January 23, 1855.

JAMES SIMPSON, President,
in the Chair.

No. 909.—"On the Construction of the Sea Embankments, across the Estuaries Kent and Leven, in Morecambe Bay, for the Ulverstone and Lancaster Railway." By JAMES BRUNLEES, M. Inst. C.E.

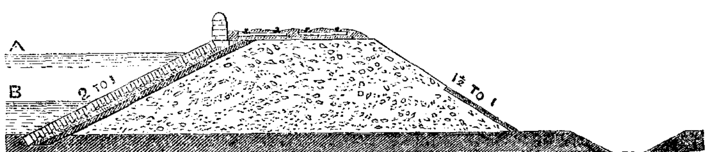
ALTHOUGH the practice of constructing sea and river embankments for railways, is of comparatively recent date, the art of forming them, for the purpose of reclaiming, defending, and irrigating land, is of great antiquity. The most ancient, as well as the most interesting hydraulic engineering works of this kind on record, were those executed on the Nile by the Egyptians, nearly forty centuries ago. The Babylonians, at an early date, used the same system of embanking, for restraining the waters of the Euphrates. The Romans had the Tiber to contend with, and bringing the art of embanking with them to Britain, are said to have practised it in reclaiming the Romney Marshes, and in restraining the Thames in its present bed. Holland, with its vast extent of low lands, has long been a model for the simplicity of its system of reclaiming, and protecting its territory, by means of sea and river banks. Those on the seaboard fens of England, on the Tay, and the Forth, in Scotland, and on Lochs Foyle, and Swilly in Ireland, with many others, all tend to show what human industry can achieve, where interest and self-protection are concerned.

Morecambe Bay is an arm of the Irish Sea, situated to the west of Lancaster; its average width is about twelve miles, and it extends about seventeen miles inland from the mouth. Its dangers are well known to all who travel the over-sands route, on account of the constant shifting of the fresh-water channels, and the treacherous nature of the sands, more especially during freshes in the rivers. A great portion of the bay being left high and dry, at low-water, its reclamation from the tides has often been talked of, and whilst being the subject of careful inquiry, the project has elicited from those most worthy of confidence very favourable recommendations. In 1837 the late Mr. George Stephenson reported on the practicability of constructing a railway embankment across it, and at the same time reclaiming from 20,000 to 40,000 acres of land. Mr. Hague also made a similar report, proposing to reclaim 40,000 acres.

The present line of railway, is being carried out by a Company, with Mr. Brogden as Chairman; the object being to connect the Furness, and the West Coast Railways, with Lancaster, and the South. The line was laid out by Messrs. McClean and Stileman, and an Act was obtained in 1851. The present sea-works are however very different from those originally proposed by the late Mr. Stephenson, and by Mr. Hague, in consequence of the present line being carried more inland, so that the structures across the estuaries of the Kent and Leven, are the principal works exposed to the sea, and though the reclamation of land has been a secondary object in laying out this line; still the railway embankments, and weirs, will so far fix the fresh-water channels, as to facilitate the reclamation of a considerable portion of the bay, at some future time.

The works were partially commenced in May 1853, but owing to the scarcity of workmen, and the want of accommodation for them in the neighbourhood, it was only in September of that year, that they were in full operation. The part of the embankment extending along the face of the marshy coast from Quarry Flat Marsh, to Cape's Head, has been formed to the transverse section Fig. 1,[1] with a sea slope of 2 to 1, and a land slope of $1\frac{1}{2}$ to 1.

Fig. 1.



Section of Embankment along the face of the Marsh of the Leven Estuary.

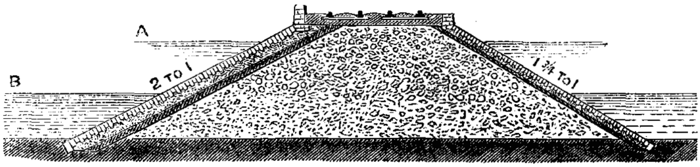
The line of embankment then extends directly across the mouth of the Leven estuary, and as in making the borings nothing but sand was found, to a depth of 30 feet, and, in one instance, where the boring was carried to a depth of 70 feet, the material continued the same, it was necessary to take great precautions for the work, particularly as a large volume of water descends the river channel: the River Leven, above this point, receiving the rainfall from an area of about 109,120 acres, including the drainage of Coniston, and Windermere Lakes.

The channel of the river is to be crossed by a viaduct, having 50 spans, of 30 feet each. In the viaduct a drawbridge of 36 feet span will be erected to maintain the navigation of the river. The

[1] In the woodcuts, Figs 1 to 4, the line A, indicates the height of the extraordinary tide of December 27, 1852; and the line B, the level of high water of ordinary spring tides.

remainder of this estuary will be crossed by embankments formed to the transverse section Fig. 2, with a sea-slope of 2 to 1, and a land-slope of $1\frac{3}{4}$ to 1.

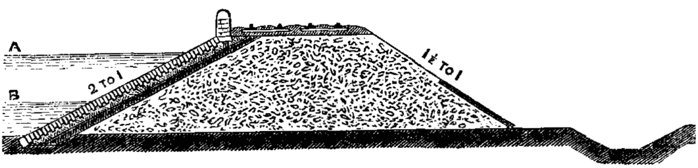
Fig. 2.



