomposed.

Decomposed granite, called by miners 'pot grawn,' was extremely troublesome in mines; it consisted principally of felspar and potash, and was the China clay (Kaolin) so much used in potteries.† This substance would appear to have been formed, by the decomposing action of the air, or of chemically-formed oxygen.

Pyrites, which appeared to have abounded in the strata of the New Cross cutting, not only had a natural tendency to decomposition, when exposed to the action of air, but also affected every thing with which it was in contact.

It had become fashionable to account for all changes, by attributing them to the agency of electricity, and since the interesting researches of Mr. Fox, of Falmouth, there was much reason for believing, that electricity was capable of producing these wonderful changes. It was easy to understand, that as soon as chemical action began, electricity might be generated; its flow would be conducted through the fissures and veins of mineral substances; decomposition of the existing material proceeded, and other forms were assumed; this action could not be continued, without a corresponding alteration of the bulk of the mass, and when it reposed on an inclined bed, of which the surface was covered with a semifluid film, such as the London clay was de-

\* Page 144.

† Vide 'Minutes of Proceedings,' 1843, page 154.

scribed to be reduced to, by the solvent effects of water, the slightest expansion or contraction would suffice to set the whole superstratum in motion, and to produce the slips.

Primary rocks were subject to the same effects, and in sinking through porphyritic rocks, fissures were frequently found, filled with foreign matter, which swelled and forced in the sides of the shafts, when such an event was least expected; such occurrences could not be guarded against, as the direction of these fissures was usually parallel with that of the shaft.

Mr. Taylor agreed in the necessity for the precautions which had been mentioned, in cuttings and other railway works, and that it was generally only in such strata as clay-slate, granite, or other primary rocks, that works could be left without artificial protection. He had driven, on the line of the Tavistock canal, a tunnel of  $1\frac{3}{4}$  mile long, through clay-slate, and granite, which stood perfectly without any internal arching.

Mr. Smith said, that although he had but little experience in the formation of cuttings or embankments, he had devoted much attention to surface drainage. He had been surprised at the visible want of the precautions, which he conceived necessary, to prevent the saturation of the slopes, and their consequent degradation. The back drains, which were frequently carried along the top of cuttings, were objectionable, and were likely to cause slips. Mr. Smith,  
(Deanston.)

Slips were also, probably, caused by the alternate contraction and expansion of the clay, under exposure to changes of weather. From experiment it was ascertained, that clay occupied  $\frac{1}{4}$ th or  $\frac{1}{5}$ th less space when dried, than when in situ. It could be imagined, that during the summer, the combined effect of the sun and the wind, formed cracks on the surface; the crumbling of the edges of these fissures partially filled them: the rain which fell in the winter, or was brought by the catch-drains from the neighbouring land, tended to restore the clay to its original bulk, but the fissures being prevented from closing, by the crumbled clay within them, which also swelled from the wet, the whole mass expanded in the line of least resistance, which was towards the cutting. This process being repeated, during several succeeding winters, would at length cause a slip.

The best method of prevention would, he thought, be a greater attention to surface drainage in the line of the slope, so as to carry off the water very rapidly. This had been attempted, by working the surface into parallel furrows and ridges, from the top to the bottom of the slopes; but neither those, nor the covered drains were alone effectual. The latter were not deep enough, they should be 5 feet or 6 feet beneath the surface at the bottom, and 3 feet at the top of the

slope, and not more than 16 feet apart, so as to be sufficiently close together, to collect and to carry off all the water that was not conducted down the slopes, by the furrows on the surface.

The gravel counterforts formed drains, and thus, he conceived, were more beneficial, than by increasing the friction between the masses, which could have but little effect, when once the mass of material was thoroughly saturated.

If embankments could be formed in very thin concave layers, equally spread and beaten down, in dry weather, while the clay was in hard lumps, leaving interstices, which, for a long time, would permit any water falling upon it to traverse freely, until the whole mass was consolidated, there would be but little subsidence. He was aware that this plan was too expensive, but the nearer it could be approached, with due regard to economy, the better would be the effect; whereas, by the present system of making embankments in all weathers, when frequently the whole mass was so thoroughly saturated, that it could never dry, nothing but failures could be expected.

Maj.-Gen.  
Pasley.

General Pasley said, that he always supposed the gravel counterforts were intended to act as drains, at the same time that they gave increased friction, and broke the continuity of the mass of earth, limiting any slip that might occur, to the extent of space between two counterforts.

Mr. Hawk-  
shaw.

Mr. Hawkshaw thought, that arbitrary limits could not be assigned for slopes in given strata; the different conditions under which the same strata appeared, in different localities, precluded any general law. Clay, which in a wet situation required a slope of 3 to 1, would in another position, stand well at 2 to 1. In the Andes (South America), he had seen granite in such a decomposed state, that it would have been very unsafe to have left perpendicular sides in a cutting through it. The drift formation of Lancashire might also be instanced. Sand was found, on the line of the Manchester and Bolton Railway, which stood well in slopes of 30 feet high, at an inclination of 2 to 1. These slopes were kept perfectly dry by drains, running at intervals from the top, down to the bottom of their faces.

In mining operations, the expansion of clay was well understood. The floors of old mines were always expected to swell up. In the tunnel on the Manchester and Bolton Railway, the timbers were frequently broken by the expansion of the clay, although it appeared quite dry.

Mr. Sop-  
with.

Mr. Sopwith instanced the 'creep' in collieries, which had been attributed to this expansive action, but he rather thought, that the complete closing of old mines, was owing to the weight of the superincumbent rocks, which acting upon the pillars and walls, forced up



the floor. The subsiding of the surface, which was so frequent in mining districts, corroborated this view.

Beneath the village of Wallsend, there was a tract of coal, which the late Mr. Buddle hesitated to get, but at last he decided upon continuing the working in that direction, and the whole village had subsided nearly 2 feet vertically; but by care in the workings, it had occurred without materially damaging any of the buildings.

