# Reclamation of Land
## from Tidal Waters

*Alex. Beazeley*

# THE RECLAMATION OF LAND FROM TIDAL WATERS

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*A HANDBOOK FOR ENGINEERS LANDED PROPRIETORS, AND OTHERS INTERESTED IN WORKS OF RECLAMATION*

BY

ALEXANDER BEAZELEY, M.Inst.C.E.

With Illustrations

Capio Lumen



LONDON
CROSBY LOCKWOOD AND SON
7, STATIONERS' HALL COURT, LUDGATE HILL
1900

# PREFACE.

THE excellent little book by the late Mr. John Wiggins, F.G.S., on "The Practice of Embanking Lands from the Sea"—the most important work in English dealing exclusively with that subject, published since Dugdale wrote—being now out of print, it was in contemplation to issue a new and revised edition. In view, however, of the extensive alterations of the text needful in order to bring it even fairly into line with present knowledge and practice, the Publishers invited me to undertake the preparation of a new work, which, while retaining such of the matter in the former one as I might deem of permanent value, should bring the subject thoroughly up to date and be of a severely practical character.

Although there is in Mr. Wiggins's book some matter that is unnecessary and some that has gone out of date, it nevertheless contains a large amount needing only revision to be useful at the present day; together with much that could not be omitted in any work professing to treat the subject thoroughly, and if not reproduced in his own words would have to be disguised by paraphrase. The reader will see for himself which of these alternatives has been preferred.

With the two other conditions—that is to say: bringing the subject up to date, and treating it in a practical manner—I have to the best of my ability endeavoured to comply. Should the endeavour prove to have been successful, this will be due chiefly to the great kindness with which my search for information has been seconded by those in whose power it lay to do so. I am especially indebted to the Council of the Institution of Civil Engineers for permission to reproduce matter contained in their Minutes of Proceedings, and to the Institution of Civil Engineers of Ireland and the Surveyors' Institution for copies of their Transactions most liberally furnished to me for the like purpose.

It is a particular pleasure to here acknowledge also my great indebtedness to the kindness of Mr. W. H. Wheeler, M. Inst. C.E., for much information personally communicated, as well as for large and unreservedly-sanctioned drafts upon his published works on "The Fens of Lincolnshire," "Tidal Rivers," and "Drainage of Fens and Low Lands," and his Papers on "Sea Coast Protection" in *The Engineer*.

The final chapter, dealing with certain legal aspects of the subject, and giving the substance of those sections of Mr. Wiggins's book which treat of the parties to works of reclamation, has been specially prepared for this volume by the kindness of Mr. R. M. Johns, of the Middle Temple, to whom my best thanks are due for thus adding to the practical and useful character of the work.

Foot-notes, as having a tendency to distract the attention of a reader, have been omitted from the pages of the text, and their subject-matter placed in the form of "Notes and References" at the end of the volume. Should these appear to any reader to be needlessly numerous, I may observe that, the materials for the present work being collected chiefly from statements of other writers, I have endeavoured to indicate as far as possible in all cases the source whence such information is derived. This information I have supplemented where needful by explanatory and additional matter, transferring to the Notes some portions which, though useful in elucidation, would but encumber the text.

HERNE BAY,
*April* 1900.

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## CHAPTER I.

### *INTRODUCTION.*

Attachment to precedent, and the desire of ascertaining antecedents in a question of practice, happily touched upon by Mr. John Scott Russell, V.P. Inst. C.E.,[1] by no means confined to the case he puts—that of English Engineers, may be said to be characteristic of the people at large; and it is extremely probable that a person about to embark in a scheme of Reclamation would wish to know, not only: What has to be done? and: What is the best way of doing it? but also: To what extent is it matter of accomplished fact?

To furnish answers to two of these demands is the purpose of the present work. It would be highly gratifying could a reply be given to the third also; and it is somewhat disappointing to find, in connexion with a subject admittedly of considerable importance, that no satisfactory answer seems to be at present possible. If negative results of diligent research and inquiry may be accepted as a criterion, it would appear that no public or authentic record exists of the total area of tidal reclamation of land in the United Kingdom, and that none is kept of annual additions to it. In view of the elaborateness with which details relating to all branches of national economy are nowadays collected and registered, this item of statistics seems not unworthy of finding a place among them.

That the total area must be something enormous appears from the fact, that in the estuary of the Humber alone about 290 square miles have by degrees been enclosed; while the Fens of Lincolnshire are said to include an area of about 680,000 acres or upwards of a thousand square miles.[2] There is reason for believing that in Ireland, tidal reclamations are more extensive than those made in recent years in this country: in Scotland also they are not unimportant.

In designing the works for a Reclamation, it is an object of prime importance to enclose the largest area of land with a bank of the least length and the smallest average cross-section; and considerable diversity of opinion exists as to the extent of land that should advisably be reclaimed at any one operation. Mr. Wiggins lays it down as a general rule that an intake of moderate size is much more manageable and less expensive per acre than a large one,[3] and recommends enclosure bit-wise: a matter that will presently be noticed. Mr. J. H. Muller, on the other hand, considers that in most cases large areas are the least expensive in the end, "for," he observes, "if a small area is selected at first, some portion of the original sea banks will be useless when an increase becomes desirable."[4] Mr. G. P. Bidder, Past-President Inst. C.E., "thought enclosure works of less than 800 acres, the area usual in Holstein, would not be remunerative, and that from 1,200 acres to 1,500 acres was the utmost extent which ought to be undertaken at one time. Beyond that area the difficulty of closing became almost insurmountable."[5] It will be seen hereafter, that this difficulty, though no despicable one, is far from being necessarily the formidable affair it was at and prior to the date of this utterance, when the old-fashioned mode of closing from the side was more generally in vogue than the then recently introduced and far preferable one of working upwards from the bottom. It is perhaps to this latter method that Mr. Muller, writing in 1862, refers in the following passage:—"When large areas at this [the half-tide] level are to be reclaimed, it is sometimes considered necessary, that the species of preparatory banks called 'cradge banks' should be previously carried out from the shore, so that with less area, there may be a less extent of water to contend with, during the construction of the sea bank, but that practice is erroneous, as the difficulty in the construction does not increase with the size of the area to be reclaimed, but depends upon the relative width of the openings left in the banks."[6]

Another point upon which very various opinions have been put forth, is that of the cost of a work of reclamation. In 1867, it was stated that this should not exceed £20 per acre.[7] In 1876 it was estimated that it would probably lie between the limits of £10 and £30.[8] Another estimate, accompanied by some remarks indicating the conditions governing the question, is as follows: "The cost of embanking must of course depend on the depth of the marsh as compared with the length of the frontage, and special circumstances arising from situation make the banks either more or less costly. A fair average for an inclosure, with banks 10 feet in height, and slopes varying from 5 to 1 in the more exposed parts, to 3 to 1 where the bank is more sheltered, on the sea side, and 1½ to 1 on the land side, may be taken at £15 to £20 an acre, including the sluice and other necessary works. In addition to this from £3 to £4 an acre will be required for levelling and ditching "[9] —in all, about £18 or £19 to £23 or £24 per acre.

The following tabular statement, compiled from various sources,[10] illustrates the foregoing questions.

| No. | Locality. | Area. Acres. | Length of Bank. Chains. | Proportion between Area and Bank. Area Bank=1. | Bank Area=1. | Total Cost. | Total Cost in terms of Area and Bank. Per Acre. | Per Chain. |
|---|---|---|---|---|---|---|---|---|
| | | | | | | £ | £ s. d. | £ s. d. |
| A. | Lincolnshire . | 60 | 40 | 1·50 | 0·67 | 795 | 13 5 0 | 19 17 6 |
| B. | Bychan . . . | 70 | 89·73 | 0·78 | 1·28 | 4450 | 63 11 5 | 49 11 10 |
| C. | Lincolnshire . | 100 | 80 | 1·25 | 0·80 | 1469 | 14 13 10 | 18 7 3 |
| D. | Do. . | 130 | — | — | — | 4000 | 30 15 4 | — |
| E. | Essex . . . | 175 | 144 | 1·22 | 0·82 | 2100 | 12 0 0 | 14 11 8 |
| F. | Lincolnshire . | 310 | 164 | 1·89 | 0·53 | 7000 | 22 11 7 | 42 13 8 |
| G. | Foulness . . | 330 | 105 | 3·14 | 0·32 | 1700 | 5 3 0 | 16 3 10 |
| H. | Essex . . . | 360 | 152 | 2·37 | 0·42 | 5650 | 15 13 11 | 37 3 5 |
| I. | Rossbegh . . | 400 | 47 | 8·51 | 0·12 | — | — | — |
| J. | Lincolnshire . | 400 | 180 | 2·22 | 0·45 | 5574 | 13 18 8 | 30 19 4 |
| K. | Do. . | 458 | 145 | 3·16 | 0·32 | 8073 | 17 12 6 | 55 13 6 |
| L. | Do. . | 699 | 105 | 6·66 | 0·15 | 5250 | 7 10 3 | 50 0 0 |
| M. | Sunk Island . | 700 | 275·77 | 2·54 | 0·39 | — | — | — |
| N. | — | 1000 | 60 | 16·67 | 0·06 | — | — | — |
| O. | Terrington . | 1000 | 320 | 3·12 | 0·32 | — | — | — |
| P. | Lincolnshire . | 1000 | — | — | — | 12000 | 12 0 0 | — |
| Q. | Do. . | 1213 | 250 | 4·85 | 0·21 | 19409 | 16 0 0 | 77 12 9 |
| R. | — | 1700 | 320 | 5·31 | 0·19 | — | — | — |
| S. | Wexford S. . | 2410 | 109·55 | 22·00 | 0·05 | — | — | — |
| T. | Do. N. . | 2489 | 155·91 | 15·96 | 0·06 | — | — | — |
| U. | Sutton Bridge | 4000 | 262·70 | 15·23 | 0·07 | — | — | — |
| V. | Dengie Flats . | 7000 | 720 | 9·72 | 0·10 | — | — | — |

It is probable that in all the above cases, the cost given is exclusive of parliamentary and legal, engineering, compensation, and other contingent expenses, and of the price of machinery where pumping is necessary: the cases that admit of the calculation showing that the cost is reckoned on the work alone. Those items, if added, would greatly swell the total expense, but would probably not to any material extent interfere with the relative proportion of the cases among themselves, which is all we are concerned with in the following considerations:—

The average cost per acre of the whole of the above is £18 16s. 6d.; but for comparison on other points, those cases only in which all the particulars are given, are available—and as their average cost per acre is almost exactly that of the whole, we can safely deal with the figures belonging to them. Their mean is:—acreage 380, ratio of area to bank 2·64, cost per acre £18 7s. 3d.

The mean of the four lowest in cost (A, E, G, L) is:—acreage 316, ratio of area to bank 3·13, cost per acre £9 9s. 7d.

That of the four highest (B, F, K, Q) is:—acreage 513, ratio of area to bank 2·67, cost per acre £29 18s. 10d.

The lowest in cost (G) has a ratio of area to bank of 3·14, which is practically the mean of the four lowest; and the lowest but one (L) has the highest ratio of area to bank, viz. 6·66: while the highest in cost (B) has the lowest ratio of area to bank, viz. 0·78.

Of course, in dealing with figures relating to matters of this sort, wherein cost depends so greatly on the special circumstances of each individual case, it is not legitimate to attempt hard-and-fast conclusions. But it is not unlikely that by many readers the foregoing results may be regarded as lending some show of justice to the contention that small areas are relatively less costly than large ones. And there can be little or no doubt that the ratio borne by area to bank does very materially influence expense—a conclusion indeed entirely accordant with what one feels to be intrinsically probable.

Upon the question of bit-wise enclosure already mentioned, Mr. Wiggins observes:—"A very important precaution is to divide the intake into as many portions as circumstances render convenient, making so many separate intakes or levels, since an intake of moderate size is much more manageable and less expensive per acre than a large one;" and again:—"One great portion of the expense . . . is incurred by the necessity [he is here speaking of a certain intake on the Nene] of what are called 'cradge-banks,' which enclose portions of the space to be finally embanked. . . . Other cradge-banks have been made, and are intended to be made, for the double purpose of reducing the area of tidal water to be contended against at one time . . . and of raising the land; which latter operation not only reduces the water in depth and force, but also makes the land more valuable when embanked. The benefit of these cradge-banks is thought to be so great, that although they do in fact constitute many temporary intakes in addition to one permanent embankment, yet the parties are constructing as many of them as will ultimately reduce the space from which the water is to be finally excluded, to a few, say 500 acres,—on the principle of lessening the force of the reflux tide, at or about the critical period of closing or shutting out the tide altogether." [11]

In the case of the River Dee Company's Reclamation, the process followed was to construct a bank rising 9 feet above the level of high-water, so as to confine the river to the south side of the estuary. The tidal water, which was admitted to flow freely between this bank and the north coast, gradually deposited layer after layer of sand and silt, and in fact shut itself out; and as soon as the surface had attained a sufficiently high level, a cross bank was constructed between the main bank and the north shore, and thus a large area was bit by bit reclaimed. The reclaiming banks were gradually strengthened, and pitched with stone on the outer face; and substantial self-acting sluices were constructed, which close against the ingress of the rising tide, but open when the tide has sufficiently fallen, allowing the drainage water to escape from the reclaimed ground, some of which is below high-water mark.[12]

This subject will be treated somewhat more in detail when dealing with the banking-out of streams intersecting an intake: in modified form the principle is applied to the prevention of flooding caused by percolation and by casualties, which so far as needful will be noticed in due course hereafter. The question of its preferableness to enclosure all at once, is but one out of many which, as we shall frequently have occasion to observe, do not admit of solution by any hard-and-fast rule, but are determined by conditions of the particular case contemplated.

In the present volume, prices of work and materials are not as a rule given: those for items of a special or unusual description are occasionally stated, as a guide to persons who may have to frame estimates for a work wherein these come to be employed. Every care has been taken to bring them as nearly as possible into agreement with rates at the present time prevailing, chiefly on the East Coast. It is probable however, that even so they are but approximately correct, and the figures are to be received with this caution —that prices occasionally vary: that they are not likely to be uniform even at the same period in all parts of the kingdom; and that circumstances of locality will almost certainly affect them in different parts of even the same district.

No attempt whatever has been made to give an estimate of the work as a whole. Mr. Wiggins, it is true, has made one; but of what value can it be accounted, seeing how widely different must be the circumstances of every individual case. A mean cross-section has to be assumed for his bank; and it is only by the rarest chance that the bank required for a given work would agree with this mean—nor, even if it did so, can it be taken that other data would at all agree with those assumed. Examination of the relative proportion between area and bank in the foregoing Table: the smallest amount of reflection upon the influence of shape and configuration of the ground on position and length of the drains, and of the amount of local and land waters upon their dimensions in cross-section and their inclination: to say nothing of height of surface, range of tides, and a score of other conditions—will sufficiently show how little reliance can be placed on any arbitrary estimate as a guide to solution of the question of cost as a whole. Of this truth another striking illustration will be found in the extreme variance in the cost of sluices, and a further one in that of the cost of pumping-stations. In fact, such estimates are worse than worthless as a guide—they actually tend to mislead.

## CHAPTER II.

### *THE SITE.*

In the course of discussion at the Institution of Civil Engineers in 1862, on the Reclamation of Land from Seas and Estuaries, it was well remarked that "as regarded the general question, it was very difficult to separate the agricultural from the Engineering branch of the subject. An Engineer was generally called upon to report upon the desirability of making the proposed inclosure, and some part of his observations must necessarily have reference to the value which the land would probably acquire by being reclaimed. . . . There was a particular class of fine sandy deposit, of a siliceous character, which might easily be mistaken by inexperienced persons for mud, but upon examination it would be found to contain so small a portion of soluble matter as to render its enclosure a profitless speculation. This showed how desirable it was that Engineers, who undertook this class of works, should address their attention to the character of the soil they were about to reclaim, because in some cases it might be worth while to inclose a small area with expensive works, while in others, however cheaply the works might be executed, the land when reclaimed might prove comparatively valueless."[13] Hence it appears that, in investigating the eligibility of a site, the nature of the soil stands first among the numerous points to be taken into consideration. The most essential among these are as follows:—

*a*) Soil, very important
*b*) Height with reference to tide-levels,
*c*) Slope and differences of level of the ground,
*d*) Intersection by streams &c.,
*e*) Shelter,
*f*) The foreshore and the foreland.
These points will now be considered seriatim.

*a*) **Soil.**—The chief constituents of soils are: alumina, clay, silica, lime, and organic matter; alumina being the pure earth of alum or oxide of aluminium, and clay a chemical compound of about 60 per cent. of silica and 40 per cent. of alumina with a little oxide of iron, no siliceous or sandy matter being separable mechanically or by washing in water. The most familiar form in which silica occurs is that of sand. Lime in soils occurs chiefly in the form of carbonate and sulphate; the former being by far the more frequent and abundant and, in the form of broken and comminuted shells, constituting in many localities a large proportion of the sand on the sea-shore, hence called calcareous sand. For agricultural purposes, soils are classified in general as follows:—

*Pure clay*, consisting of about 60 per cent. of silica and 40 per cent. of alumina and a little oxide of iron. No siliceous sand subsides from it when diffused through water.

*Clay soil*, consisting of pure clay and 5 to 20 per cent. of siliceous sand, separable from it by washing in water.

*Clay loam*, from which 28 to 40 per cent. of sand is separable by washing.

*Loamy soil* deposits from 40 to 70 per cent. of sand when washed.

*Sandy loam*, 70 to 90 per cent. of sand separable by washing.

*Sandy soil* contains no more than 10 per cent. of clay.

*Marly soil*, in which the proportion of lime is more than 5 but not more than 20 per cent. of the whole weight of the dry soil. It is a sandy, loamy, or clay marl, according as the proportion of clay it contains would place it under the one or the other of the foregoing denominations, supposing it to contain no lime or not more than 5 per cent.

*Calcareous soil*, in which the proportion of lime exceeds 20 per cent. It is a calcareous clay, loam, or sand, according to the proportion of clay it contains.

*Vegetable moulds* are of various kinds, from garden mould which contains 5 to 10 per cent. of its weight of organic matter, to peaty soil containing from 60 to 70 per cent. (in each case when dry). These soils are clayey, loamy, or sandy, according to the predominant character of their earthy constituents.[14]

It is in the highest degree improbable that a Reclamation of any considerable extent would be undertaken save on favourable reports as to the soil from a chemical expert and from practical agriculturists. In order, however, that the Engineer may form for himself a preliminary idea on the subject sufficient for purposes of classification, a good practical process of analysis given by Professor Johnston is appended in the Notes.[15] Such an analysis cannot, however, be regarded save as preliminary and general. The presence of even a small percentage of some substances is known to be hurtful. Professor Johnston instances a soil "taken from a field in which sainfoin died regularly in the second or third year after it was planted. This was naturally attributed to something in the subsoil. And by . . .

analysis . . . it was found to contain much sulphuric acid [1·4 per cent.] in combination with oxide of iron, forming sulphate of iron (green vitriol). This salt being noxious to plants, began to act upon the crop of sainfoin as soon as the roots had gone so deep as to draw sufficient supplies from the subsoil, and it thus gradually poisoned them, so that they died out in two or three years."[16] It has been stated that on the Essex coast the surface is impregnated and poisoned by something that comes from oysters.[17] A much more minute analytical examination is therefore needful, before a soil can be conclusively determined as being worth reclamation.

On the other hand, it does not necessarily follow that a soil is worthless because preliminary examination such as that first mentioned shows it to contain an undue or even an apparently excessive proportion of sand. A Danish official authority[18] states that the land reclaimed from the shifting sand (*flyve sand*) on the west coast of Schleswig gives good crops of grain, and he attributes this fertility to the fact of its intermixture with mica particles, which appear as regularly in that sand as in the marsh clay. Again, Mr. D. Stevenson, M. Inst. C. E., says:—"The area reclaimed from the estuary of the Dee, which is now fertile land, was originally pure sandbank covered by all spring-tides, and utterly unavailable for any useful agricultural purpose."[19] In some marshes at Morecambe Bay, portions of bare sea-sand, which formerly were covered with the tide every day, were scarified, sown with seeds, and liberally dressed with bones and other manures, and soon became luxuriant pastures carrying extraordinary numbers of sheep and cattle, the former sometimes looking half overhead amongst the clovers.[20]

Mr. John Wiggins,[21] in treating of the eligibility of a site for reclamation, says with reference to the question of soil:—"The best and earliest indication when a marine soil has become fit to embank is the growth of *samphire*, which demonstrates its stability and permanence of position, and is the forerunner of the marine grasses, so healthy for sheep, which are largely fed on the very extensive saltings of Essex. . . .

"The best soil for an intake, therefore, is that clayey earth whereon sufficient marine herbage grows to afford sheep-feed of some value, and this will be above the level of ordinary tides.

"The next best is silty earth, with sheep-feed like that . . . found on the Lincolnshire coast.

"The third is mud-banks with samphire, over which the spring tides always flow.

"The fourth is mud, over which the tide always flows more or less, and this is eligible in proportion to its clayey matter.

"The fifth is what is called sheer sand, which is almost barren, except as to a few plants, such as the *eringo*, the *sand-rush*, &c., but sometimes even this sand is rendered to a certain degree fertile by the calcareous matter of comminuted shells, or may be rendered fertile by raising on its surface the marly substance sometimes found beneath.

"A sixth class may be designated in those sandy and shingly dunes, which continue for ages bare of vegetation; and are only worth embanking on account of local value; and these must be deeply covered with mould to enable them to grow anything.

"In our judgment on the all-important subject of soil, we are not, however, to be misled by the black and stinking deposit of the sea amongst sandy particles,—not to mistake the mere decay of marine vegetation for inexhaustible fertility or rich manure. Such matter soon dries into a *caput mortuum*, and little but a white sand remains. To secure permanent or high fertility, there must be sufficient quantity of argillaceous matter to render the deposit somewhat slippery under foot when in a moist state, and if some shells are seen, so much the better.

"One may judge of what the sea-mud will come to when laid dry, by observation of the neighbouring shores. If they are argillaceous, so will be the soil of the intake; if siliceous, sand will predominate, since these mud-banks are but the detritus of those shores altered by the sea and its contents.

"Shells mixed in fragments, or in layers, are always a good sign, and denote fertility. There are also often to be found patches of calcareous clay amidst sandy shores, though covered with siliceous matter, and by raising such upon the surface the fertility may be greatly increased.

"It may also be well for an intake to include some acres of beach or shingle, or gravel, as that material may prove highly useful for making or repairing roads, &c., or even for draining."

Some of the points mentioned in the above remarks, and those cited on page 12 *ante*, sufficiently indicate the necessity for an examination of the subsoil as well as the surface soil.

*b*) **Height with reference to tide-levels.**—"This is important for several reasons, but chiefly on account of its drainage to seaward; for . . . unless there is height enough above ordinary or medium low water to admit of the sluices running from four to six hours between tide and tide, no sufficient natural drainage can be obtained, and it may be necessary to resort to the expensive means of steam drainage, and even that may not be effective in all cases, *i.e.* cases in which the land waters come down very suddenly.

"In Essex, no intake, as the embanked grounds are there called, is ever attempted of ooze or mud overflowed by every tide. It is only the saltings which are considered fit subjects for that speculation, and these are only covered by spring tides. The banks, or, as there termed, sea-walls, are therefore on ground generally 5 or 6 feet above low-water level, and the sea-walls seldom exceed 6 or 8 feet in height above their seat. Still it is very possible to embank and drain lower slobs than these, but the difficulties are proportionate, and on the whole it must be concluded, that any slob of less height than that which admits of four to six hours' run, unless of extreme fertility to afford steam drainage, is not eligible for embankment, as besides the drainage, the lowness of the ground must be compensated by additional height of bank, and the hazard, and the expense of security against that hazard, are thereby increased. . . . There is also another point, in which the height above tide is of consequence, viz. that in low cases the soakage from sea to land is greatest, and the hazard of the bank blowing up more imminent. Besides, low slobs have seldom attained to those qualities of soil which are essential to fertility, and which time alone can give. There is yet another objection to low intakes, viz. that they contain so much salt from the constant presence of the tide, that they are a long time in becoming sufficiently freshened for cultivation, and that time is prolonged in proportion to the tenacity of the soil." [22]

This view of the case receives support from the opinion expressed by Mr. D. Stevenson [23]:—"My experience leads me to conclude that it is in general inexpedient to attempt to enclose land by permanent banks until, by gradual deposit and subsequent accumulation due to the decay of vegetable matter, its surface has reached about the level of high water of *ordinary* spring tides. I do not say it may not be done before this level is reached, for land has, within my own knowledge, been enclosed at a considerably lower level on some parts of the Tay, where the marshes covered by reeds in sheltered places were found to be fit for enclosure, though covered to the extent of from 3 to 4 feet at high water, and on the Forth still lower slob lands have been enclosed."

While there can be no doubt as to the importance of securing sufficient fall for drainage, and of attaching due weight to the foregoing considerations as respects other points: it is to be observed that restriction of a Reclamation to the saltings or salt marshes at or above high-water level, stated to be the invariable practice in Essex, is by no means universal or even general elsewhere; and that a lower seat for the embankment may not only secure advantages outweighing the difficulties and objections above advanced, but in many cases may be the sole means of taking-in sufficient land to repay the cost of embanking at all. Thus, to cite only one example out of many that might be adduced: in some parts of the estuary of the Humber between Sunk Island and Spurn Point, extensive tracts of "outstrays" or (locally so-called) "growths" exist beyond the banks, and are submerged only at average spring-tides. These level tracts are covered with marine grasses, affording exceedingly valuable feed for young horses and sheep in the summer season.[24]

Closely connected with the question of height, is that of warping, a process whereby the level of a marsh or even of a slob may be considerably raised. This involves matters of construction not properly belonging to the subject immediately in hand, and its consideration is deferred to a subsequent chapter. It may here be remarked, however, that a judgment upon the eligibility of a site in reference to its height must not omit to take into account the facilities it may present for being raised by warping.

*c*) **Slope and differences of level of the ground.**—Although this is a minor point, it should not be left out of account in estimating the suitableness of a proposed site. The surface of the ground should be somewhat, even if but slightly, varied by more or less of water-sheds and channels, so that rain-water may have free discharge into the lows or fleets—natural depressions usually occupying a considerable portion of the surface of marsh lands—whence it is to be led into the general system of drainage. A dead flat, even when well provided with grips and drains, is apt to retain the surface-water too long, to the prejudice of vegetation ; and without some such natural advantage of surface, the reclaimed area will be more expensive to drain and less suitable for cultivation.

*d*) **Intersection by Streams &c.**—A highly important point for consideration is the intersection of the proposed site by creeks and rills, and by streams or rivers discharging inland waters. " In a mountainous country, or even such a one as presents a considerable slope towards the sea, the inland waters may be so considerable as to require great expense in conducting them to sea, clear of the intake, by means of *catchwater drains* intercepting those upland waters, and carrying them out to sea, independent of the waters of the intake; viz. those of downfall upon it, or springs rising within it: hence such intakes as have the smallest quantity of upland waters to provide for, are the most eligible subjects." [25]

Creeks and rills follow the lines of natural drainage of the site in its normal or unimproved state, and frequently afford valuable indications of the existence and position of land-springs within it. Beyond useful information on these points, their chief if not sole importance consists in the difficulty and expense they may involve in the carrying of the bank across them, their bed being occasionally deep and of a treacherous softness. This will be more fully dealt with when treating of the Bank.

Streams and rivers discharging inland waters present for consideration matters of a very different character. Their catchment-basin needs to be carefully studied, since its area, configuration, soil, slopes and surface, rainfall, and other physiographical features — affecting as they do the nature and amount of solid matter brought down by its water-courses, and the volume of water in ordinary flow and in floods for whose conduction through and discharge from the reclaimed area provision will have to be made—have an important bearing upon the value of the site and the works needful for its reclamation. "The drainage area in one situation, for example, may include large tracts of hill country, having steep and scantily soiled slopes, from which the rain is readily discharged. In other places the surface may be flat, or gently rising deeply soiled land, absorbing much of the rain that falls, and giving it off only by slow degrees. The discharge of other districts, again, may be much influenced by their geological formation and the absorbing power of the underlying strata. Agricultural improvements, also, exert an important influence on the drainage of land, large tracts of sheep grazing pasture, for example, being less absorbent than an equal area of well-drained arable land." [26]

The solid matter brought down by streams varies according to the soil and condition of the areas they drain, and nothing save careful examination can determine either its nature or its amount. Should it be found to consist of soil fertile in itself or suitable for admixture with the soil already on the site, it may in many cases be turned to profitable account by warping. Where, on the other hand, large quantities of infertile gravelly detritus are deposited by a stream on the proposed site, it is an unfavourable token; not alone as regards any prospect of advantage to be derived from it if warped, but also because the course of such a stream when embanked for conduction through the reclaimed area may be "apt to fill up with gravelly *débris*, and either to overtop or burst the banks, thus causing floods at least, if not invasions of fertile lands by a covering of infertile soil." [27] To endeavour to provide against this by widening the opening between the confining banks would not only tend to augment the mischief by reducing the velocity of the current and thus encouraging the deposit of obstructive matter, but would mean reduction of the reclaimed area available for cultivation. The remedy lies rather in contracting the channel, and this involves an increase in the height of the confining banks and additional expense in their construction.

The relation of rainfall to outflow is a question complicated by so great a variety of circumstances and local conditions, that notwithstanding the amount of painstaking observation and calculation bestowed upon it, its solution by any method of universal application has not yet been arrived-at; and save some general average results and roughly approximate rules nothing can be regarded as determined. Fifty years ago it was said to be assumed by scientific men that the proportion of outflow to rainfall was as 1 to 3.[28] From observations made in 1867 by Captain E. R. James, R.E., on the River Wey, he concluded that the proportion of outflow to rainfall might be roughly estimated as 4 to 10. Certain observations made by him in another locality gave, indeed, very different results, but these seem to be satisfactorily accounted for.[29] In course of discussion on two elaborate papers read before the Institution of Civil Engineers in 1876, Mr. C. Greaves, M. Inst. C.E., considered the proportion of the ordinary discharge of a river might be taken to be one-sixth, and of a river in flood one-tenth, of the rainfall.[30] Mr. L. F. Vernon-Harcourt, M. Inst. C.E., after giving a summary of observations on several European rivers, proceeds:—"It appears from these observations, that the . . . proportion of the rainfall that actually reaches a river may vary from 75 per cent. on impermeable strata, down to 15 per cent. on very permeable soils. These proportions, however, are merely yearly averages, and would be much less in the warm season, and greater in the cold season."[31] At the same time, however, it should be borne in mind that "perhaps the only general result to be gathered from the published observations relative to floods, is, that the flood discharge has a higher ratio to the ordinary discharge in small, than in large rivers. This is due very much to the fact, that in a small river a rainfall affects every one of its feeders, whereas, in a larger river, the influence of the rain is [perhaps] limited to one portion of the district only."[32] Taking into consideration all the circumstances, it is advisable to leave too great rather than too small a margin of safety, by providing for the passage of a maximum outflow : facing a known definite outlay in construction in the first instance in preference to risking the disastrous consequences of miscalculation in the matter. "Taking the rainfall in the Fen district as a guide, it may be estimated that provision should be made for a daily rainfall equal to about ·0076 of the average annual rainfall of wet seasons."[33]

Finally it may be observed that investigation into the level of maximum and ordinary floods, by their vestiges if any such remain, or by authentic information concerning them, will usually prove more reliable than a theoretical estimate, and should in every case when possible be used in preference to the latter.

*e)* **Shelter.**—"Another point of eligibility is the degree of shelter from prevailing winds which the position of a bank may afford, and consequently protection from seas driven up by those winds. This point is important, inasmuch as with a long sea-reach having full play against a sea-bank which stands broadside to the prevailing winds, it is so continually flogged and battered by the waves, that nothing but an expense disproportioned to the benefits can sustain the banks. It therefore becomes necessary to look carefully to this point of shelter, as one of eligibility, and for some headland or some rock, some spit of land or bank of sand, which may either act as a shelter from the winds, or as a breakwater from the heavy seas, since the more sheltered and land-locked is the site of any intake, the more eligible and secure will be its position, the more valuable its property, and the less expensive the maintenance of the sea-defences; and moreover it is in such situations, as in bays, coves, and inlets, that the richest and best diluvial and alluvial deposits of soil are most usually found."[34]

*f)* **The Foreshore and the Foreland.**—The words "foreshore" and "foreland" being sometimes employed without due regard to the distinction existing between them, it is proper to note that in the present text (save in quotations) "foreshore" is used to denote the whole stretch of ground from average high-water mark to lowest water mark, and "foreland" that lying between the outer foot of the embankment and the lowest water mark.

The foreshore of an intended site will in general be found to consist of the following four kinds of ground, in descending order:—the salt marsh, on clay or clayey soil, lying usually at a level above high-water mark of spring-tides, and seldom so low as to be overflowed save on exceptional occasions: salts, saltings, samphire-ground, slob, or slake, as is variously termed the mud or rich alluvial matter overflowed at high-water of neap-tides and extending to about half-tide level: sea-sand more or less hard and firm: and, at or about low-water mark, quicksand or sand closely resembling it. These do not always occur together on a given foreshore, but two or more of them may usually be expected to be found at any site likely to promise well for reclamation.

The matter of most importance in a foreshore as affecting the eligibility of a proposed site, is its fitness as a foundation for the bank. Mr. J. H. Muller points this out as follows:—"Experience has shown, that if the banks cannot be constructed entirely on the salt marsh, it is preferable to go to half-tide level. Banks entirely on the salt marsh are the easiest to construct, and the strongest that can be made. Those on samphire ground and mud are the most difficult. During their construction, slips are of constant occurrence, the use of waggons and horses is impossible, and a large proportion of the material is washed away, as it is deposited, and before the bank is consolidated and raised above high-water mark. In fact, for waste, settling, and contingencies, from 60 per cent. to 100 per cent. of the original quantity must be calculated upon as necessary. If a storm occurs during the progress of the works, the slopes cannot be protected; and indeed, a bank constructed on such a bottom, is always unsafe. When the line of the embankment is laid at the half-tide level, or about the limit of vegetation, and on hard sand, it is possible to make the whole of the reclaimed land fit for cultivation, and this mode of effecting the inclosure need not cost more, and is safer, than when the higher, but softer bottom is adopted as the seat of the bank."[35] See diagram, Fig. 1. At Malahide near Dublin, the estimated quantity of earthwork in an embankment was 88,000 cubic yards; but owing to the sinking of the bank—its weight displacing and forcing up the slob, the actual quantity required was 180,000 cubic yards.[36]

Not only the supporting power of the foreshore has to be considered, but also its permeability: percolation of water under the bank being a serious danger to its stability. "All natural soils are more or less porous and transmit water pretty freely; but some still retain their quasi-fibrous texture, and have their tenacity not impaired, or at least destroyed, by being infiltrated. Others become entirely disintegrated, and some almost lose their solid quality and run like a liquid. In consequence of their porosity, natural soils adjacent to water-courses become saturated to a long distance and nearly to the very level of the water itself. . . . If the natural soil be porous to a high degree, there will be leakage under the embankment to an extent which may be very inconvenient and even extremely dangerous. . . . It is sometimes enormous in quantity. If the soil be of a fibrous and tenacious kind, so that a certain continuity and coherency are preserved even in a moist or wet state, the evil will probably be confined to mere leakage, which will be embarrassing or damaging in proportion to its quantity, its duration and the means of getting rid of it by drainage. But if the soil be composed of loose and independent particles of small size, it may become exceedingly unstable and even mobile when saturated with water. A fibrous or honeycombed soil, though never so porous, yet presents, as it were, a network of capillary tubes, which afford a strong frictional resistance to the flow of water and diminish the hydraulic head by so much. But earths of the second kind permit their particles to be perfectly enveloped by the liquid and held in suspension by it, in proportion to their smallness and lightness, perhaps also to the cohesive union between the water and the particles, which is different in different earths. Hence result a variety of treacherous and semi-fluid soils, commonly classified together as 'quicksands,' which instead of remaining in place and resisting the passage of water, are actually carried by it and are, as it were, incorporated with it. It follows that such soils will transmit the pressure of the external water with comparatively small loss. It is evident that if the water stand very high against the embankment, the pressure transmitted under the bank will be exerted upon the layer of strong soil, if such there be, overlying the [so-called] quicksand, and if this be thin, will 'blow it up,' as it is called, thus knocking the foundation from under the dyke or levee. . . . This is no chimerical or merely speculative danger, but a very real and threatening one. . . . In Holland, extraordinary precautions are taken against it." [37]

The foreshore generally, and especially the part intended to be the seat of the bank, should therefore be carefully examined, as to its subsoil as well as its surface material, by trial pits and borings. The mode of dealing with defects in respect of bearing-power and permeability, will be considered when treating of the Bank.

The foreland plays so conspicuous a part in protecting the Reclamation, and so much the better does it serve that purpose the wider and higher it is, that consideration of advantage to be thus obtained may to a large extent influence a decision as to whereabouts to place the seat of the bank. Mr. J. Wiggins [38] lays great stress upon it. "There is," he says, "certainly no feature appertaining to a sea-bank of greater importance than this, since it acts as the advanced guard to the bank itself, receives the first shocks of the sea, and deadens its force upon the bank, by decreasing the depth and bulk of the wave. The broader, therefore, the foreland, and the higher above low-water mark, the greater its protection to the bank. . . . It will certainly answer the purpose of the boldest undertaker, to leave at least one hundred yards in breadth outside his intake." And though, owing to his practice having lain chiefly in the Eastern Counties, he was doubtless prepossessed in favour of the Essex practice of keeping the bank as far back as possible (*ante*, p. 15), and was content to sacrifice some of the area of reclamation for the sake of safety, yet even among the advocates of bolder undertakings the desirableness of width and height in a foreland is emphatically recognised. "Of course the best protection which can be afforded to the foot of the dyke, is a good foreland lying on its seaward side, and the probability of damage decreases with the height of this foreland. Where, however, there is deep water, this cannot be obtained, and the breaking of the waves is not only increased, but the dyke is exposed for a longer period to their operation. Everything which can tend towards the increase of foreland seems to be adopted as the surest course; such as groynes, coverings of straw and brushwood, &c."[39]

No rule, however, can be laid down for determination of the extent to be given to this most useful feature. Its value and importance once recognised, the rest must depend upon local conditions and the circumstances and requirements of each particular case.