Section of Embankment across the Leven Estuary.

The embankments from Wyke Marsh, stretching along the shore and across the small bays, to Blawith Point, are to be formed to the transverse section Fig. 3, with a sea-slope of 2 to 1, and a land-slope of $1\frac{1}{2}$ to 1. The embankment is then continued

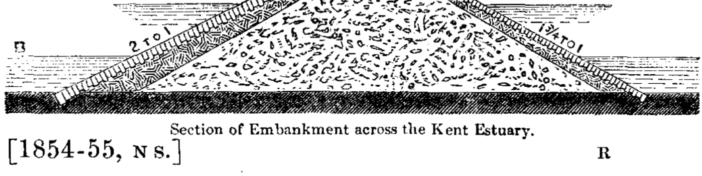
Fig. 3.



Section of Embankment along the shore of the Kent Estuary.

forwards, and is completed across that part of Milnthorpe Sands to the North of Holme Island, to the point of land where the River Winster has been diverted, and passed under the embankment by a sluice; from whence its course is directed to the channel by a stone weir. The line then crosses the Kent estuary at a short distance above its mouth, on ground where the borings showed the bed of sand to have a depth varying from 14 to 21 feet, under which was found a bed of fine blue clay. The River Kent above this point receives the rainfall of the upland districts, from an area of about 110,000 acres. The channel of the river is to be crossed by a viaduct, having 50 spans of 30 feet each, and the remainder of the estuary is being crossed by embankments formed to the transverse section Fig. 4, with sea-slopes of 2 to 1, and land-slopes of $1\frac{3}{4}$ to 1.

Fig. 4.



Section of Embankment across the Kent Estuary.

The sands are, to a great extent, composed of calcareous matter, washed from the limestone of the district, and of this the interior hearting of the banks is almost entirely composed. On the sea-slopes, so formed, there is placed a layer 12 inches thick of well-prepared clay-puddle, which serves the twofold purpose of temporarily protecting the material, during the formation of the embankment, and of permanently preventing the sand from being washed out from between the joints of the pitching, by the action of the sea. On the top of the puddle is laid a thickness of 18 inches of small rubble-stones technically termed 'quarry rid;' this prevents the action of the sea upon the puddle. The pitching-stones, varying from 8 inches to 16 inches in thickness, and of an average depth of 15 inches, are compactly set together on this bed of 'rid.' The limestone from the excavations and the quarries in the immediate vicinity of the works, yielding a very excellent stone for this purpose.

The embankment across the Kent Estuary (Fig. 4), differs from the others in the mode of execution. It is found that the sands stand well in still water at a slope of 1½ to 1; such a quantity of 'rid' is therefore being used, under the pitching, as will prevent any abrading action of the water, and avert any action upon the sand; and when it is consolidated by the passage of the horses, and carts, in the process of formation, and is set by the rains, and spring-tides, it is found to resist the passage of the water through the embankment during the flood of the tides.

The heights of the embankments vary with circumstances; the rails on the most exposed parts being 15 feet 6 inches above high water of ordinary spring-tides, and 6 feet 3 inches, and 4 feet 3 inches respectively, above the extraordinary tide of the 27th December 1852, the highest tide known in that district. The spray-wall gives an additional height of 2 feet 6 inches above the rails.

Where the sea is cut off entirely by the embankments, the land-slopes are temporarily protected, during the construction, by a thin layer of puddle, or sods; and where the tide will continue to flow up the channels, and on the land side of the embankments, until the land is fit for reclaiming, the slopes are being protected with random pitching, 8 inches deep in the bed.

The sands in the estuaries offer but little resistance to the action of the water in the river-channels, especially during floods, spring-tides, and high-winds: under these influences, what is locally termed "bracking" takes place, and the channels are frequently removed their entire low-water width, displacing during the ebb, upwards of 60,000 tons of sand, within a reach of half a mile; this being carried seaward, is to a great extent returned with the flow, and a considerable portion of it is deposited in the former bed of the channel, and on the side opposite to that from which it was removed; thus the process of excavating from the one side, and filling up on the other is constantly going on. The fixing of these channels is therefore a very important feature in the future safety of the works, and for this purpose a weir is being formed, in the Kent Channel, starting from a projecting point of land, and extending parallel with the channel of the stream, as far as the site of the intended viaduct, and thence continuing so far seaward as to prevent the channel from turning in, and undermining the embankments.

The Leven channel is also secured in the same way, by a parallel weir, with a landward branch formed of "rid" from the quarry, whence many of the pitching stones are being obtained. The action of the tides scours out the sands to a depth of from 7 feet to 9 feet under low water. This space is made good with stones, or "rid" tipped from waggons; thereby giving the work a deep, and permanent foundation. In a very short time the sands, inland of the weirs, will be silted up high enough for reclaiming, and these weirs will then form the basis of very inexpensive banks for that purpose.