Mr. Forster said, although it was well known, that in mines which Mr. Forster. were carried to a considerable depth, the 'creep' would occur, and the floor of undisturbed clay appeared to rise, he believed it to be an erroneous idea, and that in consequence of the partially supported weight of the strata above, the roof sunk down, causing the centre of the floor to form a 'horse-back,' as it was termed by the miners. When some old mines, in which this had occurred, were entered and worked after a lapse of years, the indurated clay of the floor had supported the roof, while the coal, which had been formerly left as pillars, was subsequently cut away.

It was true, that when the floor was soft, it would swell. In the Primrose Hill, and the Kilsby tunnels, if the cutting was left for a few days, without completing the brick arching, the timbers were broken. The expansion appeared to be nearly the same, whether it was caused by the air, as in the former case, or by the water, as in the latter instance.

Mr. Thomson remarked, that in the Box Tunnel, it was usual to Mr. J. G. allow 6 inches for expansion, between the face of the work and the Thomson. timbers, and that space was scarcely sufficient.

Mr. Buck said, that in the Heaton Norris cutting, which was Mr. Buck. chiefly through sand, containing much water, he had completely drained the slopes, and had stopped the running of the sand, by building at the foot, a retaining wall about 4 feet in height and from 2 feet to 3 feet thick, with a backing of 2 feet in thickness of cinders. He was induced to do this by observing, that cinders were constantly used in the neighbourhood, for forming drains, and he had generally found, that from careful observation of local habits, valuable hints might be gained.

Mr. Simpson, had devoted much attention to embankments and Mr. J. cuttings in the London clay, and had found it very treacherous and Simpson. difficult to manage; he believed that an inclination of 4 to 1 was not too much for a slope of any considerable height.

He remembered the embankments of a reservoir near London, which had been originally constructed with insufficient slopes; within a few months after they were finished large masses slipped down, and it was feared, that the whole must have been destroyed. At first, attempts were

made to repair the slips with mingled gravel and sand, but although the slopes were then formed, at an inclination of about 3 to 1, they did not stand; after 3 years, they were made up with gravel and clay, mixed with materials from the dust-yards of the metropolis, containing a mixture of all kinds of substances; this was of a dry, porous nature, and the slopes had stood well since, although they were subjected to very variable pressure, sometimes having a head of water of 20 feet upon them, and the next day much less.

In constructing embankments, it was his custom to have a footing of brickwork, resting against a toe of concrete, and with careful attention to the drainage, he found this plan always successful.

He attributed the first motion of slips in railway cuttings, to the action of water, and unless the water was diverted by complete back drainage, and that on the surface and within the slopes, was carried rapidly away, the slopes would never stand, even at the inclinations which had been mentioned.

The expansion of the London clay was certainly very remarkable; he had seen at Richmond, a well of 4 feet diameter, completely closed in one night, by the swelling up of the bottom, although there was not any water in it.

Rev. Mr.  
Clutter-  
buck.

Mr. Clutterbuck observed, that slips in railway cuttings appeared to be caused, sometimes by the geological condition of the soil, when acted upon by water, and sometimes by what might be termed its chemical condition; the latter was produced by the air, causing such a disintegration, as rendered it more pervious to water, and consequently more liable to be acted upon by its mechanical force.

All railways passing from London must, more or less, intersect the London and plastic clays; the sand beds of the latter formation rested upon the chalk, and if those sands were washed away or shaken, a slip of the superstratum would necessarily follow. The plastic clay above the sand beds, was deposited in layers, in which a certain order of superposition might be traced; he had recognized a striking similarity between those beds under London, and at the outcrop near Watford: the distinct layers were known, and names were given to them, by those persons who sunk shafts for getting the sand; it was understood, that their security in working the sand, depended on the thickness and strength of some of the beds; to their inequality of strength, might probably be attributed some of the slips that occurred in that formation.

The plastic clays were usually covered by a stratum or bed of silt, containing shells, sharks' teeth, &c., and upon the silt rested the strong blue London clay; the most inveterate slips that he had observed on the London and Birmingham Railway, occurred in those

localities, where the silt was covered by a thin outcropping bed of the London clay, not sufficiently thick to resist the infiltration of water ; the silt thus became saturated with water, and slid from the surface of the tenacious plastic clay lying beneath it.

The cutting at Brentwood passed through strata, which he believed to be silt, covered by beds, or layers of loam, sand, and gravel, all more or less pervious to water ; thus causing slips, which were attributable to the geological condition of the soil.

In the London clay, where there was no superficial deposit of gravel, the slips, he thought, might be traced to its chemical condition. A distinction was often made, between the yellow clay on the surface, and the blue clay beneath ; this difference of colour, was caused by the state in which the iron existed in the soil ; when excluded from the action of the air, it was found as a protoxide ; and in the upper beds, when subject to that action, it became a peroxide ; hence, the difference of the colour and, as he conceived, the cause of a certain amount of disintegration. The air was admitted, by the cracks formed in the clay in drying, or by the roots of trees or plants (whose course might be traced by the difference of colour in the clay) ; by the working of the earthworm, and by other causes. The water which fell on the surface, carried particles of sand and other substances into the fissures, rendering the clay, in some measure, permanently pervious to water : it was to this percolation of water, through the upper or yellow beds of the London clay, that slips, such as that at New Cross might, he conceived, be attributed.

It was the practice, on many railways, to cut a back ditch between the boundary railing and the quickset fence ; this appeared to have caused many slips. The bottom of the ditches being exposed to the action of the air would, when they received a flush of water, permit its infiltration below the top of the slope ; he had remarked, that many slips occurred, about 1 foot or 2 feet below the bottom of these ditches, which was about the angle, at which the water would drain towards the face of the cuttings.

In some cuttings, apparently with the object of economizing space, the slope was carried to the edge of the quickset fence ; where that was done, the slips seemed more frequent, than where the ditch was further removed from the edge of the slope.

Sir Henry Delabèche said, that he viewed railway works with Sir H. T. Delabèche. great interest, as opening a large field for the economic geologist. The causes of the slips, which had so frequently occurred in cuttings, deserved careful investigation, and great benefits would result, not only to the scientific world, but in the practice of engineering, if those who had charge of such works, carefully watched and recorded

every event connected with their progress ; such as the nature and position of the strata, their amount of natural drainage, the effect of weather, and all other points calculated to produce any changes.