## CHAPTER III.

### *THE BANK.*

THE subject of the Bank or Dyke, *i.e.* the mound whereby the sea is excluded from the area to be reclaimed, may be divided under the following heads, viz :—

*a*) Location,
*b*) Materials,
*c*) Form and Dimensions,
*d*) Construction,
*e*) Closing,
*f*) Permanent Facing,
*g*) Streams and Cradge-banks,
*h*) Groynes and other Protective Outworks; and these in their order will now be considered.

*a*) **Location.**—The location of the bank depends upon circumstances such as: the nature of the foreshore, the amount of shelter afforded by the configuration of the coast and by shoals or sandbanks, the quarter whence come the prevailing winds and the heaviest seas, the direction and force of currents, &c.—conditions varying with each particular case. It is also affected by considerations respecting the proportion borne by the area desired to be reclaimed to the amount of embankment needed for its enclosure: it may, for example, be prudent to keep the bank well back in a position of safety and expend little on its construction, in the case of an area of small extent or one promising only a small return upon the cost; while on the other hand an area, worth enclosing by a bank of moderate extent and cost, may be capable of being so greatly augmented by bold treatment as to warrant the construction of a highly expensive one: circumstances alone can decide the question. Another point to be considered is the amount of inland waters other than those whose outflow is by a river or stream separately embanked and having a special channel to the sea independent of the drainage-sluices. This point will be dealt-with in detail when we come to treat of Drainage: its bearing upon the location of the bank consists in this—that the greater the amount of outflow to be provided for, the higher above low-water mark must the bank be placed, unless the number or the discharge-capacity of the sluices be increased, or power-drainage resorted to. Upon some points relating to location of the bank there is, as will presently be seen, divergence of opinion. But there exists a general agreement as regards the placing of its seat at such a height above low-water level as to allow sufficient time for natural drainage of the enclosed area; the alternative being a necessity for the employment of power-drainage or the proportional increase in number or dimension of the sluices. "Banks on a lower level than that of the half-tide mark, are not advisable, on account of the shifting nature of the bottom which is ordinarily met with, and the large openings, and low levels, which are required for the outfall sluices."[40] "The bank, therefore, must be placed sufficiently above the tide at ordinary low water to admit of the sluices remaining open as nearly six hours as possible, and in general for four hours at least. If placed *at* low-water mark, the return tide would evidently shut the sluice valve, or door, almost as soon as it was opened by the tide receding, although so long as the weight of water inside the sluice is greater than that outside of it, so long will the sluice remain open. When placed so low, however, the run is stopped whenever the tide does not recede so much as usual, which often happens when the wind keeps up the water, and also in neaps. Therefore the sluice must be placed, as nearly as circumstances will admit, so far above the low water of spring tides as will allow it to have six hours' run between tide and tide, beginning to run at half-tide of ebb, and continuing to half-tide of flood. But the sill of the sluice should be at least 2 feet below the level of the land, therefore the proper height of the foot of the bank above low-water mark is 4 feet at least. Most speculators will, however, carry their line of bank to within 2 feet of the low-water level; but this is imprudent and injudicious, as the greatest fault of an intake is being too low with reference to the tide, and the more especially when it is flat as well as low, in which case its drainage is difficult and expensive, and, however good the soil, its cultivation must be imperfect without the expense of machine drainage, in addition to what natural drainage can be obtained. We conclude, therefore, that the most eligible situation for a bank is such as will allow of about 2 feet from the sill of the sluice to dead low water, that sill being placed 2 feet below the general level of the land, *i.e.* the land being 4 feet above low-water level; but this must depend on many circumstances, amongst which the quantity of water intended to stand inside the intake, or what is usually termed 'the fleet,' must be taken into the account; and if all cannot be drained, it will be important to determine how much beforehand, and to place the bank accordingly. Thus, for instance, should the proposed intake consist of 1,000 acres, and should the chief part, say 700 acres, of its surface, be 4 feet above the dead low water, it would be sufficient; although 200 acres more might not be above 3 feet higher than low water, and even 100 acres either not above 1 foot higher, or never ebbing dry, since these lower levels may either remain as fleets (lakes), or, if worth while, be drained by steam." [41]

Of course, at a site where the rise of tide exceeds 8 feet, the heights above mentioned would place the seat of the bank below half-tide level, which would be not in accordance with the recommendation quoted at page 28; but in both cases the statements should be understood as expressing and illustrating a well-defined general principle rather than a hard-and-fast rule.

Fig. 1 is an imaginary cross-section of a foreshore, showing the general succession of the various soils and the several positions of a bank at different heights above low-water.

The limit of size of intakes, and their proportion to the bank needful for their enclosure, were dealt-with in the Introduction; and what was there stated will serve as a general guide on that head.

As regards the line and direction on plan of the bank with reference to prevailing winds, the run of the heaviest seas, and the flow of currents, there is much diversity of opinion. The distinguished Dutch authority Caland, is cited in favour of a line with as few salient angles as possible, set somewhat aslant to the run of the sea; and he nowhere appears to contemplate the construction of banks having concave curves or retiring angles. Where salient angles on plan cannot be wholly avoided, the several straight lines of the plan should be joined by a curved sweep; rectangular corners, as he points out, being always dangerous points of attack for waves and currents.[42]

Mr. J. Wiggins[43] takes a somewhat different view of the matter. "The best line of direction is not one at right angles with the prevailing winds and seas, but one rather in the same direction as these,—not a straight line, but one affording such curves as

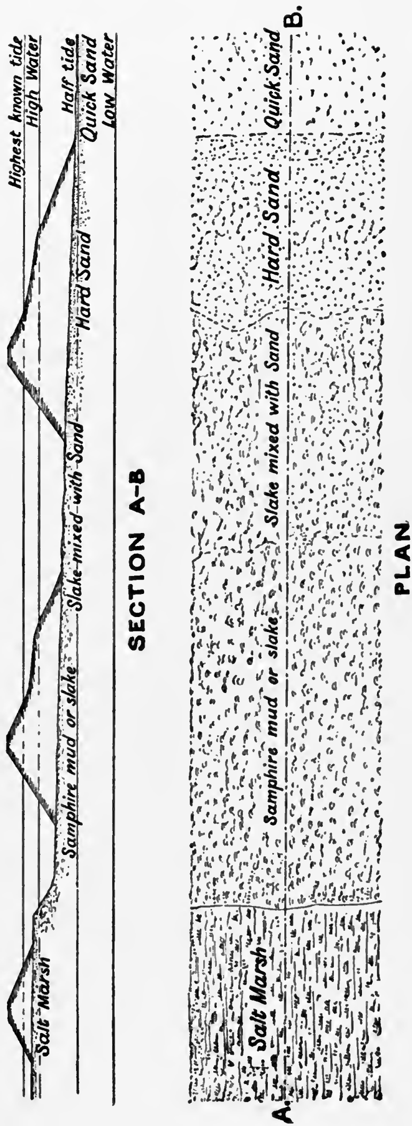



Fig. 1.—Diagram of Foreshore and Banks.

that the salient angles may protect the retiring lines,—not actually zig-zag, but with projecting elbows here and there, so placed as to embay the spaces between them. The benefits of these projections are considerable. They shelter, under some circumstances of wind and tide, very extensive reaches of bank to leeward of them, and in other cases they break and divert waves that would otherwise rake the bank for miles. They act as jetties also, and tend to accelerate, if they do not actually cause, the accumulation of silt and mud in the bight to leeward of them, and so not only strengthen the bank, but also prepare for another embankment outside of the first. Care must however be taken to enable these advanced guards to sustain the rudest shocks of the ocean, and, with this view, they must be *well* covered with stone over the whole of their height above tide. The position and distance of these points must depend on the general form of the shore and on the form of the line chosen for the embankment, but it would be well to place them upon any rocky or gravelly points that may exist on, or near, the line, or even any little mounds that may occur on the line, if of sound materials, but also so as to present one of their projecting sides to the most prevalent wind and sea, and so that it may throw off to seaward any wave striking that side. The distance of such points may be from one to two furlongs, and in the case of bays between, they may be more distant, even to a mile. The bank in the intermediate spaces between these points had better be rather curved than straight, and the curves had better be rather inward towards the land than outward towards the sea,—because the power of the wave will be diminished by the inlet or bay thus made, and it will have a tendency to fill up and strengthen the bank. In choosing a site for a sea-bank, care should also be taken to avoid those spots which are exposed to any great current or rush of tidal or land-flood waters against the bank, since the force of such waters may be so great as inevitably to overcome the resistance of almost any bank. In estuaries or inlets where the entrance is wide but suddenly narrows, these currents are often very strong,—the tide comes up with an 'eager' or 'bore' as it is variously called, *i.e.* a wave of several feet in height,—as in the Severn for instance, which scarcely any bank could receive 'full on' without destruction, although it might pass innoxious from end to end *along the line* of bank. Sometimes also, the most tempting land-locked situations are liable to this objection, and where it seems only requisite to join two opposite projecting points by a bank, in order to gain a large extent of land, and yet such a bank may be almost impracticable by reason of the strong current with which the tide sets in against it. On the other hand, there may be very eligible situations for a sea-bank, even in such estuaries as are filled by a rapid tidal current, because there are often in such estuaries projecting points of land which break the force of the current, and in the bight of which the tidal rise is almost tranquil."

Mr. J. H. Muller's opinion differs considerably in some respects from those above given. "The principal object to be kept in view, is to inclose the largest area, with a bank of the least length, and the smallest average cross section. These points are regulated by the direction of the outer portion of the embankment, or sea-bank. It is sometimes recommended that it should be, as nearly as possible, parallel with the current, and at an acute angle to the prevailing winds. But experience seems to show, that where creeks do not interfere, a different system is preferable. When the embankment is placed at an acute angle to the prevailing winds, the force of the wave acts on a greater length of bank, without much diminishing its intensity. A current which runs parallel to a bank, also occasions a chafing similar to that which is produced by the action of a stream on the sides of a river. . . . It is best to construct one side of the embankments boldly exposed to the full force of the gales, so that the sea bank will shelter, or protect the other two sides. By this arrangement, a less extent of bank requires supervision during gales, and in executing the work, if the sea bank is first made, the other two sides can be finished in comparative security. A direction, at right angles to that of the current, also possessed advantages, on account of the small extent of bank which is acted upon by the current, and the eddy which is produced occasions an accumulation which forms a protection, throughout a considerable length of the bank. Indeed, the direction of the original currents are generally so much changed, by the altered outline of the foreshore, that in most cases it is only necessary to take the current into consideration with regard to the difficulty of constructing the bank, but not with regard to its maintenance." [44]

In the case of an embankment on the River Crouch, in Essex, the sea is said to wash the bank in a peculiar way, coming from the German Ocean with a sort of cutting side-wave that probably has a more wearing effect than if it came directly upon it.[45]

It is not easy to determine a question respecting which so great a diversity of opinion exists. The probability is that the several writers had in view examples wherein the conditions differed widely: it is self-evident that what might be perfectly efficient in one case might fail in another. Whether the bank should squarely present a bold front to the sea, or one retiring at a greater or less angle, depends upon the gradual or rapid deepening of the sea-bed beyond low-water mark, the steepness or flatness of the foreland, the materials of which the bank is constructed, and the force of the tidal currents at different levels of the tide, quite as much as upon the existence of shoals or rocks that may diminish the force of the waves upon the bank itself. Where the water deepens rapidly and the foreland is steep, it may be in a general way assumed that a bank somewhat aslant will answer best, and *vice versâ*—but such an assumption can never be more than of a very general character.

The "projecting elbows" advocated by Mr. Wiggins, besides serving as breakwaters to shelter the bank, are evidently intended to act as groynes in the accumulation of protective material at the foot of the bank, much in the same manner as contemplated by Mr. Muller when recommending that one side of the bank should be boldly exposed as a shelter to the retiring sides. When we come to treat of groynes, it will be seen that the same end may be accomplished in a simpler and less expensive manner than that of making the bank itself serve the purpose. Boldly to take the full force of the sea in a gale, the face of a bank must be effectually fortified; and any projections serving as breakwaters will need to be strongly constructed. Whether under any circumstances a curve concave to the run of the sea is advisable, must be extremely doubtful; and unless cogent reasons exist for its adoption, it would be well to avoid both it and a strongly convex line. If one or the other is found to be unavoidable, the point at which the line of run of the sea is normal to the curve will need to be specially protected; because if the curve is convex that part will receive the full force of the waves and turn them aside, and if concave will have to stand not only their direct shock but also the uprush at the meeting of the currents occasioned by the run of the sea along the curve on either hand. That this would be the case appears to be corroborated by an observation made by Captain O'Brien, R.E.,[46] that on the concave sweep of the shore at Romney Marsh, the middle of the curve or bight of the bay was the part that suffered most from the waves in a gale, and was always liable to be scooped out unless means were taken to prevent it.

*b*) **Materials.**—The choice of material for a bank depends, not always so much upon what is intrinsically the very best, as upon what is most easily procurable at or near the site, the question of expense being in general a highly important one; and experience has shown that even with poor material a good bank may be constructed if proper precautions are observed. It is found in practice that a bank of almost any material, presenting a proper slope and suitably protected on its surface, will at least for a while withstand the action of the waves, if it be high enough to prevent them from running over its top. Moreover, materials which rank as best are not always exclusively used throughout a work even where they are readily procurable; some being better suited for one purpose or in one part of the work and others for another. It is therefore desirable to consider the several materials themselves, and the opinions of experts concerning them; leaving the details of their employment to be more fully dealt with as may be needful, under subsequent sections.

The employment in sea-walls of stone in the form of masonry, being almost exclusively confined to those intended for coast-protection, does not come within the scope of the present inquiry. Its use in works such as we are now dealing with is chiefly in the form of pitching and rubble, its weight rendering it valuable for loading as well as protecting softer and lighter materials. A bank of rubble, however, is not of itself sufficiently water-tight to exclude the tide, and needs to be rendered so by a core of impervious material or by a layer of puddle and clay on its sea-face—the latter indeed would in any case be required if the bank is intended to be overgrown with vegetation other than seaweed. Where stone is abundant and easily procured, such a bank might possibly prove to be the cheapest in construction; but a coast presenting sites suitable for reclamation by embanking is usually deficient in stone.

Where stone for facing, weighting, or other purposes, is not readily procurable, and shingle, gravel, and lime are so, concrete may be advantageously employed. Although inferior in specific gravity to stone, it possesses one great recommendation in being easily moulded into blocks of any desired size or shape.

Gravel is by Mr. Wiggins regarded as one of the most important and at the same time often the most easily procured material for a bank. "The uses of gravel," he says,[47] "are manifold. At the outer edge of the bank gravel is the very best material wherewith to form the lower portion of the slope or facing, where it forms a *natural sea-beach* almost impervious to the water, and also a roadway, the traffic on which consolidates the sand below. In this latter use it may also be applied with advantage to the inner edge or foot of the bank. This material also, being spread over the stone facing of the bank, insinuates itself into the interstices between them, and keeps them better than the best masonry. But the use of gravel should be almost confined to the *outside* of the bank (the internal material requiring to be of the most cohesive kind that can be obtained); a coating of gravel of several inches in thickness being spread previous to the stone facing being applied.

"Gravel also might be advantageously used as a *substitute* for stone, in the facing of that portion of the bank which is above the main bank. . . Gravel might, indeed, in many cases, be substituted for stone or any other *facing* of the whole bank; and to qualify it for this valuable application, it is only requisite to give the bank sufficient slope, so as to resemble a natural sea-beach; and if the original shore is muddy, a coating of 6 inches of gravel, over 18 inches of mud, would probably form a facing not to be surpassed. . . . Even soft wet mud, costing 3d. per cubic yard to throw up, may be fixed and consolidated into cement by the addition of one-third gravel brought to mix with it, costing 1s. per cubic yard, making the whole to average 6d. per cubic yard. . . . A wall of *pisé* or rammed gravel in a frame might very judiciously be adopted for 2 or 3 feet of the centre of the bank."

Respecting sand as a material for the bank:—

Mr. (afterwards Sir John) Hawkshaw, M. Inst. C.E., considered that the sand of the sea-shore, with a slope of 6 or 7 to 1, "proved an effectual barrier against waves if it was long enough."[48]

At Folkestone, when the sand was left bare by the washing-away of the shingle, the unprotected surface stood at a slope of 9 to 1, and resisted the force of very heavy seas.[49]

The bank at Holkham in Norfolk, for a length of about 1,400 yards was formed entirely of sand inside, protected on the sea-face by 2 feet thickness of puddle and on the land-face by 1 foot of puddle, the upper portion of the external slope being covered with grass sods 3 inches thick and the lower portion with shingle. This bank is but little exposed to destructive action of the sea, there being no long fetch of waves to break upon it. In 1867 it was stated that in the nine years then elapsed since its construction it had needed no considerable repairs save those of a breach caused by one severe storm accompanied by unusually high tide; and the opinion was expressed that experience had shown sand to be the better material for the construction of these banks, no settlement having occurred in the large one so formed, while the smaller one, entirely of clay, had required additions to be made to maintain the original dimensions.[50]

Several of the banks in Schleswig are of sand; and where that material is used both slopes are covered with clay. In some cases where sand or earth is used, percolation will sometimes take place unless a core of clay is carried up from a considerable depth in the ground. The same result is found to occur in some of the banks on the shores of the Humber, and the remedy is the same.[51]

Sand was generally used in the hearting of some 13 miles of banks on Lough Foyle and in Morecambe Bay, the sea-slopes being covered with 12 inches of clay puddle and about 15 inches of pitching, and the banks are stated to have stood several years without any failure.[52] Limestone for the pitching was in the latter case readily procurable from excavations and quarries in the immediate vicinity of the works.

An embankment on The Wash, 3 miles in length, of sandy loam well puddled, covered with 15 inches of clay and 12 inches of Norfolk clunch, stood well and resisted the action of very heavy seas.[53] Linings of sand are frequently introduced into the body of dykes in Holland, to prevent rats and moles from damaging them.

Mr. Wiggins strongly objects to the employment of sand; and his statements, although perhaps not quite free from *petitio principii*, are too important to be wholly neglected. "Sandy material," he says,[54] "is the most difficult to manage, and the least to be depended on. If it be used in raising the bank, great part is taken away by almost every tide, of what has been previously collected between tide and tide, and sometimes much more is taken by a tide than was collected between that and the preceding tide. This material melts away like sugar in water, and must be collected again and again to perform the work, which after all is always liable to escape particle by particle;—when dry, running as in an hour-glass through every aperture, or blowing away with every wind; or sinking to a level, when wet. Thus the working with this material is attended with infinite mortification, and at least twofold the cost of any other material upon the spot. Many expedients are in use to prevent its escape; as covering the bank of it every tide with sods, which are removed when the work recommences on the recession of the tide: indeed in the case of those loose running sands which we are now contemplating, it is absolutely necessary to fix them with from half a yard to a yard thickness of clay outside, according to the exposure. . . . In the case however of such loose sands, no doubt the most effectual, safe, and permanent—consequently the least expensive mode ultimately—would be to avoid using a single shovel-full of such sand, but to bring all the materials for the bank from the nearest dépôt of good material, and lay it upon the sandy surface [of the sea-shore]. It is true that carts and horses being used to raise the bank with such sands, the pressure of these has a great effect in consolidating this loose material, but still it is treacherous, and much of it escapes at every tide, and if thus raised at sixpence per cubic yard, it would be better policy, all things considered both present and future, to incur a charge of one shilling per cubic yard for better material."

"There is however another kind of sea-sand, locally named '*silt*,' which seems when wet to be somewhat muddy and argillaceous, and which in that state not only retains its position when laid up in bank, but seems ponderous and sound. But even this kind of sand dries into a running sand, though not much liable to blow, and less prone to escape than that just mentioned. Such sands are best collected by means of planks and barrows, or by horses and carts, and perhaps the cheapest and best way of embanking with them, in cases where stone is too expensive, is that of raising a bank of great bulk, turfing or gravelling the sea face, and mending every little 'peck' or injury as it occurs, until the bank has become so firm as to bear the tide. It would however be extremely prudent either to cover the whole of such a bank with turf or with some feet in thickness of clay, or at least a foot thick of such gravelly or stony earth as would soon admit of vigorous vegetation over *the whole* surface."

"But the policy of making sea-banks across very *loose* sea-sands is at least questionable, even in cases where the level of those sands admits of a good drainage to seaward, since to bring all the materials from a distant spot may be very expensive, and to throw up the sand itself is dangerous, where they are covered at every tide, and the water dwells long enough to saturate them fully, and that continually, so that in course of time a communication takes place between the water-soaken sand outside or seaside, and that inside or landside of the bank, the silicious particles become separated by the aqueous particles, and when the latter become predominant the bank blows up. This has been experienced even in cases where all the materials were brought from a distance, and the sand untouched, and therefore sea-banks can only be made with absolute security with this material, in cases where the sandy soil is above ordinary tides and covered with vegetation: even then, the bank must be very well packed and covered with mud, so that the water cannot penetrate between its clods when it has shrunk in drying, and it must also be guarded on the sea-side with stone if liable to any great *swash* of the wave. Another fault of sand-banks is their liability to sink, from the finer particles of sand being drawn out by the suction of the retiring wave; and if the smallest particle of sand escapes, then it will be followed by another and another, the mischief silently going on till it becomes apparent in visible depression of the front and top of the bank, which perhaps may at first be taken for a shrinking or settlement of the materials in that place more than another, or to the consolidation of the sands beneath, and the parties may proceed to make up the deficiency, under the idea that their bank is stronger than before, till new instances attract notice, and the real cause becomes known. It has been found in such cases, that a broad footing of *gravel* increases the seat of the bank and checks the percolation of water underneath it, especially when that footing is made a common road for traffic. If sea-banks are built over, and with sands, it becomes also a very essential point to make use of a great quantity of ponderous stone, not only to break the waves and to prevent their tearing away the face of the bank, but also to *weight* the sand and compress it, so as to bring it to as near an approximation to a solid state as circumstances will admit, and thus lessen the chances of the water insinuating itself amongst the sand forming the foundation of the bank.

" After all, no art or expense whatever can always insure a sea-bank on a sandy shore, and in an open exposed situation, from considerable damage. . . . Such, therefore, should only be risked in sheltered spots, and where the rage of the ocean is mitigated by projecting rocks or spits of land, protecting the bank from the inclement points, or the shore is observed to be increasing. But if banks of sand are attempted they should be of ample height and dimensions, and the front or facing guarded with clay, turf, sodding, and stones, besides constant watching and repairing every little breach."

Peat-moss appears to be a good material for a bank. Its tough fibrous nature, its elasticity, and the readiness with which it consolidates into a dense mass, render it peculiarly valuable for the purpose. It is found also to possess advantages as a material for puddling, since it readily imbibes and retains moisture, and does not crack from dryness as clay puddle frequently does. In case also of holes being made in such puddle by vermin or by external injury, it is found that they soon close again, owing to the elasticity of the peat and its tendency to grow together. It is sometimes used as a puddle between two stone walls, sometimes as a backing instead of clay, and is particularly recommended for use in combination with rubble stone. The action of the waves against it even adds to its security, since from its fibrous nature it retains any silt thrown up with the water, until all the interstices between the stones are completely filled. In 1841 it was stated that upwards of twenty years had elapsed since some of the first banks were constructed, and that up to that time they had perfectly answered their purpose.[55]

Mr. Wiggins says it is apt to split in drying, forming crevices, necessitating occasional opening of the face of the bank for the purpose of stopping them. In other respects he speaks well of it; and mentions that a peat sea-bank which was opened after being built for seventeen years, exhibited the material as fibrous and undecayed as when first deposited. It had been covered and compressed with layers of stone and gravel. This bank was built across a sandy estuary, where it was deemed too hazardous to make use of sand in its construction.[56]

Owing to its lightness, this material needs to be well loaded, and thus seems to be most suitable for use when in combination with stone.

Clay is the material most commonly employed where obtainable, and may on the whole be regarded as the best; although (cf. pp. 39, 45, 46) authorities are not unanimous on the latter point. In what follows, it will be observed that even among those who advocate its use, some recommend that it should be mixed with sand.

"On the whole," says Mr. Wiggins, "it must be concluded, that of the materials for a sea-bank, tenacious clay is the best, and *loose* sand the very worst. All the intermediate modifications of soils will have their respective merits or demerits, but they will be eligible in proportion to their ponderosity—their cohesiveness—and their power of resisting the action of water, either in penetrating or dissolving them : and these soils will be ineligible in proportion to their lightness, their looseness, and their aptitude to run and blow away when dry, or to melt away when wet." But he immediately adds: "A mixture of materials, bad and good together, when in a wet state, would probably reduce the whole mass to an eligible condition ; and although the expense might be thought too great at first, it might be found economy in the end." And of clay generally, he observes: "Even stiff clay requires to be very carefully packed." [57]

According to Caland, all the properties required in a material for a bank are best found in common clay, having the greatest weight, particles so fine as to be imperceptible to the naked eye, and the greatest continuity of known soils.[58]

The material used in the dykes in Schleswig and Holstein is sometimes of clay, sometimes of moor or bog earth. The best material is considered to be "clay, mixed with sand ; and as the marsh ground itself is usually of this nature, it is generally used. Clay alone, without intermixture of sand, easily bursts after exposure to the rains, or dries suddenly by excessive heat. Common soil is frequently used, and is considered good, though not equal to the sandy clay, as moles, rats, and foxes can more readily make passages through it, which at high water may sometimes become dangerous, and the holes are not easily stopped. Where good materials cannot be procured, in sufficient quantities, for the formation of the dyke, it is customary to cover the water slope with clay, several feet in thickness; and if the material is of fine sand, or of bog earth, both slopes are covered with clay." For closures also, clay alone is regarded as an unsuitable material. "It was liable to crack and dissolve, and a great portion of it was generally washed away. Clay and sand combined resisted the action of the water much better."[59]

On the other hand, it is stated that a bank at the entrance to Wexford Harbour, in what appears to be a not very exposed situation, failed "in consequence of being built of sand, fascines, and clay, mixed together."[60] No details are given of the dimensions, slopes, or face-protection of this bank—particulars which may have had as much influence upon its stability as the material composing it.

*c*) **Form and Dimensions.**—The form of the bank in cross-section is (very roughly speaking) a trapezium, its longest side being the base, its shortest the top, and the other sides forming the sea- and land-slopes respectively, the longer slope being seaward. The materials composing it may be approximately taken as weighing about 123 lbs. per cubic foot: theoretically therefore, an impervious bank, its summit above the highest tide-level and its materials lying at their natural slope, will safely withstand the pressure of quiescent water. In practice however, these conditions do not concur: it is scarcely possible to render a bank perfectly waterproof, the materials composing it cannot always be laid at their natural slope, nor is the water that presses against it ever perfectly quiescent. Hence the necessity of artificially increasing its resisting power, by augmenting its bulk and protecting its surface against the wash of tides in their rise and fall, the erosion of currents, and the destructive force of waves. Of these agencies, the first is the least and the third the most formidable; and their operation is counteracted by increasing the thickness of the central portion or body of the bank, flattening the slopes and covering their face with clay or puddle of some kind, and as it were "armour-plating" that covering with material hard and heavy enough to withstand the shock of waves and sufficiently tenacious or well bonded and secured to resist their tearing and scooping action. The conditions and extent of the destructive agencies to which a bank is exposed, differing according to circumstances, there is great variety in the particulars of its form and dimensions, and these we shall now proceed to consider.

Some small banks at several weak points along the neck at Spurn Point; from 6 to 7 feet in height, their top from 3 to 4 feet above high-water mark of spring-tides and 4 feet 6 inches to 6 feet wide, had slopes 4 to 1, protected at foot by stakes and wattles, and planted with mat-grass (*arundo arenaria*), and stood well.[61] This situation is an exposed one.

Those at Lough Foyle and Morecambe Bay (*ante* p. 39), protected by puddle and pitching, had sea-slopes 2 to 1.

At Dymchurch, the severest storms between 1837 and 1847 laid the shingle at a slope of 12 to 1; while with a slope of 8 to 1 the waves were found to wash out every particle of sand and shingle from the interstices of the stones. The situation is very exposed.[62]

The banks on The Wash (*ante* p. 40) had a sea-slope of 5·12 to 1. They are said to have stood well against very heavy seas: the situation may therefore be regarded as an exposed one.

The bank at Holkham, in a somewhat sheltered situation (*ante* p. 39), had a sea-slope of 4 to 1 for 8 feet from top and 5 to 1 for the remaining distance or cess. The top was 5 feet wide. The land-slope was 2 to 1 for 8 feet from top, and from thence 3 to 1 down to the level of ground: the land-slope for a portion of the length of the bank was 2 to 1 throughout. A breach in this bank was repaired with shingle, laid to a slope of 5 to 1 on the land side and 12 to 1 on the sea side, the latter exactly coinciding with the slope to which the shingle at Dymchurch was brought by the action of the sea.

Some dykes were constructed in 1850 on Sunk Island at the mouth of the Humber, of alluvium, silty sand, and material from the foreland, and faced with grass-sods. The top stood about 4 feet above high-water mark of spring-tides. In well-sheltered situations it was 3 feet wide, the land-slope 1 to 1 and sea-slope 3 to 1. In the most exposed portion (which however may be regarded as partially sheltered) the top was 4 feet wide, the land-slope 1½ to 1; and the sea-slope, constructed at 5 to 1, was by settlement and wave-action brought to 6 to 1.[63]

At the Wexford Harbour Reclamation, the dykes were 6 feet wide at top and their crown 8 feet 6 inches above high-water mark of spring-tides. The land-slopes 1 to 1. The sea-slopes were stone-pitched: that of the north bank being straight in cross-section, with an inclination of 1·5 to 1; that of the south bank concave in cross-section, its chord apparently sloping at 1·33 to 1. It is stated that the curved section was adopted with a view of preventing the waves running up to a height which was there found objectionable.[64]

On the coast of Denmark, much diversity exists in the height and slopes of the banks, a typical cross-section whereof is shown in Fig. 2. The section adopted is entirely relative to the extent of the foreland, the position of the dyke, the height of its seat above ordinary high-water mark, and its exposure to direct action of the waves and winds: even the same dyke has often a different section in different parts. In determining the width of the top and the inclination of the slopes, regard is had not only to the position of the dyke, but also to the materials of which it is to be constructed (*ante* pp. 39, 45). The width of the top is from 8 to 10 feet in the smaller dykes, and from 10 to 20 feet in the larger ones, the width depending mostly upon whether it is to serve as a road, which is usually the case. The banks are generally seated at or wholly above ordinary high-water mark; and the great height to which they are carried is owing to the excessive variations of the level to which the water sometimes rises during strong winds. For exposed situations, with a low foreland, the standard height above ordinary high-water mark is 18 feet 6 inches; for exposed situations with a higher foreland, or for less exposed situations with a low foreland, 17 feet 6 inches; for unexposed situations, from 16 feet 6 inches to 14 feet 5 inches. Generally, the inner slopes

Fig. 2.—Section of Bank on Danish Coast.

have an inclination of 1½ to 1. The sea-slopes vary considerably: the general type in Schleswig having a cess or lower slope of from 8 to 1, to 15 to 1, up to a height of 10 or 12 feet above ordinary high-water mark, and above that a storm-bank with a slope of 3 to 1 up to the full height of the dyke. The sea-slopes in the Eider and the Elbe (Fig. 3) are sometimes 3 to 1; but in situations exposed to the run of the sea they are 6 to 1 or more, according to local circumstances. In those of the dykes on the island of Pelworm and at several places on the coast of Holstein, the lower part of the cess is curved and pitched, as shown in Fig. 3, and this is held to be the best and strongest form of construction for slopes not wholly faced with stone. The stone facing is carried up to a height of about 4 feet above ordinary high-water mark, and the chord of its curve is at a slope of about 3 to 1. Where the sea-slope is wholly faced with stone, an inclination of 2 or 3 to 1 is adopted, and the pitching is carried up 12 or 16 feet above ordinary high-water mark. There is reason for believing that where any serious breach has occurred in a main dyke in Schleswig or Holstein, it has rarely been caused by direct action of the sea on the outward face, but rather on the inner slope, the waves rolling over the top and undermining the foot.[65]

On the Zeeland coast the dykes, if exposed to the full force of the sea, are carried at least 9 feet above the level of high storm-tides, or 17 feet 6 inches above ordinary high-water mark, leaving about 1 foot 8 inches high and dry dyke above the wash of the highest waves, which is reckoned to reach 8 feet 3 inches or 8 feet 6 inches above the highest tide-level. The longer and higher the foreland, the less can the waves rise against the dyke, for they have

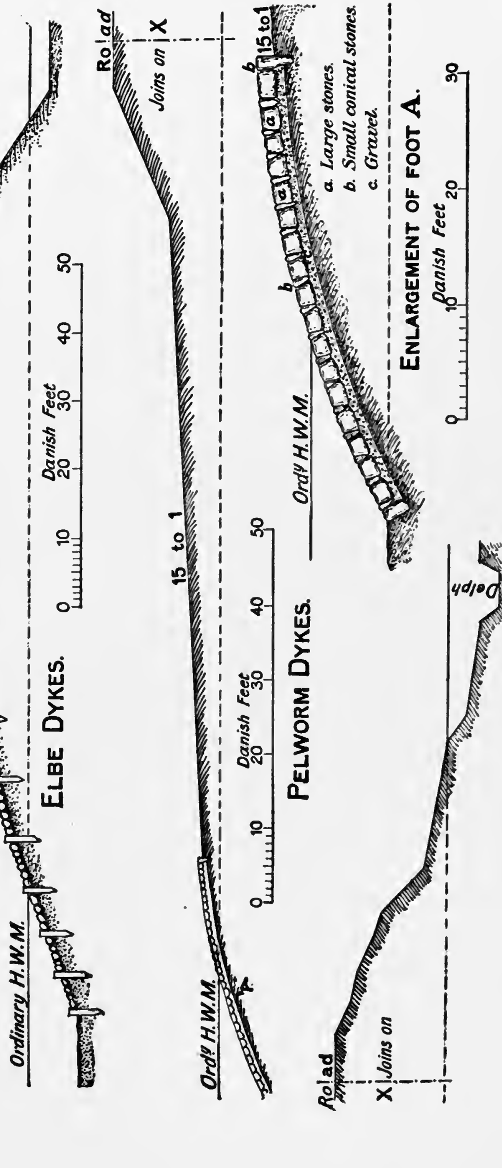



Fig. 3.—Dykes on the Elbe and at Pelworm.

further to run up and further to run back. If it can possibly be avoided, the Dutch never leave a steep slope exposed to the direct action of the sea: a case is mentioned of a bank at Flushing, with a sea-slope of 3·75 to 1, being seriously injured, while (in the same storm) another in an equally exposed situation but having a sea-slope of 13·3 to 1, was scarcely damaged at all. The sea-slope of the Zeeland dykes, which are well protected with grass, is never steeper than 6 to 1, and where possible is made 12 to 1, and preferably with a convex face. The inner slope seems to be about 2 to 1, the steepest being 1·75 to 1. Caland's rule for the sea-slopes of dykes of various heights, in exposed situations, is given as follows:—

| Height of crown above toe of bank. ft. | ins. | Inclination of sea-slope. |
|---|---|---|
| 26 | 3 | 10 to 1 |
| 24 | 6 | 8·8 „ 1 |
| 23 | 0 | 7·67 „ 1 |
| 21 | 7 | 6·6 „ 1 |
| 19 | 8 | 5·6 „ 1 |
| 18 | 0 | 4·73 „ 1 |
| 16 | 5 | 4 „ 1 |
| 14 | 8 | 3·2 „ 1 |
| 13 | 0 | 2·5 „ 1 |

And for the breadth of the crown, he recommends half the height from low-water to high-water of ordinary tides.[66]

That Caland's rule as to slopes is not always observed in practice, appears from the statement in the foregoing paragraph that the Zeeland dykes never have a sea-slope steeper than 6 to 1—and also from the following particulars recorded by Mr. G. B. W. Jackson, Assoc. Inst. C. E., who also assigns to the dykes a less height than that mentioned in the beginning of the paragraph. It is probable that the latter discrepancy may be accounted-for by supposing that the dykes respectively referred-to are very differently situated as regards exposure to the violence of the sea :—

"The dykes . . . are raised to the level of 1 foot 8 inches, and 3 feet 3 inches, above the highest tide at the equinox; and, if not intended to be used eventually, for the high roads of that portion of the country, they are from 3 feet 3 inches to 6 feet 6 inches wide on their summit. The angles of the slopes depend on their position, but two to one inside, and four to one towards the sea, have been frequently adopted." The sea-dyke at Koegrass near Nieuwdiep, whose top is 11 feet 6 inches above ordinary high-water mark (Amsterdam standard) and from 9 to 10 feet wide, has a sea-slope of 4 to 1 and a land-slope of 3 to 1.[67]

It will be seen that Mr. J. H. Muller, of the Hague, prefers steep slopes, alternated with a cess or bench at about the level of high-water, to flat slopes without a cess; assigning as a reason, that the best cross-section is one in which the centre of gravity comes nearest to the bottom and to the toe of the bank. He illustrates his remarks by some cross-sections, one or other of which he considers will be found available according to special circumstances :—

Fig. 4 (A) is the section of a bank on salt marsh. The top of the bank is about 3 feet wide, and 3 or 4 feet above level of highest known tide. The inner slope is not greater than 1·5 to 1; steeper slopes being liable to slip, and not presenting sufficient surface for the growth of the grass intended for their protection. The outer slope is 3 to 1.

Fig. 4 (B) is the section of a bank above the level of half-tide. The top of the bank is 4 feet wide and 4 feet above the level of the highest known tide. The inner slope is 1·5 to 1. The outer top slope is 3 to 1, and extends from the top down to the level of the highest known tide, at which point there is a cess 20 feet wide, having a fall of 1 foot 6 inches or 2 feet. The lower slope is 3 to 1. The inner slope and the crown are covered with a layer of clay 8 inches thick, the upper slope and the cess with a layer 12 inches thick, and the bottom slope with a layer 18 inches thick. The outer bottom slope is further protected by fascine-work.