The formation of the embankments in both estuaries, has been delayed for some time, on account of the shifting of the channels. They are, however, now so far under the influence of the weirs, that both have been led into their permanent positions. The old channel courses are fast silting up, so that the loss will eventually be more than made up by the decreased quantity that will be required to form the embankments.

The railway embankments are being formed of the sands taken form the seaward side of them, and owing to the high price of labour during the last season, two-wheeled carts have been used, instead of wheelbarrows, and up to 14 feet above the sands no difficulty has been experienced in carting. The *modus operandi* is to carry on such lengths as can be raised to a safe height, puddled and pitched, between spring tides; the open end of each length being laid to a flat inclination, up which the material for topping off is carted. The end is then protected during the springs, with clay and stones. In this manner from 10 to 11 lineal yards of the embankment have been formed per day, or at the rate of a mile in six months, from one face.

Nothing is more difficult than acquiring a correct knowledge of the force and action of the waves, tides, and currents of the sea, in the different localities, and under the various circumstances in which engineering works are to be placed. Observations have been made by many scientific men, both in this, and in other countries, and many theories advanced as to the power and effect of these various forces, but the most practical attempt at ascertaining the impact of waves, was made by Mr. T. Stevenson, of Edinburgh, with his "Marine Dynamometer." The greatest force ascertained being 3 tons per square foot, at Skerryvore, during a gale in the Atlantic, when the waves were supposed to be 20 feet high. The next greatest force registered was 1½ ton per square foot, at the Bell Rock, in the German Ocean.[1] The waves in Morecambe Bay, do not, however, attain the height either of those of the Atlantic, or of the German Ocean, but assuming that they might even reach the height of the latter, and exert a force of 1½ ton upon each square foot of the embankment, there is necessarily, from the width required by the railway, a resisting power of double that force.

There is still much diversity of opinion among Engineers, as to the best form at which sea-slopes ought to be made; some advocate the concave, and others recommend the rectilinear form. The Author, when engaged on the Loch Foyle reclamation works, observed that the concave slopes originally used there were very objectionable; the waves were forced up the flat part of the slope with great velocity, then accumulating on the more abrupt part, they curled over and in their recoil fell with such force on the flat part of the pitching, as to cause many breaches in it. That form was ultimately changed to the rectilinear, and then the banks withstood very heavy seas without the slightest breach. Opinions vary also as to the angle of inclination for sea-slopes; some contend for a very small angle of inclination to the horizon, while others advocate the upright wall. Admitting that the percussive effect of waves, driven by the wind on sea-slopes, is decreased in proportion as the impinging particles are spread over a greater surface, then the angle must depend upon the kind of protecting material to be used. The slopes may be formed of mud, or silt, as in Holland, at so small an angle as will permit them to be thatched with straw, or reeds only, or they may be formed at a greater angle with a shingle protection, as is shown by the shingle beaches of Morecambe Bay, which are left after heavy storms at a slope of 7 to 1, and they may be formed at a still greater angle, with good pitching stones; the latter, where the material is at hand, being not only the most economical in first cost, but also the least expensive to maintain, while it affords the greatest amount of security under all circumstances.

The abundance of stone, and the great facility with which it could be obtained for pitching, naturally indicated the kind of material to be used for facing the embankments in Morecambe Bay. The question, however, remained as to the inclination at which the stones ought to be placed, so as to give the greatest

[1] Vide Trans. Royal Soc. of Edinburgh, Vol. XVI., Part I.

amount of adhesion to each other, and to resist most effectively the disturbing force of the waves; to aid in determining this, the Author tried some experiments on several slopes of equal heights, but of various inclinations. Each slope was formed of firebricks, set on end, so as to equal a depth of 9 inches in the bed; the centre brick was extracted from each slope, by means of a chain working over a pulley, and the direct power of weight being gradually applied. The results given below are the average results of several trials on each slope.

Ratio of slope.	Weight required to extract the centre brick.	Height of slope.
1 to 1	105 lbs.	4 feet
2 ,, 1	148 ,,	,, ,,
3 ,, 1	144 ,,	,, ,,
4 ,, 1	98 ,,	,, ,,

From general observations of the action of the sea on slopes, and natural beaches, assisted by the results of these experiments, the present works have been designed, and on the length of about three miles already executed, the result is very favourable, no breach, or failure of any kind, having occurred to the finished works, although severe gales and high tides, have been unusually prevalent, during the last as well as the present winter months.

In designing the sea embankments, it was at first intended to form the slopes in the most exposed parts of the estuaries, at an inclination of 3 to 1; but those already constructed having stood so well at a slope of 2 to 1, it is not intended to deviate from that inclination, and even under the lash of heavier seas than those experienced in Morecambe Bay, the Author would prefer using a slope of 2 to 1, with an additional depth in the pitching stones, to a flatter inclination with less depth of stone facing.

The viaducts over the river channels will not be commenced before next spring, and are therefore not treated of in this paper; it is, however, intended to erect them on "Mitchell's Screw-piles," and they may at some future time form the subject of another paper.

The paper is illustrated by a large chart-diagram of Morecambe Bay and sections of the embankments, whence the woodcuts are taken.

Mr. Brunlees