With respect to the origin of slips in general, but more particularly of those in the London clay, Mr. Clutterbuck had treated the subject so well, and his remarks contained so much truth, that there remained but little to be said.

Whether the attention was turned to cliffs on the sea coast, to mountain cuttings, or to artificial embankments, it would be seen, that in the majority of cases, the slips were caused by the action of water. Wherever there existed a soft vein, beneath strata with fissures which enabled the water to percolate, the substratum became mud, and being squeezed out by the superposed weight, caused the whole mass to slip.

There were many instances of this kind in the oolitic escarpments near Bath. They were extremely interesting, from being the scene of the labours of Mr. Smith, who had justly been styled the father of geology in England. In that district, Mr. Smith had cured and also prevented many threatening slips, by introducing a system of surface drainage, at the same time tunnelling into the face of the escarpment, to drain the beds, and to prevent the water from reaching the softer strata beneath.

At Lyme Regis, the strata, having a certain degree of inclination, became saturated with water, the softened mass was forced out from the lower parts, and caused the slips which so frequently occurred on that coast.

It was evident, that the various angles at which different earths would stand, depended, in a great measure, upon the relative tendency of the materials to form mud.

The Directors of the Eastern Counties Railway had requested him to visit the Brentwood cutting with Mr. John Braithwaite, their engineer. The strata in that locality were nearly horizontal, and although the material cut through, would have been easily set in motion on an inclination, he was of opinion, that the banks would stand well, if they were perfectly drained. The ground was, however, very full of water; it was also of a very tenacious nature; but he had observed much water running out from beneath the upper and dryer beds. A good system of drainage was the only preventive or cure; Mr. Braithwaite was so well convinced of that fact, that he planned and executed the dry shafts which had been mentioned: the credit of all the good they had produced must be given to Mr. Braithwaite.

Sir Henry Delabèche did not attribute much advantage to the

friction of the gravel buttresses; their weight, force, and friction, might retard a slip for a time, but unless the buttresses entered the water-bearing strata, and served as perpetual drains, they would not be efficacious.

The London clay was not homogeneous in its nature; it was more or less pervious, and abounded with fissures in all directions; many of these were filled with a slimy substance, which was easily converted into mud by the percolation of water, and hence slips so frequently occurred, where cuttings were made through the dip of the London clay, as at New Cross. Surface-drainage was not sufficient for such strata; the main springs must be tapped, and regular drainage be established, otherwise slips would be of constant occurrence.

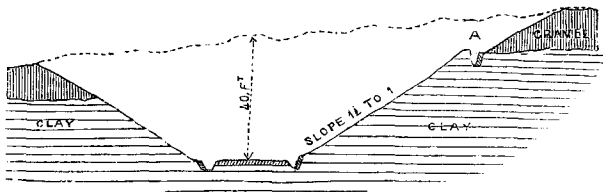
The rocks of Rossberg (Switzerland)\* and the Undercliff at the back of the Isle of Wight, might also be quoted, as instances of the same action of water, in converting the lower beds into mud, upon which the superstratum slipped, in spite of all attempts to restrain it.

Captain Moorsom had seen several instances where, in forming embankments of gravel upon a clay bottom, the wet substratum had been squeezed out, and had caused the foot to spread, until it was stopped by weighting it, and thus re-establishing the equilibrium. Capt. W. S. Moorsom.

He thought, that back-drainage was essential, and he had rarely found it unsuccessful, if it was commenced far enough from the edge of the cutting. It should be so contrived, as to allow the surface-water to flow rapidly and freely away. He had repeatedly found tapping and under-draining ineffectual, unless the surface-drainage was thoroughly completed.

He had used benching with good effect, where an overlay of wet gravel rested on clay; the method he adopted was to remove the gravel in the upper part of the slope, sufficiently to enable a good catch-water drain to be formed, along the bench in the clay, as shown at A, Fig. 6.

Fig. 6.



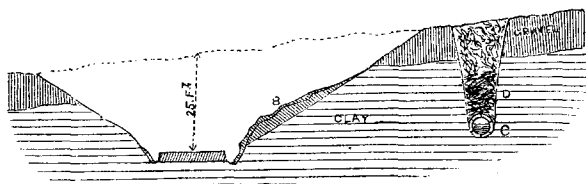
This plan he considered very effectual in certain positions, as a means of preventing slips. Slopes of  $1\frac{1}{2}$  to 1 for a maximum height

\* Vide Lyell's 'Principles of Geology,' vol. ii., p. 235. 8vo., 1833.

of 40 feet, which had been so constructed, had stood well for upwards of 5 years.

In other situations, after slips had occurred, he had used back-draining with good effect, where tapping and leading-drains had failed. The method pursued, (Fig. 7) was to cut a drain at the

Fig. 7.



back of the slip, (B,) so as to intercept the water which flowed thither, either from springs or by infiltration.

At the bottom of the drain was placed a round pot drain (C,) covered with a thickness of brushwood, (D,) and the remaining depth was filled in with gravel or rubble. For positions where it was practicable to cut the back-drain, he recommended this system.

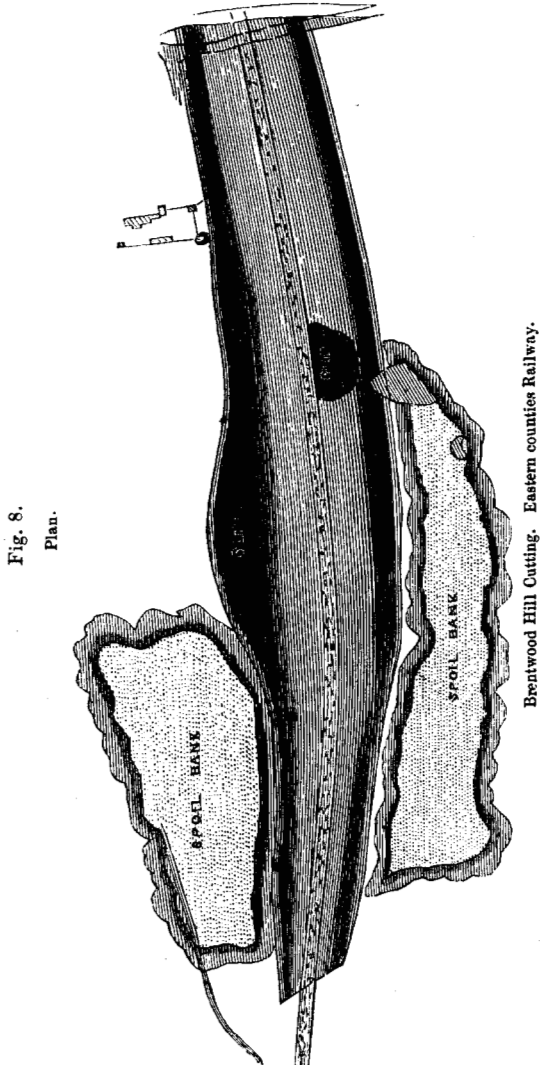
With reference to the depth of cuttings and the angle of slopes, in various materials and under different conditions, he thought, that each case must be regulated by the particular nature of the soil, the facilities for drainage, and the means adopted, besides many other local considerations, so that it was nearly impossible to lay down any arbitrary rules on the subject.