Fig. 5 is the section of a bank seated below the level of half-tide, where a stone protection is proposed to be adopted. The top of the bank is 6 feet wide and should be at least 6 feet above the level of the highest known tide. The inner slope is 1·5 to 1. The outer top slope is 4 to 1 and covered half-way up by a wooden or fascine protection. The cess is 20 feet wide, and has a fall of 2 feet or 3 feet, and the outer lower slope is 5 to 1 or 6 to 1 according to circumstances, covered with a stone defence such as is commonly constructed by the Dutch on islands exposed to the ocean. When the slope is trimmed, a layer of clay 12 to 18 inches thick is spread over it and sometimes covered with a straw matting. Over this are laid one or two courses of bricks, then 6 to 12 inches of brickbats, and then stone pitching 12 to 18 inches thick.

"It will be observed," he proceeds, "that with a stone defence, the slopes are recommended to be flatter, and the banks to be higher, than where wood protection is employed. In steeper slopes, the rows of stone would rest upon one another, and if a wave removed or disturbed one stone, the removal or displacement of those above it would almost necessarily follow. The bank is made higher on account of the flatness of the slope. If

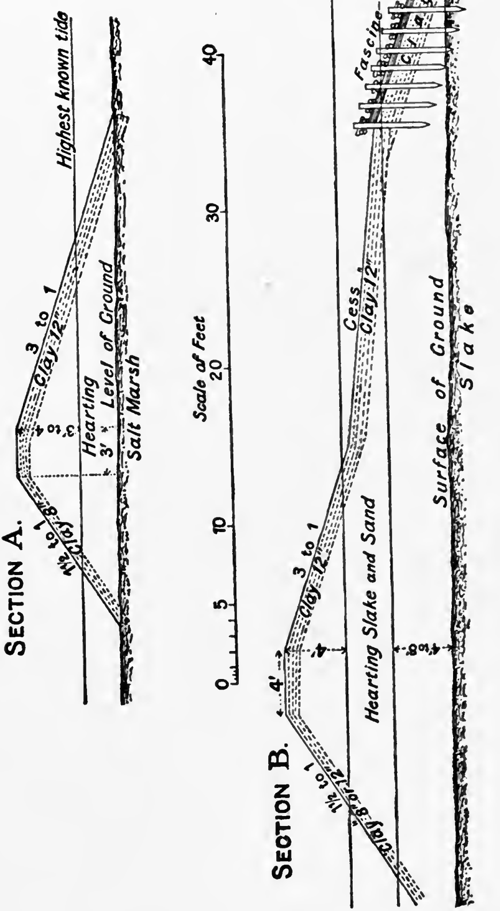



Fig. 4.—Bank on Salt Marsh (A). Bank above Half-tide level (B).

the rule is adopted, that the shock of the wave increases with the sine of the angle made by the slope with the horizon, the momentum remaining the same, the amount of force, or intensity, saved by the flatter slope is expended in the velocity with which the wave runs up the slope. But whatever may be the cause, it is certain that waves ascend much higher on flat slopes than on steep ones; so that, although the shock may not be so great, the protection must be carried up higher. . . . In exposed situations, an additional width may be given to the cess with great advantage. The wave rushes up the slope until it arrives at the cess, when its direction being altered, it is checked, and if the cess is sufficiently long, its force is almost expended before its direction is again altered by the upper slope."[68]

Mr. John Wiggins has laid down some rules for the form and dimensions of sea-banks in general, which he regards as the best possible. Whether they are so or not, they have been worked out by him with so much care, and with so evident a reliance upon experience, that they ought not to be omitted in a treatise on the subject.

"The form and features of the sea-bank," he says, "are matters of the greatest moment, although its form appears to have been, until lately, but little regarded; the usual form given to them, from the Roman banks in Lincolnshire to those of the Essex marshes, being most generally a mere steep mound of earth, which in the latter cases has been defended by rows of piles, the spaces between those rows, called '*rooms*,' being filled with chalk or stone, stowed closely in, and in some cases fourteen of these rows have been placed tier above tier. But of late years it has been found that another form, more consonant to nature, is

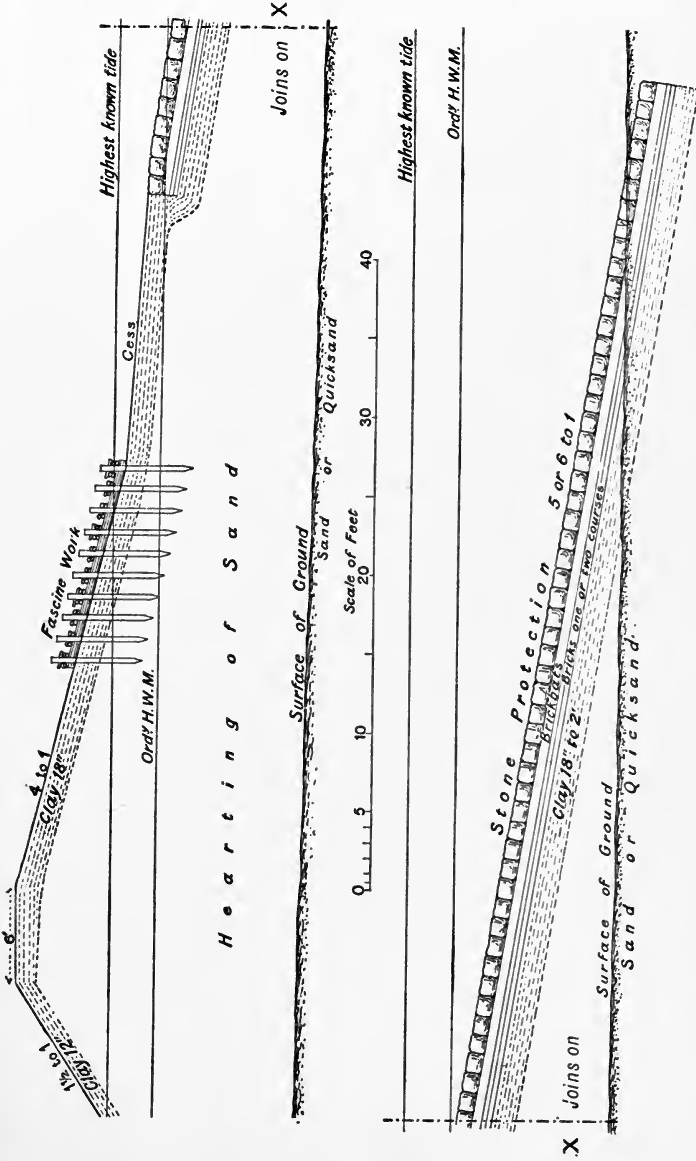



Fig. 5.—Section of Bank below Half-tide level.

better adapted to these sea-defences, and that instead of a steep face, embankments should have a slope in front, resembling a natural sea-beach, and be of sufficient thickness and substance to withstand the assaults of the ocean, whilst they ought to have slope enough in the rear to admit of a luxuriant vegetation; and to effect these objects we propose the threefold bank, of which the diagram [Fig. 6, p. 61] is a section, consisting of—

"1st. *The main bank*, built to the full height of ordinary spring tides, which is taken by way of example at 10 feet. It is 20 feet wide at top, and with a slope to sea side, partly of 5 feet base, and partly of 4 feet base, to 1 perpendicular, as the minimum slopes.

"2nd. *The outburst bank*, 5 feet high and 8 feet wide at top, and with a slope of but 1½ to 1, because this part of the bank will have to sustain but a transient stress from the top of the tide, and this only occasionally. On this is set

"3rd. *The swash bank*, which, having only to sustain the broken tops of the waves, is but 2½ feet high and 2½ feet wide at the top, though its base is 8 feet, and should be made amply sufficient to prevent any part of the highest seas going over the bank.

"The construction of this diagram is as follows:—

"Having drawn the base line *a b*, construct the cubes *d* and *c m*; draw *a c′*, 5 base to 1 perpendicular. Set off 6 feet from the top of the cube *d* towards the base line, for the high-tide wave. Draw the line *d s*, intersecting *a c′* at *s*. Draw *a s* and *s m* and *h b*, and this completes the *main bank*, with the double cubes of its height backed by a half-cube, besides the front with a base of 4 to 1, the gravel footing bringing it 5 to 1. For the other proportions construct the cubes *e* and *f*, and draw *m c″*, also *g* and *g h*, giving ample weight, substance, and slope to the bank for ordinary cases.

"The rationale of this construction will appear as we go on, but its outlines are these. The cubes *d* and *c m*, with the half-cube *b h*, are considered to be very ample for the body of the *main bank*, which is 20 feet wide at top. The slope of 5 to 1 is lessened at *m*, to 4 to 1, in order to afford a greater base for the upper bank, and because the space from *m* to *s* is stone-faced, that space being 6 feet perpendicular from the top of the main bank, which is considered the usual height of great waves near the shore. The gravelled footing is on the slope of 5 to 1, and is not stone-faced, because the sea has not acquired much force at that height of tide. This completes the main bank. The *out-burst* and *swash banks* are drawn with a narrow apex in order to give as much slope as possible to the line *m c″*, but where the soil is tenacious, this line may retire still more, and the line *g b* may be steeper.

"The essential features of the bank recommended in section A are the following:—

"*a b* is the seat of the bank, or base on which it stands.
*a c″* is the slope.
*e c′ c″* is the height.
*d e f* is the thickness.
*f′* is the facing.
*g* is the top.
*h* is the back.
*i* is the delph.
*k* is the foreland.
*l* is a gravelled footing on both sides.

"On each of which features some observations of importance may be made.

"The general *form* of a bank is required to be such as to receive the wave easily, *i.e.* without any great concussion, or with the least degree of concussion; such as may enable the top of the wave at its highest range to run along the top of the bank, without meeting with any great resistance or sudden check, and such that if the wave should even top the bank, and the swash go over the back of the bank, it may not cut away the soil to any dangerous extent.

"The form given . . . in section A, is thought to be such as fulfils all these conditions; and the hollow in front is considered to be such as to reduce the force of the wave when it arrives there, which can only happen at great outbursts of the sea, or when the wave is raised by the wind far above its ordinary height, because the hollow only commences at a point just below the height of equinoctial spring tides, *i.e.* the utmost height of the body of the tide, the wave above that being but transient, and making only a temporary, though it may be a powerful, impression on the upper part of the bank.

"The *width* of the seat or base of the bank should be regulated by the amount of adhesiveness in the material upon which it is placed, and of which it is built, because it is necessary . . . to guard against any escape of those materials from the drawing out or suction of the sand, by the reflux of the wave, or by the soakage of water under the bank.

"The width therefore of the seat or base must be such as to throw the sea as far distant as possible from the sandy material, which being prone to run away in minute particles when dry, and to melt like soft sugar when wet, and being equally prone in both states to escape particle by particle, through the smallest aperture, and with a very small declivity, must be kept as much as possible in an undisturbed state. This however is by no means easy, since the waves will be sure to find apertures too minute to be readily discernible, wherein the sands will steal away both in the dry and wet state. Small animals also will burrow in the sand from both sides of the bank, and the apertures thus formed will enlarge by degrees, and may become dangerous before they are observed. Such insidious apertures are very apt to take place amongst and below the stone facing of banks, and should therefore be carefully guarded against. But after all they will inevitably happen, and the only sure safeguard is such a wide base or seat as may give the bank substance enough to admit of rather more than slight apertures and channels without endangering its safety. This substance cannot be given without width of seat, which is therefore an important feature of a sea-bank.

" The proper width for the base or seat of a sea-bank will, however, depend much on its other dimensions; but independently of these, it will be necessary to consider the state of the soil on which the line of bank is proposed, and to ascertain whether it be a sound clay or a loose sand; whether of uniform and firm texture, or interspersed with

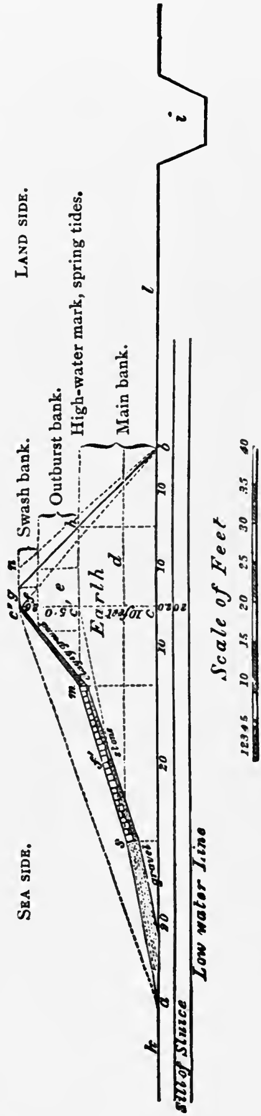



Fig. 6.—Mr. Wiggins's Diagram A.

soft watery spots; whether likely to sustain the weight of a bank, or to yield to its pressure, and spread on each side; whether such as to remain impervious to water, or to admits its percolation, however slowly, from seaward to landward;—in short, whether the foundation on which the proposed bank is to rest be firm or otherwise, *i.e.* compact or porous; for according as it may be one or the other, so must be the width of the seat or base of the bank, whatever its weight, height, or thickness.

"This width of seat may be increased, in fact, without adding to the bulk of the bank, by means of a gravelled footing or beach in front, and if this gravelled footing is also used as a road, either during the building of the bank, or afterwards, or both, it will add much to the consolidation of the materials, and to the prevention of percolation. If, again, another such road was used on the inside of the bank, it would also be productive of the same benefit as a wider seat to the bank or sea-wall.

"The *slope* of the bank to the seaward is one of its principal features of strength and safety. A steep bank enables the wave to strike it with great force, and ultimately to batter it down, or greatly to reduce its substance, by means of those violent or continuous assaults which the power of the ocean often exercises. In all such cases, the safest plan is to follow nature as far as possible.

"The slope of the bank, therefore, should be as similar to a natural beach as all the other considerations will admit. This, however, will depend on the nature of the material:—thus, we may assume for argument, that a loose sandy beach will probably slope itself 10 base to 1 perpendicular; and a living rock will be brought by the action of the sea to nearly a perpendicular, according to its hardness. Therefore, the best line seems to be the medium between the two extreme lines taken in nature, viz. the nearly perpendicular face, and the slope of 10 base to 1 perpendicular, that is, 5 to 1. This, therefore, may be taken as the best slope that can be given to any sea-bank; that more is generally unnecessary, and less insufficient in exposed situations; but that *this* slope need not extend, in ordinary cases, beyond the height of the ordinary spring tides, when another kind of bank may commence, which having only to sustain occasional and transient outbursts of the sea, may have only such a slope as the material will admit. A slope of nearly 5 to 1 in front also lessens the necessity for *thickness* at top of the bank; besides the very important consideration, arising from the compression of the earthy matter of the bank, by the weight of water upon its face, the degree of such compression, and consequent increase of strength of the bank, being in direct proportion to the degree of slope.

"This slope also admits of the easy flow of the sea up and along the inclined plane of the face of the bank; since if stone-faced where the chief stress lies, the waves run harmlessly along the whole face or slope without striking the bank as they would if it were steeper. The stone facing is necessary, for without this a greater substance of bank will be requisite, though strong clay, with a stone footing only, might perhaps be trusted with a slope of 5 to 1, in consideration of its adhesiveness when well covered with suitable vegetation.

"But it is expedient also to consider the bank and its slope in three portions, viz.—that from the base to the line of spring tides, which we shall call the *main bank;* that next above, which is to guard against extraordinary *outbursts;* and that which is only to sustain the *swash* or spray of the waves; and to construct the bank as shown in the preceding diagram A, in which the slope *a c′* is 5 to 1 of the height, *c c′*, to which the ordinary spring tides rise. This height is here set out at 10 feet, and the seaward base at 50 feet, which gives a slope almost equal to that of a natural sea-beach on a shingly shore, and greater than that of a shore of large loose boulders.

"The whole seaward slope being thus divided in the diagram A into three portions of different inclinations, each dip considerably and variously from the hypothenusal line of the whole height *a c″*, and this dip in the surface of the front of the bank, which in practice will be worked into a curve, is thought preferable to the straight line *a c″*, because the wave impelled by wind will be less likely to roll over the top of the bank, since the hollow will expend part of its force, and give it a tendency upwards or back again into the sea, whereas the inclined plane will encourage its onward tendency, and enable it to continue under the same impulse till it roll over the bank.

"The *height* of a sea-bank up to its outburst line and exclusive of the swash bank must depend on two conditions, viz. the rise of tide in the particular locality, and the height to which the greatest outbursts of the sea have ever reached. It is indeed the last-named point that must regulate the total height of the bank, though other points may govern the height of stone facing in land-locked cases. Some marks must be ascertained on the land by the testimony of old people, up to which some outburst of the sea *has* at any time arrived: the greater number of such marks that can be spoken to the better, and the more they agree in horizontal level upon the land the better; but the highest must be taken, even if it should not be very well authenticated. It is sufficient if there be a possibility of the sea having ever flowed so high; and when it is considered how much the wind forces up the water on the side against which it presses, its flow on that side will occasionally reach heights almost incredible; but whatever that height may be, it must regulate that of the bank, which must be not less than 2 feet above the height of such outbursts in land-locked and sheltered situations, and not less than 3 feet above it in exposed situations, and such as have a long sea-reach in front, so as to occasion a heavy swell on the bank. No escape from these conditions as to the height of the bank can prudently be attempted. It is in vain to conclude, that as the sea has only been known to reach such a height once or twice in the memory of man, it *may* never reach that height again, or at least that the chances are against its reaching that height again, before the embanking parties have effected their purpose. Such a conclusion will be an infringement of *bonâ-fide* dealing as regards others, and a self-delusion as regards the adventurers. The rules laid down for the height of the bank are imperative, and cannot be neglected with impunity; nay, it will be ultimate economy rather to exceed than to fall short of them.

"It is therefore of the utmost importance to determine accurately the three points of height before mentioned, viz. that of the ordinary springs, that of equinoctial springs, and of extraordinary outbursts, and to provide *weight*, *strength*, and *height* of bank accordingly, not forgetting the *swash* of the wave at the top of the highest tide.

"In the diagram [page 61], the height of the bank up to the point of the highest ordinary springs is assumed at 10 feet, which is, in fact, a considerable height for any sea-bank, and greater than is generally found to have been hitherto adopted in the intakes of Essex, on which coast these banks are more frequent and extensive than on any other, as 220 miles of them may be measured on the Ordnance Map: of these the author had the management of a considerable portion for many years, exposed to boisterous seas. The equinoctial springs and outburst bank is assumed at 5 feet above this 10 feet, which, being half the height of the main bank, will in general cases be found sufficient; but in the case of very exposed situations, and such as have a great weight of sea on them, or where prevailing winds raise the wave and drive it slanting on the bank, the outburst and swash banks together should approach the height of the main bank,—subject, however, to the ascertainment of actual heights of flow of tide, as before mentioned.

"The proper *thickness* of the *main bank* is the double cube of its height, supported by a half-cube at the back, and the slope in front for that division of the height, viz., ordinary springs, which we term the *main bank.* The equinoctial springs and *outbursts*, and the *swash*, may diminish to one cube and a half or less. At each of these respective heights the tide exerts a peculiar force, which, though lessening as the height advances, requires a proportionate resistance; and a double cube of the height of each division, or nearly so, backed by a half-cube, seems to offer that resistance in the most complete manner, since it affords the requisite degree of weight, and also places that weight in the most efficient form, besides securing that degree of economy which is so essential an ingredient in such works.

"The double cubes *d*, *m*, and the triangular half-cubes at the back thereof, the cube and rectangular half-cube *e* with its triangular half-cube *h*, and the cube *f* with its triangular half-cube, are the several stages of thickness or bulk which we assign to a well-constructed bank, over and above the frontage forming the slope, and this for the following reasons.

"It has been previously shown that the weight of materials comprised in the triangle *a c c′*, together with the half-cube *h b*, are more than equal, under any circumstances, to the resistance of the water opposed to it. The like holds good of the triangle *a*, *c″*, *b*; but the whole height of the bank in the diagram is 17½ feet, and except in open sea, waves seldom, if ever, rise to more than 6 feet, or, in other words, the sea in other situations than open ocean is seldom, if ever, agitated to more than that depth from its surface. We are, therefore, not called upon to provide for the full effect of the weight of this depth of water, but, in fact, only for 6 feet of it; since, if we supposed 6 feet in depth of water to exert its full force above the line *d*, and upon the face *f′*, it would strike with a force of 6,894 lbs., and be resisted by a force of 24,750 lbs.; the one being as the Δ *s m*, and one-fifth more, and the other as the solid contents of the whole 6 feet in height above *d*. Taking also each distinct height of bank separately, it is clear by inspection of the diagram, that each division contains a sectional area over and above that of the mass of water which will be exerted against it; and that this excess amounts in the main bank to double the cube *d*, and in the outburst bank to once and a half the cube *e*. It may, therefore, be safely concluded that this feature of thickness in the diagram gives a bank of weight and strength fully sufficient to withstand the heaviest seas, especially if a central nucleus be worked up with well-rammed earth. In some cases, where the *fertility* or the *locality* render the subject of embankment sufficiently valuable, it might answer well to take up from the foundation a *pisé* wall of gravelly earth well rammed into a *cassoon* or frame, the latter to be removed when filled. We have seen such pisé walls, when just finished, allow of windows being cut in them, and the embedded flints were cut in halves rather than separate from the mass."

"The *top* or *apex* of the bank is a feature of which the only question is the width of it, and this must depend greatly on the nature of the material with which the bank is built. If topped with stone, the narrower the better, to prevent a footpath or the tread of cattle, which might displace the stones, and then it might be brought up to a sharp edge. If the material of the bank be clay, two or three feet of width at the extreme top will suffice when swarded over. The width given in the diagram of 2½ feet at the extreme height is sufficient, because the sea-defence of that bank does indeed stop at the second or outburst height where it is five feet broad, the *banklet* above that being only added to prevent the swash going over, and as a guard against any very extraordinary but transient outbreak . . . ; and the width at top of it may be proportioned to the height of the bank by adopting the proportions of the diagram, viz. half the height of the main bank for the outburst bank, and half the height of the outburst bank for the swash bank, which, however, should always be kept up by repairs, as the shrinking of the newly deposited materials, and the washings of the rains or tides, may reduce its width or height.

"But if the material of the bank be sand or sandy earth, the width of the top must be greater, and the [sea-]slope and the slope at back greater also. This extension of width must be proportioned to the looseness and want of weight or cohesion of the sandy material, and even then care must be taken to cover its surface with vegetation as soon as possible. In ordinary cases, however, where the width of the top of the bank is required to be greater than in the diagram, say 4 feet, such width may be given by the addition of the space at *n*, without destroying the proper slope of the back of the bank.

"The *back* of the bank will require not only such a slope as will enable the material to stand well, but also such as will admit of a good and firmly established vegetation, and this degree of slope will depend much upon the material of the bank. Good ponderous adhesive earth will stand well at a slope of 1 to 1, or less, and the slopes of the back of the bank in the diagram are so, of each of the three thicknesses, and this is a good and sufficient slope for any earthy material that is likely to be employed in the construction of a sea-bank, and upon this slope vegetation is sure to prosper. The sea-banks of silty sand on the coast of Flintshire are sown with lucerne, . . . For ordinary localities, however, it may be as well to secure the surface of the back of the bank as early as possible with ray grass, couch grass, and such strongly rooted grasses, and maritime or brackish plants, as can best be obtained on the peculiar soil, since it is first on the back of the bank that any impression is made by an accidental overflow of the tide. This part once giving way, the bank is eaten away by the overfall of the wave from back to front, by a process called 'pecking' by sea-wallers; the sea then breaks in, and a 'breach' ensues. The safety of the bank, therefore, much depends upon the security of its back."[69]

Some observations by Mr. John Scott Russell, on waves, have an important bearing upon the question of slopes. There generally exist, he says, two or more kinds of waves in the sea: one kind, which he terms waves of the second order (the immediate effect of the existing local wind), short, high, and superficial; the other, elsewhere by him called waves of the first order—also known by the name of ground swell (the result of some previous wind or storm), long and low, their effect extending to a considerable depth. He has never noticed a wave so much as ten feet high in ten feet of water, nor so much as twenty feet high in twenty feet of water, though he has seen waves approach very nearly to those limits. He gives a table of the lengths, periods, and velocities of waves, as an assistance in calculating the force to which sea-works are likely to be exposed; and some diagrams showing the behaviour of waves on meeting various forms of shore or sea-bank,[70] from which Fig. 7 has been compiled. He points out, that if a wave expends its force in breaking upon one point of any work, it injures [or at least has a tendency to injure] that part; and the object of the Engineer is to allow the wave to act where it can do the least harm, and afterwards expend its force over the whole surface instead of at one point. Fig. 7 (A) is the section of a moderately steep slope having a vertical wall at top and a convex curve at foot: the slope may be flatter and the foot steeper, but the curve is recommended to be parabolic. The curved foot deflects the water upwards, causing the wave to break almost immediately upon reaching the slope: it continues to break until it reaches the vertical wall, which it strikes, and is then thrown back.—If now we imagine, instead of a vertical wall, a cess with a flat slope as shown by the line CD, it is evident that the further progress of the wave will resemble that shown in Fig. 7 (B), representing the breaking of waves on the natural slope of a sea-beach; and we have only to conceive the slopes from E to D and from H to J to be steepened as shown at E F and H K, to see that by the time the wave has ascended the latter it will have expended nearly the whole of its destructive force.

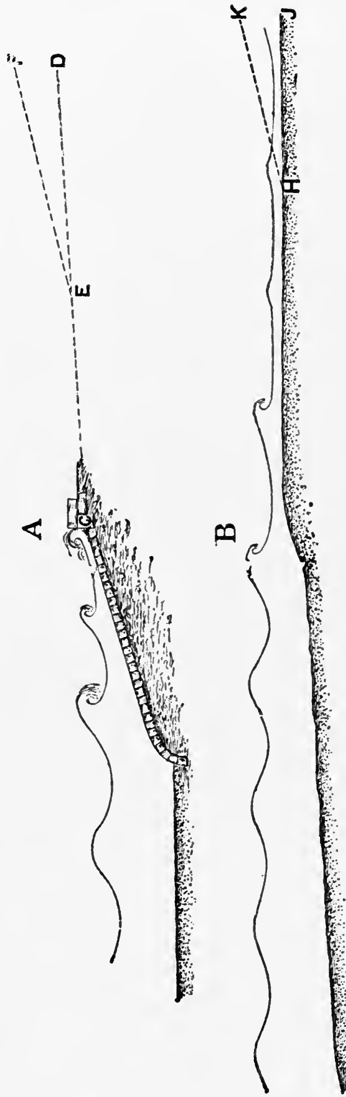



Fig. 7.—Break and run of Waves: (A) on a Slope, (B) on a Shore.

*d*) **Construction.**—Fascine-works of various kinds being much used in embanking, we shall have frequent occasion to mention them; and it will be convenient to give some description of them before dealing with the construction of the bank itself.

Mr. W. H. Wheeler, M. Inst. C. E., states that fascines used in the Fen districts are made of thorns cut from the hedges, tied in bundles with tarred rope, their maximum length being 6 feet and their girth 3 feet. Cost per 120 delivered at any accessible place on the river-side, 14s. 6d. Conveying by boat from the place of delivery to the work, including loading and unloading, 4s. per six score.[71] It does not appear that the several fascines are bound together for revetment and training work, their thorny branches entangling and interlocking so as to form a sufficient bond.

Those employed in Holland are generally brushwood of willow; but ash, alder, aspen, oak, and hazel are also used. They are from 10 feet to 11 feet 6 inches long, 17 inches in girth at the thick end and 14 inches at the other. These faggots form the basis of all fascine operations, and their cost is from 5s. to 7s. per hundred. Fascines under water are chiefly used in the form of what in English is termed indifferently "mattress" or "cradle"; and Mr. T. C. Watson, M. Inst. C. E., has so clearly described their construction, that his account may with advantage be here reproduced almost verbatim.

The first requisites for a mattress are the ropes of fascines (Fig. 8), which form a network above and below the mattress, and are constructed as follows:—Two stakes are driven into the ground about 2 feet 6 inches apart, to which is secured a cross stick about 2 feet 3 inches above the ground. A series of these frames, about 2 feet apart, is erected, the number being dependent on the size of the mattress and consequent length of the rope. The stage being ready, those bundles or fascines which have most branches and twigs are opened and the contents placed on the cross sticks of the stage, the brushwood being drawn out lengthwise so that each bundle overlaps and bonds well

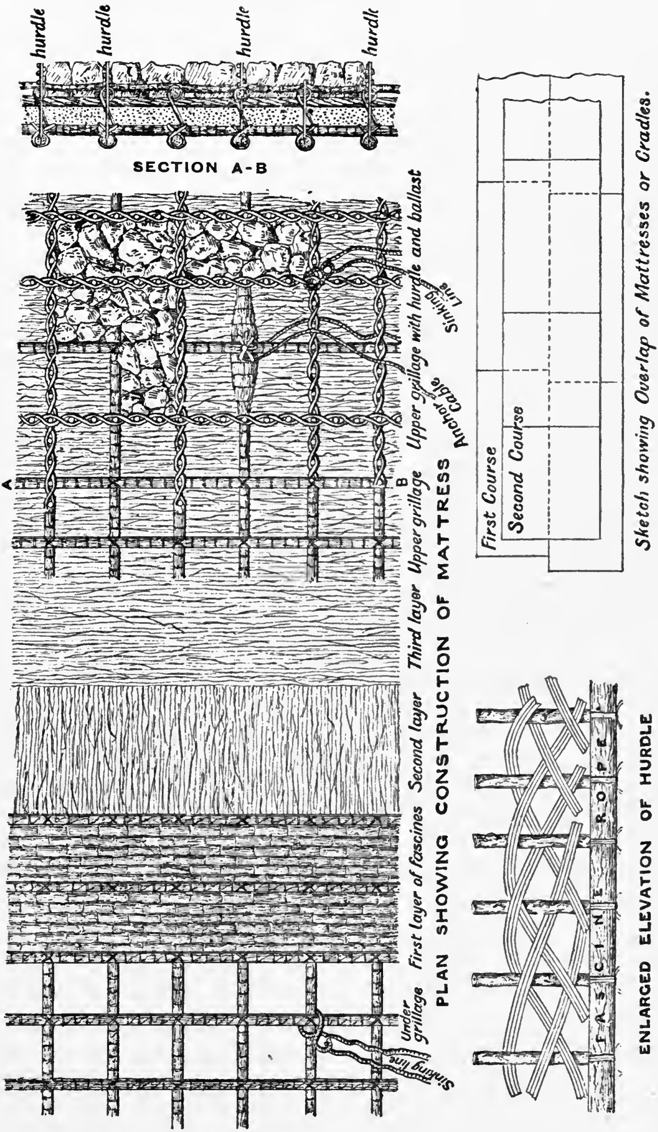



Fig. 8.—Mattress and Cradle Construction.

into the next. They are laid of such thickness that, on being bound round in the form of a rope, the girth is 17 inches. When the full length for one rope has been laid out, it is tied at intervals of about 16 inches with osier bands tightly twisted, their ends tucked under like a faggot band. Lighter intermediate bands are then put on about 4 inches apart, and the rope is ready. The ropes are now laid out on the ground in parallel rows 2 feet 6 inches to 3 feet 3 inches apart, to the full width of the proposed mattress. These are crossed by a second layer at right-angles to the first, thus forming a network the exact size of the projected mattress, with meshes 2 feet 6 inches to 3 feet 3 inches square.

The site for making the mattress should be between high and low water mark, for convenience of subsequent floating; it is, however, frequently prepared on the surface of the water [but this method is much less convenient than that of working on the ground, and probably is resorted-to only when circumstances render the latter impossible]. Every alternate crossing of the fascine-ropes is securely tied with ½-inch tarred rope, the ends of which are left about 4 feet long and temporarily secured to stakes thrust vertically into the rope. The other crossings are secured by bands of withe. The crossings on the two external rows are generally lashed with rope.

The lower network, being now complete, is covered with a layer of fascines one bundle thick; a second course is laid across the lower one, and a third at right-angles to the second, the three layers being together about 18 inches thick. A corresponding network of fascine-ropes is next laid on, and fastened to the lower by the rope ends described as being left over.

Mattresses are much employed in Holland as a foundation for the bank where the ground is soft or yielding. When the seat of the bank is below low-water mark, the mattress for this purpose has to be floated out and sunk in its destined place. In order to sink and hold it, it is loaded with stones. To prevent these rolling to one side in sinking, or on a sloping bottom, the upper surface of the mattress is divided into rectangular cells, in the following manner:—Stakes are driven into the crossings of the fascine-ropes and all round the edge of the mattress; between these, wattles are interwoven, three sticks together. When the wattled work is about 7 to 9 inches high, the stakes are driven down into the mattress, the tops remaining about 6 inches above the wattles, and the cells thus formed not only serve to retain the ballast in place, but add greatly to the strength of the mattress.

The position of the mooring posts, by which the mattress is towed to its destination and held by cables and anchors before sinking, is decided on when the lower grillage is being formed, and always at a crossing. The fascine-ropes are there worked much thicker, and securely bound with tarred cord on each side of the crossing as well as to the upper grillage. A large and heavy stake is now driven through the mattress and stayed by six or seven others radiating from it in a sloping direction. The posts thus secured cannot give way without tearing the mattress. The mooring cables are turned two or three times round the posts, so as to be easily cast off when the mattress is sunk.

The mattress is now towed to its place and loaded with stone so as just to float. Anchors are placed on all sides, their number dependent on the velocity of the current, the time chosen being about half an hour before the turn of the tide. Barges of from 10 to 15 tons burden, loaded with stone, are secured to the edges of the mattress by ropes (marked "sinking-line" on Fig. 8) running under the fascine-ropes of the grillage, both ends being fast on board the barge; other vessels, with fresh supplies of stone, being kept in reserve outside. The ballast is first carried by men (standing on the mattress) towards the centre pockets, and worked towards the outer edges. When the mattress begins to sink in the centre, and the strain on the sinking-lines becomes severe, a halt is called for a few minutes, while the crews of the barges pile up their remaining cargo on the planksheer of the vessel towards the mattress. This weight, with the tension on the sinking-lines, gives the barges a considerable list; but being stout and of great beam they stand it. At a given signal, every captain stands by the sinking-line; and at a second signal, all the lines are let go simultaneously, the crews throwing out the stone as rapidly as possible, to keep down the outer edges of the mattress, which otherwise might be turned and rolled up by the current. The vessels meet near the centre of the mattress, which now lies on the bottom; and the ballasting proceeds until a load of about 3½ cwt. to 7 cwt. per square yard has been deposited as evenly as possible over the whole surface.

Smaller mattresses are employed for building-up the faces of the bank, and are made and sunk in the same manner. Mattresses in foundation are laid so as to overlap each other lengthwise about 3 feet 3 inches; and, wherever used, care is always taken that the joints of a course below are covered by the course above. Although they will not wholly prevent the bank from sinking in soft ground, this takes place regularly and gradually: there is however a possibility of the mattress being too weak to carry the weight of the bank in the centre of its cross-section, and in consequence being torn asunder longitudinally. When this happens, there is nothing to be done save to add material until a solid bottom is reached. In some cases, where the bottom is firm, as on sand, and the bank much exposed only on one side, mattressing is not used over the whole width, but only for building-up the outer side to prevent the stuff forming the body of the bank from being washed away during construction.[72]

The cost of mattresses depends much upon local facilities for procuring materials, but may be approximately estimated at from 4s. to 5s. per square yard : it is reckoned that twenty men will construct a mattress 200 feet × 60 feet in four days. The sinking, if all goes well, occupies about two hours; but the time and labour required for this operation are wholly regulated by the circumstances of the case, and these are variable to so great a degree that no reliable estimate can be framed to apply to all cases.

Willow mattressing is said by Mr. W. H. Wheeler, in his account of the groynes at Scheveningen, to last not longer than about twenty years.[73] Groynes, however, are exposed to alternations of wet and dry, which may perhaps shorten the duration of the mattressing. Moreover, in the case of a bank, it is not unreasonable to expect that in the course of twenty years the work will be so settled that its stability would not be affected even by the decay of the mattress : there does not appear to be any record of its needing renewal, nor of injury to a bank owing to such a cause.

Mattresses are employed in the United States chiefly as a protection to river-banks, especially on the Mississippi. The mode of their construction differs in many respects from European practice, canes and saplings being used along with brushwood, and wire and even steel cables for binding the fabric. They are frequently put together on specially-built barges with sloping platforms for convenience of launching. Their dimensions are occasionally enormous: mention is made of some measuring from 1228 × 152 feet to 1750 × 175 feet, and of one 2010 × 175 feet or upwards of 8 acres in extent.[74] Those employed in European practice for sea-works are smaller, their dimensions usually not exceeding from 164 × 92 feet to 197 × 78 feet, or a little over 15,000 superficial feet; one sunk in 1856, near Flushing, measured an acre.

Fascine-work for protection of slopes above low-water, in Holland is thus made:—Reeds are laid horizontally along the line of bank to a thickness of 1 inch; at right-angles across these are laid faggots, 5 or 6 inches in middle diameter, their thinner end pointing up the slope, forming horizontal layers along the line of bank, the thick end of the faggots in each layer overlapping the thin end of those in the layer below. Through these, at intervals of 14 inches, are driven stakes about 4 feet long, forming rows parallel to the line of bank and from 16 inches to 2 feet apart. The heads of the stakes are left 8 inches above the faggots, and are bound together with wattles after the manner of hurdle work. When this wattling is complete, it is driven down with a mallet onto the fascines, and a peg or key is fixed through the head of every fourth or fifth stake to prevent the wattles from lifting. If the proper sort of wood is used, this protection will last from five to seven years, and is quite able to resist the action of the tide. In English practice each layer recedes by about 12 or 18 inches from the one below it, forming steps; and when the layers are horizontal the work is termed "rise-heading": when the fascines lie horizontal and the layers up and down the slope it is termed "arming." The protection is the strongest of all temporary ones. So effective is it, in fact, as to be not unfrequently treated as a permanent form though periodically needing repair and partial renewal. It is sometimes loaded with stone filled in and firmly wedged between the rows of stakes, 8½ cwt. to the square yard. In England it is said to last three or four years; and the cost without stone may be taken at about 1s. 6d. per square yard.