In one situation, he had seen a cutting through gravel and sand, stand excellently at an inclination of  $1\frac{1}{2}$  to 1, although the cutting was 86 feet deep, and on one side was placed a spoil-bank of 24 feet in height, making 110 feet in all, forming a regular slope. In another position, he had made a cutting of 57 feet in depth, through gravel, which stood well at a slope of 1 to 1.

Mr. Bruff. Mr. Bruff stated, that the timber staging, erected on some of the Eastern Counties Railway embankments, had not been resorted to for obviating the formation of the clay banks in wet weather, but was merely contrived for expediting the work, so as to admit of the railway being opened to the public, at an earlier period than would have been possible, had solid embankments been first formed. The timber staging was erected on three embankments, which could not be completed in time, and on another where the nature of the material, in its then wet state, would not admit of its being formed to more than half its height; all these embankments had, however, since been filled up to the regular level.

The cutting through Brentwood Hill, presented some features in the execution, different from those on the Croydon Railway; he presented to the Institution a copy of the contract plan (No. 3615), of the Eastern Counties Railway, with such amendments and additions as were considered desirable, during the progress of the works, and since their completion.

The drawing gave a ground plan, (Fig. 8) exhibiting the position of



the cutting, spoil-banks, &c., with longitudinal and transverse sections (Figs. 9 and 10) of the cutting, showing the extent of the excavation and the slopes, the benchings, culverts, wells, drain-pipes, and gravel counterforts.

The nature of the material of the cutting was sand, sand with loam, gravel, and silt.

The great difficulty experienced in draining the slopes, had arisen from the slimy nature of the silt, from which the water could not be separated. Its power of holding water might be imagined, from the fact of a face of nearly 50 feet of slope, being exposed during 2 years, without producing any sensible effect in the drainage of the material.

The silt had a constant tendency to flow away with the water, and great attention was directed to that point, in order to prevent the slopes from being injured.

The provision for upholding and draining the slopes comprised in the contract, consisted of a fence ditch at the top of the cutting, a benching 10 feet wide, half way down, and the ordinary side drains at the foot, with drain pipes, running in various directions, along the face of the slopes. To this was subsequently added a culvert, on the benching on each side, with proper outfalls; then the wells (Fig. 10.) were adopted, and lastly gravel counterforts. The wells were not placed with any regularity, but were sunk at the wettest parts of the slopes; they were steined as in ordinary well work, until within a distance of about 3 feet from the bottom, where an inner ring of brickwork  $4\frac{1}{2}$  inches thick, was built in cement. The bottoms of the wells were not bricked, but each had an outlet pipe of about 2 inches diameter, into the open drain below it. There were twenty of these wells, in the upper part of the north slope, ranging in depth from 15 feet to 20 feet, and  $3\frac{1}{4}$  feet in diameter. In the lower part of the same slope, there were twenty-five wells of the same diameter, but only 10 feet deep. In the same slope, seven gravel counterforts of a prismoidal shape were afterwards added; they were formed by cutting out the requisite cavity, and barrowing in dry gravel from above, without pounding.

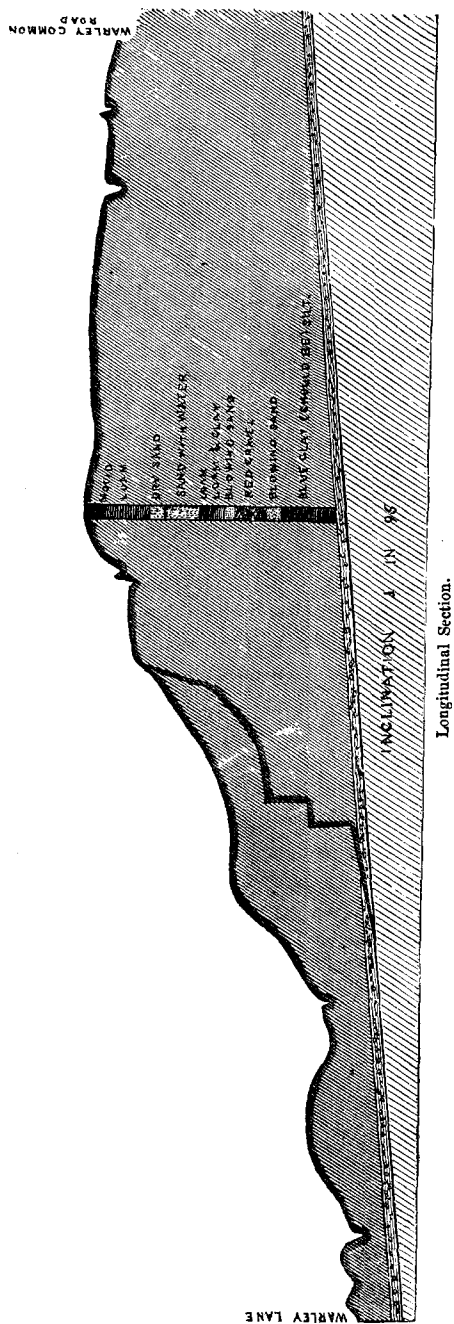
Neither wells nor counterforts had been adopted on the south slope, which was on the lower side; the cutting being through ground slightly inclined to the south.

These plans for draining the cutting were, Mr. Bruff believed, all designed by Mr. John Braithwaite; Mr. Phipps had tried a somewhat different plan.

A narrow trench was cut along the wettest part of the slope, as deep as it could be excavated, without much shoring of the sides;



Fig. 9.



Longitudinal Section.



a small culvert was laid in the bottom, having an outfall into the open drain at each end. On the lower side a puddle wall was raised, and at its back, a dry rubble wall with straw above it, to prevent the sand and loam from washing into and choking the interstices. This plan was simple and inexpensive, and was stated to have answered its intended purpose.

With respect to the general question of slips in cuttings, Mr. Bruff was convinced, that want of thorough drainage was the proximate cause. In the Brentwood cutting there had been two slips, both of which, in his opinion, arose from the surface water being checked by the spoil-banks, and being allowed to soak through the surface down to the slopes.

In most cases where slips occurred in side-lying ground, it would be observed, that the upper slope almost invariably gave way first. In embankments on side-lying ground, slips generally occurred first on the lower side, which might be ascribed to want of friction, as well as to the agency of water.

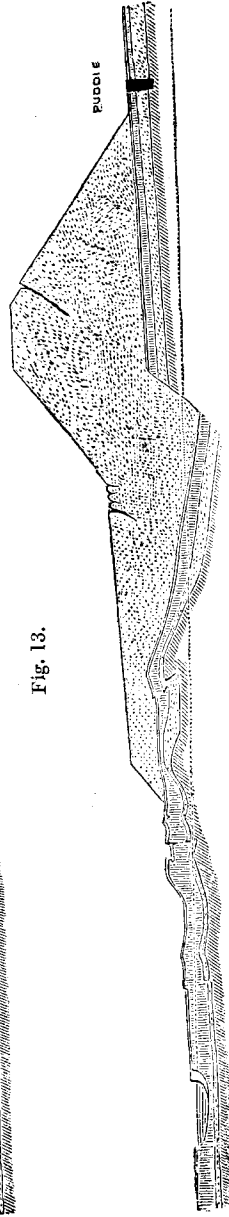
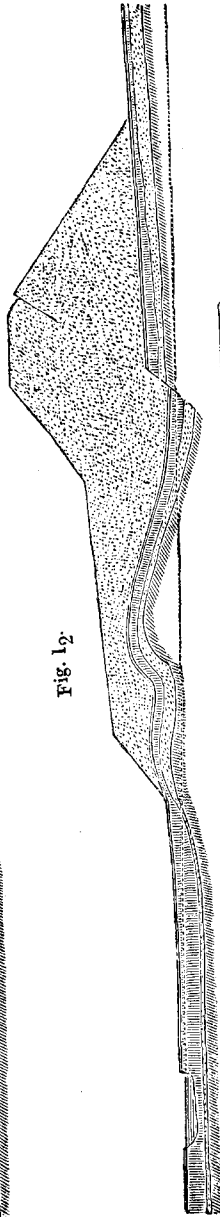
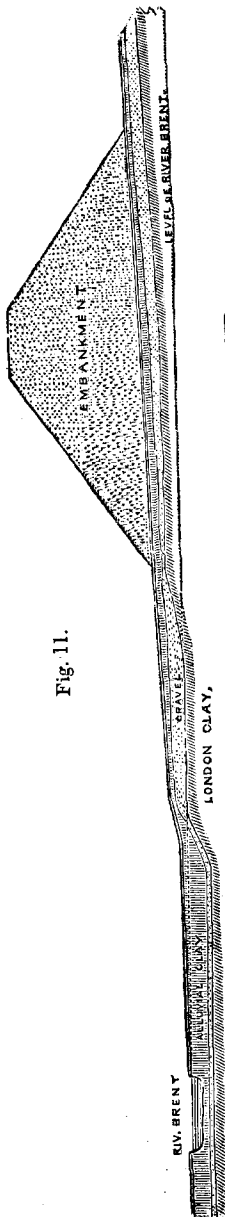
The effect of a drain above and near to a slope, in an excavation, had not hitherto been sufficiently attended to; in inclined ground, a rubble catch-water drain should, in his opinion, be formed parallel to the whole length of the cutting, at a distance from the upper edge of the slopes, varying with the depth and nature of their material; in a depth of 20 feet, he thought, that it should be set back at least the length of a chain.

Spoil-banks placed near to the slopes of cuttings, also appeared to him to be injudicious; in the cases of the Croydon and the Blisworth slips, which had been mentioned, he had no doubt, that the spoil-banks contributed as much to produce slips, by checking the drainage, and by the increased quantity of surface-water they threw into the slopes, as they did by their great superposed weight on the edge of the banks.

It was a curious fact, which he deemed worthy of notice, that serious slips seldom occurred, until 2 or 3 years after the completion of the earthwork; the large sums usually left by contractors, to cover one year's risk of maintenance, might therefore, he conceived, be dispensed with.

Mr. Colthurst exhibited and described, three sections of the embankment across the valley of the Brent, at Hanwell, on the line of the Great Western Railway, (Figs. 11, 12 and 13.) Mr. Colthurst.

The embankment, which was formed of gravel, was 54 feet in height; it rested on vegetable soil, beneath which was a thickness of 4 feet of alluvial clay; then occurred a bed of gravel, varying from



Brent embankment at Harwell, Great Western Railway.

3 feet to 10 feet in thickness, resting upon the London clay,\* which was traversed in all directions by slimy beds or joints.

The surface of the country sloped gradually towards the Brent, which was at a level of about 20 feet below the south side of the embankment.

The subsidence of the embankment commenced during the night of the 21st of May, 1837; the next morning, the foundation was discovered to have given way, and a mass of earth, 50 feet in length by 15 feet in width, was forced from beneath the north or lower side of the embankment, towards the Brent. For four months this protruded mass increased in dimensions, and the subsidence of the embankment continued, until the surface assumed an undulating outline, which, on being cut through, showed that the subjacent beds corresponded accurately with the curvatures produced at the surface by the disturbance. The state of the seams or strata beneath the surface, was ascertained by sinking trenches at right angles to the embankment, to the full depth shown in the sections, Figs. 12 and 13.