In Denmark, the arrangement is somewhat different from either of the foregoing. The fascines, about 10 feet long and 3 feet in middle girth, are laid side by side about 1 foot 6 inches apart, their length lying up and down the slope; the brushwood composing them is then spread out, making a continuous layer 6 inches thick. Obliquely across this are laid fascine-bands, 1 foot 6 inches apart, fixed by stakes driven into the bank, and the intervening spaces packed with stone. For securing the foot of a bank, fascines, their inner ends sunk in the bank and inclining downwards, are placed close together side by side, and secured by stakes driven through into the bank. The tops of the stakes project 8 or 9 inches and are wattled together, and each layer is covered with broken stone. Upon the first layer another is similarly laid and secured, the outer end retiring: it is customary to place four or five layers, giving a height of 6 or 8 feet. The steps formed by the layers, are packed with stone.[75] This forms an excellent toe-protection, and is illustrated in Fig. 9. It is to be noted that, in order to avoid needless repetition, the foregoing descriptions of fascine-work include an account of that used for constructive purposes and for permanent as well as temporary protection. For permanent protection of other descriptions see *infra* pp. 120-131.

Where reeds are easily procurable, they form a useful temporary protective covering for slopes likely to be covered by only a few extraordinary high floods. The reeds are cut while green, laid to a thickness of 4 inches, and secured by long pegs wattled together. It is said to last about a year, and to cost about 6d. or 7d. per square yard.

The application of straw as a protection, has no universally-recognized name in English. "Straw thatching" best explains the nature of the thing; but as it is also variously termed "straw band," "straw mat," "cramp mat," &c., we shall employ the Dutch term "krammat," comprehending as it does all these several names. It is used on slopes and berms above low-water level where the wash is not great. Wheat or rye straw is combed-out straight, and spread closely over the surface (its direction up and down the slopes, sometimes diagonally) in a layer of from 1 to 3 inches thick. This is kept in place by well-twisted straw bands about 4 inches in girth, laid at right-angles to the straw, a loop or bight of the band being thrust 6 or 8 inches down into the bank at intervals of about 6 inches. Sometimes the bands are pinned down with strong forked pegs or twigs. The straw bands are laid about 2 feet apart. This form of protection, although possessing some disadvantages, particularly as regards durability, is considered most generally advantageous by reason of the rapidity with which it can be applied and its cheapness. It is used under urgent circumstances, where loss of time would mean risk of damage to the work, as for example during construction, or before the surface is grass-clad; and also where fresh earth has been used for repairs. It costs about 2½d. or 3d. per square yard, and will last from 6 to 12 months. In Holstein, straw protection is described as being made thus:—The men employed kneel with their backs to the sea, having beside them bundles of straw, of which they make ropes an inch or two in thickness. When they have made one about a foot long, they press the middle part of it into the soil of the bank to the depth of several inches with a kind of forked chisel, the two points of which prevent the rope from opening while pressed down by the flat part between them. With that end of the rope

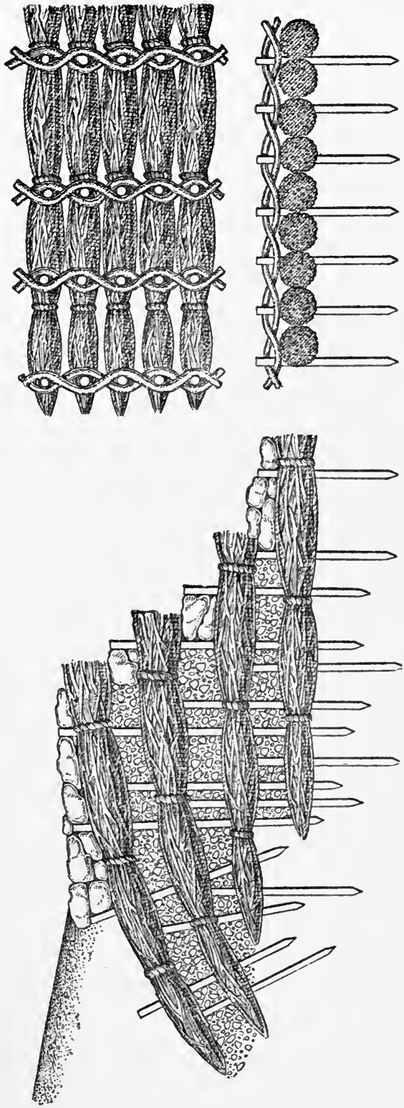


Fig. 9.—Fascine Protection to Foot of Bank.

which remains out, they interweave fresh straw, and when it is sufficiently lengthened they again press it down into the bank at a distance of 5 or 6 inches from the former place. This work is carried on all along the bank from the top to the bottom, each new rope being laid close to the preceding as regularly as in a beehive. The grass soon springs up between the straw ropes, and after a while entirely conceals them.[76]

Mr. Wiggins mentions some other materials as being suitable for temporary protection. "The refuse of flax," he says, "would also doubtless suffice for a time to prevent the abrasion of the soil by the waves, and so would rushes or flags. Any kind of linen or coarse woven fabric, such as hop-bagging or the like, would doubtless temporarily protect the soil from further damage, where the turfy covering might be torn up, and so would wads of sea-weed. These latter indeed are much relied on for the sea-banks of the islets near Portsmouth."[77] Sea-weed, weighted with stone or otherwise secured, has been employed in Denmark, and its use has been strongly recommended by a Danish Dyke-Inspector. Gunny-bagging may also be added to the list of useful materials for protective purposes.

Permanent protection will be treated-of later on. Some of the foregoing methods are suitable for that as well as for temporary purposes, and in order to save repetition have been in this place described because they belong to the general class of fascine-work, straw-work, and the like. With reference to all methods of surface-protection, however, whether temporary or otherwise, it is to be observed that none save the throwing-in of rubble or similar material to find its own slope and take its chance of remaining, is in practice available for places more than a very small depth below the lowest tide level, since they cannot be applied at any considerable depth without coffer-damming or other expensive means of laying dry the surface.

The construction of a bank seated below low-water mark proceeds in general as follows. If the bottom is weak, a layer of mattresses is first put down, as already described. Upon this — or upon the ground itself if satisfactory and firm — are raised two longitudinal banks of narrower mattresses, one on the land side and the other on the sea side, at such a distance apart as to be just included within the width of the bank, each successive layer retiring inwards from the one below. As fast as these are sunk in position and weighted down, the hearting of the bank is filled-in between them. When the bank is thus brought up to near the level of low-water, the work proceeds in much the same manner as if the seat were at that level. Banks have been thus constructed in a depth of as much as 27 feet of water, and with such success that even when the hearting was chiefly sand none was washed away. The foot of the bank, and the slopes below low-water, should be fortified with rubble stone tipped in sufficient quantity to repose at its natural slope. In some cases, where the bank is not much exposed on one side, only one lateral dam is needed to prevent the stuff forming the hearting or body of the bank from being washed away during construction.

The objection to fascine-work thus executed below low-water level is its slowness, since the mattresses can be sunk only during calm weather and at or about low-water. And the durability of fascines so employed seems to be as yet an open question. For these reasons, as well as for those given at pp. 28, 29, it is probable that only under special circumstances will a bank be so seated: the method of proceeding in its construction is, however, given in order to meet such cases.

In the case of a bank seated above low-water mark, it has to be decided where and of what width the openings for influx and efflux of tide during construction are to be. If the site is intersected by a stream or streams of land-water (as distinguished from creeks and rills of tidal water alone), these have to be dealt-with in a special manner, and their discharge provided for, as hereafter described at pp. 132-139. If there are no such streams, or if they cannot be so dealt-with as to be utilised for the ebb and flow of the tide, openings must be left in the bank for that purpose. The width requisite for these openings is a matter of high importance, because the difficulties of construction occasioned by the tide do not necessarily increase with the size of the area to be reclaimed, but depend to a very great extent upon scour caused by the alternate filling and emptying of that area as the embankment proceeds. From an elaborate calculation made by Mr. J. M. Heppel, M. Inst. C.E.,[78] it would appear that while, as an approximate rule, the openings left for final closing should have an aggregate width—extending down to the foot of the bank or to low-water mark as the case may be—amounting to 1 foot for every 10 acres of the area to be enclosed, additional openings for influx and efflux during construction must be left, their aggregate width depending on conditions that vary for each particular case, and needing to be calculated accordingly. In illustration of the difference in practice occasioned by different conditions, it may be remarked that in reclaiming a piece of land ot 1,000 acres, by a bank three-quarters of a mile in length the seat of which was 6 feet below high-water mark, only a single opening, 7 chains in width, was left. In another case, in reclaiming an area of 1,700 acres, by a bank four miles in length the seat of which was 8 feet below high-water mark, three openings, respectively of 5 chains, 7 chains, and 12 chains in width, were needed. In neither case was the speed of the outgoing current materially increased during the progress of the works, nor indeed until the cross-section of the openings was diminished. In completing the latter of these two works, the aprons of two of the openings were raised 18 inches or 2 feet at a time, by woodwork, stone, and clay. It was expected that the current would increase in the third opening when the other two were raised; but this was found not to be the case, as the water within the enclosure did not rise to so high a level as that without, and in fact never attained to high-water mark.[79]

Respecting the situation of the openings to be left for final closing or "shutting-up," Mr. Wiggins makes a suggestion that calls for notice. Much judgment, as he points out, is required in choosing the place of shutting-up. This is often fixed at the deepest part or main channel [he is here speaking of existing creeks &c.], as the natural inlet and outlet of the tide, and sometimes no other can be adopted; but it will be matter of serious thought, whether the shutting-up could not with advantage take place on higher ground, and the main channel be previously crossed by the bank. "It is true," he continues, "that this will impound a lake inside, of the same extent and depth as the channel, but this water will be ultimately worked out by the sluices; and by having higher ground to shut up on, longer time will be gained for working between tides, and less material will suffice. It should also be considered whether two or more 'gaps' for final closing are not preferable to one."[80]

It is not, however, always advisable to carry the bank over, and wholly close, the natural channels in the first instance. In fact—as will be seen in the case of the work at Sunk Island hereafter mentioned (p. 102), especially when judged-of in connexion with the always critical and sometimes costly and laborious operation of shutting-up—economy of time and expense may be effected by judiciously turning them to account. The importance of Mr. Wiggins's remarks, and the value of the suggestion concerning the selection of ground higher than the bed of the deepest channel for at least some of the closure-places, will nevertheless be generally admitted; and as they touch the question of how best to deal with existing creeks and such-like natural passages for ebb and flow of tidal water, this subject will be here considered.

In the case of a bank whose seat is below low-water mark, such creeks should always be at once filled-up over the whole width occupied by the seat of the bank. Where the depression of their bed below the general surface of the ground is only a yard or so and the slope of their sides is gentle, this will be sufficiently effected by the mattressing (if any) and the other materials laid down in forming the base of the bank itself. If the bed is deeper, or its sides at all steep, it is best to bring it up to the general level of the ground with suitable filling before laying down the bottom of the bank. When the seat of the bank is at or above low-water mark, all creeks whose bed (either naturally, or

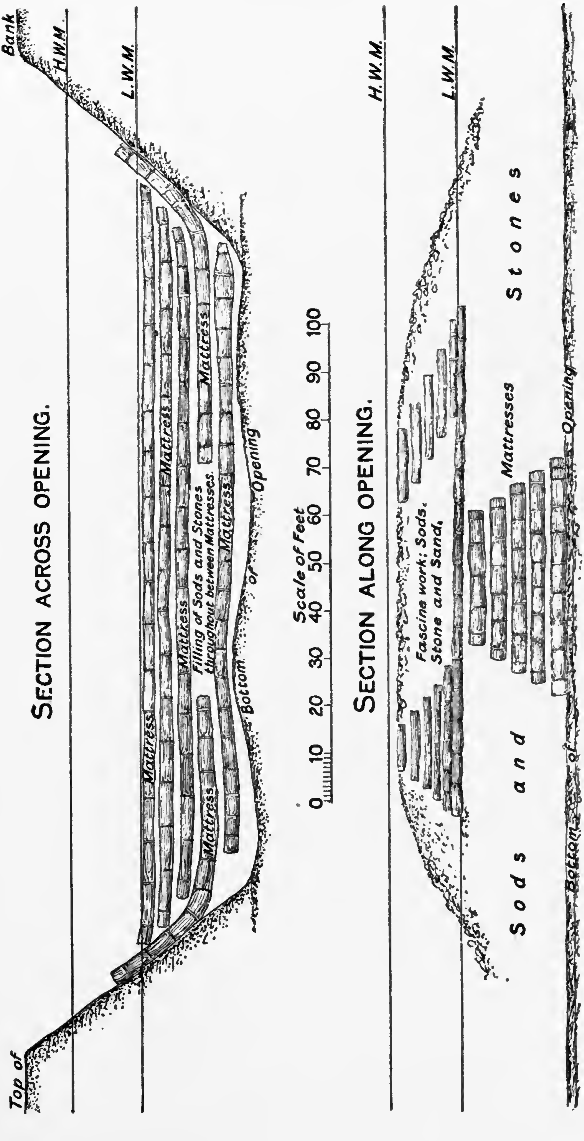



Fig. 10.—Closure Work in Creeks.

after the loose mud and slush have been taken out of it) is below low-water mark—*i.e.* all such as contain water at low-tide, should be at once permanently brought up to that level. The procedure in both cases is illustrated in Fig. 10, and the description given at pp. 75, 76 applies, on a smaller scale. In the case of a creek where the seat of the bank is above low-water mark, there is far less difficulty in the operation, and when the bed has been brought up to low-water level mattresses are no further required. The total width of opening for tidal flow and ebb, when determined (*ante*, p. 84), should be made up by creek widths, which will in almost all cases suffice. Any deficiency has to be made up by intervals left in the earthwork. Creeks (if any) in excess of the needful openings should be cleared of slush and soft mud, bottomed with brushwood, furze, or the like, filled-up with clay well rammed and beaten down, and the bank carried over them. Of all the openings, whether on the site of creeks or otherwise, it is to be especially noted, that they must be substantially paved with well-bedded stone or concrete, laid over the whole space to be occupied by the bank and fanned-out for at least 30 feet beyond on the land side and not less than 60 feet on the sea side if the foreland is sufficiently wide: if not, then carried to lowest water mark. When stone and concrete are quite out of the question, the best shift will be made with planking, laid across the set of the in-and-out current, close-jointed, and securely fixed in place. The sides of the openings must also be protected as the bank is raised, by strong fascine-work and clay, up to the highest tide level. No reasonable expense should be spared in this paving and protection of the openings: the stability of the bank itself, and success or failure in the final closure, depending upon its soundness. For a reclamation of 7,000 acres on Dengie Flats, Mr. G. W. Hemans, M. Inst. C. E., proposed to have four or five outlets, each from 100 to 200 feet wide, for the purpose of draining out the water: that these openings should be provided with stone sides and proper aprons and, where necessary, with inverts; and that the openings should be of such a width that at every ebb tide the inside area would be dry, so that the work of raising the banks could be carried on. Each opening should, in the first instance, be converted into an apron of stone, of sufficient size to resist the velocity of the water.[81]

The situation and dimensions of the sluices have also to be determined and the sluices constructed, before the bank is commenced, or at latest before the earthwork reaches the spots at which they are to be placed. Their construction will be dealt with when treating of Drainage. Their capacity of discharge is not to be included in calculating the dimensions of the outlets above mentioned; and their doors should be kept shut until the time arrives for closing the bank, so that in case of need they may be opened to assist the outflow and relieve the temporary openings should scour anywhere be noticed.

Should there be any weak spots on the seat of the intended bank, they have to be cleared out if not too deep, and filled with sound material. If too deep to be completely cleared, they should if possible be so for a yard or a yard-and-a-half down, fascines in two thicknesses at right-angles to each other laid over the bottom, and the place filled with sound stuff If the whole or any extensive part of the site is weak, a foundation of mattresses should be laid, and it will be matter for consideration whether in such a case it would not be advisable—after clearing out and filling the weakest spots as mentioned above—to let the mattressing extend over sound and weak places alike until the whole area affected by weak spots is covered and a sounder portion of surface reached.

It may be that the seat, although not unsound in respect of bearing-power as a foundation for the bank, appears to be defective as regards impermeability. In the United States of America, means of cutting off percolation under the bank have been tried, and successfully. In the Mississippi valley it is the almost invariable practice of the levee Engineers to put in what is termed a "muck ditch" under the embankments, that is, to excavate a portion of the natural soil and to replace it by strong well-tamped clay, causing a projection as it were of the embankment into the ground, after the manner of a tongued and grooved joint. The object of this is to supply as far as possible the want of a foundation extending to an impermeable stratum, and to stop at least a part of the leakage, by substituting a tight for a porous soil for part of the depth; and it gives the water a somewhat longer distance to traverse in order to get through. It is thought to be especially indicated in sandy soils. Occasionally sheet-piling has been used to a limited extent, and it has been proposed to put in longitudinal diaphragms or vertical walls or cores of cement or concrete, but neither in the United States nor in Holland have these expedients had a fair trial. Even muck ditches, though known to the Dutch Engineers, are not much favoured by them. They think they do not extend deep enough to do much good, and cannot be rendered efficient without great expense. What is the use, they say, of going six or eight feet into a sand stratum which is twenty or thirty feet thick? Nevertheless, the experience of American Engineers is that muck ditches, when of considerable dimensions and well filled and tamped, perform an important part in arresting percolation. The levees built on the Mississippi since 1890 have muck ditches 12 feet wide at the top, 6 feet wide at the bottom, and 6 feet deep. During a flood in 1891, these levees and the land behind them were unusually dry, though previously very much affected by percolation.[82] Similar contrivances seem to be in use in Denmark, although perhaps not to a great extent. Where good materials cannot be procured in sufficient quantities for the formation of the bank, "it is necessary to fill up the interior with clay, laid a considerable depth in the ground, as experience has shown that the water will, without this precaution, sometimes find its way through the ground, and issue behind the dyke."[83] When the stratum, from which danger is apprehended of percolation under the bank, is close to the surface, the thinness of the strong top soil may be remedied by artificial means. A layer of several feet of earth, forming a berm or banquette, may be placed upon the natural surface on the inner or land side of the dyke to serve as a counterpoise to the upward pressure of the external water, or on the outer side to add weight to the top soil and compress the permeable stratum as well as to remove the source of percolation to a greater distance. The upward pressure of the water in the soil when far removed from its source is so diminished by friction that it ceases to be dangerous. There are numerous examples of interior and exterior banquettes in the Holland dykes, of various dimensions from 3 to 10 feet high and 20 to 100 feet wide, the inner banquette being the one most frequently adopted.[84] In reference to the foregoing and to the woodcut accompanying it in the original, it is to be remarked that it is open to question whether a horizontal banquette on the outer side, thus described and figured, might not be advantageously supplanted by employing the same amount of material in an extension of the sea-slope, which not only removes the maximum head of water but also renders the bank stronger to resist the action of waves and the run of the sea. Indeed, this appears to be recognised by Dutch Engineers, for it is immediately added that the new South Linge dyke has banquettes, their cross-section being usually a long convex segment whose chord has a slope of from 1 in 5 to 1 in 10. In place of a banquette, an ingenious device is very commonly employed in the United States of America, and occasionally in Holland. A low interior cradge- or inset-bank is constructed, distant 20 or 30 feet or more from the main bank and returned into it at each end, forming an enclosure which is allowed to fill with the water percolating beneath the bank. The water thus impounded exerts a counter-pressure against the external water, and relieves the ground or the banquette inside from some of the upward pressure.[85]

If the materials available for construction of the bank cannot be relied-on as sufficiently good to prevent percolation through the body of the bank itself, it may be necessary to arrange for the carrying-up of a central core along a portion or even the whole length of the bank. It is true that a good facing of clay will as a general rule suffice to prevent water from penetrating to the interior; but there are circumstances under which it may be desirable to provide additional safeguard. A core of pisé, to which reference has already been made (*ante*, p. 68), is well worth consideration on account of its cheapness as compared with clay puddle or concrete, and will in the majority of cases answer the purpose. Whether this, or concrete, or puddle is adopted, it will be founded on the clay in the muck ditch if one has been put in: where this has not been needed owing to soundness of the natural surface, it may be founded directly on that surface, and carried *pari passu* with the bank and a little in advance of it as to height, so as to allow the frames or planking within which it is brought up, to remain undisturbed until it has set, before being drawn. The height to which it is carried must depend upon the more or less reliable nature of the material forming the bank: half the height between the seat of the bank and high-water will generally suffice, and it will rarely need to extend above ordinary high-water level.

Sheet-piling has also been recommended as a core for prevention of percolation below or through the bank: there are cases in which it would be more efficacious than those above mentioned. Its location in the centre of the bank would protect it against the teredo—that great enemy of timber-construction in sea-works: its extensive employment in Holland and elsewhere even where quite exposed, seems to sufficiently dispose of objections sometimes urged against its durability; and in some situations it might be preferable even on the score of economy.

As a protection against percolation owing to weakness of the material of the bank, as well as that caused by the burrowing of rats, crabs, and other creatures, it has been proposed by Mr. Driggs, of New York, to form a core or diaphragm of cast-iron plates, thin and sharp at the bottom, and of sufficient length to reach both the high and the low water marks. They are made to fit together at the sides so as to form a continuous wall, and are pressed or driven down into the bank.[86]

The toe of the bank should be put in before the earthwork on that section is commenced. Whether the sea-slope is to be stone-faced or not, the toe should if possible be of stone or concrete, sunk 18 inches or more below the natural surface of the shore and carried up 2 feet or 2 feet 6 inches above that surface, which if at all tender should be excavated behind it to not less than a foot deep and filled with sound and well-rammed stuff. Filling and ramming is to be continued until a good solid backing some 6 or 8 feet wide, with a slope on top of 5 or 6 to 1 inwards, is formed up to the top of the toe-wall. Where the cost of stone or concrete is too great, or local conditions—as for example the nature of the foreland, the sheltered situation of the bank, or other circumstances—render their employment unnecessary, the foot of the bank can be protected by a row of piles 5 or 6 feet apart, parallel and close to it, driven into the foreland and sheeted with 2½-inch or 3-inch planking with close and well-backed joints, and thoroughly coated with tar. This, if kept low—say not more than 2 feet or 2 feet 3 inches high, and placed not against the slope but at the point where it runs out, forms a good revetment, and the filling and ramming behind it is done as above described for a stone or concrete footing, and carried back level on top until it meets the slope. There are some situations in which groynes are said to be preferred even to a stone toe. In Holland, "wherever the shores are exposed to heavy prevailing storms, the outer slopes of the dykes are defended by banks 50 yards, or 60 yards apart, running out from the face mostly at right angles, and intended to break the first shock of the waves. This method is preferred to placing masonry on the toe of the dyke. These protecting banks, or groynes are of various kinds," [87] and are described as being of a very substantial character. In such cases, it is probable (although not so stated) that fascine-work similar to that described at p. 79 and illustrated in Fig. 9 is employed to strengthen the toe. To the passage just quoted it is added that "where the foreshore is very long, a parallel shore-work [presumably of like construction with the groynes described], with occasional openings, is laid down at spring tide level." The question of longitudinal protective works will be more fully considered when treating of groynes.

Whatever the kind of footing adopted, it must ever be borne in mind that expenditure is well incurred upon this feature, as a safeguard against continual loss of material at the commencement, and risk of undermining by washing-out during the progress, of the bank.

The official General Regulations ("Algemeene Voorschriften") of Holland require that when an embankment is designed to keep out water, the seat must be broken with a spade or plough to the depth of 8 inches, and chopped fine. This applies also to existing earthworks to which the new work is to be joined. And in our own country it is a general opinion that the seat of a bank should be more or less pecked-up or stepped in order that the earthwork may have a good junction with the ground. The idea is correct in theory and, as regards an embankment on dry land, especially where the ground has any considerable slope, in practice also. In embanking on a nearly level tide-washed shore however, it may in practice be a question whether, if the ground is originally firm and sound, it is not best to leave it undisturbed save for insertion of the stone or concrete of the toe.

The materials for the bank have to be procured, partly or wholly, either on the spot or from a distance; and these two points require some consideration.

Respecting the first of these cases, Mr. Wiggins remarks as follows [88]:—" Where the *material* of the slob or shore to be embanked is *applicable to the building* of the bank, much expense and delay may be avoided, and there can be but few cases where that material is wholly inapplicable, since any soil which is so entirely devoid of argillaceous matter, as to require to be wholly rejected, can hardly be a fit subject for an intake. In general, indeed, the whole or nearly the whole of any sea-bank may be thrown up from its own vicinity, either by means of barrows running on planks, or by horses and carts . . .; and one of the advantages of these modes is, that as much force as is wished may be employed along the line, and the work done in the shortest time possible, *i.e.* within the working days of one season, reckoning 200 days from the 1st of March to the 1st of November, so as to obviate the necessity of leaving the unfinished bank . . . for a whole winter. In cases where *all* the bank cannot safely be built with the material on the spot, it will be necessary to determine what portion of it that material is fit for, since it may be extremely ineligible in a wet state, but quite the contrary when dry. It may often be highly eligible for the parts above ordinary springs, or for the front of the bank beneath the stone-work, when it sets hard after being wet, or it may do for the back of the bank, when covered over with vegetable mould. All this must be well considered, taking into account at the same time, that any saving of expense which detracts from the stability and permanency of the bank is very bad economy, and the worst policy. Amongst other precautions in building a bank with the materials which the line of bank affords, one is most important, viz. to go out to some distance for them from the sea-foot of the bank, so as to avoid causing deep water at the immediate foot. Another precaution is to avoid favouring any channels; and to this end, digging away the earth in spots with bars left between them. If the water comes up at all turbid, these hollows will soon fill with warp. A channel along the foot of the bank is particularly to be avoided as probably mischievous. It seldom happens, in the case under notice, that carts and horses can be largely employed to collect the materials, by reason of their wetness and softness, or from the rills and inequalities of the surface. Planks, barrows, and 'box-horses,' are therefore the usual implements employed; and . . . it is an advantage of barrows and planks, and in some degree of horses and carts, that they admit of any number of hands being employed, so as to exclude the sea in one season,—this being of great importance, in order to prevent its ravages upon an unfinished bank. Thus it becomes expedient to have several reaches or portions of the bank going on at once, by different gangs, and this will occasion several gaps or places for closing, which will be an advantage, since the force of the reflux tide will be divided, and the closing more easily effected."

In constructing some embankments at Sunk Island in the Humber, the contractor was required to use the soil excavated in forming the drains, and the remainder was to be taken from the ground lying outside the line of works, under the restriction that the excavation was not to be made within

6 feet of the outer slope nor to exceed 4 feet 6 inches in depth, that the sides of the excavations nearest to the banks should have a slope of not less than 2 to 1, and that channels should be provided for the purpose of discharging the water that might accumulate in the pits after each tide. The soil of Sunk Island so consolidates and unites as to be perfectly compact and impervious to the pressure of water, therefore no difficulty was experienced in that respect, and the entire lines of banks formed by the material found *in situ* proved from the first perfectly water-tight. The total settlement of the bank along the shore of the river, in a somewhat though not very exposed situation, amounted to 15 inches in a maximum height of 8 feet 10 inches, and is said to have been due partly to the consolidation of the soil composing the bank and partly to the subsidence of the ground on which the bank was seated.[89] That this subsidence of the ground was, in part if not chiefly, due to the too great nearness of the borrow-pits on the foreland, seems probable; because another portion of the bank, 7 feet 6 inches maximum height, seated on firmer ground and lying very sheltered along Patrington Channel (a narrow muddy creek then rapidly silting up), underwent very little settlement.

The precautions specified by Mr. Wiggins, viz. to avoid excavating material too near the bank, and to so arrange the borrow-pits as to prevent the formation of channels in the foreland, are carefully observed in embankment-works in Denmark and Holland. Wherever suitable material is to be had outside the bank, it is always used, care being taken that the excavations are not cut in a direction parallel with the current, nor continuously in connexion with one another, the natural surface being left undisturbed between them for a width of from 17 to 20 feet, to prevent the formation of a channel, the scouring-out of the foreland, or other injury. Where circumstances make it necessary to obtain material from inside the bank, the utmost care is exercised in doing so, and a breadth of from 50 to 80 feet of natural surface is left undisturbed along the inner foot of the bank. The Dutch regulations prescribe that no excavation in the foreland shall be less than 33 feet from the outer foot of the bank, and that the strips of undisturbed natural surface shall be not more than 328 feet apart.

As regards stone, fascines, and timber, it is commonly the case that these are not found on the spot, and that almost as a matter of course they have to be brought thither. But it also occasionally happens that the materials at hand for the earthwork of the bank are unsuitable as to quality or insufficient in quantity; and it then becomes a serious question, whether to make shift with inferior materials and to supply the lack of others by substitution as best one can, or to incur the sometimes considerable expense of obtaining better or more abundant ones from elsewhere. This point is calculated to test and tax in no small degree the skill and ingenuity of the Engineer, the embanking of an intake for agricultural purposes being seldom an undertaking in which cost is of trifling moment; and the decision calls for careful thought and sound judgment on his part. By augmenting the bulk or adjusting the slopes of the bank and protecting it with additional facing and the like: by making-up the deficiency of one material with another—as for example that of stone with concrete, or that of both with timber; or by other devices and means—good and substantial work may be constructed even with inferior materials and scanty resources. The conditions of the problem are different in every individual case, and it is not possible here to offer any specific advice in assistance of that judgment. The following general considerations may, however, be found suggestive and useful.

"The expenses of the work will of course be greatly enhanced, not only by reason of the transport of earthy matter from a distance, but also by reason of having to purchase the material, as well as to transport it, and form the bank. There are, however, some advantages as a set-off against the expense in this alternative, such as the avoidance of the loss of any part of the valuable ground to be embanked: and what is of still more importance, the avoidance of cutting away the fore shore or foreland lying outside the bank, and so deepening the water immediately outside the bank, and consequently increasing the power of the sea upon it. Still the additional cost will seem at first . . . perhaps more so than it really is, when all the advantages are considered; for besides those just mentioned, there is the advantage of not losing material thus collected, in anything like the ratio which is inevitable where that [of inferior quality] on the spot is used,—and the further advantage in all cases, over sandy material on the spot, of having ultimately a much more safe and substantial bank than any such sandy material would furnish, and probably a consequent saving of bulk or stone-work, equal to the additional expense of a better, though a more distant material; besides which, something may be reckoned for the advantage of earth capable of immediately bearing fresh-water plants, instead of waiting many months before that kind of security can be obtained." [90]

While on the subject of obtaining material, it may be mentioned that in the Eastern Counties a local custom exists for measurement of earthwork for embankment works. "The labour attending the removal of heavy clay is measured either by the floor or by the cubic yard; the floor is the most local, and the cubic yard the most scientific and universal measure. . . . The floor of earth differs locally as the perch differs; thus the statute perch is 16½ feet, whilst the marsh or sea-waller's perch is in some places 18 feet, and in others 20 feet. So the floor of earth being the square of the perch, and 1 foot deep, is either 324 feet (generally in practice 320 feet), or 400 feet, as the one or the other perch may locally prevail. It is important to recollect this in putting out or settling for walling-work, since otherwise much confusion and misunderstanding may arise, and sea-walling being done at so much per floor, may inadvertently be measured and paid for by the square of the statute perch or rod of 272 square feet, instead of 320 square feet or 400 feet, as the case may be. The floor in most general use is that of 400 feet, which contains a trifle less than 15 cubic yards, and that quantity is generally calculated. The floor of 320 feet contains rather less than 12 yards cubic, and for the sake of uniformity it is highly useful to reduce these local measures into the more universal denomination of cubic yards."[91] In Lincolnshire (and possibly elsewhere) the same custom obtains. "Earthwork is always paid for by the floor in Lincolnshire = 400 square feet, 1 foot deep = 15 cubic yards."[92]

The following detail is given of Dutch practice in the actual execution of a bank, and indicates the general procedure advisable in similar work elsewhere:—The grass is first taken in regular sods from the excavations, and piled on one side. The seat of the bank is cleared of all [soft] mud, vegetable growth, and rubbish, either all at once or in sections as the execution of the work may require. To allow for compression and settlement, the bank is built higher than the intended finished work, by an amount varying—according to the material and the mode of construction and other circumstances—from one-seventh to one-twentieth of the intended finished height. To obviate too great shrinkage [at any one time], the bank is carried-up in layers, level longitudinally and somewhat sloping inwards transversely, from 12 to 16 inches thick if carts are used, and from 8 to 12 inches thick if built with wheelbarrows. Horses and carts are greatly preferred to wheelbarrows, and should be used if possible, at least in part. The teams must not all travel precisely the same road along the work, but must change their tracks constantly [this is probably with a view of assisting consolidation]. The earth is well rammed: as a general rule there should be one tamper to four shovellers. Old cavalry horses are also used for treading-down and consolidating the earthwork. The earthwork being finished and the slopes trimmed, the sods that have been taken up and piled aside are then placed upon the slopes regularly in rows, beginning at the bottom, closely fitted, beaten in place with heavy wooden paddles or mallets, and covered with fine earth. If sods cannot be had, the bank is sown with clover-seed.[93]

It is often convenient to carry-on a bank at several points simultaneously in order to expedite the work. Where openings are left for influx and efflux of the tide during construction, as mentioned at pp. 84, 85, this mode of execution becomes inevitable. In carrying out the work at Sunk Island, gangs of men were set on at several places along the line, so as to raise the bank fully to the height of ordinary spring-tides, but the principal natural creeks were left open for the passage of tidal water. The creeks were afterwards simultaneously filled up, and the whole embankment brought to one level and to the full height required.[94] This bank, nearly 3½ miles in length, was commenced in April: by the beginning of July the tide was excluded from the land, and in December the whole was completed. The economy of time and trouble thus ingeniously effected by taking advantage of the existing natural channels as tidal openings will be best appreciated when we come to treat of the operation of shutting up.

With exception of the method now generally approved for closure work, perhaps no change in modern practice as contrasted with that prevailing in the early part of the nineteenth century is more marked than in the manner of constructing the earthwork of the bank itself: a change based, like the other, upon the principle of reducing the velocity with which the tide in its ebb and flow streams over the work in progress. It seems to have been invariably the custom to carry-on the bank by pushing it forward at its full or nearly its full intended height, from the two ends towards the opening left for closure; the idea probably being to encounter the sea with a mass the biggest possible, complete so far as it extended. There does not appear to be any mention of a different system of procedure in this country prior to 1850. In 1852 Mr. Wiggins, a good practical authority, who evidently spared no pains to bring up to date his treatise on the subject, speaks of carrying-on at full or nearly full height as being almost indispensable. "It will be necessary," he says, "to use the precaution of building the bank from the two ends, approaching each other towards the place of 'shutting up,' as it is called, *i.e.* closing, or finally excluding the sea; and each end should be of the full height, or at least the full height of spring tides; because wherever the tide overflows an incipient bank, much of the material is washed away, and the mischiefs that otherwise happen are considerable. The bank therefore should be built up to its safe height at once." And further on:— "Other precautions of a general nature are well worthy of attention, viz. to raise the bank to its *full* height as soon as possible, and to allow in so doing for its *settling* and shrinking from one-eighth to one-fifth of its height." His mentioning as a point worth consideration the leaving of several gaps for closure in preference to a single one, seems to show that the practice was not a common one: it is the only means he has to propose for obviating or diminishing the difficulties thus described:—"As the line of bank advances along the shore, . . . precautions will probably be more particularly requisite as the two ends of the bank approach each other, towards the place of shutting up. The tidal way will then be contracted, and the rush will be great, both of the influx and reflux of tide. Much of the material at the ends of the bank will thus be carried away, unless guarded with turf kept down with stone during the flow of tide, and removed at its reflux when the work is renewed." [95]

The earliest mention of a change in English practice as respects the raising of the bank to its full height from the first, appears to be in 1862, when Mr. Gibbs, M. Inst. C.E., who was well acquainted with Dutch embanking, stated that by raising a closure-dam in horizontal layers, the velocity of the water was not increased; and that "he had constructed an entire embankment upon the same principle. The material of which it was composed was so deposited, that at each tide, the top, as far as was practicable, presented a level surface, for the water to pass over, and the scour of the overflow was guarded against by temporary aprons." Nothing is said as to the way in which the water on the land side of the bank was got rid of when the tide fell. This, if it remained, increasing in depth as the bank was raised, might occasion much inconvenience. It is possible that tidal openings, although not mentioned, were left, and that the raising in horizontal layers refers, not to a wholly continuous line of bank, but only to the sections between those openings. The obvious objection to this as an explanation is, the mention of guarding against the scour of the overflow by temporary aprons—unless by these is meant a krammat or similar temporary covering to the slopes and the top: had tidal openings been left there would have been no overfall to guard against, the water slowly rising on both sides of the bank and submerging it, and sinking again as the tide ebbed. At any rate the difficulty, if there was one, was overcome somehow, for it is added that the work was successfully executed.[96] The advantages of the new method were not long in being recognized. In 1864 Mr. Heppel, speaking of the works proposed for a Reclamation at Dengie Flats, describes a modified form of it. "It is evident," he says, "supposing the banks to be carried forward at their full height like a railway bank, that as the open space left between them, for the passage of the water in and out, is diminished, the velocity and scour would increase; and when this open space became very small, . . . the scour against the ends of the banks, and the ground between them, would be very nearly the same as that through the closing places; and although the latter, having been constructed with special reference to resisting such a scour, would suffer no injury from it, there would obviously be a great deal of difficulty, and risk of failure, in carrying forward an embankment exposed to its action. To avoid this difficulty, it was intended to stop the carrying on of the banks to their full height, as soon as any injurious amount of scour should begin to show itself; and to make up the intervals then remaining, over and above the final closing places, by bringing up the banks, as evenly and simultaneously as possible, in horizontal layers. . . . The raising of a bank, in horizontal layers, would have the effect of continually diminishing the velocity of the water flowing over it, so, that if any injurious action occurred, it would most likely be at the commencement of the operation; and that if it did not then take place, no great apprehension need be felt for the future stages of the work, even though it should extend over several tides."[97]

When circumstances require that the work should be rapidly performed, and time is of more importance than solidity of construction, the old mode of carrying the bank forward by tipping from the end as in ordinary railway work will probably be practised. Apart from the question of scour and closing, it has the great drawback of depositing material without any possibility of consolidation save by the slow effect of pressure upon the lower portion by the weight of the superincumbent mass, this of course diminishing from the bottom upwards and becoming *nil* at the top. In nearly all cases therefore, it may be assumed that whether constructed in two continuous lengths or in several sections, the bank will be raised in horizontal layers. In addition to the advantage of obviating or greatly reducing scour, this method possesses another in the facilities it affords for properly consolidating the work throughout, the importance whereof can scarcely be over-rated. Whatever the material, "the most special care must be taken in putting it together. Some banks have failed in consequence of the sods even of clay being loosely thrown together by means of planks and barrows, and mixed with loose earth : the water thus being enabled to percolate the earth, surrounded the sods, and rendered them almost buoyant, so that the whole mass separated and dispersed; whereas the loose earth ought to have been either collected under the pressure of carts and horses, or *rammed down hard with iron-shod rammers*, and the sods placed carefully outside to defend the most exposed part. . . . Horses and carts might, with a little ingenuity, be so worked in collecting the material, either on the spot or from a distance, that the weight of the carts and the tread of the horses might be available pretty uniformly over every portion of the bank; and where this is not done, the ramming of all the earth that is loosely cast should be adopted, in order to consolidate and give it that cohesion which is one ingredient in its strength, besides preventing or checking its loss by the washing of the tide, which latter effect alone would in some cases repay the expense of ramming; and in one case I have known a breach, and 10,000 acres, drowned, where ramming would certainly have prevented that catastrophe." [98]

The conveyance of material from a distance will be by railway, tram, cart, or barge: of that obtained on the spot, by tram, cart, or wheelbarrow. Our concernment here is solely with the mode of its being actually brought to bank, *i.e.* deposited in the place it is to occupy; and we shall briefly consider those several modes, with special reference to the question of consolidation as the work proceeds in a bank built in horizontal layers.