The symptoms of failure in the embankment, at this period, were confined to a subsidence of about 15 feet, with a fissure extending all along the top of the south slope, at the side opposite to where the foundation had yielded. From the dip of that fissure, Mr. Colthurst inferred the nature and inclination of a rupture of the ground under the embankment, as shown in the sections, Figs. 12 and 13.

Immediately on the commencement of the slip, Mr. Brunel directed a terrace to be formed, on the swollen surface, at the north foot of the embankment; the weight of the mass thus placed, succeeded effectually, in stopping the further progress of the subsidence, which up to that period, had exceeded 30 feet. The swollen ground extended over nearly 400 feet in length, by about 80 feet in width, and was elevated nearly 10 feet, with a horizontal movement of about 15 feet. The general disturbance, ranged to a distance of 220 feet from the foot of the slope, towards the river Brent, the south bank of which, was forced forward about 5 feet.

The section, Fig. 11, showed the position of the strata, at the time of the forming of the embankment.

The section, Fig. 12, showed the state of the strata, when the slip or swollen ground was being covered by the terrace on the north side.

The section, Fig. 13, gave the form of the terrace, and of the ground beneath it during the further subsidence; but all under the

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\* Stourbridge clay contains usually about 12 per cent. of water. London clay, taken at a depth of 120 feet from the surface, in the well now sinking near Trafalgar Square, contains 10 per cent. of water.

embankment in Figs. 12 and 13, must be considered as inferential from the appearances above. The rupture of the ground beneath the embankment, was indicated by the crack near the upper part of the south slope.

In a letter received recently from Mr. Bertram, one of the engineers on the Great Western Railway, it was stated, that the Brent embankment had subsided very little for several years ; indeed from the nature of the material, there was naturally less sinking, than in loosely formed clay embankments ; a coating of ballast from 6 inches to 9 inches in thickness, applied once a year, was found sufficient for all purposes.

The slips which occurred in embankments formed of clay, occasioned trouble at first, by their immediate effect on the road above, and the difficulty of adding material to them. Mr. Bertram had found in many such instances, in the London clay district, that a temporary measure, of forming the softened mass which had slipped down, into large raised beds or ridges from 8 feet to 12 feet wide, by dressing with the spade, surface punning, &c., had the effect of keeping rain-water out, allowing the raised parts to dry, and retaining the mass in its place, until better weather and matured arrangements, permitted the more permanent proceeding, of forming an extended footing and working up the mass with additional material, so as to fill up the space with an increased slope.

When the Acton cutting slipped about 3 years since, Mr. Bertram was induced (from the difficulty of bringing gravel to the spot, and the quantity of surplus stuff in the cutting), to try burnt clay for the drains, for forming an open backing to collect water, and also for mixing with the soft clay in punning up again ; from what he then saw, he gave a decided preference to that material, over any kind of gravel, for mixing with clay, to retain it in its place. When gravel was used, there was generally a slight subsidence and opening at the top, but with burnt clay neither occurred. The usual system pursued, was to form with that mixed material, continuous abutments and revetments, upon the original face, and in all cases to make sure of thorough drainage from the back.

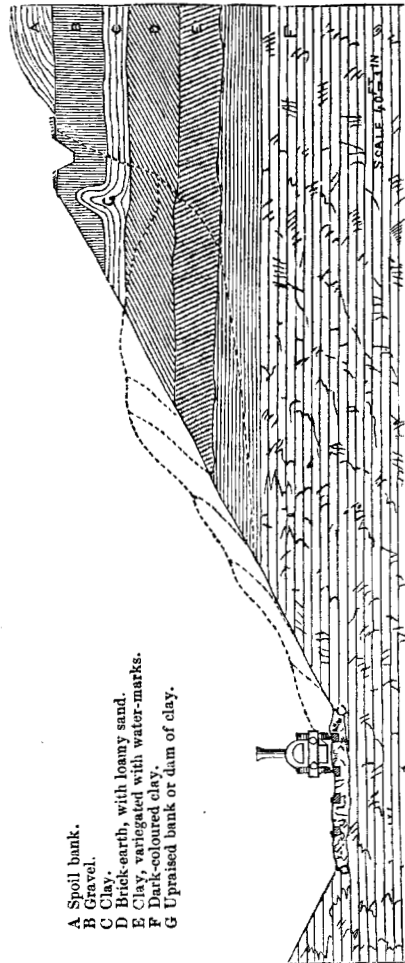
He had always been able to trace an immediate connexion, between the courses of septaria and the slips at Acton. Those courses were not sufficiently open to act as natural drains : he had made many surface and deep drains leading from them, but the quantity of water drawn off, was not equal to that which was obtained by the means before described.

At Ruscombe, he had removed the gravel stratum from the top, laying bare and well draining the surface of the clay, using the gravel

as a footing or buttress below, at such portions of the cutting as had been forced up by previous slips; when there was under drainage from longitudinal culverts, that plan answered very well.

At that portion of the Sonning cutting, which slipped so suddenly 2 years ago, the stratum of gravel was found to be broken into, by an upraised bank or dam of clay, at G (Fig. 14), which after much wet

Fig. 14.



- A Spoil bank.
- B Gravel.
- C Clay.
- D Brick-earth, with loamy sand.
- E Clay, variegated with water-marks.
- F Dark-coloured clay.
- G Upraised bank or dam of clay.

Transverse Section of Sonning Cutting, Great Western Railway.  
The dotted lines show the form of the slip.

weather, kept a reservoir of water penned back, until it broke out the mass of clay, down to the next stratum at D, and so out at E; the

dam G had been cut across at different points in the slope for the purpose of drainage, and when that was done, all that portion of the cutting became particularly dry. A drain was led from the back of the dam G in dressing off the slip. That continued to bring away a great deal of water, which previously had some other outlet, over the lowest point of the bank.

Mr. Sibley. Mr. Sibley thought, the causes of the subsidence of the Hanwell embankment were very obvious. In laying out the foundations of the Lunatic Asylum, in that immediate vicinity, and in the formation of a deep sewer, with a soil pit 20 feet in diameter, and 20 feet in depth, at the side of the Brent, he had ample opportunity for examining the strata, and it appeared to him, that had a trench been made in the direction of, and at the foot of the embankment, the marshy piece of land where it was situated, would have been sufficiently drained, to enable it to carry the weight of the mass laid upon it.

The trustees of the Uxbridge road had their great store of gravel, in fields to the west of this embankment, and excavations had been going on there for about half a century. The springs in that neighbourhood, accumulated in a reservoir, which was formed by an escarpment of clay, skirting the river Brent; part of the waste water, together with the percolation from the reservoir, was permitted to traverse the site of the embankment, rendering the ground marshy, even in the driest seasons.

The late Mr. M'Intosh had frequently told him, that a larger quantity of material was used in maintaining, than in constructing the Hanwell embankment.

Mr. Colthurst. In answer to questions from members, Mr. Colthurst explained, that the fissures shown in the clay, beneath the embankment, were assumed from the form of the depressions of the surface. The sections of the ground were taken weekly, during the whole time of the subsidence, so that he contended, the form of the substratum might be assumed as being correct.

The spreading of the lower side of the embankment, displaced the bank of the river Brent for some distance.

Sir H. T. Delabèche. Sir Henry Delabèche remarked, that if the sections (Figs. 12 & 13), which were exhibited, approximated to truth, it would appear, that the embankment was formed upon a fault of greater magnitude than usual. The consequences were inevitable; when the fault yielded, the embankment sunk, and continued to subside, until the mass was stopped by weighting the foot, and thus restoring the equilibrium.

Mr. Colthurst. Mr. Colthurst said, that the slimy beds, and the fissures, which ran in all directions in the clay, were most difficult to be guarded against, and they were, he believed, the principal causes of slips and subsidences.



Mr. Braithwaite said, that from the observations of Sir Henry Delabèche, it might be inferred, that slips and other movements of earth, were more frequently due to mechanical, than to chemical action, although in the case of the New Cross slip, the latter cause had been much insisted upon. Mr. F. Braithwaite.

Mr. John Braithwaite gladly availed himself of the geological knowledge of Sir Henry Delabèche, and his approbation of the measures pursued was highly gratifying to him.

With respect to the Brentwood cutting, although the strata were nearly horizontal, and it might have been imagined, that there would be little tendency to slip, yet from the ground being so full of water, more than ordinary attention to its drainage was required, for it was so retentive of moisture, that a drain had but little influence at a few yards from it.

The draining shafts which were sunk, had operated well, to the extent to which they were carried, and he believed that generally, the mode of treating the Brentwood cutting was considered successful.

He had understood, that the trenches which had been alluded to, had not been extensively used.

Mr. Phipps explained, that the trenches and the wall with dry backing, were tried under his direction merely as an experiment, prior to the examination of the ground by Sir Henry Delabèche. The dry shafts were subsequently sunk, and the only doubt he entertained was, whether there was a sufficient number of them to drain the bank effectually. Mr. Phipps.

Sir Henry Delabèche said, there could not be any doubt of the ground being completely drained, if a sufficient number of shafts were sunk to intercept the water, but then the question of their cost must be considered. Sir H. T. Delabèche.

In answer to questions from the President, Mr. Green stated, that his experience did not enable him to lay down any rule for the prevention of slips in cuttings or embankments. They were generally to be attributed to the presence and pressure of water, acting upon the substratum; the method of discharging the water must depend on the direction and the nature of the strata; in all ordinary cases, he conceived, that with proper application of the known methods of drainage, successful results might be attained. Mr. J. Green.

He had not made any particular observations, as to the relative duration of the tendency to slip, exhibited by the slopes of embankments and cuttings, in canals and railways; but he conceived, that in a canal, the weight of the water acted as a support to the internal slopes, and tended also to counteract the upward pressure of water in the substrata. He had frequently observed this in cuttings, with

embankments on the sides; while the canal was full of water, the banks stood well, but when the water was drawn off, the banks subsided, and the bottom of the canal rose up.

A curious instance occurred, in forming part of the Exeter ship-canal, through mud lands in the estuary of the Exe. The embankments on the sides of the cutting, remained firm, so long as their weight only just balanced the upward tendency of the water, in the substratum of the bed of the canal; but when the increased weight of the mass, destroyed the equilibrium, the embankments sunk down, and the bottom of the canal was forced up in proportion.

This occurred in several places, even after the works had preserved a perfect section for some months, but the canal had not then been filled with water. It was found on examination, that at a few feet only below the bottom of the canal, there existed a bed of peat, which, although capable of resisting the weight of the banks for a considerable time, at length gave way; thus the embankments sunk down, the bottom of the canal rose up, and it became necessary to drive strong piles in the line of the bottom of the canal, on each side, in a lateral direction, and to support these piles by rough inverted arches of stone, at intervals of about 20 feet, for a considerable distance, after which the banks being slowly raised, stood well.

The President.

The President said, it must have been observed by all engineers, that in the embankments and cuttings of canals, the slips generally occurred, within the first 6 or 8 months after the works were completed; but in railway works, the slips constantly occurred even after years had elapsed. He observed on many of the railways, upon which he travelled habitually, that the slopes were almost as frequently under repair, after being open for many years, as they were within a few months of the first opening. He was decidedly of opinion, that although water might be the primary cause of the slips, the vibration caused by the passage of the trains, was the more immediate cause.

When, as had been so ably explained, the lower beds became converted into mud, and the adhesion of the particles was destroyed, the mass only required a slight impulsive force, such as the vibration consequent on the passage of an unusually fast or a very heavy train, to set it all in motion and to cause a slip.

Some of the methods proposed for the formation of embankments, such as only constructing them during suitable weather, and with thin layers of material, regularly laid and pounded, &c., might be used in the construction of reservoirs for retaining water; but they were not compatible with the manner in which extensive works required to be carried on, independent of the extra cost they would occasion. Experience had shown him, that the best method of con-

structing a heavy embankment was, to run forward two tips, parallel with each other, forming the outsides of the bank, and leaving a void in the centre, which was subsequently filled up. The greatest amount of pressure, was thus brought to act vertically upon the material, and the two sides having become somewhat consolidated, were better able to resist the pressure, and they had not any tendency to slip away. This method had been ably treated by Mr. J. B. Hartley, in a paper read before the Institution some years since.\*

He had not found any difficulty in inducing contractors to adopt that method; when proper precautions were taken to insure thorough drainage, he believed, that embankments would generally stand well, although made in the wettest weather. Moisture would only cause the mass to become more consolidated, and when once that was the case, but little water would subsequently percolate.