Railway earth-wagons, and the smaller ones used on tramways of narrower gauge, are suitable up to a height of perhaps 3 feet above the seat, in the case of a bank constructed in sections: when that height has been reached, they are suitable only where, or so far as, the bank is continuous from one or both ends, or the rails carried across the openings by a gantry, raised from time to time as the bank rises. Unlike carts, they contribute in their passage to and fro nothing to the consolidation of the ground over which they travel, save the tread of the horses by which they are drawn, or in the case of trams propelled by hand, that of the men. Their rate of delivery is so rapid, and of such considerable amount—a railway wagon holding about 2½ or 3 cubic yards, and a tram about 1 or 1½ cubic yard, according to size—that where, as usually the case, time is of importance, they are undoubtedly serviceable. They should tip from the side; and the track should be so laid that the stuff tipped alongside it by a train of wagons will, when spread and well rammed, form a layer along the bank 12 or 16 inches thick, between the track and the edge of the bank. This done, the rails are shifted so that each succeeding strip shall fill-in between the track and the strip last completed. Two or more tracks can be in use simultaneously; and when the strips so formed cover the whole width of the work, the first layer is complete. Upon this the tracks are then laid and the second layer formed, and so on.

A barge contributes nothing to consolidation; but stuff so conveyed can be very quickly and easily brought to bank if she is beached at high-water upon the foreland or on the sea-slope where she will lie close to the work. Her freight, unloaded as in coal-whipping, can by proper management be discharged wholly or in part upon the spot where it is to lie, or into trams or barrows by which it may be run thither. The amount of stuff that can at one time be thus brought to bank, is limited only by the number of barges for which there is berthage alongside the work.

Carts possess the recommendation of consolidating the ground as they pass and repass; and by constantly changing their tracks a great deal may be accomplished in that way. The dobbin or three-wheel cart is preferable to the ordinary two-wheel one. Although it carries only about three-quarters of a cubic yard, it is more easily hauled over a soft and uneven surface, its three wheels distributing the weight over more lines of pressure and therefore with less tendency to sink in. Whether the cart used is the ordinary one or the dobbin, its wheels should be extra broad in the tire, so as to roll-down rather than cut-up the stuff already banked.

Wheelbarrows, running as they must upon planks, are useless as regards consolidation. They are however, handy and manageable, and in many situations afford the only practicable means of moving stuff.

Whatever the mode of bringing material to bank, and whether its delivery be fast or slow; it is never to be lost sight of that the number of rammers must be proportioned to the amount banked, and constantly maintained at the full number required for the thorough performance of the work.

Mr. Wiggins describes a mode of construction with clay, which would seem to be, if properly performed, an excellent one. "Stiff clay," he says, "requires to be very carefully packed. This material, which is principally in use in Essex for sea-walling, as embanking is there called, is taken from the saltings or oozy forelands outside the walls, and is therefore in a wet state and very ponderous. It is dug in spits, and packed into a sea-wall by a process called '*flood-flanking*,' the barrow-men delivering the spits to the packers, who take each spit on a pitchfork, and striking it hard into its place, it adheres closely; but as these spits contract in drying, the crevices outside are therefore filled with mud, which is called '*sludging*.' Yet, when the packing has not been carefully performed, or the bulk of the sea-wall has not afforded sufficient weight to close the clods on each other, in drying, open spaces still continue, into which the water penetrates on the sea side, and mice, rats, &c. on the land side; so that if not carefully watched and timely mended, the water is let in to the interior, and a breach ensues. . . . The labour attending sea-walls is performed by gangs generally consisting of six runners to two fillers, a lad to clean barrows and planks, and three men to pack on the bank,—these proportions, however, somewhat differing with weather, length of run, and other circumstances. . . . A man will *pack* or '*store*' nearly as much as three men can *run* . . ., and by this operation the '*spits*' of earth are made to fit, and the sorts of earth mixed properly."[99] The work thus described is, however, expensive. According to the prices quoted by Mr. Wiggins, it would cost from 1s. to 1s. 6d. per cubic yard: at the present time it probably could not be done under from 1s. 6d. to 2s. 6d.

The foot of the landward slope of the bank, up to about 3 feet above the seat, should be of large spits of good clay well packed together and sludged (grouted with clayey mud), the courses extending 6 or 8 feet inwards and having a slope inwards of about 1 in 6. The layers of earthwork in the bank should have a slope of 1 in 60 landwards, up to high-water mark, from whence upwards they should run level across the whole breadth of the work.

If the body of the bank is sand, or very sandy material, it will be advisable that its exterior, both landward and seaward, for at least 3 feet inward from the face, and up to the very crown, be of well-packed and sludged clay spits, carried up just in advance of the hearting, the courses tilting inwards.

As the bank gradually rises, the land and sea slopes should be approximately trimmed, beaten to a plane surface, and, together with the top, protected by krammat or other temporary covering before the tide reaches them.

The portion of the bank at its junction with the land is not unfrequently apt to prove its most vulnerable part; and precautions should be observed accordingly. Its top should rise somewhat towards the end: the inner and outer slopes (especially the latter) should meet the solid ground with a slight curve rather than run butt up against it, and should be stepped or otherwise securely bonded into it. If during wet weather water trickles down the natural surface at this place, it should be diverted above by a drain discharging it well clear of the outer slope of the bank.

*e*) **Closing**—Allusion has already been made to the fact of a great change having taken place within a comparatively recent period in the method of shutting up or finally closing a reclamation-bank. Mr. Vignoles, M. Inst. C.E., speaking in 1862 on the subject, stated that until 1789 the Engineers directing the works in Holland considered it an innovation to attempt to close a breach otherwise than by piling across it. The more intelligent of the country people, however, contended that the best method was to use bundles of faggots or fascines filled with as much gravel or broken brick as could be bound up in them. After this controversy had existed for some time, the suggestion was adopted, and eventually so improved as to produce the present system, namely that of protecting the bottom of the gap with an elastic covering now called a mattress. Instead of narrowing the opening by working from the sides, it was made shallower by laying mattresses across its entire extent and filling it up horizontally. As the bottom thus rose, the velocity of the water decreased, until a level was attained at which the velocity became so small that the opening could be closed without difficulty. Subsequently this system was adopted almost universally in Holstein and Northern Europe. The employment of fascines bound up with gravel and broken brick, and heavy enough to sink in a stream and remain where deposited, must have been common in Holland and the Low Countries at a period not less than three centuries before its revival under the circumstances described; and it was singular that the art of so employing them for closure work should have been neglected until it was forgotten by technical men in the Low Countries. In the Spanish Peninsula, the old method of closing by piling had even very recently been advocated.—On the same occasion, Mr. Gibbs said that about 1842 he found in Holland a variety of systems in use, whereof the best and cheapest was, he thought, that of forming the skeleton of a dam by driving across the opening two open rows of piles, and making the closure by planking them and filling in between with earth, bringing up this dam by degrees, at periods of low-water.[100]—A consensus of opinion was expressed in favour of the new or horizontal system.

That this system was by no means in general use ten years previously, seems well-nigh certain, otherwise a practical man such as Mr. Wiggins would hardly have presented us with the following picture of the process of closing:—"Stores of stone, of grass turf, and of heath, furze, fir tops or bushes should be provided at an early stage of the work. The loose or falling earth should be retained in its place by a judicious use of these materials, which themselves may be required to be retained by piles, for which Scotch fir thinnings and boughs of little value may be used. . . . Wherever the shutting up takes place, care should be taken to collect sufficient material of every kind likely to be wanted to shut up *in one tide;* and with this view, the two ends of the bank must be advanced accordingly with guards of turf, heath, and stone, as already mentioned. As the earth thrown in attains a position ranging with the general front line of bank, it should be covered with stones thrown down at random, but close, and secured with spray of some kind as a key. A boom also across the gap is often useful, whilst shutting up, to check or equalize the current. In very difficult cases, sand-bags, *i.e.* about half a cubic yard of any kind of ponderous earth enclosed in coarse hempen bags, must be provided in great numbers, ready to throw into the gap at such critical moments as may require the most strenuous exertions for the purpose of shutting up between tide and tide, because shovel-fulls of earth, and even large stones, are carried away by the force of the current; whereas these sand-bags are weighty, and contain many shovel-fulls, though taking scarcely more time to throw in than one shovel-full, and they afterwards accommodate their forms to each other, and pack very closely together; but they should be afterwards guarded by a coating of stone outside, and staunched with a thick backing of adhesive ponderous earth on the land side."[101] That abundance of materials should be collected in readiness, and that closing must always imply a more or less critical and anxious time to all concerned, is unquestionably true; but the foregoing passage points to a hurried and (so to say) scrambling state of affairs that ought to be quite needless under the improved system.

When the catchwater drains, and the embanking of streams provided with special outfall, are completed, or have progressed so far as to answer their purpose of leaving no inland waters to be dealt with; and the earthwork of the bank has been raised to not less than high-water mark of spring-tides, and returned into and well joined to the shore at each end: the work of closing can be taken in hand. Although not absolutely necessary, it is in the highest degree advisable, that the operation should be performed in a single tide.

Calm and settled weather, and (save in the case of a bank seated a good deal above half-tide level) a time of spring-tides, should be chosen, even if this involves a few days' waiting.

If the configuration of the shore has allowed some of the tidal openings to be situated on relatively high ground, and they have been properly distributed from the highest to the lowest level, it will prove of much advantage. As the tide rises, they come successively into use, permitting the inflow to the proper extent required and relieving the lower ones from undue scour; and, as the tide ebbs, the higher openings run dry first, and work can be begun on them earlier than on those lower down. The wisdom of using as many as possible of the natural channels and creeks for tidal openings will now become apparent; those depressions, already brought up (as described on p. 88) to low-water level, are solid ground, instead of oozy channels still to be filled at the cost of time now doubly precious, and serve to drain-out the area to the lowest possible level.

That this view is not universally accepted, appears from the following statement by a speaker on the subject in 1883. "In a small enclosure on his own land," he said, "he had to deal with three or four very bad rills—one 250 feet across, another 200 feet, and another 220 feet—as well as two smaller ones, and, after taking the best available advice, he made up his mind to leave the two deeper rills to the last. As a caution to others it was only right to say this proved to be a great mistake, for having to compete against the great rush of water, which at the last was necessarily confined to a very narrow space, the difficulty of shutting out the tide had been very great. . . . He had not anticipated any difficulty in stopping the water out, but the rush was so great that one rill cost him £5,000. . . . He had now spent about £19,000 on the work. The two wide rills had absorbed the greater part of the outlay, costing, as nearly as possible, £10,000. The rush of water was so great that one day the boat conveying the men from their work was swept away, and two of the occupants were drowned." [102] Such a statement of personal experience undoubtedly seems at first sight to tell against the practice of using the natural channels of creeks and rills as closure-places. But on examination, the case is the reverse of conclusive against the method above recommended. There is nothing to indicate that the channels were filled up to the level of low-tide before shutting-up was commenced; while the mention of a great rush of water and its confinement to a very narrow space renders it next to certain that an attempt was made to close from the sides instead of working up horizontally from the bottom. And the concluding sentence shows that provision was not made for completing the work in a single tide.

When the seat of the bank is below low-water mark, openings will not be requisite until it is brought up to low-water level of neaps: the situation of the openings has then to be determined, and the height of the bottom of each can be adjusted at pleasure to the requirements of inflow and outflow of tidal water, so as to save time in the work of closing. The fanning-out of their aprons is carried down to the lowest possible level; and the building-up of the bank in sections differs in no essential particular from that already described; but the bringing of materials to bank for them will of course be, as it was for the lower part, by barge. If the difference in level between low-water of neaps and of springs is small, the time available for closing may be too short for the purpose; in which case the entire bank will have to be raised until a height has been obtained for the floor of the openings allowing sufficient time for the work. The consequent excess height of the water impounded inside of the bank will be somewhat reduced through the sluices while they run, and will do no harm. The best alternative procedure seems to be that of employing sliding panels (*infra*, p. 218); or else of forming skeleton dams across the openings (*ante*, p. 112), and planking and filling up to above high-water mark, a sufficient number of hands being put on to do this more rapidly than the tide rises: in this case the bottom plank will have to be sunk into the floor of the opening and the junction made tight with a good bulk of well-puddled clay on the outside. If this alternative be adopted, the piles at each side of the opening should be driven, and planked to the full height, before the earthwork of the raised sections of the bank reaches them, so that the bank end of the planking may be well buried in it and the junction made good with puddle before closing is attempted: this planking should not project more than is requisite for its junction with that of the dam to be subsequently made.

This mode of proceeding applies also to the case of any bank seated so low as to allow no sufficient time for closing in any other manner.

It is not indispensably necessary that the closure-bank should in the first instance be constructed with the slopes of the finished work: if good materials are used, the sea-slope may be steepened (according to the time available for closing) to 2 to 1 or even 1½ to 1, and the land-slope may be 1 to 1. But of course, if the quantity of stuff requisite to make the full slopes can be properly put in during the time available, so much the better.

The amount of material required for closing being ascertained beforehand, the importance of providing for its rapid and continuous supply is so vital that special arrangements must be made for the purpose. A sufficient number of loaded barges should be moored outside each opening of a bank seated below low-water; and, as they will be afloat the whole time, they can be removed as soon as emptied and their place supplied by full ones as needed: the moorings should be so laid as to allow for the rising of the tide and the hauling of the barges nearer to the work as it proceeds. In the case of a bank seated above low-water, as many barges as will lie within accessible distance when aground should be moored opposite the openings before the tide has gone down; and, as it may not be possible thus to supply all the material required, a line of rails—double, or else with suitable turn-outs for passing—for trams or earth-wagons should be laid along the landward side of the bank, so that stuff can be run from both ends and a constant supply kept up. These lines will have to be laid before the time comes for closing; and if the work is carefully done, a few fillings and emptyings of the area meanwhile by the tide will not harm it. It will save much time, if the barges and wagons are loaded with proper tumbling automatic skips containing the materials: these, whipped-up by steam-derricks on the ends of each section of bank, can be discharged exactly where requisite. If the opening is too wide for the reach of derricks at the ends, others should be placed at intermediate spots, on the landward side. All this will cost money; but the outlay so incurred will be true economy.

As each opening successively runs dry, it is to be filled-up in layers, the soundest procurable material being used. It is to be observed, that the earthwork of the bank has already had some time to settle, and has been so washed by successive tides that its crevices may be regarded as pretty well filled-up and sludged; and no pains should be spared to render the new work solid and substantial to match it as nearly as possible and obviate shrinkage and undue subsidence. The ramming of every layer should be thoroughly performed; and especial care taken to unite the new with the old work, and to use clay and sand, well puddled together, along all junctions. Precious as time is in closure operations, there should be no hurrying or scamping: a sufficient number of hands should be employed, in order to allow the closing of each opening to be commenced the moment the tide leaves it, without interfering with the men already at work upon other ones.

Should anything occur during the progress of the operation in either case, to retard it, so that it evidently cannot be completed in a single tide, the work must not be allowed to proceed so far as to shut up too many openings; and, if any are already closed, those yet remaining must be protected by every possible means against the scour certain to be caused by their absence. Should the check in the work occur when the gaps still open are too few for safety, it will be better to cut down to a suitable level one or more of those already shut up, rather than risk destruction of some of the bank (and when this once begins, nobody can say where it will end,) by a too great rush of water through the remaining openings. If the delay be owing to neglect of providing enough hands or sufficient material in readiness, the error, whether due to incapacity or to parsimony, is likely to prove a costly one.

The openings having been securely closed, no time should be lost before proceeding with the work of completing them to match the rest of the bank; particular care being bestowed upon the junction of the new with the existing slope, so that no gullying may occur on that very vulnerable line.

*f*) **Permanent Facing.**—After completion of the earth-work, there will have to be considered whether to lay its permanent facing at once, or to await settlement and consolidation before doing so, trusting for its protection meanwhile to the temporary coverings laid down during its construction. Mr. Wiggins's recommendation is, "to let the earthwork remain, for one winter, without any stone facing, till it is seen what effect the sea has upon the bank, what slope it *takes*, and how far it may consolidate and take a natural bearing, before the external facing is put on. It is true that some little escape of materials may take place, but this would be much checked by well ramming the earth in front, after covering it with a thin coating of gravel; and the loss will be amply compensated by additional solidity." [103]

There can be no doubt that, even with the utmost care in construction, some settlement will afterwards take place: in anticipation of this, allowance is made beforehand, and the varying amount prescribed for that allowance would seem to depend upon the material of which the bank consists and the exposure to which it is subjected. It appears equally certain that the latter, in the form of atmospheric influences and the action of the sea, will promote settlement, and should be allowed free scope to the utmost extent compatible with avoidance of serious injury. Where the situation is such that the sea has considerable fetch, and breaks with violence upon the bank, the work will have to be permanently faced as soon as built. Even if moderately or indeed well sheltered, a bank of sand or very sandy material will need, as already described, to be constructed with a good casing of clay, and possibly on the sea-slope a facing of turf will be needful in addition. One of good gravel or clayey earth will in most cases need only krammat or similar covering, protecting it from injury and yet leaving it exposed to sea and weather for the purpose of hastening its due settlement. When this has satisfactorily taken place, all dawks, fissures, and local depressions will have to be filled and levelled up; the surface planed, beaten close, and trimmed to its proper slope; and the bank will then be ready to receive its permanent facing.

Of this, the most general forms are perhaps clay, and turf. The thickness to which clay is laid varies according to circumstances, being sometimes 2 or 3 feet all the way up, sometimes decreasing towards the top of the slope. The thickness on the inner slope may as a general rule be taken as not exceeding half, or at most two-thirds, of that on the sea-slope, with a minimum of 12 inches at bottom and 9 inches at top. These dimensions do not apply to what was said respecting the clay casing or shell to a bank of sand. The clay is packed and sludged as already described (*ante*, p. 110), and its cost will be at the rate there mentioned.

Turfing or sodding is laid either upon clay facing, or upon the earthen face if but little exposed. The sods should be not less than 12 inches by 9 inches and 3 inches thick: those laid on the Schleswig dykes are 1 foot square and 6 inches thick. They should be closely packed, beaten flat, and covered with fine earth well beaten down. If the sea-slope is an exposed one, each turf should be secured by a wooden pin driven not less than 12 inches into the bank, and the whole protected with krammat until the sods are well established and the grass grown. The cost may be estimated per yard super., at from 6d. to 9d. and upwards, according to the distance of the spot from whence the sods are brought.

Respecting the merits of wood as a permanent surface-protection, opinions differ. As "arming" and "rise-heading," one of its forms has been already described; and of this Mr. Wiggins says that it is largely in use on the coast of Essex, where it is called "thatching." He remarks that it has perhaps been adopted in consequence of the great quantity of woodland in the immediate neighbourhood. He estimates its cost at a rate equivalent to 1s. 6½d. per square yard, and adds:—"This covering does not, however, prevent the constant or frequent surging of the waves from carrying away a certain portion of the earthy face of bank, and then the wood becomes loose, and almost useless, and requires to have fresh wood drawn in, and the piles driven afresh. . . . And when it is considered that the brushwood of this kind of protection seldom lasts more than two or three years, and is not unfrequently carried away in less than one year, although the piles may be more long-lived, we shall not be understood as describing this kind of sea-defence in order to its recommendation, but rather the contrary. . . . Still it may happen that such a mode of facing may be judiciously adopted, in some cases where wood is abundant near, and almost valueless from the facility of obtaining coal, and especially as a temporary expedient, until preparation can be made for a more permanent and efficient covering to exposed sea-walls. But as to a permanent covering, its cost, even with the precarious prolongation of frequent repair, cannot with interest thereon be reckoned at less than twenty shillings per annum for every square rod of 320 square feet, an annuity worth in ready money full £20, which is a sum many times sufficient to stone the whole exposed face of the bank, as we shall presently demonstrate; and yet where this improvident mode has for a long period prevailed, it may not always be convenient to change the habit for a better." [104]

On the other hand, Mr. Muller points out that in the case of a bank seated on a lower level than the salt marsh, wood possesses great advantages over stone, which cannot be laid until the bank is consolidated. As to its merits generally: whilst regarding the question of employing wood, or stone, as one which must be decided by the relative cost of the materials in the locality, he believes that in most instances, if the compound interest on the excess of the original outlay for stone as compared with wooden protection be taken into consideration, the balance in a given term of years will be found to be in favour of the employment of wood, notwithstanding the frequent renewals which it requires. The unavoidable supervision being the same in both cases, the wooden protection as requiring less expenditure is more likely to be preferred by proprietors or shareholders.[105] This difference of opinion may perhaps be ascribed to the discrepancy between the reported duration of the wood in England and in Holland; and this again is probably owing to the quality of the material, that employed in Holland being of a better description than what is used in this country (*ante*, p. 72). Another matter mentioned by Mr. Muller deserves consideration as a not unimportant point in favour of wood. "In neutralising the action of the wave," he observes, "wooden protection has an advantage over the stone. The slope being steeper, more of the power of the wave is expended while rushing up it, and the numerous stakes encountered so subdivide the wave, that it becomes a mere ripple before it reaches the cess. On the other hand, the surface of the stone protection is so [comparatively] smooth, that waves seem invited to ascend. In some cases it has been found advantageous to introduce rows of oak stakes, at intervals above the surface of the stone, to break the force of the waves. The stakes should be about 1 inch or 2 inches apart, and their tops should be 12 inches or 15 inches above the surface of the stones. An oak framework of piles, 12 inches in scantling, connected together by walings, has been used to break the wave in exposed localities, such as those of West Kapelle in Zeeland and Petten in North Holland." This is probably the protection thus described by Mr. Wiggins :—" In Holland . . . it has been customary to use a great deal of timber in sea-defences, and amongst the modes of using this expensive and perishable material, is that of facing the bank with a framework of strong oak, very accurately built, and the compartments filled in tightly with stone; but such costly modes of expense [? defence] soon become nugatory, from the constant shake occasioned by the action of the sea, the frames sometimes becoming loosened and letting the stone escape, and sometimes the stone is shaken out, though the frames remain firm. Sometimes, also, the sea finds its way behind this kind of facing, and renders it useless."[106]

Wharfing is another form of timber-protection; of which Mr. Wiggins says that it "has been a mode of sea-walling formerly practised to some extent on those parts of the coast where timber is plentiful on the estates to which such sea-defences belong. This is a method of facing sea-banks with stout planking set upright, and the joints backed by other planks, the whole being secured by means of land ties and stout connecting bars mortised through their projecting heads, the earthen bank being closely stowed in the rear of all, in imitation of many of the dykes in Holland, where much timber is used in the sea-defences. The first expense of these wharfed sea-walls is however so great that they are limited to very exposed points, and cannot extend very far on those, and they have been found, after a lapse of a few years, suddenly to fail in some spots where the planking has become decayed; and though the apertures may be small, the reflux wave has drawn out with it an alarming quantity of the earth at the back of the planking, the land-ties have become loose, and much expense has been required to restore the strength of the wall, which it would have been good economy to remove, and replace with a sloped bank, faced with stone."[107] Wharfing is in fact a timber retaining-wall. It is sometimes constructed of planking laid horizontal and spiked to piles which are secured by land-ties: the wall thus formed having usually a battering face. Timber does sometimes last a very considerable time: in Holland it appears to answer very well, and the average duration of oak or fir piles is said to be at least 30 years. The teredo is bad only below mean-tide level: where it is not abundant, pile-work is much in vogue in the Netherlands.[108] Its duration is promoted by tarring: the tarred boxing to a concrete wall at Reculver lasted some thirty years and was then destroyed by a storm. As a toe-protection to the sea-slope it is serviceable where stone or concrete is not obtainable; and, should this be partially or even wholly destroyed, its backing remains to wash-down to a natural slope in front of the toe. As a retaining-wall however, it is not to be recommended. A retaining-wall to a reclamation-bank is at best an untrustworthy and makeshift substitute for a slope: if any failure occurs in it, a nearly vertical face of earthwork, whereof it forms the sole support, is exposed, and this means a threatening of the entire bank. An apparently insignificant aperture in the planking may be the beginning of injuries far more serious than those mentioned by Mr. Wiggins. A striking example of this was recently afforded by the wharfed sea-face of the parade at Herne Bay. The piles and planking, though old, were in the main fairly sound. The timber land-ties were somewhat decayed and those of iron a good deal rusted, but had they been ever so sound they could not have prevented the catastrophe that followed. During the storm of 29th November 1897, some of the planking began to give way: the back-draught of the waves brought out some of the earthen backing, the blows of succeeding ones stove-in more of the thus unsupported planking and exposed the backing to further and more rapid washing-out; the result being that within a few hours the parade was wrecked for a length of upwards of four hundred yards.

Pitching with stone, although in almost all cases the most expensive, is the best and most permanent facing for a bank. Owing to its cost, it is seldom applied save where considerations of safety render it indispensable: the toe of the bank, and the lower portion of the slope, being the places where this necessity most frequently occurs. Rounded and water-worn stones are difficult to fix securely in position; but if such stones of large size are procurable, and lime is cheap, fairly sound work may be made by packing and wedging them with spawls and small stones and grouting the whole. Nothing less than 9 inches deep should ever be attempted with pitchers; nor less than 12 inches with boulders if wedged and grouted, or 14 inches if wedged only. Whether for pitchers or boulders, a firm bed must be prepared. Roughness of surface greatly assists in breaking-up the run of waves: flaggy stone is good in this respect; and if of good depth, laid on edge with the joints at right-angles to the shore-line, solidly bedded and well packed and wedged with spawls, it may safely be employed.

In Danish practice, the sea-slope is covered with a layer of clay and small stones, about 1 foot thick, on which are packed stone blocks of at least 300 lbs. weight, the smallest section of the stones lying uppermost.[109] Much steeper slopes are used than where the facing is merely of clay.

The stone facing usual in Holland has already been described (*ante*, p. 54).

With reference to English practice, Mr. Wiggins says:— "Stone facing is the usual mode, but previously to the facing with stone a facing of clay should be spread as a foundation for the stone, especially if the bank is built with sand or of any other earth which is liable to run, either in a wet or dry state. The clay facing to the sand should be not less than 3 feet thick, and if over this a coating of gravel be spread, if only 3 inches thick, it will be a great saving in the end, and with such coating the stone must be 15 to 18 inches in thickness or depth from the surface. The manner of stone facing must depend on the kind and form of the stone which is obtainable for the purpose. If it be rounded or boulder stone, it must be mixed with angular stone to give it stability, and in that case promiscuous laying or placing may be better than regular pitching, the several kinds and shapes of stone keying each other, especially if small and large gravel be from time to time spread over the face of the bank, and allowed to take its position either amongst the stone used for the facing, or be washed down to the foot of the bank, where its service will be equally effectual. If the stones be flaggy and flat, it will be necessary to pitch them edgeways, although the action of the sea on their exposed edges is to shake them to and fro until they be loosened and washed out. Still they will not have sufficient bearing on each other to lie flatways, and would slide away into heaps, so that there is no remedy but pitching, and keeping tight with small stones and fragments. But when the stones are angular and tolerably massive and ponderous, like Kentish rag-stone, 12 to 15 inches in thickness, or less, will suffice, and there is no better way than placing them side by side till the surface is covered, taking care to entangle and hitch the angles of each stone with those of its neighbours; then by encouraging such maritime plants as the soil of the bank will produce, the interstices between the stones are much better occupied than by a continuous mass of stone, since the roots below interlace and keep the stones in place, and the vegetation at top eases off the wave and renders it innoxious." [110]

At some considerable reclamation-embankments executed in England and Ireland under the superintendence of Mr. (afterwards Sir James) Brunlees, M. Inst. C.E., stone was plentiful in the locality and was therefore used for facing. "The hearting was generally of sand, which was covered with a layer of puddled clay of 12 inches in thickness, and upon that, on the sea-slope, was placed from 2 to 4 feet of 'quarry rid' and broken stone, and afterwards the pitching, which varied from 16 inches to 18 inches in thickness. By placing broken stone immediately under the pitching, the waves did not run so far up the slope, nor were they so destructive when receding. The water in the advancing wave was dispersed through the joints of the pitching, and received into the rid. It was with the object of making the receiving power of the rid equal to the quantity of water likely to break upon the slope that its depth was varied from 2 feet to 4 feet." [111] In this case, open joints in the pitching seem to have been adopted on principle. The danger of injury owing to compression of air within the body of the work by impact and pressure of water, and consequent blowing-out of the facing-stones, has been frequently and by many writers pointed out: in the foregoing example this does not appear to have taken place, it being stated in 1862 that the work had stood without any failure since its completion some nine or ten years previous. Most probably this immunity was owing, as mentioned, to the great depth of the bed of broken stone placed for that purpose.

To what has already been said concerning methods of permanent protection, may be added a remark leading to some further consideration respecting treatment of the surface of a bank. "It is only in cases of extreme exposure and peril that the whole face of the bank need be protected with so expensive a material as stone. In many cases where it would be prudent to erect a sea-bank, it would be sufficient to guard as much only as might be subjected to the frequent assaults of the ocean, viz. so much as the spring tides reached, as shown in the diagram [Fig. 6]; above that the attacks of the tide would be few and far between, and though violent, would continue but a short time. It might therefore be enough for safety, to coat that portion above ordinary spring tides with clay and gravel, or clayey gravel, as before mentioned, and to cultivate upon it the plants most likely to thrive, amongst which may be reckoned the common couch or twitch grass, very much employed in Essex for this use, the net-work roots of which bind the surface effectually; so also does the sand rush (*arundo arenaria*), called Maram grass in Norfolk, where it is much relied on. If the soil be sufficiently fresh, sowing ray grass seeds answers a good purpose, and every locality affords also other plants easily propagated. It may however happen that the surface is of too loose and sandy a nature to be left exposed until vegetation can take place, in which case it must be turfed over; but . . . even when the intake is [originally] sufficiently swarded to afford materials for turfing, its productiveness is [thereby] too much reduced." This refers to the sea-slope. With reference to the land-slope it is remarked:—"The sea-banks of silty sand on the coast of Flintshire are sown with lucerne, the crop of which is large and valuable, being in a district abounding with horses employed in mining. The roots of this plant are strong and elastic, and penetrate deeply, so that the recently collected materials are firmly bound together for several years, when the grasses gradually overcome the lucerne, and a strong external sward takes its place. For ordinary localities, however, it may be as well to secure the surface of the back of the bank as early as possible with ray grass, couch grass, and such strongly rooted grasses, and maritime or brackish plants, as can best be obtained on the peculiar soil." A further and considerable advantage possessed by couch grass is mentioned further on:—"The sea-walls in these counties [Essex, Suffolk, Norfolk, and Lincolnshire] . . . are generally swarded over with grass of some kind, but couch grass or twitch forms not only their general, but their best covering and protection, from the matting nature of its roots and its distastefulness to cattle, enabling it to renew itself plentifully by seed as well as root." [112] In Holland, a mixture of salt-marsh and meadow grass with clover seed, is recommended.[113]

There are various opinions as to the maximum steepness of the slope on which grass will thrive. Mr. Wiggins says that 1 to 1, or less, is a good and sufficient slope for the land side of a bank, and that upon this slope vegetation is sure to prosper. By another authority it is stated that grass, where not washed by salt water, will grow well on a thin stratum of good arable soil at a slope not steeper than $1\frac{3}{4}$ to 1; but that sea-dykes which are covered by each storm-flood require one not steeper than 4 to 1 on the sea-face to get a good turf; and though the grass will look sickly in the spring, by May and June it will have got round.[114]

Of all growths for binding together the face of a sea-bank, the most esteemed appears to be *Arundo arenaria*, in English called Marram, Marum, Sea-reed, Mat-grass, and many other names.[115] It has the property of flourishing in the driest soils, and possesses extraordinary power in strengthening sea embankments; its spreading roots, frequently 30 feet long, binding together the loose particles even of sand. The protection afforded by this grass was held to be of so much moment three hundred years ago, that by an Act of Parliament in the reign of Elizabeth it was made a penal offence to cut it down; and in the reign of George II. another Act was passed on the same subject. For the first offence the penalty was 20s. or three months' imprisonment; and for the second offence the punishment was twelve months' imprisonment with hard labour. A penalty of 20s., or three months' imprisonment with hard labour, was also imposed for being found in possession of this bent-grass within 5 miles of the sand-hills. In Scotland the regulations were still more stringent, it being a penal offence to be found in possession of it within a distance of 8 miles from the shore.[116] Another highly esteemed plant is Lyme-grass (*Elymus arenarius*), extensively used in the Eastern Countries and in Holland for the same purpose.

After being sown or planted, the slopes should be covered with krammat, which will scarcely ever need to be renewed when the grass has grown.

*g*) **Streams and Cradge-banks.**—Intersection by a stream of inland water is an objectionable feature in a proposed intake, since its passage to the sea has to be provided-for by an intercepting-drain discharging independently of the local drainage from the site, or by regulating its channel and conducting it through the main bank: works that not only involve additional and sometimes considerable outlay, but occupy space which, together with that taken up by the channel, is so much deducted from the area available for cultivation. Although, under favourable circumstances, its natural channel may be turned to account as a means of drainage for the site itself, any saving thus effected will seldom if ever counterbalance the cost of regulating and embanking the stream. Whether the method adopted be that of an intercepting-drain or an embankment of the natural channel, depends upon the particular circumstances of the case. The former where possible is almost always preferable, and will be dealt with when we come to treat of Drainage. At present we shall consider the alternative procedure.

If there are more streams than one, it is in principle desirable that they should be united, and discharged by a single outlet. In practice, however, it is not always so: their distance apart may be too great, or the depth of the intake landwards too small in proportion to that distance: the one may bring down a much greater volume of flood-water than the other; or other conditions, not uncommon in shallow intakes of long stretch coastwise, may render it advisable to have two or even more outlets. We will assume, as an example, that there are two streams, and that they can be joined in a V of moderately acute angle on the landward side of the bank, and thence led by a single channel to the place of discharge. The example will serve to illustrate the mode of procedure where there is only one stream, and also where more than two can be joined; and whatever be the number of outlets required, one or other of the above three cases will apply.

The volume of ordinary and flood water of the streams forms a measure for calculating the dimensions of their respective channels, and of that common to both below their junction. The natural channel should be straightened; and, if bends cannot be wholly avoided, they must be made as slight and as gradual as possible: a new channel being cut wherever the old one is unsuitable or cannot be rendered so.

The training and regulation of a channel is shown in plan Fig. 11 and in section Fig. 12; and the process is as follows:—

The line of the new channel is set out, commencing at the existing channel, and proceeding across the marshes to where the two channels again cross. The fascine-work is commenced at the upper end, at a concave bank of the old channel, and carried out into it. As soon as the contraction begins to be felt, the material is scoured away from the opposite or convex bank. The training-wall on the other side is then commenced, and gradually pushed on; and so both sides are continued until a new channel is scoured out along the intended line. Where the training-wall has to be laid below the level of low-water, the fascines are conveyed to the site in barges, two barges of faggots being moored

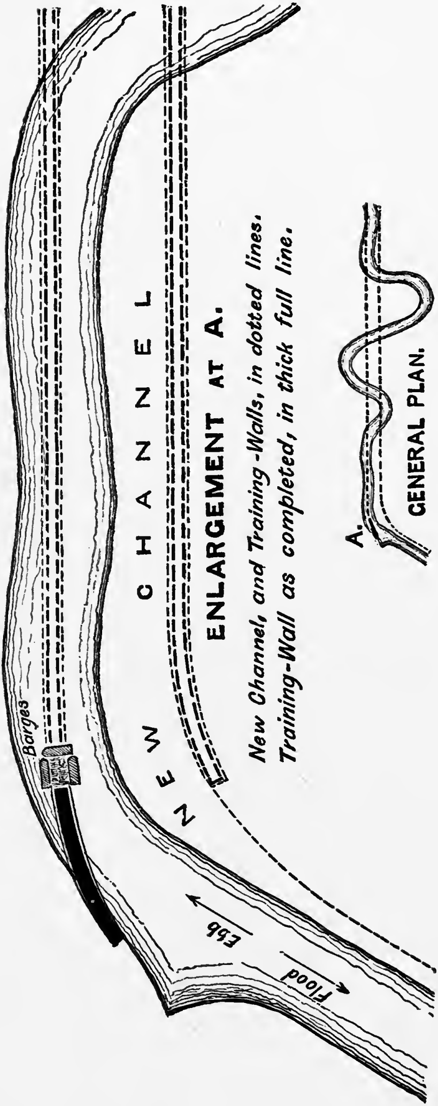



Fig. 11.—Plan of Training-work for New Channel in a Tidal River.

in the river in the line of the wall and parallel with it, and one barge across the end, loaded with clay or marsh sods. At low-water the fascines are placed in the water in the space left between the three barges, transversely to the direction of the wall, overlapping each other one-half the length of the faggot, and covering a space equal to the intended width of the wall. Each layer is weighted with clay or sods till it sinks, being directed to its place by poles fastened in the ground. This is continued until the wall attains half-tide level. The wall is made as far as practicable to a batter of 6 inches horizontal to one foot vertical. Training-walls constructed in this manner have been put in where the depth at low-water has been as much as 20 feet, and where there has been a tidal run of 4 knots, and even after the lapse of

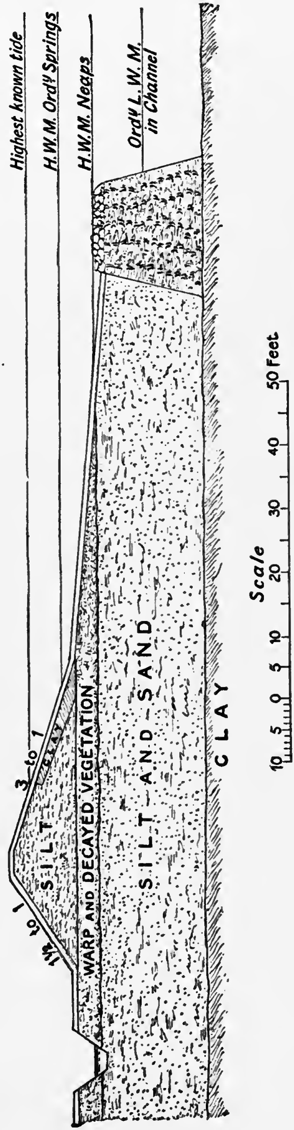



Fig. 12.—Section of Cradge-bank and Training-wall for a Tidal River.

twenty years needed no repairs. Sediment rapidly accumulates on the land side of the wall, and in the course of a short time the fascines themselves form the face of the channel. Thorns are well adapted for this work, as the branches interlace and hang together in a way that is not common to other brushwood; and the spaces between the branches become filled with soil and sand, forming a tough and solid bank capable of withstanding the strongest tidal current, and so compact that when any of the work has to be removed, it can only be done by cutting the thorns out branch by branch. If built on sand which afterwards scours out, it settles down in a mass needing only additional fascines and clay put on the top to bring it to the original level. As the work of constructing the wall proceeds, a few heavy stones are placed on the end to prevent the fascines from being washed-up by the flood-tide, and these are removed forward for the same purpose as the work progresses.[117] It is well to permanently load the top of the completed work with hand-packed stone, about 2 cwt. to the square yard.

The cost of this work varies according to the distance the material has to be conveyed, and other circumstances. A similar wall constructed a few years ago by Mr. Wheeler in the Witham, 16 feet high, with base 22 feet and top 13 feet, cost at the rate of 19s. 3d. per lineal foot. Each lineal foot took about seventy faggots. For getting and delivering the clay (obtained from the foreshores at the mouth of the river) the men were paid 30s. per barge-load containing about 30 tons. Conveying the faggots by boat to the work, including loading and unloading, cost 4s. per hundred, the distance being about 5 miles and the boats only able to navigate the river on the tide. One hundred faggots require 10 tons of clay.

The cost of labour in building the wall was 3s. per hundred. The whole cost may be summarised as follows :—

| | £ | s. | d. |
|---|---|---|---|
| Fascines per hundred (six score) . . . . | 0 | 14 | 6 |
| Conveying by boat . . . . . . . | 0 | 4 | 0 |
| Labour building wall . . . . . . | 0 | 3 | 0 |
| Ten tons clay at 1s. . . . . . . | 0 | 10 | 0 |
| Stone for top, ¼ ton at 6s. . . . . . | 0 | 1 | 6 |
| Total per hundred fascines . . . . | 1 | 13 | 0 |

Or allowing seventy fascines to each lineal foot to the dimensions given above, the cost of the wall comes to 19s. 3d. per lineal foot, or 1s. 8d. per cubic yard.[118] The cost of bank-protection (*infra* p. 138) may be taken at about the same rate.

The embanking of streams amounts, in fact, to dividing the intake into two or more separate ones, a principle which, as was seen in the Introduction, has been recommended. This, and some attendant precautions, are pointed out by Mr. Wiggins. "If any rivers cross the ground," he says, "as is almost sure to be the case in large undertakings of this kind, it is much better on all accounts to construct separate, independent intakes between those rivers, even if they should be but insignificant streams, than to attempt to enclose such streams within the bank, and afterwards sluice them out, because, however contemptible such streams may be in summer, they almost always (especially in mountainous countries) pour down a vast quantity of water at particular seasons, which it may not be possible to carry off in time for vegetation. And in banking out such rivers and streams care must be taken to embank them quite as securely as against the sea, leaving them a good wide berth diverging gradually but sufficiently towards the sea, and taking care that they disembogue clear of the sea-bank."[119] Where the embankments along a stream are exposed to wave-action, as will probably be the case near its outfall if the opening through the sea-bank is wide, they must of course be strong in proportion to their degree of exposure. In more sheltered places, however, they may in general be much less massive than the sea-bank.

In order to reduce to a minimum the space occupied by streams, it is an object to give the sides of their channels as steep a slope as possible: where they are protected by fascine-work (see Fig. 12) this may be a batter as small as 6 inches to a foot. It is pointed out that such a revetment or retaining-wall presents to the current a surface with plenty of friction, and that such a surface is advantageous: the fascines protecting not alone that part of the bank which they cover, but also, by retarding the velocity of the current, to some extent the adjacent bank and the one opposite.[120] The sides of the channel at and for some distance below the junction of the streams, and those of the V for some distance upward, need to be specially well protected and strengthened by similar revetment: the former being liable to erosion by cross-currents and eddies occasionally set up, and the latter having to stem and divide the current (if any) of flood-tide into the channel. In fact, the sides of the channel throughout will need to be attended-to with the utmost care: a slip or caving-in may bring down the embankment they carry. "The usual way of executing this work," says Mr. Wheeler, "is to commence by excavating as far below low water of spring tides as practicable, a slight dam of earth being left between the excavation and the water. From three to four fascines are then laid in, overlapping each other, and with their butt ends at right angles to the channel, the outer layer having the brush end towards the water. On this a layer of the excavated soil is placed, and then another row of fascines, the process being continued until the top course is brought up to the level of ordinary high water, the depth of the courses of fascines gradually being diminished till the last finishes up with a single fascine. The brush is then trimmed off to a neat face. Provided that plenty of clay or similar material is used, this work is of a permanent character, any interstices of the fascines becoming filled with silt. Fascine work executed in this manner in the fen rivers fifty years ago is still in good condition." [121] As a further precaution against disaster from caving-in, it is advisable to have between the embankment and the back of the revetment a cess, of from 35 to 60 feet according to circumstances, with a slope of 10 or 12 to 1; so that in case of the bank of the stream giving way, there may be time to take steps for protection of the intake before the damage extends so far inwards as to affect the embankment.

The division of the intake into three portions, in the example we are now considering, is by the very nature of the case obligatory, the streams forming the boundary between them. Where there is no embankment of streams to necessitate it, a division if desired is effected by banks small relatively to sea-banks such as we have heretofore described. In general, a Reclamation made bit-wise will be begun by a bank situate further back and therefore on higher ground than one intended to encounter the sea direct. Such a bank, although its top must of course be above high-water mark, will not measure so much in height from seat to crown; nor, in most cases, will it need to be so massively built, the force of the waves being diminished by its shelter of position, or by expenditure upon the greatly-extended foreland they have traversed. A bank of this description is known in the East of England by the local name of "cradge" or "cradge-bank," a term applied also to those for embankment of a stream; and with suitable change in details the manner of its construction is the same as that of the larger ones called by way of distinction "sea-banks" or "main banks." When an intake has been thus secured, another cradge is in due time pushed out in front of or in some other way connected with the former, and so on: measures being at the same time taken, by groyning or otherwise, to raise the foreland as much as possible, so that the work on no one of these several banks is so heavy as if it had in the first instance been built equally far out.

*h*) **Groynes and other Protective Outworks.**—Substantial and well-constructed though it may be, and however great the care bestowed upon due employment of the means needful for keeping it in proper condition and repair: the bank is strong so long only as its foundation remains secure. That foundation, if in itself sound, depends for its stability wholly upon the unimpaired condition of the foreland. This, save in situations favouring the deposit of warp and the formation of marsh, is continually menaced by the action of the sea, forming lows, gullies and channels, cutting out and eating away the ground, and, if not arrested, undermining the bank itself. To preserve and strengthen the foreland is therefore of vital importance. This is best effected by keeping it heaped up with material, and most permanently so by making the sea itself perform the work. We shall here consider the means of accomplishing this end.

Among these, groynes are on all hands admitted to be the most effectual known. "There is no feature of greater importance in connection with the dykes than the projecting works, or groynes. Where they are short and low, although they prevent the outer ground from being hollowed out, they do not cause any raising of it. It has been found [in Denmark], that where they have a height [at their upper end] of 2 feet above ordinary flood, with a length of 1,300 feet to 1,700 feet, they afford practical protection to the dykes, as they cause the outer ground to rise considerably, and they are indeed quite indispensable." "No doubt groynes constructed at right angles to the shore would arrest the shingle. . . . Groynes were an effectual means of arresting the shingle and obtaining an accumulation of that material." [122]

With respect however, to particulars, the variety and even conflict of opinion is as marked as the unanimity prevailing on the former point. Height, length, distance apart, direction on plan—every diversity of detail relating to construction, dimensions, and arrangement, has found an advocate.

As these opinions cannot be grouped exactly according to the various systems advocated or mentioned, they are here placed in chronological order as nearly as may be of the date of execution of the several works, when known: failing that, in order of the date at which the opinion quoted was spoken or written—so that an idea may be formed of the extent to which previous experience was in each example acted upon or disregarded.

In 1847 it was stated that in exposed situations in Holland, groynes for protection of the dykes are placed mostly at right-angles to the shore, and 50 or 60 yards apart. Their construction is of a very substantial kind. Those at

Petten are from 500 to 600 feet long, and about 800 feet apart. Where several groynes are carried out from the shore consecutively, the work should commence with the lowest down the current.[123]

Writing in 1852, Mr. Wiggins says that, where the shingle is shifting, it is important to retain it, for which purpose "some expensive works are requisite, such as those called '*horses*' in Essex, and '*groins*' in Sussex and Hants. These are rows of oak piles, not less than 6 × 6 inches, and often 9 × 9 inches, and from 12 to 14 feet long. They are driven into the ooze below the shingle at least 6 feet, and stand 3 feet apart, in such manner that an inch and a half elm plank fits between pile and pile, so as to have alternate piles on each side of the plank, which are spiked to the pile . . . Three men will drive four of these piles per day; the rows extend out for about 10 rods from the shore, and are always placed at right angles with it; some horses placed at an oblique angle failed, by being broken up the first storm. The effect is to gather shingle on, or rather to prevent its escape from, the leeward side in winds raking the shore . . . Their distance must be proportioned to the nature of the shore, but 10 to 15 to a mile are sometimes needed. . . . It often happens that some particular projecting points are very expensive to sustain, by reason of their exposure, although they themselves protect a long line of bank, and then any mode of retaining the beach upon them becomes extremely valuable. In a case of this sort in practice, a sluice on one side of such a point was lengthened in order to obtain a better run to seaward, and the effect was to gather the shingle about the projecting point, so that it afterwards needed scarcely any repairs. The same effect would have happened by means of a horse, but as the sluice stood but 2 or 3 feet out of the general level of the shingle, it would seem that *horses* of smaller height than those usually erected, viz. 6 feet, would have a better effect. It is however worth while to consider and determine their absolute necessity,—and this some are inclined to doubt, since the shingle often leaves the beach in spite of them; at best they collect it but on one side, and for a time only, and where the wind is 'full on' the shore, the shingle would gather as well without these *horses* as with them. Therefore we may conclude that a stone footing to the sand-bank, which usually forms the sea-wall of such beaches, would answer better at less expense, and with greater permanency, although we may decline changing the established mode." [124]

Of some groynes constructed at Spurn Point between 1863 and 1868, we read: "The first six that were erected are of Dantzig timber piles 10 inches square, shod with iron shoes and driven various depths into the beach. The planking is 3-inch red wood, secured to the piles by $\frac{3}{4}$-inch screw bolts and nuts. All butt-joints are made on and secured to the southern piles by $\frac{11}{16}$-inch wood screws and clip-plates. The length of the groynes varies with circumstances, likewise the levels and rake of the pile-heads. When they were erected most of them stood five to seven planks above the sea beach at the land end. In September 1876 five of the groynes were covered with shingle to depths of 3 to 4 feet along most of their length"; and in 1878 it was estimated that a belt of beach at least 100 yards wide, 7 feet in average thickness, and $2\frac{1}{2}$ miles in length, equal to 1,250,000 tons of shingle, had been collected there by these works. The cost of the groynes was about £2 per foot run.[125]

In 1870-71, Mr. R. Pickwell, Assoc. Inst. C.E., put down six groynes for protection of the foreshore at Withernsea. Before their erection the beach was very low, and after a north-west gale the whole of it was not uncommonly swept away down to the bare clay. The groynes were from 300 to 350 feet long, 200 yards apart, and at right-angles to the beach: Mr. Pickwell subsequently believed they might with equally good results have been 300 yards apart instead of 200. The top of the groynes at the land end was 12 feet above high-water mark of ordinary spring-tides, or 8 to 10 feet above old top of beach, and the outer end 4 to 6 feet above the old beach. The main piles, 5 feet apart, were Dantzig red wood, 13 inches square, 22 to 24 feet long, shod with 14-lb. shoes, and driven 11 to 12 feet into the boulder-clay below the sand. The planking was of red wood, 4 inches thick by 11 inches wide, in 20-feet to 25-feet lengths, secured to the piles with a 1-inch screw-bolt to every plank in each pile. Cast-iron washer plates were used, as less liable to rust than wrought-iron. The planking was alternately on the north (or up-stream) and the south side of the piles, and every butt-joint had a clip-washer, and was made to occur on the north side of a pile. Every fourth pile was strutted on the south side, the struts of red wood, 13 inches wide by 6½ inches thick, dovetailed and halved onto the piles and secured with 1¼-inch screw-bolts; the strut-piles of red wood, 13 inches square and 12 feet long, driven 8 to 9 feet into the clay. The top five rows of planking were only added as the beach accumulated. In 1876, groynes Nos. 1 and 2 (the most northerly) were buried for two-thirds of their length, and the other four entirely buried. The ordinary high-water spring-tide mark was in 1878 from 50 to 80 yards further seaward than formerly; and it is estimated that there is an average constant beach of 1,200 to 1,400 yards in length, by 100 yards broad and 8 to 10 feet thick, or an accretion of 500,000 tons of shingle due to the effect of the groynes. In addition to the sea-beach proper, there is a large accumulation of drift sand at the foot of the cliffs and the groynes, forming a high and dry beach, in many places covered with vegetable growth. The cost of the groynes was 22s. 5d. per foot run.

About 1876 some groynes were erected at Hornsea, of sheet-piling secured by walings fixed to main piles; and of these, Mr. Pickwell in 1877 expressed the opinion that this form is not desirable, because the sheet-piles, being fixed at their ultimate height of 9 or 10 feet above the beach, present too great a resisting surface to the breakers, and are more exposed than that form of groyne which admits of the top planks being added and built up as the beach accumulates. His own experience of the difficulty which exists in penetrating the wet sand beach down to the clay in order to fix the bottom planks if the planking is horizontal, led him to believe that a combination of sheet-piles at the bottom and of planks at the top is the most efficient form of groyne, both as regards strength and as offering a minimum of useless resistance to waves. Fig. 13 illustrates the form he proposed; the main piles, 5 feet apart, being so driven as to be alternately on one side and the other of a waling 6 inches thick by 12 inches deep, put down between them and fixed at the then level of the beach; sheet-piles 6 inches by 12 inches being driven on the weather side of the wale down into the clay, and the top planking gradually added in horizontal layers dropped down above the waling as the beach accumulates, and kept 3 or 4 feet above it. Such a groyne would, he estimated, cost about 30s. per foot run.[126]

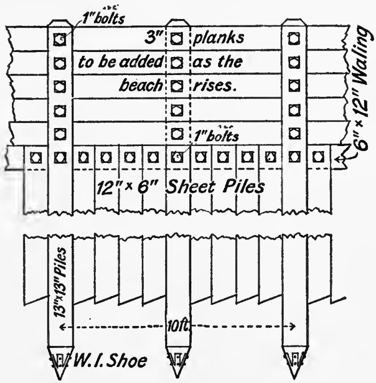



Fig. 13.—Groyne with Sheet-piling.

Mr. G. H. Kinahan, C.E., in 1876 pointed out the disadvantage of erecting high groynes in the first instance, and their injurious effect upon the beach. "Groynes," he says, "are usually erected the full height at the first. This, however, in some localities is objectionable, as the driftage fills up one side rapidly, while the other is empty; consequently the water-fall, or 'overfall' over the groynes forms a current that carries away the beach [already loosened by the downpour of water]. Groynes, therefore, in most places ought to be made low at first, and heightened as the beach accumulates." He also thus describes a groyne of very singular construction :—"I have seen, in the west of Ireland, an effective groyne made of seaweed and straw 'suggauns' (coarse ropes). This was to keep the sea out of turf banks. The seaweed was tied in bundles, and the suggauns run through the tyings as each was placed in position; the bundles, as placed, were weighted with sand, while the seaward end of the suggaun was weighted with stones. When the wall was of sufficient height it was backed with sand, and the groyne was complete." [127] The simplicity of this construction, and the inexpensive nature of the materials, seem to render it in an especial degree adapted to remote spots where none but the most ordinary unskilled labour is obtainable, and for persons of small means to whom the price of timber and other more or less costly materials would be prohibitive. It is questionable however, whether a groyne thus constructed would prove sufficiently strong for any but a very sheltered situation; and it is much to be regretted that information concerning the location and durability of this very interesting example was not added.

At Ardmore a sea-wall, which was being undermined by the cutting-away of the beach, was strengthened by the addition of a paved toe; and Mr. L. Duffin, M. Inst. C.E.I., the County Surveyor, added a groyne as a further protection. "It was built of timber, and stood only 3 feet over the beach, and extended 33 feet seawards. It was built in a zigzag, the Engineer thinking that form best calculated, on account of the undertow, to catch the accumulation which chiefly consisted of sand. It was constructed in the usual form adopted for these groynes, viz.: rough piles driven in pairs, and 3-inch sheeting dropped between them, and spiked through with half-inch spikes, clenched; stayed in some cases on the weather side. The groyne filled rapidly up to the level of the top of the paved toe, and since it was completed in May 1880, no damage has [up to February 1884] occurred to the wall; although there have been unusually heavy gales and great damage done to the coast in other places. The cutting-out gales have often almost emptied the groyne, yet the foundation of the wall [which it was built to protect] has never been laid bare. It was subsequently doubled in length, the last bay being only 1 foot over the beach. As it appears to have effected the object it was intended for, nothing further has been done to it." This groyne cost at the rate of 6s. per foot run.

In Dungarvan Bay, Mr. Duffin put up three groynes, all of timber of the construction above described. The first one erected was in the autumn of 1881. It was at first only 4 feet over the beach, but was subsequently raised about 3 feet at the shore end as the beach rose, the lower end being left untouched. The advance of the sea was quite checked at the place protected by it, although very rapid on the adjoining coast. The others though only a few months up in February 1884, were then rapidly filling. These groynes were so placed as to make an acute angle, about 80°, with the line of direction of the tidal stream, and Mr. Duffin believed that this direction makes them fill better than if placed at right-angles. The upper end of the groyne built in 1881 was generally buried; but it was found necessary to put rubbing-pieces on the piles at its lower end on the lee side (with reference to the tidal stream), that being exposed to the cutting-out winds, as they were rapidly cut by the shingle, those on the weather side being untouched. The cost of these groynes averaged about 6s. 8d. a foot run.

At Ballyvoile Mr. Duffin built a groyne of rock concrete on a rock foundation. It is a vertical wall, 132 feet long, 9 feet high and 4 feet thick at the shore end, 4 feet 6 inches high and 2 feet 6 inches thick at the sea end. It makes an angle of about 80° with the line of direction of the tidal stream, and curves to the leeward for the last 13 feet of its length. The concrete was put-in in lengths in a moveable frame, and cost about 17s. 6d. per foot run. The section (Fig. 14) shows the surface of beach when completed in October 1882, and the surface in February 1883, the high-water mark being moved back 70 feet. Since then the beach has risen slightly, and the shingle travels on the top of the groyne.

About the same time, for protection of a low sea-wall carrying a road along the shore near Tramore, some more groynes were built, about 45 feet in length, their shore end about 50 feet from the wall. They did collect beach to a certain extent, but it was soon found that the shingle travelled between them and the wall, and they were therefore extended back to it. They were of cheap construction, costing about 5s. per foot run, and stood 4 to 5 feet above the beach at the wall and 2 feet 6 inches at the seaward end. The two furthest to leeward were not long in forming a bank of shingle 20 feet wide on top, with a steep slope, which never moves even in the cutting-out gales: when the shingle has been thrown up to a certain height, the sea loses its drifting power, and is only able at the top of the tide to push it back slightly. One or two of the middlemost groynes

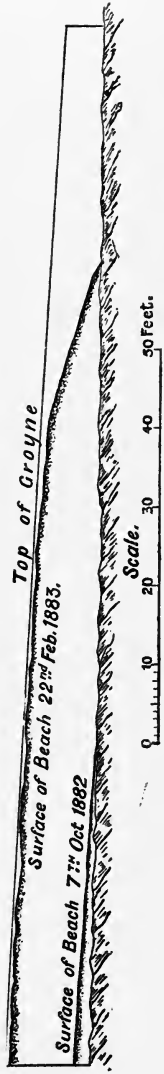



Fig. 14.—Groyne at Ballyvoile.

did not fill well; and their direction was altered so as to make an angle of about 80° with the direction of the tidal current as mentioned concerning those in Dungarvan Bay, and they soon began to fill up.

As the result of experience, Mr. Duffin believes that when a length of coast has to be protected, the groyning should commence at the furthest point to leeward, and be carried on slowly against the stream, which will allow the leeward groyne to fill before it is robbed of shingle by its weather neighbour. This will also give the correct distance between them, which should be such that the shingle should be thrown well back on the next groyne. They should not be made to the full height or length at first, but be added-to gradually as the beach rises, and this should also proceed from the leeward. In a bay like Dungarvan, where two tidal streams meet, the work should begin near the point of meeting, and proceed in both directions; and it is probable that a groyne placed near that point would fill pretty equally on both sides. Long groynes should be divided into three sections of different construction, having regard to the different work they have to perform. When groynes are correctly spaced, the landward section soon becomes buried in shingle, the gravel being backed up from the leeward by the next groyne, so that it is not exposed to any wear, and the pressure is pretty equal on both sides; and the work might be of light construction. The middle section has to support the pressure of excess of gravel on the weather side, and should be of heavier build, having to act as a retaining wall. The seaward section being bare (and there will always be a bare end to a groyne, varying in length from one-third to one-fifth of the whole length), it is exposed to the stroke of the sea and the wear of the shingle, and should be designed accordingly. The scour round the seaward end of a groyne, although it appears greater than it really is, owing to the gravel being piled against the weather side and kept back from the sea—is a source of difficulty. Mr. Duffin in all cases makes the top line of his groynes slope faster than the beach, thus giving a low sea end, which he believes lessens the scour. As to the length of groynes, he believes in the efficiency of a number of short groynes more than in that of a few long ones, but prefers that they should extend somewhat beyond the natural beach, otherwise they will fail to catch the shingle, which is always scattered over the flat beyond the beach after storms. After cutting-out gales the beach is frequently found empty, and the flats strewn with the shingle. Beaches are found to fill-in most during calm weather or off-shore winds, although the filling-up will be most apparent after a gale has heaped-up the shingle collected during the calm. Ground swell, before and after storms, has great effect in sucking out the shingle; the gales from the line of greatest exposure are not those which do most damage to a beach.[128]

Mr. Wheeler, who has devoted much attention to the subject, has made an exhaustive examination of what has been done in the construction of groynes, and of their practical effect. The recently published results of this investigation, whereof the following is a brief abstract, may be taken as fairly representing the present state of knowledge on the subject:—

Groynes cannot in themselves be regarded as a protection, but are serviceable in the effect they produce on the beach. They do not create fresh material, but simply stay the littoral drifting action, and so prevent denudation and assist in accumulation. Provided they stay the drift of the shingle from the length of coast to be protected, that is all that can be expected of them. Beyond the prevention of lows on sandy shores and beaches, they are of no service on a coast where there is no material to collect and no wasting cliffs to provide fresh supplies. The process of accumulation will be effected as well, or better, by a few groynes placed at considerable distances apart than when they are spaced near together. No general rule can be laid down as to the space that should intervene between groynes; so much depends on local circumstances that experience of these alone can determine it, but it is better to proceed tentatively, and add to the number, if experience shows this to be desirable, rather than to place them near together at first. In many cases where the length to be protected is not great, a single groyne placed at the leeward end, carried sufficiently far down the beach, and raised from time to time as the material accumulates, will be found as effective as a number of groynes placed at short intervals, and will make a much better and more level beach at far less cost.

After a beach has been raised to nearly high-water mark, or to a little above mean tide level, the accumulation of shingle will proceed without artificial aid when there is a continuous supply of drift. Groynes, if properly arranged and not carried too high, will become buried by the accumulating shingle, and therefore there is no need to make them of a more substantial and permanent character than is necessary to serve the temporary use they have to fulfil.

Groynes are of no service in moderating the force of the waves or preventing their breaking on the beach, but on the contrary tend to add to their destructive effect. When the momentum of a wave is suddenly checked by an obstruction, such as a high groyne, the water is projected upwards, and in falling cuts out and erodes the beach. The retiring wave, flowing back in a considerable volume, carries with it in its undertow this loosened material.

When groynes project much above the beach, and are placed within short distances of each other, the water drawn into the bay between them is forced above its normal height in consequence of its momentum being checked. Owing to this increased elevation, the wave retires with greater velocity than when it has a freer course, and is thus more effective in the removal of material down the slope of the beach. When waves are driven by the wind obliquely into these shore bays, the water also eddies round and cuts out the shingle. Owing to the irregularity in the breaking of the waves, due to the obstruction caused by a high groyne, it frequently occurs that the crest of a wave is on one side of the groyne while the trough is on the other, and consequently the water pours over the top like a cataract, and, falling as in some cases 8 or 10 feet on the bare beach on the other side, disturbs and cuts out the surface. Beach is frequently found heaped up to the top of a high groyne on the windward side, but never accumulates on the leeward side.

With direct on-shore gales, shingle is drawn down and the upper part of the beach becomes denuded. Groynes do not prevent this removal. When however, a shingle bank has become accumulated by their aid or otherwise, the destructive effect of the waves is diminished in proportion to the extent of the material over which they have to play and the decreased depth of water in which they break. Shingle drawn down from an accumulated bank is returned by the action of the tides, after the cessation of the gale.

With reference to the most effective direction to be given to groynes, the general practice is to place them at right-angles to the shore line, and experience has shown that this on the whole gives the best results. The worst direction is at an angle sloping to the windward side, *i.e.* towards the source from which the regular supply of drift comes; and although examples are to be found of groynes placed in this direction, experience cannot be said to justify the system. Groynes sloping to leeward, *i.e.* away from the source of supply, are advocated by Mr. R. F. Grantham, M. Inst. C.E., who has had considerable experience in works of coast protection on the South Coast. The groynes he has constructed at Lancing and Middleton have been made to point in a south-easterly direction, and he considers the result as satisfactory.

As to the length of groynes: they ought to extend from the cliffs or the sea-wall to low-water of spring-tide, or even below this. Although shingle accumulates only at the upper part of the beach, there is always, and especially after on-shore gales, a certain quantity spread all over it down to or below low-water. A groyne extending the whole depth of the beach will collect any coarse sand or shingle drifted against it, and material thus stopped from travelling will gradually work along the groyne to the upper part of the beach.

The late Mr. E. Case, Assoc. M. Inst. C.E., the Engineer of the Romney Sea Defences, who paid great attention to groyning and had considerable experience of its effect, was a strong advocate of the use of long low groynes, and advised strongly against the use of high ones, contending that the building-up of the foreshore should be gradual and progressive, and that the object to be sought is the remodelling of the beach to its natural inclination of repose. This inclination varies according to the material of which the beach is composed, being steeper where shingle exists than where sand alone prevails. For a beach containing a mixture of shingle and sand, he puts it at 1 in 12 for the upper part, flattening to 1 in 40 lower down, and towards low-water of spring-tides 1 in 70. He contended that groynes should accordingly be placed at this angle, the planking being placed horizontally and stepped to meet the varying slope. He further advocated that the groynes should not be carried up the bank beyond the point to which mean high-water reaches. It is doubtful if the stopping of the groynes at this point will be found satisfactory, especially when the beach consists principally of sand. An examination of some of the groynes erected on this principle shows that the waves running round the end of these groynes tend to scour out the beach; and it is to be apprehended that these shortened groynes will aid in developing the lows or hollows, running parallel with the coast, which are produced during gales by the waves on sandy beaches at or about the point reached by high-water.

"The conclusion arrived at after an inspection of the principal works of groyning along the coasts of England, Belgium, and Holland, is that the best results have been obtained—

"(1) By the use of low, inexpensive structures of wood, extending out from the sea wall or cliff to low water of spring tides.

"(2) That there is no advantage derived from placing groynes near together. As a general rule it may be taken that the distance should never be less than the space lying between extreme high and low water of spring tide, but may with advantage be made greater than this.

"(3) That in many instances where the length of coast to be protected is not great, a single groyne placed at the extreme leeward end of the beach, and carried as far below low-water mark as practicable, and raised from time to time as the shingle accumulates, is sufficient to prevent the drift of material, and will provide a level and even beach.

"(4) That the tops of groynes should not rise more than about 2 feet, or at the most 3 feet above the natural surface of the beach, provision being made for raising them as the beach accumulates.

"(5) That the best direction for groynes is at right angles to the line of coast.

"(6) That the inclination of groynes should vary as they proceed seaward, in harmony with the natural slope of the beach.

"(7) That as regards the length, the leeward groyne should extend from the cliff, or extreme high-water mark, to a short distance below low water of spring tides." [129] These opinions and conclusions are illustrated by copious details of groyning at home and on the Continent.

Another form of defence, used instead of or in combination with groynes, is a breastwork, detached from the bank and parallel to it or to the beach that is to be protected. It is stated that, in Holland, "where the foreshore is very long, a parallel shore-work [probably of like construction with the groynes], with occasional openings, is laid down at spring tide level;" and again; "The Dutch usually placed parallel protection works in front of their sea walls, leaving openings in them, to permit the waves to retreat; the seas broke upon these before reaching the walls, and in retreating did not scoop out the stones, or other materials." [130] A writer who made an especial study of the embanking-works of Holland, mentions that pile-work is generally placed in front of the bank and not on it, so that the sea-slope may be sodded, and the force of waves so broken that the sods are not injured. [131] The use of longitudinal instead of transverse outworks does not, however, appear to be generally approved in this country; experience tending to show that they do not in fact tend to promote the accumulation or the retention of driftage, but rather encourage the formation of lows or channels in the beach. There is a scarcity of records concerning them, owing to the disfavour with which they are regarded and the consequent infrequency of their employment.

Mr. D. Stevenson mentions a case in which longitudinal work was found remarkably efficient. The locality was on the shore of the Bristol Channel, "where large tracts of low-lying pasture, the most valuable lands in the country, were exposed to be flooded when high winds and high tides coincide. High isolated groynes were found not to encourage a uniform deposit of shingle, which shifted from side to side of the groynes according to the wind, while the exposed face of the groyne, from which for the time the shingle had been removed, acted most injuriously as a decoy to the sea right up to high-water mark. These groynes were therefore removed, and a continuous line of piling, parallel to high-water mark, was substituted, presenting no obstacle to the run of the waves along its surface. Occasional lines of low groynes were put in front of the higher continuous pile-work to arrest the shingle, and the ends of these low groynes were at some places, where the scour of shingle was greatest, connected by lines of low piling parallel to the higher continuous piling; and this mode of construction proved very successful, not only in encouraging a more uniform collection of shingle, but also in preventing the run of the sea, during high tides, from overtopping the shingle beach and deluging the adjoining lands. In proof of this, it was found, on making an examination after the occurrence of an unprecedentedly heavy storm accompanied by high tides, that wherever the continuous upright piling and planking had been constructed, there was no influx of anything beyond spray upon the adjoining land, but that at all other parts of the coast (which is about six miles in length) where the face of the beach was sloping and the upright piling had not been applied, the water passed freely over in considerable depth, carrying drift timber far into the fields, and in some places heaping up heavy shingle on the land to the depth of two or three feet."[132]

It is hardly needful to remark, that the work thus described is in reality neither more nor less than a bank constructed of piling and defended by low groynes; and that the accumulation of shingle, preventing the run of the sea from flooding the land, was due to the groynes and exactly what might be expected.

## CHAPTER IV.

### *THE DRAINAGE.*

In preparing a scheme for the drainage of a reclaimed area, account has to be taken not only of the moisture falling upon it as atmospheric precipitation, but also that intruding in the form of surface-water or of springs, the result of atmospheric precipitation elsewhere. When the area lies sufficiently high to allow it to run off of itself, the removal is said to be effected by gravitation, or " natural drainage " : all that is needful in such a case is to provide the outlets with sluices permitting escape when the tide falls, and preventing influx when the tide rises. Where the land lies so low, or where the amount of water is so greatly increased by floods in wet seasons, that there is not always time for it to run wholly off while the tide is below the outlets, the drainage is of a mixed character, effected partly by gravitation and partly by mechanical means. The discharge from an area lying below low-water level has to be effected entirely by mechanical means, or " power-drainage."

**Drainage by Gravitation.**—Drainage by gravitation being thus limited to situations where the water can run off between tide and tide, it is an object to deal with the least possible quantity. For this reason, and because surface-water from land not included in the reclaimed area has a better chance of being so got rid of owing to its coming from relatively higher ground, it is always advisable, where possible, to intercept it by catchwater drains and lead it out separate from that belonging to the reclaimed area itself. If that area is intersected by a stream that is embanked as already described, the catchwater drain may be led into it—with advantage to the stream provided the drain does not bring down a disproportionate amount of sediment and thus tend to silt-up the channel. Such a junction should be made at the upper end of the stream and outside the encircling main drain or "marsh fence," into which it would otherwise discharge. In some cases the main drain itself is made to serve as catchwater drain also. When no junction with a stream can be effected, the catchwater drain should be led to an outlet of its own.

"A large fall of rain at any particular period does not necessarily produce a flood in flat districts. When rainfall succeeds a season of dry weather, it takes some time to saturate the land; and owing to the large capacity of the arterial drains, . . . it occupies some time before these become fully charged. On the other hand, if rain falls after a continuance of wet weather, the land, together with the drains, is already charged, and any exceptionally heavy rain, although even for a short duration, is at once succeeded by a flood, as the drains cannot carry off the excess in their surcharged state. . . . The quantity of drainage which was provided for by the old Fen engineers was that due to the water arising from a continuous rainfall of a quarter of an inch of rain in twenty-four hours, making no deductions for soakage or evaporation. This calculation was also adopted by Sir John Hawkshaw for the engines erected for the drainage of the East Fen in Lincolnshire, and by Sir John Coode as the maximum quantity to be lifted by the engines proposed to be erected for the drainage of the North Level. Taking the rainfall in the Fen district as a guide, it may be estimated that provision should be made for a daily rainfall equal to about ·0076 of the average annual rainfall of wet seasons [*see* Note 149]. . . . In Ireland, for the Rathdowney drainage on the River Erkina, provision was made in the channel for a discharge of 600 cubic feet per square mile per minute, equal to a continuous rainfall of about three-eighths of an inch in twenty-four hours. The soil was a deep alluvium . . . on the lower limestone. At the Wexford Harbour Reclamation Works, where the rainfall of wet years amounts to over 50 inches, and the mean from 45 to 48 inches, it was estimated that three-fourths of this quantity, or 34·2 inches, would have to be pumped; but the machinery was made of sufficient capacity to lift nearly an inch of rainfall in twenty-four hours." [133]

Springs within an intake are sometimes a cause of trouble. When their water rises naturally to the surface, it can be led away by the ordinary drains. If the depth of these is not sufficient to reach the source, an auger-hole will generally suffice to tap it, and if the spring is fed from a higher level the water will rise and flow off by the drain. Care should be taken to bore no deeper than suffices to ease its ascent: if continued deeper, the result may be the tapping of a lower and perhaps powerful spring whose waters find a natural outlet elsewhere, and the remedy may prove worse than the disease. Instead of putting-down a bore-hole, a well may be sunk to the needful depth, and filled with loose stone, through which the water will rise as in the bore-hole, with less liability to choke up.

The amount of water for whose discharge provision is to be made, being ascertained, two questions forming as it were the key-note of the whole scheme have to be dealt-with, viz.: First, the depth below the surface of the land at which the water in the soil can be left to stand (this level being practically that of the water in the ditches); and second, the level at which the sill of the outlet-sluices can be placed.