He concurred in the opinion, that the gravel counterforts acted rather as drains, than as supporting buttresses; for he believed, that they stood generally at a steeper angle, than the slopes which they were supposed to support.

Mr. Clutterbuck said, in confirmation of the President's opinion, Rev. Mr. Clutterbuck. he had been told by the persons who worked in the sand-pits, under the plastic clay, near the London and Birmingham Railway, that they were afraid to remain under ground, during the passage of the heavy luggage trains, on account of the extreme vibration of the earth.

Mr. Green was convinced of the correctness of the President's opinion, Mr. J. Green. as to the effect of vibration upon banks saturated with water. He had seen instances even in canal embankments, where, at the head of locks, the vibration arising from the sudden and careless closing of the lock-gates had produced slips.

He did not think any commensurate benefit would result, from the extra expense of pounding the earth in embankments, as had been suggested. The degree to which earth might be safely consolidated by pounding, could only be determined by great attention to the nature of the material, and to the circumstances under which it was used. He had known much injury caused by the earth-backing for walls, being too much pounded, when, from defective drainage, the expansion of the earth had subsequently thrown the walls down.

Mr. Hughes presented a specimen of Watson's drain pipes Mr. Hughes. (Fig. 15). They were made of Staffordshire clay, which possessed great strength and durability, and they had also been made of cast iron. A, B, and C, showed the forms of the apertures in the periphery; they enlarged inwards so as to prevent the possibility of

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\* Vide 'Minutes of Proceedings,' 1841, page 143.

their choking up. The holes were so small that but little earth could be carried in with the water, but if any did enter it fell through

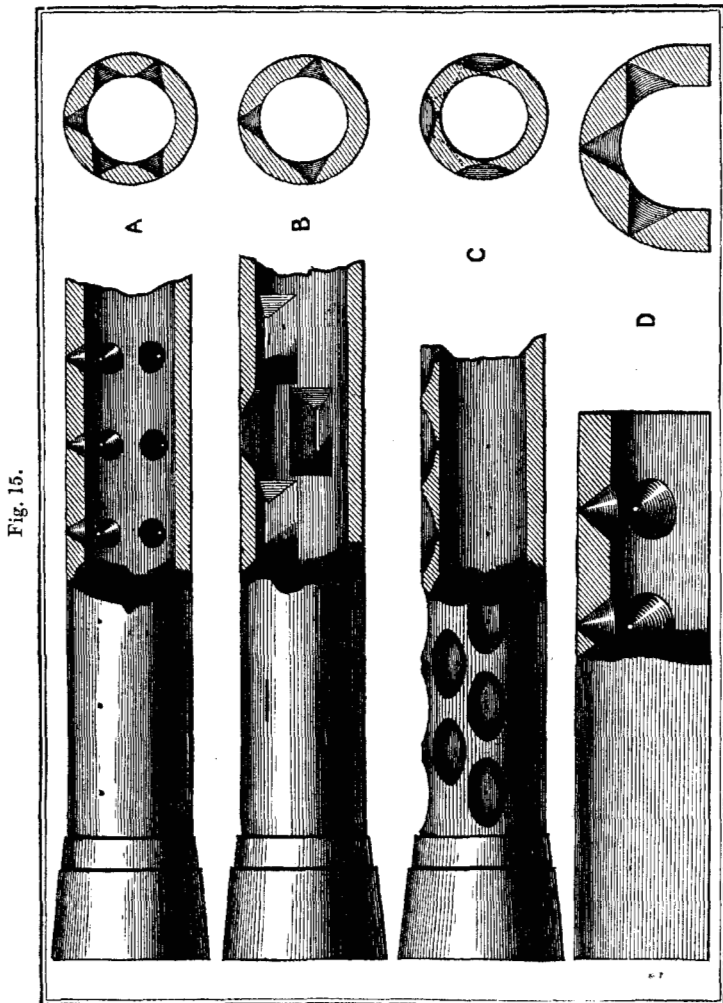


Fig. 15.

into the body of the pipe, and was washed out by the water. (D) was the drain tile, also having the same kind of apertures.

These pipes had been successfully used for some time in the cuttings of the London and Birmingham, and the Croydon railways:

and Mr. Hughes promised to give, during the next session, a report of the method of using them, and of the result of their application in several wet cuttings.

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April 2, 1844.

The PRESIDENT in the Chair.

The following candidates were balloted for and elected :—Alfred Stanistreet Jee, as a Member ; Adolphe du Bois de Ferrières, James Hunter Tasker, Bernard Snow, Arthur Collinge, and Thomas Hughes, as Associates.

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The discussion of Mr. Gregory's paper, (No. 668,) "On Cuttings and Embankments of Railways" was renewed, and was extended to such a length as to preclude the reading of any paper during the meeting.

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April 16, 1844.

WILLIAM CUBITT, V.P., in the Chair.

No. 661. "Account of the Railway from Amsterdam to Rotterdam, and of the principal works upon it." By the Chevalier Frederick Willem Conrad, M. Inst. C. E. ; translated from the French by Charles Manby, Assoc. Inst. C. E. Secretary.

This railway, the first that has been constructed in Holland, is due to the enterprize of a public company, called "The Railway Company of Holland ;" whose affairs are managed by a council of administration, consisting of five commissaries and the engineer. The difficulties of construction, arising from the peculiar physical character of the locality, were amongst the least that the company had to contend against ; the directors were however satisfied, that the utility of the undertaking would be finally understood in the country, and that by perseverance, all obstacles would be overcome.

The company was formed on the 8th August, 1837, at Amsterdam, and within a short period, the statutes received the royal sanction ; but no sooner had the contract been made, for the execution of the first division, from Amsterdam to Haarlem, than numerous law-suits arose, owing to the hostility of the proprietors of the land, over which