As to the first point, Mr. Wiggins lays it down as a rule, that the waters of an intake should never stand less than 18 inches below the lowest level of the land, except where lakes must remain.[134] Another writer states that the practice in the Fens of Lincolnshire shows that the most beneficial distance from the surface for the free water is about 2 feet, and that in general the best depth is from 2 feet 6 inches in heavy clay to 3 feet 3 inches in friable loam.[135] In the case of a Reclamation at Wexford Harbour (*infra*, p. 245), it is mentioned as untoward that the water had never been more than 3 feet below the surface; and a confident anticipation is expressed that, when with the help of improved pumping machinery it can be kept down 5 or 6 feet, the land will become more valuable by 25 or 30 per cent. Mr. Wheeler says it "should not be less, where obtainable, than 3 feet or 3 feet 6 inches, to allow the under drains to run clear. In peat land, two feet below the surface is considered sufficient for the water-level. Taking the depth to be 3 feet 6 inches, and allowing for 1 foot of water in field ditches, the bottom of these will require to be 4 feet 6 inches below the surface. The depth of the main drains and level of the water must be such as to provide for the drainage of the lowest land situated the greatest distance from the outfall, and also to allow for the necessary fall in the surface of the water from this land to the outfall. . . . There are many cases, however, in fens and marsh land, where the state of the outfall ditches will not allow of a greater depth than 2 feet. The pipes *should never be laid so low* that their ends are buried in the water in the ditches into which they empty; such a practice is simply laying pipes for the purpose of soddening the land with water instead of draining it."[136] Where pipe-drains are laid, and the land is to be cultivated with the plough, another consideration comes in: that, namely, of the depth to which the plough penetrates. "Mr. Stephens calculates the depth of a furrow-slice with a two-horse plough at 7 inches; but in cross-ploughing, 9 inches. If four horses be used, the depth of the furrow will be 12 inches; and if the four-horse plough follow the common one, the depth will be increased to 16 inches. Subsoil ploughing will penetrate 16 inches below the common furrow of 7 inches. Allowing 3 inches between the lowest disturbed part of the soil and the surface of the materials in the drain, and restricting the effectiveness of the drain to that portion of it which is below the ploughed surface of 7 inches in depth, the minimum depth of drains should be such as to allow 19 inches below the furrow-slice, or 26 inches below the surface and above the constructed portion of the drain, and so much more than this if subsoil ploughing be practised. Allowing 6 inches for the depth of the drain occupied by the pipes or tiles, Mr. Stephens estimates 33 inches as the minimum depth of drains in porous subsoils, and 50 inches in clay subsoils, with an additional 6 inches in each case if stones are employed as filling materials in the drain."[137]

As regards the second question, *i.e.* the level at which the sill of the sluices should be placed, Mr. Wiggins says:—"Sluices, as has been said before, are the most simple means of this natural drainage, and these will run a shorter or longer time, according to the height of their sill above low-water level,—to the degree of ebb of tide,—and to the height of the water standing upon the sill of the sluice. Thus, the sills of some sluices laid down have been but 6 to 12 inches above low-water mark, according as the tide ebbs out more or less at springs or neaps, when not acted on by winds or otherwise kept up. These sluices at the period of a good ebb, and having 12 inches of water on their sills, will run four hours. They would therefore run dry if the tide ebbed 12 inches lower, so that it appears that if the sill of a sluice has 2 feet fall to low water of springs, it will generally run six hours when the tide is not kept up by winds,—and when there is much pressure of water on the inside, it will run nearly seven or eight hours. But as the waters of an intake should never stand less than 18 inches below the lowest level of the land, (except where lakes must remain,) and as 6 inches should be allowed for the water to stand usually or often in wet times on the sill of a sluice, that sill should not be placed at less than 2 feet below the general level of the land where the bank is placed; and as there ought to be at least 2 feet fall from the sill of the sluice to the low water of springs, it follows that the line of bank should at its foot be at least 4 feet above low-water mark at springs, as above stated, and it must depend upon the quantity of water to be discharged, what number of sluices should be put down, and the width of their several runs." [138] This matter will be further considered when treating of the sluices themselves. Meanwhile it is well to note, that a fall of 2 feet from the sill of the sluice to low-water, although desirable as lessening the risk of blocking-up by sand or shingle, is not always obtainable; the level at which it can be placed depending upon the circumstances of the case.

From the data ascertained respecting amount of water to be got rid of, the height at which that in the drains is to be maintained, and the height at which the sill of the sluices can be placed—the requisite form, dimensions, and fall to be given to the drains can be estimated, and a scheme of drainage prepared. The method of doing this cannot be better explained than by a brief abstract of the very clear practical instructions given by Mr. Wheeler.

The object to be sought in laying out a drain in a flat country is to provide a channel wherein the water shall be moved along its intended course with such ease that as small as possible an inclination and area shall be used. Every increase beyond what is absolutely necessary is a waste of land and expense in excavation.

The greater the depth within certain limits in proportion to the width, the better will be the discharging power of the drain. The greater the body of water as compared to the area of rubbing surface, the more free is the water to move. The proportion of rubbing surface of the sides and bottom to the area of the water is termed the *hydraulic mean depth*, and is found by dividing the latter by the length of the former, or the area by the wetted perimeter. The best form of channel for conveying water is when the width is double the depth, *i.e.* when a semicircle described with the water-line as diameter touches the bottom of the drain. Such a form however, is not in practice attained in land drains, and the width will generally be from four to six times the depth.

The velocity of water in drains is governed by the rate of inclination of the surface of the water, and not of that at the bottom of the drain. The velocity due to gravity is retarded by the friction of the water against the rubbing surfaces with which it comes in contact, this rubbing surface consisting of the sides and bottom of the drain, weeds, sides of bridges, or other impediments. The velocity is greatest in the centre of the stream. The mean velocity is generally taken as about four-fifths of the surface velocity in the centre, and is expressed by the formula $V = (\sqrt{R \times 2F})C$. V equals mean velocity in feet per second; R equals hydraulic mean depth in feet; F, fall of surface in one mile in feet; C, a constant, varying from 0·90 in rivers and large streams with considerable depth of water to 0·60 for small drains in good order. The surface velocity in the centre of the stream, as found by floats or by a current-meter, must be multiplied by 0·83 to find the mean velocity of ordinary drains. The following may be taken as the factors by which the theoretical discharge is to be multiplied to allow for friction, and as generally applicable to drains in low flat districts.

| | Depth. Feet. | Mean Width. Feet. | Factor. |
|---|---|---|---|
| Main drains . . | 6 | 30 | ·80 |
| Secondary drains . | 4 | 20 | ·70 |
| Small drains . . | 2 | 10 | ·60 |

Every inch of fall being of value in flat districts, the area of the drain is so proportioned that the surface inclination of the water in the drain is reduced to as low a rate as is compatible with the efficient discharge of the water. Main arterial drains in well-drained flat districts flow with an inclination of from 1½ to 3 inches per mile.

The determination of the slope or batter to be given to the sides of the drains must depend on the nature of the soil, but will also be guided to a certain extent by the width and depth of the drain. It is frequently advantageous to lay out the sides of the main outfall drains at a flatter slope than the nature of the soil absolutely requires, in order to afford larger storage room during the time the flow of the water is stopped by the tide, the rapid increase in the area above the mean water line affording a large reservoir for the water without increasing the width at the bottom. Soils of a sandy nature will require very flat slopes, as the soil is easily removed by the wash of the water. In the alluvial soils of marsh districts the large drains may frequently be found having slopes of only 1 to 1: but as a rule their slopes are seldom steeper than 2 to 1, and are 3 to 1 in light soils. Clay, according to its nature, will stand at a good slope so far as the wash is concerned, but is liable to slip if laid too steep. Peat requires very little batter: in fact many of the secondary drains in peat districts may be seen with their sides almost vertical. Careful observation of the existing drains or watercourses in the neighbourhood, and the slope to which they have adapted themselves, will form a guide as to the section to be given to a new drain. As the drains diminish in size, the slopes may be made 1½ to 1 or 1¼ to 1 for the second-class drains, and ¾ to 1 for the main ditches.

In excavating drains where the substratum consists of soft alluvial soil, overlain by material of a denser and more stable character, the bottom will spring up and let the sides down. When ground of this character has to be encountered, the soil excavated must be moved to a sufficient distance to prevent its weight forcing the sides into the cutting, and should not be placed nearer than six feet. It may even be necessary in very bad places to build up the sides with fascines to prevent them from slipping in.

No fixed rule can be laid down for the designing of a system of drainage applicable to all districts, as regards the number of the drains, their arrangement, width, or depth, as these must all be governed by the particular conditions of the land to be drained and the outfall.

A typical case for illustration of the method of making such a design from given data may, however, be taken, having an area of flat land containing 20,000 acres, discharging into a tidal stream which allows the sluice doors to be open only fourteen hours out of the twenty-four. The rainfall is assumed as being at the rate of a quarter of an inch in twenty-four hours, the whole of which is to be discharged off the land. The quantity of water due to this rainfall would be equal to 210·07 cubic feet per second : the main drain, running only 7 hours each tide, would require a capacity equal to 359·22 (say 360) cubic feet per second. Taking the district as 6¼ miles long by 5 miles wide, this would require one main drain along the centre, with lateral drains on each side at intervals of every fifty chains ; ditches branching out of these lateral drains would be required at intervals of every ten chains, leaving the areas of the fields drained by them twenty-five acres each. Taking the main drain as having 26 feet bottom width at its lower end, with side slopes of 2 to 1, a mean depth in floods of 8 feet, a rise of 4 inches per mile in the bottom and 2 inches per mile on the surface of the water, its discharging capacity would be as follows :—

| | Feet. |
|---|---|
| Bottom width . . . . . . . . . . | 26 |
| Width of surface of water . . . . . . | 58 |
| Mean width . . . . . . . . . . | 42 |
| Mean depth . . . . . . . . . . | 8 |

$$\begin{array}{ll} \text{Area } 42\cdot0 \times 8\cdot0 \quad . \quad . \quad . \quad . \quad . & = 336\cdot0 \\ \text{Contour } 17\cdot6 + 17\cdot6 + 26\cdot0 \quad . \quad . \quad . & = 61 \end{array} \qquad \frac{336\cdot0}{61} = 5\cdot508 \text{ H. M. D.}$$

Fall per mile $0{\cdot}166 \times 2 = 0{\cdot}332$

$\sqrt{5{\cdot}508 \times 0{\cdot}332} = 1{\cdot}352$ velocity per second.

$1{\cdot}352 \times 0{\cdot}80 = 1{\cdot}0816$ ,, ,,

Area $336{\cdot}0 \times 1{\cdot}0816 = 363{\cdot}42$ cubic feet per second.

The dimensions in the drain at the middle would be 40 feet 6 inches top, 10 feet 6 inches bottom, 7 feet 6 inches depth, and discharging capacity 182 cubic feet per second. The quantity of drainage to be discharged at this part of the drain would be that due to the rainfall on 10,000 acres, viz. 180 cubic feet per second. At the top end the drain would diminish to 1 foot at bottom, 29 feet at top, and 7 feet depth. The twenty lateral drains would each take the drainage of 1,000 acres. The mean dimensions of these drains in the middle of their length would be 2 feet 6 inches bottom, 6 feet 8 inches top, slopes 1¼ to 1, mean depth 1 foot 8 inches, fall in bottom 1 foot per mile, in surface of water 6 inches per mile, discharging capacity 5·19 cubic feet per second, the constant for friction &c. being taken at 0·70. The quantity of water coming in at the middle of each of the lateral drains would be that due to the rainfall on 500 acres, viz. 5·25 cubic feet per second. These drains are taken as running the whole 24 hours. The field ditches will have 1 foot width at bottom, slopes ¾ to 1, mean depth of running water 1 foot. Supposing that in floods, during the time the sluice doors were closed by the tide, the water rose 1 foot above the mean level as before given, and fell at low-water to 1 foot below mean level, the drains would hold between low and high water a quantity equal to the rainfall of five hours. Supposing that in anticipation of a flood, and before the water had swollen in the outfall, the water in the main drain were run off within 3 feet 6 inches of the bottom, the drains would hold up to 3 feet below the surface of the land a quantity equal to about one day's rainfall. The area of land occupied by these drains would be 282 acres, or $\frac{1}{71}$ of the whole area. If the water had to be pumped, and the pumps worked night and day, the area of the drains would be proportionately less; as would also be the case if the sluice were situated sufficiently high to allow of a longer discharge than seven hours each tide.

The sluice for this district (Figs. 15, 16, 17, 18) would require to have three openings of 14 feet each. The water would approach with a velocity of 1·078 feet per second; and as the piers of this sluice have pointed ends it may be assumed that it would pass through at the same rate, the velocity of approach being sufficient to overcome the friction due to the sides and bottom of the openings. The depth of the water on the sill being 8 feet, the same as that in the main drain, the area of the waterway would be $3 \times 14{\cdot}0 \times 8{\cdot}0 = 336{\cdot}0 \times 1{\cdot}0816 = 363{\cdot}42$ cubic feet per second.[139]

Mr. Wiggins recommends that the main and secondary drains should be made to answer the ulterior purpose of fences, as well as of drains to carry-off the surface water; and that one of these should entirely surround the reclaimed area. "The fences of an intake," he says, "are usually marsh ditches or dykes, standing wide and deep enough of water or mud to prevent cattle attempting to cross them, and an intake seldom admits of any other description of fence. Such water-fences and drains must, in the first place, be drawn all around the intake, *i.e.* from the sluices by which the water is to escape along the land side of the sea-bank or wall, and along the edge of the higher lands of the adjoining country. The proper dimensions of such fences [he appears to be here speaking with regard to the typical reclamation of 1,000 acres to which he subsequently refers] are

10 feet wide at top, 5 feet wide at bottom, and 5 feet deep, the water always standing 3 feet 6 inches in depth, which will be 18 inches below soil; and the surface of the water will be then level with the sill of the sluice, or near thereto—since, as the sluices will be in the lowest parts, some water will probably always stand on them, unless the intake be on a dead level, which is not desirable. By the same rule, should any inequalities of level exist on the surface of the intake, the dykes or ditches forming the water-fences must be dug accordingly, deeper than 5 feet and wider than 10 feet, so as to have nearly the same . . . depth of water, throughout."[140] The putting-in of an encircling drain is in accordance with Dutch practice. "With regard to general drainage, the system adopted in Holland, so far back as 1650, by Van Ens, and which is not materially altered up to the present time [1847], is that of dividing the whole country of Polders, into zones, or districts, each of which is on the same level, and is surrounded by its own water channel. Thus the higher water flows off into the lower channels, and eventually reaches the sea, each district being drained separately."[141]

While on the subject of the drains, mention must be made of one important feature—the delf or delph.[142] In Holland, "when the dyke is completed, a parallel ditch about 10 feet wide is cut at the foot, on the [landward side of the] inner slope, in order to receive simultaneously the waters which filter through the body of the dyke, and those which are thrown over by the waves and extraordinary high tides, and also with a view to unite and lead off, by the dyke sluices, the rain water and springs. Between this inner ditch, and the foot of the dyke, a raised benching, or road, generally of 15 feet to 20 feet wide, is frequently maintained, which, whilst it serves to consolidate the earthwork, is also used for carriages." [143] "The *delph* or drain," says Mr. Wiggins, "which in Essex and elsewhere, in strong soils, is dug on the land side of the bank or sea-wall, for the double purpose of a drain and a fence, is a feature of some importance, inasmuch as if dug too near the land foot of the bank, it may be injurious by favouring and promoting the percolation of water from the sea side to the land side, under the bank, and in cases where this effect is not so likely to take place, by reason of the adhesive nature of the soil, as in more porous soils, the danger is still imminent of its causing the base of the bank to slip and give way. On this account alone, on some occasions, several miles of delph have been filled up, and dug afresh at a greater distance from the bank foot. Twelve yards from the foot of the bank is the true distance, even when no roadway is intended, but it will always be found convenient and judicious to set out the space wide enough for a drift-way between the bank and the delph. The delph should not be nearer, although there is a great temptation to bring it nearer during the building of the bank, in order to make the materials from the excavation available for the bank at a smaller distance. The usual dimensions of the delph, when cut independently of its materials, are 12 feet wide at the top, 6 feet wide at bottom, and 4 or 5 feet deep; generally, for a fence against cattle, 3 to 4 feet depth of water is requisite. . . . In soft, loose, sandy soils whose tenacity is insufficient to enable their sides to stand in excavation, the delph must be omitted, as it might tend to bring down the bank, and only a slight rill or channel be permitted to carry off the soakage from the bank, which, in such a soil, must be considered as inevitable. In soils which have an ordinary degree of tenacity . . . and the excavated sides of which will stand, the delph is highly useful in keeping the bank dry, and carrying off any water which might otherwise remain stagnant." [144] The distance between the delph and the foot of the inner slope of bank differs greatly in different cases. In Holland it appears to be from 7 to 20 feet. In the banks at Pelworm it is given as 33 feet. In those of Schleswig and Holstein, where probably the tender nature of the ground has influenced the matter, it is from 50 to 80 feet. In practice it will vary according to the nature and stability of the soil; but care should be taken that the minimum breadth of undisturbed surface is such that the inner slope of the bank, if produced, would nowhere intersect the nearest side of the excavation forming the delph—and even this as a minimum in cases only where it is not possible to give a greater breadth.

In sluices for large drains, the doors, Mr. Wheeler says, are made in pairs, the opening for the pair seldom exceeding 20 feet in width. The doors being self-acting, a greater width is unadvisable, the concussion of the doors as they come together on closing with the head of the rising tide throwing a considerable strain on the frame-work of the door and on the masonry. The doors shut against a solid wooden sill at the bottom and a pointed wooden frame at the top, hooded over. In some sluices the doors are made of sufficient height to be above the rise of the highest tide. This adds considerably to their cost, weight, and liability to strain, without any corresponding advantage. The angle at which the doors are set is generally about 25°, the angle they form with one another when closed being about 130°. The angle of set should be not less than 20° nor more than

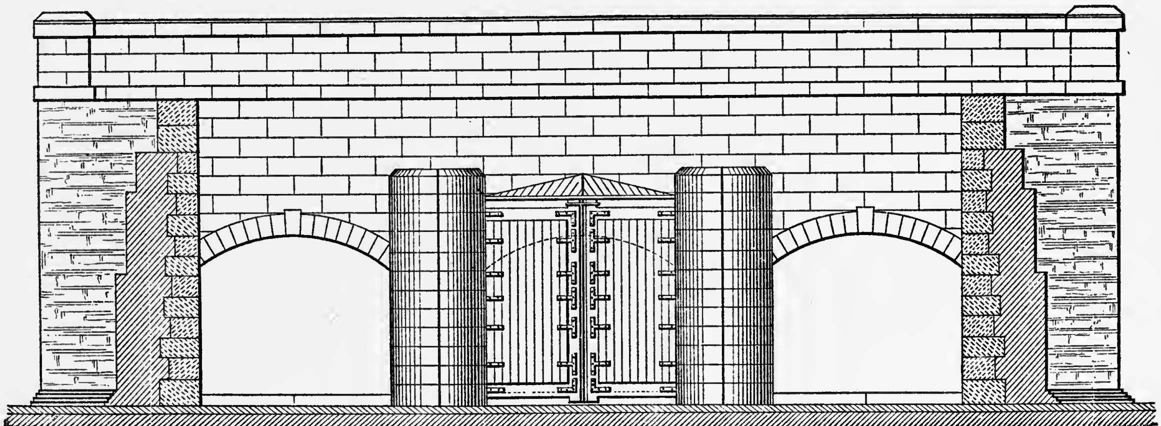
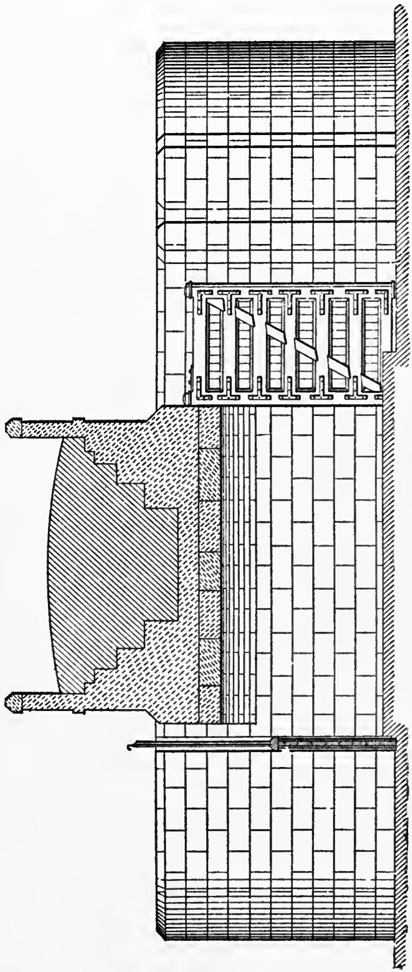



Fig. 15.—Large Tidal Sluice.



LONGITUDINAL SECTION.

Scale
INS. 12 0 2 4 6 8 10 20 FEET

Fig. 16.—Large Tidal Sluice.

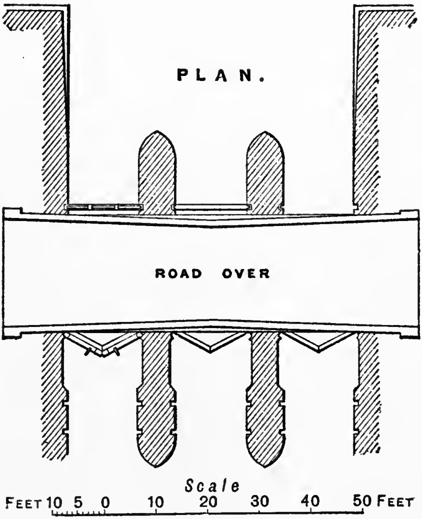



Fig. 17.—Large Tidal Sluice.

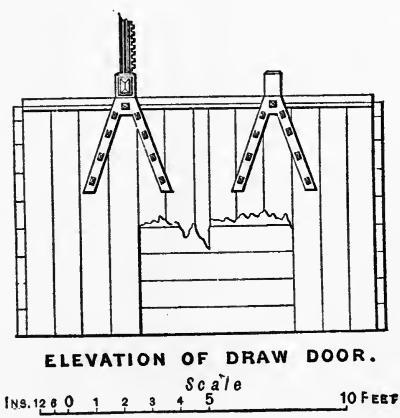



Fig. 18.—Large Tidal Sluice.

30°. The heel-post works on a pivot at the bottom, and is held in place by an anchor-strap at the top. These doors do not open back flush with the wall, as those of a lock do, but stand off sufficiently to allow the rising tide to get in behind and act on the back so as to close them. To give stability to the structure, the masonry opening is made of considerable width from in to out, and forms a bridge over the drain. The projection of the piers against which the doors open is about double the width of the opening, and their outer and inner ends are pointed or rounded. On the inside of the arch, draw-doors working in grooves are made so as to lift up and let down by a cast-iron toothed bar actuated by pinions and gearing. Large draw-doors have counterbalance weights, suspended by chains over pulleys. These doors are kept open to their full extent in floods, and lowered when the flood is over: they serve to regulate height of the water in the drains and ditches for fencing or other purposes.

Smaller sluices, with openings not exceeding 4 to 5 feet, are made either with a single door, hung in the same manner as already described, or with a "tankard-lid" door, hung from the top and frequently provided with a counterbalance weight on a lever fastened to the door.

An improved method of hanging flap-doors has been designed by Mr. Stoney, whereby such doors may be used of considerable size. Attached to the door is a pair of lever bars with counterbalance weights. These bars, instead of turning on fixed pivots, are carried on a circular segment, which rocks on a horizontal path, reducing friction and rendering the opening and closing very easy. Doors of this description, 6 feet 3 inches wide by 4 feet 6 inches high, used for the sluices of the Ballyteigue and Kilmore

Reclamation Works, were found to open with a head of $\frac{1}{4}$ to $\frac{3}{8}$ of an inch.

In addition to the sluice doors at the outlet, it is frequently desirable to place doors at the end of drains discharging into the main outfalls, to prevent backing-up of the water when it accumulates during heavy floods and at tide time, especially if the main drain has to receive water from high land. By the use of doors a large amount of embanking may be saved; and even where embankments already exist they save great pressure and minimize the risk of a breach.

Great care is required in making the foundations of sluices, to prevent water from finding its way under the floor during high tides, when, owing to the head on the outside, the power of the water to penetrate through the ground is very great. The lands enclosed generally consist of deposits of alluvial matter; and the site of the sluice being on the sea-shore or on a river, the soil is frequently nothing but silt or sand of such a depth that no material of a more tenacious character can be reached within a distance that would warrant the foundations being carried down to it. When the soil consists entirely of silt, the danger to guard against is that of the water finding its way under the floor of the apron and the invert of the culvert. Several cases came under Mr. Wheeler's experience where this occurred, the sluices, otherwise well built, being left standing on the bearing-piles with the material entirely washed away from under the concrete below the floor. The only reliable course to pursue in dealing with foundations in sand or silt is, to build the sluice on bearing-piles and to completely box-in the whole of the site covered by the foundation with sheet-piling, driven eight or ten feet below the bed of the

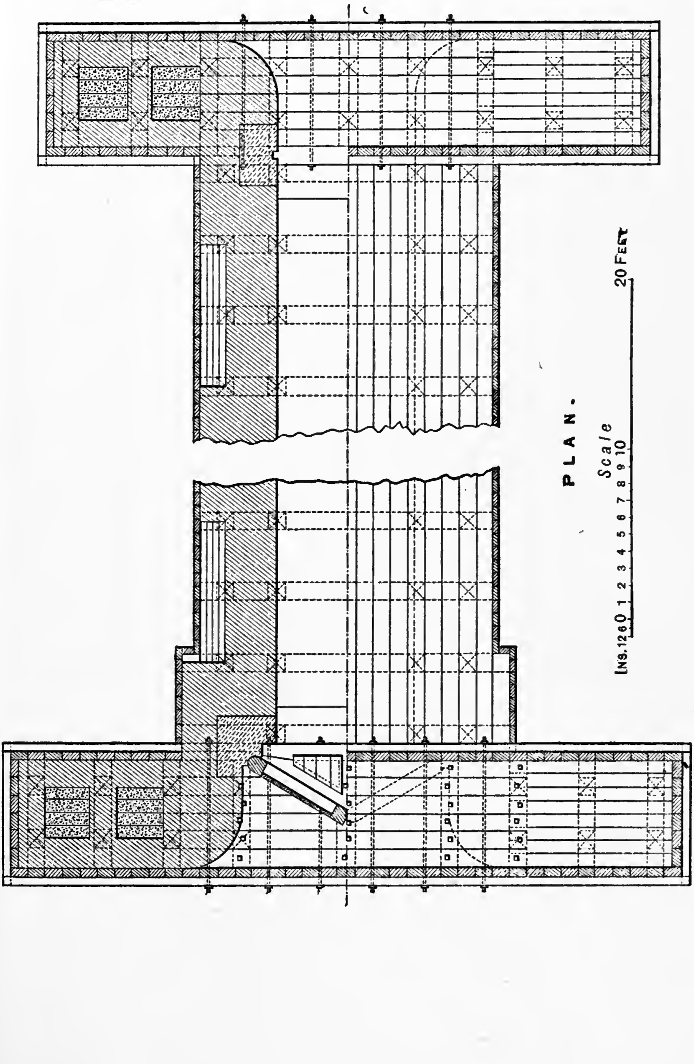



Fig. 19.—Small Tidal Sluice.

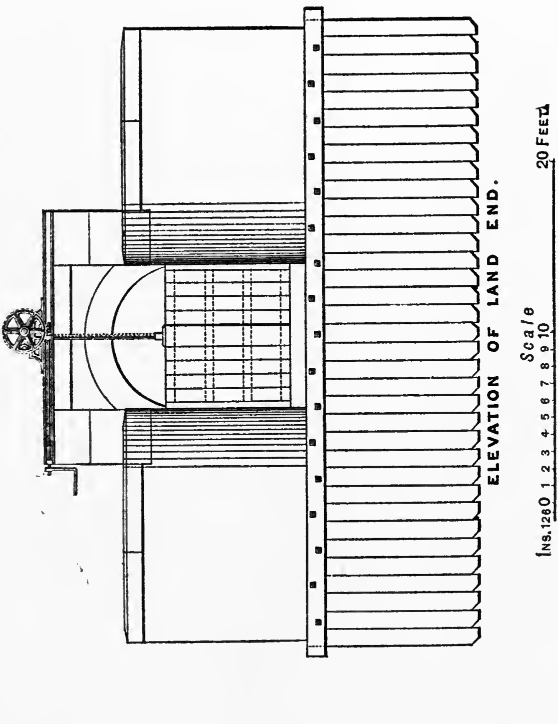



Fig. 20.—Small Tidal Sluice.

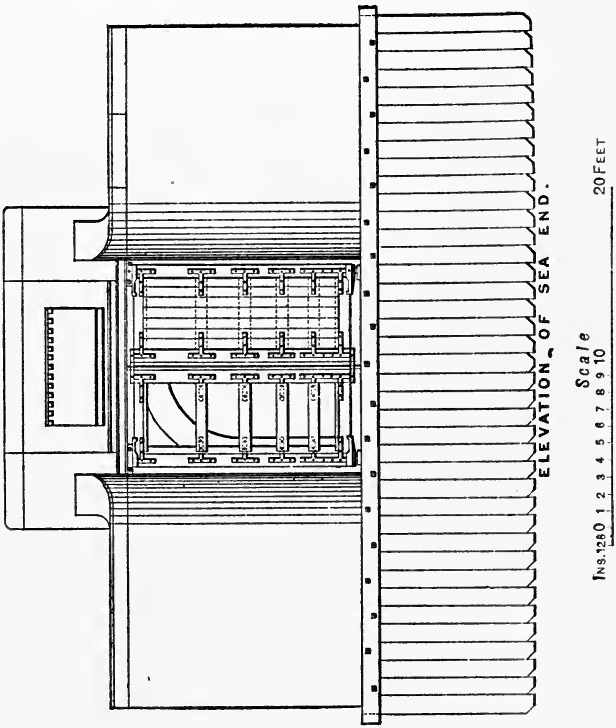



Fig. 21.—Small Tidal Sluice.

channel into which the sluice discharges. Within the box a solid bed of cement concrete should be placed, and on this the planking for the floor. Wings should be carried out with box-piling for some distance on each side, both at the inner and outer ends, to prevent the water making its way round outside. The brickwork of the piers and culvert will rest on the planking, bearing-piles being driven to carry the walls;

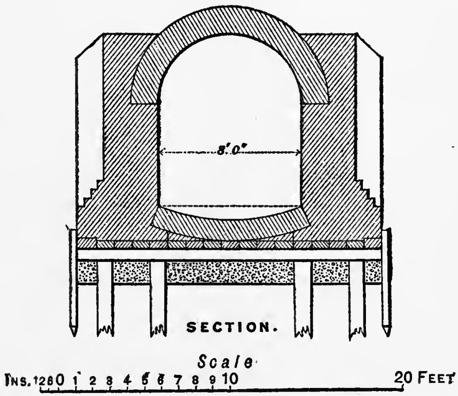



Fig. 22.—Small Tidal Sluice.

and the whole upper part surrounded with puddled clay. In fixing the depth to which the piles are driven, consideration must be given to the probability of the deepening of the outfall by improvements or by natural scour. After the sluice has been built, cement-grout should be forced under the floor, by pumping it in through holes bored in the planking and afterwards plugged. By this means every cavity becomes filled up. Figs. 19, 20, 21, 22 show an example of a small sluice of 8 feet opening, built on a silt foundation; and Figs. 15, 16, 17, 18 a larger sluice with three openings of 14 feet each.

In selecting the site for a sluice discharging on the sea-coast, the position chosen should be as sheltered as possible, where the sand is least likely to drift and fill up the outfall. Shifting sands are frequently a source of great trouble; and where sluices discharge on sandy forelands it often becomes necessary to carry the outfall from the sluice for a considerable distance by means of a covered wooden tunnel.

Where the coast is flat, the water, after leaving the sluice, frequently has to travel through a long stretch of marsh and sandy foreland. Where creeks already exist, it is generally necessary to deepen and straighten them. To prevent the shifting of the channel through the sand, and its sides from being washed down in storms, fascines properly laid in place, and bedded with sand, form inexpensive and efficient training-walls which with slight care will last for a great number of years.

Where the sluice discharges into a river, the site should be fixed at a concave bend, where the water is always deeper than in other parts and the sill less likely to become blocked by deposit in dry weather. The position of the sluice should be such that the outflowing water may join the ebb current at as small an angle as possible, so as to cause a minimum of disturbance at the junction of the two streams. Where the district to be drained is at a low level, the sill of the sluice has generally to be placed at the lowest level to which the river is likely ever to be scoured-out or deepened. When every inch of fall is of consequence, it may even be advantageous to place it a certain depth below the bed of the river. The outflowing water will always keep the doors clear; and any deposit that may accumulate in summer is soon washed away when rains cause the water in the drain to rise. For the purpose of scouring away this deposit, small sluice-doors are placed in the larger doors, near the bottom: these being drawn by means of rods worked by gearing, permit a current of water to pass out at low-tide, having sufficient head to wash away the deposit so as to allow the main doors to open.

The velocity of water due to head, is for practical purposes taken as $V = 8 \sqrt{h} \times c$, and

$$h = \left(\frac{V}{8 \times c}\right)^2$$

$V =$ velocity in feet per second.

$h =$ height in feet. In the case of sluices or bridges, this is the vertical difference in the surface of the water above and below the opening.

$c$ is a constant

= for the opening of a bridge or sluice with pointed piers and smooth masonry . . ·96

= for the opening of a bridge or sluice with square-ended piers, or rough masonry, or where the doors are so hung as to cause eddies . . . . . . . . ·86

= for small openings of sluices, as in a lock, whether submerged or not, or sluices with tankard-lid doors causing resistance on all four sides . . . . . . ·64

The quantity of water that will pass through a sluice is found by multiplying the area of the water-way by the velocity, the dimensions being taken at the down-stream or outer side of the sluice: the full velocity due to the head not being acquired until the lowest level is reached, the depth if taken on the inside would give too great a result.

In a tidal sluice, both the depth of water and the velocity will vary, from the time the doors are first opened until they are closed again by the rising tide. The calculation must therefore be made on the mean velocity of the water. The velocity is governed by the head, less the frictional resistance of the sides and the disturbance caused by the eddying of the water as it leaves the confined space between the walls for the open stream. If the piers have rounded or pointed ends, the frictional resistance will not amount to 4 per cent. With square ends and rough masonry, the loss due to friction will amount to 15 or 20 per cent. In sluices with doors that do not open freely, or with lifting doors that are not raised freely out of the water, there is resistance on four sides; and the discharge in such cases may amount to no more than 64 per cent. of that due to the head. The amount to be allowed for frictional resistance must be a matter of judgment determined by the facility for outflow with the least possible friction or disturbance arising from eddies caused by projections. In calculating the velocity, allowance has to be made for the head due to the velocity with which the water approaches the sluice. If the sluice is of sufficient capacity, this will overcome the friction and carry the water through without any heading-up.

For example: take the case of a sluice with three openings of 16 feet each, and a depth of 9 feet, the drain running with a velocity of 1·50 feet per second, and discharging 1,200 cubic feet per second. The quantity passing through each opening would be 400 feet, and the velocity required with the area of the sluice would be 2·778 feet per second. The head required for this velocity, allowing 4 per cent. for friction (that is, multiplying by the factor ·96), would be ·1308 feet. Deducting the head due to the velocity of approach of 1·50 feet (= ·0381), leaves the head required at the sluice ·0927 feet, or a little over one inch.

Area of waterway = 16·0 × 9·0 × 3 = 432 feet.

Total quantity coming down drain divided by area of sluice $= \frac{1200}{432} = 2·778$ velocity required.

| | Feet. |
|---|---|
| Head required for this velocity $= \left(\frac{2·778}{8 \times ·96}\right)^2 =$ | ·1308 |
| Less head of approach $= \left(\frac{1·50}{8 \times ·96}\right)^2 =$ | ·0381 |
| Head required at sluice . . | ·0927 |

The proportion of depth to total width of the water passing through sluices, varies in practice from one-fourth in the smaller sluices to one-fifth and one-sixth in those of larger capacity.[145]

The work required in the construction of sluices depends so much upon circumstances, that their cost—especially when viewed in relation to the size of the opening—differs very greatly. The following gives that of some constructed in recent years for drainage-works discharging to the Wash[146]:—

Slippery Gowt, on the Witham. Opening 4 feet 6 inches. Culvert 25 feet long under the sea-bank, with doors 6 feet 6 inches high. Built on concrete boxed-in with sheet-piling. Including approach and temporary dam. Total cost . . . . . . . . . . £380

Fivie Towns, on the Welland. Built in 1882. Opening 8 feet. Culvert 53 feet long. Inclusive of cost of a new cut to the sluice (say) £225, the average of tenders was . . . . . . . . . . £2,595

Risegate Eau, on the Welland. Built in 1885. Opening 8 feet. Cost . . . . . . . . £2,800

Sutton Leam, on the Nene. Built in 1887. Opening 8 feet. Culvert 88 feet long. Including banks and temporary works. Total cost . . . . . £4,080

Wainfleet Clough, on the Steeping. Built in 1886. Opening 12 feet. Built on silt foundation. Total cost . . . . . . . . . . £3,000

Slasker. Two openings, each 12 feet 6 inches. Total cost . . . . . . . . . . £800

Syphons of iron, led from the main drain up through the bank and down to a point below low-water of spring-tides, have been tried as a substitute for sluices. The principle is correct; and if all risks of their running dry can be obviated there seems no reason to doubt they would prove efficient. They have not, however, come into anything even approaching to general use; and, the question of their employment being eminently a practical one, it is to be concluded that upon the whole a sluice is preferable.

**Power-Drainage.**—The relative cost of wind and steam as motive powers for pumping-machinery, has been investigated with great care by an American Engineer, Mr. A. R. Wolff, whose estimate, arrived-at by observation of actual results, is that "the economy of the windmill averages about 2·25 times that of the steam-pump, when there is included for the latter a charge for boiler capacity, and for the services of one-tenth of the time of one man." The calculations include interest on capital, repairs, depreciation, attendance, and oil (and coal for the steam-engine), and are based upon the performances of the best types of steam-machinery and of windmills of American pattern—the latter, it may be observed, being now obtainable of English manufacture, from the Woodcock Works at Warminster, and other makers. "American windmills," Mr. Wolff says, "differ from the European mills . . . most conspicuously in the form of wheel receiving the impulse of the wind. Instead of the small number of sails of large width, common to the European or Dutch mills, the American wheel is made up of a great number of blades or slats of small width. This . . . gives an entirely distinct appearance to the American wheel, since it resembles a closed surface as compared to the large open spaces between the arms of the European mill, though, of course, ample room is provided between the slats to permit the free escape of the impinging air. This division of the receiving-surface of the mill . . . enables a much smaller aggregate weight of parts for a desired strength, size, and capacity of mill; so that the American windmill is lighter in weight, as well as in appearance, than the European mill."[147]

There is something extremely attractive in the idea of a motive power which in itself (as distinguished from the machinery it actuates) costs absolutely nothing; and it is difficult to discard the notion that this must be specially adapted for the pumping-work of reclaimed land. Unfortunately, such is not the case: the one defect in its application for this purpose is the uncertainty of the wind. Experience in the United States goes to show that a windmill will on the whole perform work equivalent to a daily average of eight hours of a 16-mile wind. This however, cannot be counted-upon daily: calms and light airs may intervene and prevail for long periods; and the motive power may be entirely absent at the very time when most needed. While therefore for domestic water-supply, dynamo-electric machinery, and other purposes where the results of intermittent work performed by a motor can be stored up for use as required, wind power appears to be effective and inexpensive; it cannot be regarded as comparable to steam power in point of availability at short notice and for as long a period as needful: an indispensable requirement for the discharge of water from a reclaimed area where it becomes necessary to employ an auxiliary to, or substitute for, drainage by gravitation.

**Pumps, &c.**—The contrivances in use for raising water for the drainage of land, are bucket pumps (sometimes called piston pumps), Archimedean or screw pumps, scoop wheels, and centrifugal pumps; and the following is a brief abstract of the excellent and comprehensive account given of them by Mr. Wheeler.

Bucket pumps are employed for the drainage of Lake Haarlem, and in several districts in England. Trials have shown pumps of this sort to be as effective as any of the machines above mentioned. They are not, however, advantageous for situations in which the lift is variable; and the valves are ill-adapted to cope with water charged with mud and grit, and weeds and pieces of wood which frequently find their way to the inlet.

The screw pump consists of a cylinder in the centre, carrying one or more wide spiral threads, sometimes enclosed in a cylindrical external case. The number of screws running round the core varies from one in the simplest machine to three or four in larger ones. Fig. 23

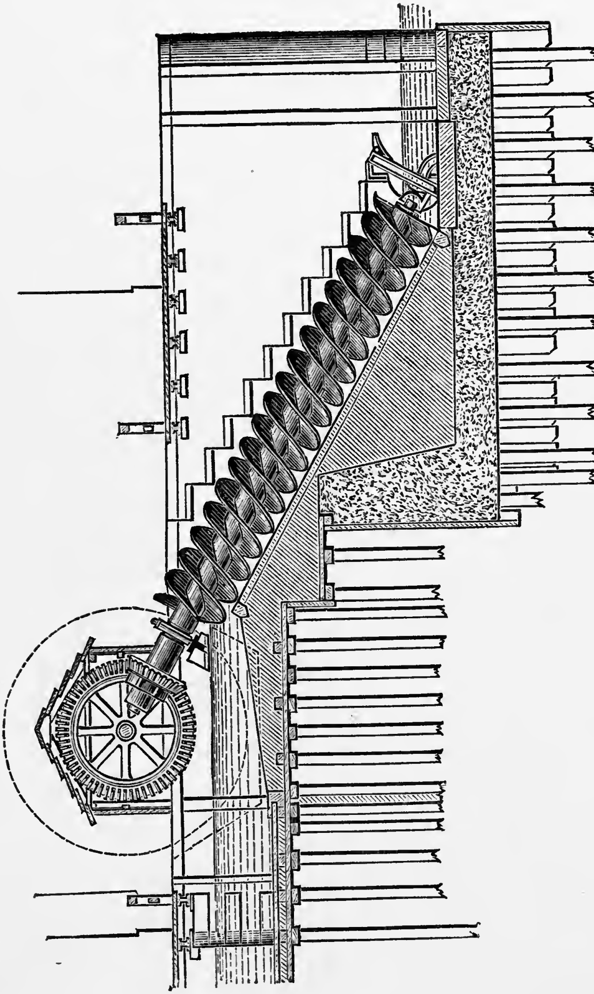


Fig. 23.—Archimedean Screw Pump.

shows one having two threads. The ends of the core terminate in gudgeons which revolve in bearings, the lower one fixed under the water, and the upper one on a beam across the delivery-opening. The efficiency per revolution of this machine being unaffected by the speed at which it runs, it is suitable for being driven by steam, wind, or hand power. In small pumps, a crank handle is attached to the upper part of the core for use by hand. One man can raise in an hour at the rate of 1,738 cubic feet of water lifted one foot high, the pump making 40 revolutions per minute. If worked by machinery, the pump is driven by a spur-wheel and gearing as shown.

The water-level on the inlet side may vary without affecting the efficiency of the pump, except so far as concerns the increased weight due to the greater length required to meet the variation. But any change in the level on the delivery side immediately affects the efficiency. These pumps therefore are not adapted for use where there is much change in the level of the water into which they discharge.

The "spiral angle" is the acute angle which a line on the surface of the core parallel to its axis, makes with a tangent to the spiral at the point of intersection with that line. The "tilt" is the angle of the axis of the core with reference to the horizon. The best results are obtained with a spiral angle of about 40° and a tilt of about 30°. A longitudinal section through the axis of the core and the thread of the screw shows, in pumps of the best form, that the plane of the thread is not at right-angles with the axis, but forms with it an obtuse and an acute one. The pump is most effective when the acute angle is on the side towards its lower end.

In pumps working under similar conditions, the discharge is as the cube of the diameter; and approximately it may be taken that, under favourable conditions, a pump one foot in diameter will discharge 0·32 cubic feet of water for every revolution. The number of revolutions varies according to the kind of power applied and the size of the pump. Small pumps of about one foot in diameter may be run at 60 revolutions per minute, the large sizes not reaching more than 20. For drainage purposes these pumps can be run at from 20 to 40 revolutions per minute. The practical limit of height of lift is 14 feet, and of delivery 3,500 cubic feet per minute. The Dutch screw pumps work without an external casing, the screw revolving in a semi-cylindrical trough of masonry (Fig. 23). The weight of the water is thus borne on the masonry and the screw relieved of the strain.

The efficiency of these pumps is about the same as that of scoop wheels, and varies from 50 to 80 per cent. of the power applied.

The scoop wheel resembles a breast water-wheel with action reversed. In its simplest form (Fig. 25) it consists of an axle carrying discs, to which are attached radial arms A terminating in the rim B, whereon are fastened arms called "start-posts" carrying boards C called "scoops." On the inside of the rim are cast-iron cogs fastened on in segments, and geared into these is a pinion on the shaft of the fly-wheel of the engine. In some a wheel F is fixed on the axle of the wheel in place of the toothed segments on the rim. The former construction occupies less space, but the wheel is more difficult to repair in case of damage to the teeth. The wheel revolves in a trough connected at one end with the drain and at the other with the place of discharge. The scoops beat or lift the water from the lower to the upper end, the waterway at the outlet end having a

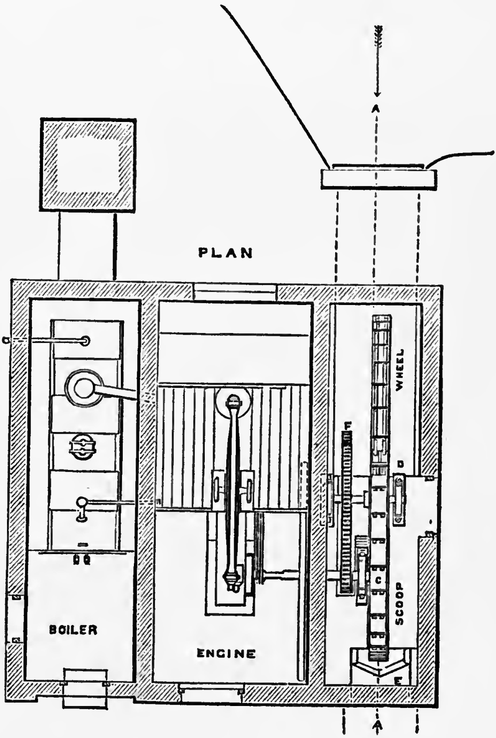



Fig. 24.—Scoop Wheel.

self-acting door E, which closes when the wheel stops. The trough in which the wheel revolves is of masonry, carried up as high as the centre of the wheel. The invert is made of the same radius as the wheel plus the amount of clearance :

the latter in the best machines being $\frac{4}{10}$ of an inch at each side and at the bottom. In order to allow the water to get freely to the scoops, the inlet raceway is made about one-third wider than the wheel, gradually narrowing to its minimum width at a point vertically below the outer rim of the wheel, the angle of convergence at each side being about 17° from the straight line. The outlet channel should have the same width as the trough, and immediately beyond the

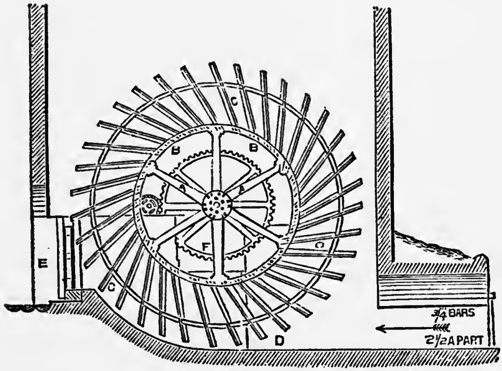



Fig. 25.—Scoop Wheel.

outlet-door it should rapidly widen to the outfall drain ; and the outlet-door should be at some distance (say 1 or 1½ times the maximum lift) from a point vertically below the extreme range of the scoops, and prevented from opening more than so as to be just parallel to the sides of the trough. To prevent the scoops from dipping too deep, and the wheel from being overloaded, when the drains are in flood, the inlet is fitted with a shuttle (A A, Fig. 26) to regulate the supply. It consists of a wooden framework with a sliding door, fitted in the raceway close up to the wheel, sloping at such an angle as to be tangential to the circumference of the wheel. The door has friction-rollers on the side next the wheel, running on a frame, and has a balance-weight, and a rack and pinion for raising and lifting. A shaft geared to the pinion can be carried into the engine-house so that the shuttle may be adjusted in the engine-room, a float indicator

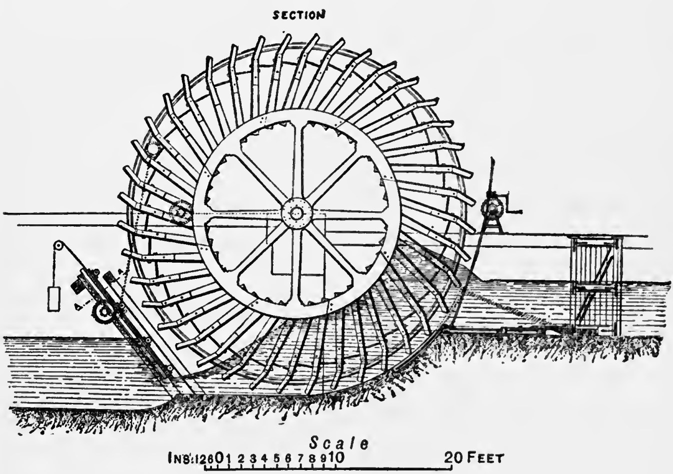



Fig. 26.—Scoop Wheel with Shuttle and Movable Breast.

being also placed there to show the height of the water. When the wheel has to contend with a great depth of water on the outside owing to floods or abnormally high tides, the scoops as they come round churn up a large quantity without discharging it: the wheel thus becomes choked, and its free discharge impeded. To obviate this, an iron plate, hinged to another plate which lies on the floor of the outlet channel, is fitted in a recess cut in the masonry of the outlet sill. By means of a segmental toothed rack and a pinion (Fig. 26) this movable breast can be raised or lowered, and the sill of the discharging channel adjusted to the height of the water.

The diameter of the wheel is regulated by the formula $D = 8{\cdot}75 \sqrt{H}$, when $D =$ diameter of the wheel, $i =$ the immersion of the scoops, $l =$ the lift, $H = i + l =$ the height from the lowest point of the wheel to the highest external level to which the water has to be raised, and $8{\cdot}75$ = a constant giving a result closely approaching Dutch and English practice. The measurements are in feet. In Holland the largest wheels do not exceed 33 feet diameter. In England, the largest diameter is 50 feet, there are many wheels of 35 and 40 feet, but the best limit for efficient working is about 36 feet. It is not advantageous to use scoop wheels for lifts exceeding 12 feet: for greater lifts centrifugal pumps are more effective and economical.

Owing to the large diameter and great weight of the wheels, it is necessary that the foundation be rigid and the wheel very nicely adjusted, as the slightest settlement causes the wheel to grind in the trough.

There does not appear to be any determinate relation between the diameter and the breadth of the wheel, nor between these and the number and area of the scoops.

The angle made by the face of the scoop with the surface of the water when first it comes in contact with it, is termed the angle of ingress: that made by the back of the scoop with the surface of the water when it leaves it being termed the angle of egress; the outer end of the scoop in each case being taken as the apex of the angle. In determining the angle to be given, the mean level of the water, both on the inlet and the outlet side, must first be settled. The centre of the wheel is then so fixed as to divide the head (= lift) and dip (= immersion) in equal proportions, but the dip is seldom made to exceed 6 feet.

On the whole, it may be taken that flat scoops, with an angle of ingress of 30° and an angle of egress of 45°, give the best results.

The speed at which wheels with flat scoops run should not exceed 8 feet per second at the periphery. Those in England have generally a speed of 6·27 to 7 feet per second. Some of the Dutch wheels have as low a speed as 3·46 feet. Wheels having curved scoops can be run at a higher velocity than flat-bladed ones.

The work performed by a scoop wheel is measured by the quantity of water lifted in a given time. This is ascertained by multiplying the mean circumference of the immersed portion of the wheel by the area of the scoops (=width × immersed radial length), and deducting from the result the bulk occupied by the scoops and start-posts, and the loss by leakage between the scoops and the trough. *Example:*—Diameter of wheel=30 feet, dip=5 feet; width of scoops=4 feet. Deducting half the dip from each of the radii of the wheel, the mean diameter of the immersed part=30−5=25 feet, and mean circumference=78·54 feet. Area of scoops=4×5=20 feet. Then 78·54×20=1570·80 feet. Deducting bulk occupied by scoops (say) 129·8 feet, leaves 1,441 feet, and this less 7·6 per cent. for leakage =109·5 feet, leaves 1,331·5 cubic feet for each revolution of the wheel. The number of revolutions per minute=4, the discharge per minute=1,331·5×4=5,326 cubic feet.

A number of careful observations on the performance of wheels gives, for those with flat scoops, a result of effective work averaging 70·6 per cent. of the power indicated: the maximum efficiency reaching the very high figure of 81·97 per cent.

The centrifugal pump consists of an outer case having inlet and outlet pipes, in which revolves a fan at a high velocity. This high velocity adapts it well for gearing direct to engines running at high speeds. A very large displacement of water is effected in a short time. The machines are compact and occupy small space. The weight being about one-twentieth that of a scoop wheel, the area of buildings required is small, and the cost of foundations comparatively inexpensive. The first outlay is also considerably less : the average difference of cost of pumping-stations erected in Holland during recent years is £20 per actual horse-power in favour of the pumps. Another great advantage of the centrifugal pump is that it readily adapts itself to the varying lift which must be encountered in most drainage stations, and automatically adjusts the work thrown on the engine as the lift varies. At first starting, the engine-drain is full and at its highest level. The lift being therefore smaller, the pump discharges a larger volume of water : as the water in the drain lowers, the lift increases and the quantity pumped diminishes in proportion, giving more time for the water to flow from the distant drains down to the engine-drain and keep it fed. Further, when permanent settlement of the land occurs, the cost of adapting a pump is trifling, all that is necessary being a lengthening of the inlet pipe. Where proper precautions are taken by protecting the approach to the pump with gratings across the entrance to the raceway, no practical difficulty has been found to arise from weeds and other substances which find their way into the pump-well.

There are two types of these pumps: the one having a horizontal spindle, and being almost invariably fixed above the level of the water; the other of the turbine form, having a vertical spindle, the fan and case being submerged. All the larger stations in England have been fitted with the turbine form, while in Holland and Italy the pump with horizontal spindle has been most generally used.

The pumps having horizontal spindles are, owing to the ease with which they can be fixed, eminently adapted for temporary purposes, and for drainage in places where it is not considered desirable to cut through a river-bank. For small drainage areas pumps of this type are preferable to those which are submerged, owing to the greater facility of access to the fan should it become choked with weeds, ropes, or other matter liable to be twisted round the blades. Substances, intruding through the protecting gratings, that will readily pass through the openings in large pumps, frequently get wrapped round the fans and spindles of the smaller pumps; and if not actually bringing the pump to a standstill, seriously affect its efficiency and throw a greater strain on the engine.

Pumps with horizontal spindles require charging with water before they can be started: this can be done by a small donkey-pump, or by exhausting the air by a steam-jet.

The turbine type of pump (Fig. 27) has a vertical spindle, and must be placed below the water, at the lowest level from which the water is to be pumped. Pumps with single fans can be run at a smaller number of revolutions than those with two—an advantage when used for drainage purposes. The pump is fixed in an iron case or a brick well, the outlet from which is at the lowest level to which the water in the outlet channel is ever likely to fall: there should be not less than 2 feet of water over the pump, since within reasonable limits its depth below the surface does not appreciably add to the work to be done. No delivery or suction pipes are required. The opening in the well is protected by a self-

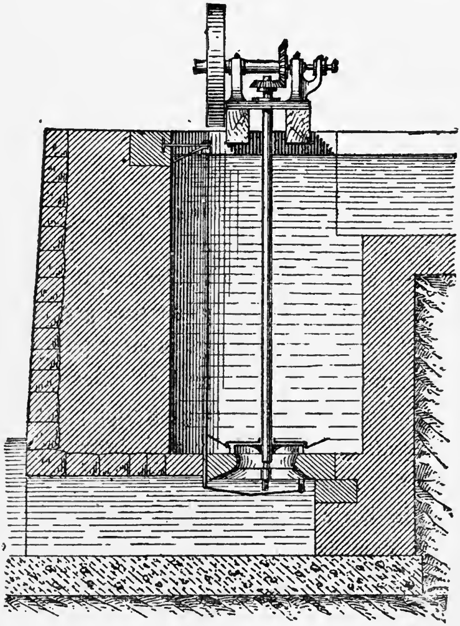


Fig. 27.—Centrifugal Pump: Turbine type.

acting valve to prevent back flow when the pump is not working, or doors are placed at the end of the channel leading into the main outfall drain. The pump is hung by its spindle to a girder across the top of the well, by an accessible gun-metal bearing; and the spindle is stayed by horizontal guides in the well. No foot-step is required; and the fan can at any time be taken out for repairs, and replaced, without emptying the water from the pump-well. The case or well should be so arranged that it can at any time be pumped dry if necessary—a precaution seldom needed. No valves are required, the pump being always charged and ready for starting; and being covered by a considerable depth of water, it is free from the action of frost—the water left in a pump exposed to it being liable to freeze and burst the case. The friction of the water along the suction and delivery pipes necessary in the other type of pump, is also avoided.

The action of a centrifugal pump of either type is as follows:—As soon as the fan begins to revolve, the blades carry with them the water, which is then pushed forward and driven into the case partly by the action of the blades propelling it, and partly by the centrifugal action of the rapid rotary motion caused by the fan. The place of the water expelled from the fan is immediately filled by a fresh supply from the inlet. The water driven out by the fan is propelled along the discharge passage or rises up the well until the outlet is reached. A continuous stream is thus created, and the water is kept in motion along its whole passage. The discharge increases with the increase of velocity, a small increase in the number of revolutions producing a large increase in the delivery. Unless the speed at which the pump is intended to run is attained, the machine does not work at its best, and fuel is wasted. It is therefore important that the engine-man in charge should know the velocity for which his pump is speeded. Makers usually furnish particulars whereby the quantity discharged can be ascertained when the lift and speed are known.

The great advantage a centrifugal pump has over all other machines for raising water for the drainage of land where the lift is constantly varying owing to the rise and fall of the tide in the outfall river or the lowering of the water in the inside drains as the pumping proceeds, is that it adapts itself to these variations in the lift without any alteration in the speed of the engine, employment of differential gear, or attention on the part of the engine-driver. If kept working at the ordinary speed, the pump will discharge either more or less water according as the lift diminishes or increases.

The various sizes of these pumps are generally described from the diameter of the inlet pipe: a "30-inch pump" would be one having a suction pipe 30 inches diameter at the inlet.

In best-class pumps with low lifts, such as are required for drainage purposes, the following may be taken approximately as the rate of discharge: the amounts given are above those attained by pumps in ordinary use:—

| Diameter of Suction and Discharge Pipe, in Inches. | Water discharged per Minute. | |
|---|---|---|
| | Gallons. | Tons. |
| 15 | 5,000 | 22·32 |
| 18 | 7,000 | 31·25 |
| 24 | 11,000 | 49·10 |
| 30 | 18,000 | 80·35 |
| 36 | 20,000 | 89·28 |
| 42 | 27,000 | 120·53 |
| 48 | 40,000 | 178·57 |
| 54 | 70,000 | 312·50 |
| 60 | 100,000 | 446·43 |

The duty to be expected from a centrifugal pump of the best construction used for drainage purposes may be taken at about 70 per cent., the effectiveness diminishing, in small-sized pumps and in those not of the best construction, to 50 per cent.[148]

**Steam-engines.**—Engines used for draining land should always be of as simple a character as possible, free from all complicated parts, and of the best workmanship and ample strength. The more nearly they approach the type of engines used for agricultural purposes, the less will be the difficulty in obtaining experienced engine-men. The fewer parts of a simple machine reduce the risk of breakdowns; and drivers of the agricultural class have generally sufficient intelligence to deal at least for a time with such accidents as may happen. In the case of engines used in pumping mines, or for town water-supply, or for similar purposes, experienced men and skilled mechanics are at hand to carry out repairs and rapidly remedy defects: in the event of a mishap with a drainage-engine, a messenger has to be dispatched from some out-of-the-way place to a perhaps distant town to obtain the services of an engine-fitter.

In recent pumping-stations in England no one particular class of engine prevails. In Holland the type of engine most commonly in use is the horizontal condensing single cylinder; but there, as also in France and Italy, direct acting horizontal compound engines have most generally been applied for driving centrifugal pumps. Vertical engines require less foundations, and are less subject to strain if (a common occurrence in fen-land) settlement of the foundation takes place, than those of horizontal type. Where the area of land is small, say not exceeding 2,000 acres, and therefore not sufficient to warrant the cost of brick buildings, the most economical arrangement is to use a semi-portable engine driving a centrifugal pump, the whole enclosed in a galvanized-iron shed. The cost of foundations and erection of a chimney is thus avoided. The pump can be driven by belt or by direct gearing from the crank-shaft.

Although in drainage-engines the saving of coal as between one type of engine and another may not be of such consequence as in engines used for commercial purposes, yet the total consumption is important, because on this principally depends the annual cost of the pumping-station and the amount of taxes required to meet expenses. If more fuel than necessary is used, this is due to some fault of engine-man, engine, or pump. The excess has to be paid for. A good engine-man may save his wages many times over by careful stoking: an incompetent man may not only run up the coal bill, but do serious damage to the machinery by bad management.

Dutch Engineers in their contracts for engines &c. generally stipulate that the coal consumed shall not exceed 6·60 lb. per horse-power per hour for water actually raised (W.H.P.). Allowing an efficiency of ·55 for the machinery, this is equal to 3·63 lb. per indicated horse-power (I.H.P.). Some of the best pumping-engines for land drainage in this country consume from 4 lb. to 4·5 lb. per I.H.P. (=7·25 lb. to 8·25 lb. per W.H.P.) per hour. At the trials of the machinery put up at Fos, Bouches du Rhône, the consumption was at the rate of 2·47 lb. per I.H.P. (= 4·45 lb. per W.H.P.); and in that for drainage of the Ferrara marshes 2·5 lb. per I.H.P. (= 4 lb. per W.H.P.) per hour.

**Engine-Drains.** — Pumping - machinery should be adequate to the maximum rainfall of wet years. Assuming for example an area of 1,000 acres, with a lift of 5 feet, and daily rainfall of $\frac{1}{4}$ inch; this is equal to 39,394 lb. lifted 5 feet every minute, or 196,970 foot-pounds, which divided by 33,000 the unit of horse-power, is equal to 6 horse-power.[149] Allowing that 50 per cent. is absorbed in overcoming friction and leakage, 12 I.H.P. would be required. This is on the supposition that the engine during extreme floods is running night and day, which in cases of emergency is generally done. If the work is required to be done in less time, the power required will be proportionately larger. The best advantage is obtained when the machinery runs continuously night and day. If the drains are capable of delivering a full supply, a pump works at its best, and the scoops of a wheel being fully charged deliver their full quantity with less lift than if the water-level is lowered and gathers again during the night. The coals used in getting up steam and re-starting are saved, and usually a better result is obtained. If the machinery does not run at night, it will have to be so much larger as to be capable of discharging in 14 or 16 hours (as the case may be) the rainfall of 24 hours, and the drains must be proportionately large to supply the increased capacity of the pump or wheel. The wages of the night men for the short time they are required will not, in the case of a large pumping-station, amount to so much as the annual payment of interest and sinking-fund on the extra cost of the machinery and drains. If the main interior drains of the reclaimed area are of sufficient capacity, an inclination of even 2 inches per mile will be enough to bring the water to the pump: these drains, and especially the main engine-drain, serve not only as conveyers of water to the pump, but also as reservoirs to collect it when the engine is not running, and should therefore be larger than shown by a calculation founded merely on their discharging capacity. When steam is once up, it is bad management to allow the engine to stand still for the water to gather because the drains are not of sufficient capacity to keep up the supply.[150]

**Pumping-Stations.**—The cost of erecting a pumping-station depends upon the circumstances of each case, and does not appear to bear any definite relation to the area to be drained or to the lift of water. The mean of seven somewhat typical stations, of very different acreage and engine-power, gives the cost for buildings and machinery as £0·74 per acre of land drained, the maximum being £1·84, and the minimum £0·20. For the cost per W.H.P. employed, the five of these stations of which the data admit of the calculation give a mean of £82·73, the maximum being £101·08, and the minimum £55·90.[151] Mr. Wheeler, well acquainted with the subject, considers from £70 to £80 per W.H.P. may be in a general way taken to represent the cost.

The annual cost of maintenance and working-charges seems to average, per acre of land drained 9·48d., or per acre per foot of lift 2·2d.

## CHAPTER V.

### *THE MAINTENANCE AND REPAIR.*

The importance of strengthening and preserving the foreland has already (p. 140) been touched upon. It may here be added, that where the nature of the foreland is such as to allow of the growth of vegetation upon it, this may be promoted by cutting sods from the marsh already formed, laying them about, singly, on the site, and pegging them down: they become fixed, and the grass gradually spreads until the separate sods are united and the whole surface covered. This method, locally termed "inoculation," is in many places practised with success, and deserves consideration all the more because, when the land-waters that formerly kept open the creeks and rills are diverted into the permanent outfalls from the sluices, their old beds, after being bushed and properly filled up, may with advantage be thus grassed over. (See also *infra* p. 229.)

Not less important is the care of the bank itself. The expense of its maintenance will of course be affected by the degree of soundness of the work bestowed upon its construction; but be this greater or less, its durability will nevertheless in great measure depend upon the attention subsequently paid to keeping it in good condition. Although disasters occurring to sea-walls are generally attributed to some exceptionally severe storm, there can be little doubt that in many cases they are primarily assignable to want of diligent inspection, proper keeping up, and timely repair: the storm does but find out the weak places. All seems to go well until it comes, and then the damage results.

The expense of maintenance is very different in different cases. On the Lincolnshire coast it is given as from 6d. to 8s. and 10s. per acre of embanked area. At one place in Essex it is stated as being at the rate of 7s. per acre; and on one Reclamation with an area of 700 acres at Tendring in the same county it is said to have been for many years as much as 20s., for several years 30s., and in 1883 no less than 35s., in the £ of annual value. There is nothing said as to whether in any of the foregoing the cost of extraordinary repairs was included. In the case of Canvey Island, the cost during a period of 66 years averaged 4s. per acre, exclusive of the heavy repairs occasioned by damage done by the gales of 1881 to the bank, which had not been duly kept up.[152]

Constant attention has to be given to the preservation of the turf on the slopes of the bank, and to that on its top if not laid out as a road; and to the immediate filling of all holes and cracks noticed, and the turfing-over or otherwise protecting the fresh earth used for that purpose.

Mr. Wiggins lays great stress on the importance of constant attention to the facing, strengthening, and topping of the bank; and regards as a feature of prime importance the maintenance of the bank at its full height, "which," he says, "is apt to be diminished by the tread of cattle and the natural degradation occasioned by rains and other causes. The first-named cause of this diminution of height ought to be prevented by limiting the grazing of sea-walls to sheep;[153] but even in this case, the other causes are powerful enough to render much vigilance requisite in restoring the lost height, before any higher tides than usual cause a '*drown*,' and this is done by the operation called *topping*, or placing a sufficient quantity of earth on the top of the bank. In this operation allowance must be made for the settling or shrinking of the wet earth generally used, which may be calculated at nearly one-third of the height to which it is put on. Topping put on 5 feet base, 3 feet at top and 2 feet high, took about one floor (400 feet) to 2½ rods. . . .

"The *back* of the sea-wall has already been mentioned as requiring a certain degree of slope, not only to give stability to the materials of the bank, but to enable it to derive that support which the matted roots of grasses, and other vegetation, are capable of giving. In old banks this slope becomes lessened in time, and in some cases the bank slips down at the back, or it becomes worn by the tread of cattle. The back of the bank is also sometimes honeycombed by rats, moles, &c., or split by the shrinking of the spits or clods originally used in its construction, and not properly packed and flood-flanked at that time. In either of these cases it requires to be made up by the operation called '*siding*,' or the addition of fresh earth to the requisite extent. Sometimes this operation is deemed necessary in order to give a greater degree of solidity to banks which appear to be deficient in thickness or substance. Siding is usually measured with a string for the breadth, and the average depth of earth is taken. The earth should be taken from the marsh or land side, and . . . as the material both of siding and fronting sea-walls, when of a tenacious nature and used wet, is apt to shrink in drying, and crack so as to fall away, a process called 'sludging' is performed, which consists in plastering up and filling the fissures with sea-mud.

"It takes about one floor and a quarter to side a rod in length, in ordinary cases . . . ; but in another case, seven floors sided a 10-foot wall for 6 rods in length. The expense of siding must, however, of course depend entirely on the quantity of material employed, and this having to be more carefully placed or packed of unequal thickness in places, is worth more than the more bulky work of repairing the bank; it depends however much on the nature of the earth, its distance, and the quantity to be added."[154]

In Holland, it is considered inexpedient to allow pasturing on the bank to be begun until the second or third year, or at any time to allow it to continue after the 1st of October. Low places and cracks are filled in the spring with fine earth. Pasturing by cattle is regarded as the best means of preserving the grass on the bank in good condition. Calves and sheep are not allowed, because they graze too closely; nor horses, because their hoofs cut the sod.[155]

As regards the manner of pasturing, it may here be observed that grass, if close-cropped, especially by sheep, develops small and fine roots, but covers the surface with a compact carpet of turf; while, if suffered to grow rank, it is apt to coarsen and run into tussocks, which disturbed, as they are liable to be when pastured by cattle, are apt to leave holes in the bare soil. The question is one for agricultural experience and expediency rather than for an Engineer to decide: it certainly demands careful consideration.

"Trees on dikes are highly prejudicial. They prevent the dikes from becoming thoroughly dry. Grass does not grow well in their shade or under their influence. They are shaken even to their roots by heavy winds and the ground loosened accordingly. Add to this, that there are frequently cavities under the arch of the roots of large and especially [of] old trees, and that considerable streams of water may be conducted through the dike by means of the lateral roots. The latter are subject to decay and then constitute formidable channels."[156]

Where a bank has proper slopes, and is of sound and good construction, a serious breach rarely occurs by direct action of the sea on the outward face; the danger to be apprehended being rather that of the waves rolling over the top during a coincidence of heavy storm with unusually high tide, cutting-up the land slope, and undermining its foot. The support afforded by the backing being once lost, the outer face gives way, and a breach ensues. Such at least is the teaching of experience with respect to banks in Jutland (cf. p. 50), and there is no sufficient ground for supposing the matter to be otherwise in this country. In case of emergency, then, the main object must be to avert disaster by a temporary raising of the bank. Rows, 4 feet apart, of stakes are driven into the top of the bank, and planks or fascines secured to them, the space between being filled with earth. When fascines or planks are not readily procurable, clay, brushwood, stones, and sand-bags are rammed in between the stakes, and the heads of the stakes are then bound together. In this manner a bank can be easily and quickly heightened 3 or 4 feet. The bank itself being above highest tide level, the overflow to be guarded against is little more than that due to the breaking and run of the waves; and, slight as seems the barrier thus raised, it has been found effectual: a sudden danger has more than once been thus averted and the land saved from inundation. In view of possible recurrence of a like event, the work so executed will advisably be left in place as an additional storm-bank, earth and turves being added as opportunity offers, by way of making it stanch and permanent at small extra cost.

The following recommendations relating to Dutch practice in the matter of repairs, will be found useful and worthy of adoption, being equally applicable to banks in this country:—

Damages should be speedily repaired, or they will lead to increased trouble and cost. If the sodding be injured and the slope badly washed, the damaged spots should be levelled-off and the place covered with a krammat or a dressing of brushwood. If the damage occurs in winter, a permanent filling of the gaps or holes in the facing is not recommended, it being difficult to secure a good and firm sod during the winter season, and there is risk of storms washing away the new work. It is best therefore to adopt adequate though only palliative measures, and to postpone the complete restoration of the slope to a later season; and filling-in with fresh earth or clay should be resorted-to only in extreme and unmistakably urgent cases. Brushwood dressing should be used in places previously protected by it, or where krammat would be insufficient. Brushwood is especially recommended where the earth is so much injured that paring-away without filling would not make a slope suitable for the reception of a krammat; because brush, by tight and strong wattling, can be made to stand at a much steeper slope, and is much better as a protection for new earth if that must be used. The greater cost of brushwood dressing is in some measure made up for by the fact that most of the material can be saved and used again.

If, as often happens, the outer slope is so far cut away by the storm as to encroach upon the crown, it becomes difficult to restore the slope so that a brushwood dressing will stand, without a filling of some kind. Then fascine-work may be resorted to, or a facing of stakes or timbers backed by hurdles or planking. The foot of such a structure needs protection against wash. For this purpose, the bottom plank of the revetment may be sunk 8 or 12 inches in the ground, or short upright planks may be driven. If preferred, a layer of brush or straw, of good thickness and 6 or 8 feet wide, may be secured at the foot of the revetment. If the slope is covered with stone, and this be so injured that it cannot be at once restored (as, if possible, it ought to be), the displaced and injured material should be cleared away and replaced by a good facing of brushwood, or, if the bank is so washed-out as to need filling, by fascine-work made up to a good face.

One of the most serious accidents that can happen is a sudden sinking or collapse of the bank, caused by undermining below water. These slips are not always the result of storms, being sometimes due to the steady action of currents, and frequently occur in time of calm weather. In general, the first thing to be done is to build up the bank under water with fascine-work to prevent further sliding. When the damage is not extensive, this work may be carried on until the sea-slope is rebuilt. The fascines are laid in tiers, and weighted with cubes of clay [as described at pp. 133-136, 138 for the construction of training-walls and the sides of channels]. If the injury extends to the inner slope, it may be necessary to build a new bank on the land side of the old one.[157]

The important part played by fascine-work in construction of banks and training-walls seated below low-water mark as well as above that level, has been shown when treating of the subject (pp. 75-77, 83, 133). How great a difference of opinion may exist on points of practice, is evidenced by contrast of the preceding paragraph with the following :—"If a slip takes place, in any part of tidal embankments, great care must be observed not to allow any fascines to be used, as there is always a danger and liability of fagots forming conductors for the water." [158]

When a breach occurs, the work of repair may be far more difficult and expensive than that of closing tidal openings left during construction. Unlike these, it has no flooring, side-guards, or aprons, and is almost always (at any rate in the first instance) much narrower relatively to the quantity of water passing in and out at each tide. The result is a much greater velocity of current, a more or less rapid deepening of the bed by scour, and a wasting-away of the sides. The last is of small consequence, the difficulty of closing being due to the deepening of the bed, and the velocity—sometimes 8 or 10 miles and upwards per hour, of the tidal stream. Hence the impolicy of delay in the commencement of repairs : every tide working further mischief and enhancing the difficulty and ultimate cost of making good. Matters are even worse when, as at St. Germains on the Middle Level and in other cases, the breach is caused by the failure of a sluice ; because the drainage this carried cannot always be led to and got rid of by other existing ones, and provision for its discharge has to be made by building a new sluice or possibly sluices, which can rarely if ever be done exactly on the site of the old one. This involves some alteration and perhaps diversion of the outfall drain; and if much scour has there taken place—that of the Middle Level had for a quarter of a mile been scoured-out to a depth of 15 feet below its original bed—the portion abandoned at and near the breach may prove a source of additional difficulty.

Owing to the fact that the particular conditions and circumstances of each individual case of breach have to be taken into account and dealt-with accordingly, it is not possible to lay down any fixed rule for the work of repair. All that can be done is to indicate methods of procedure which have been followed in various similar works, leaving to the Engineer the selection of the one best suited to the requirements of the affair he has in hand. Three points, however, having a practical bearing upon almost all cases, may be premised.

First:—Working "in the dry" is far easier than working below water: if therefore the method adopted for closing the breach admits of it, it is desirable that the bottom of the opening be as soon as possible brought up to low-tide level. Experience goes to show that the readiest, safest, and most effectual way of doing this is by the use of mattressing and loading. Mr. Muller, who had considerable experience in the matter, says:—"Filling up a gap by this method possesses the great advantage that there is comparatively no loss, or displacement of the material. There is no chance of any scouring taking place under the cradle, and the hollows between the lumps of clay and stone being soon filled up with sand by the tide, the bottom of the creek or gap is, in a few hours, permanently raised several feet. The sides of the opening are next protected with similar cradles, the lower end of each resting on that first laid. Subsequently, other cradles are sunk over these, until the work reaches low-water mark, when the width of the embankment is gradually increased, by throwing in sods on the outer side, protected by fascine work, weighted with stone. The same process is then pursued on the inner side. . . . From his own experience he believed, that by adopting the system of laying layer upon layer, horizontally, the largest breaches could be easily closed. . . . Between 1853 and 1860, he had successfully closed seven large openings, the greatest depth of which varied from 28 feet to 42 feet, below the level of high water. The size of the cradles need only be limited by the strength of the current, and the facilities which existed for sinking them."[159]

Second :—However low the bottom of the opening, the water on the inundated area will never fall below low-tide level; and therefore the lowest level to which it can be reduced by gravitation will not be affected by bringing up the bottom of the opening to that height.

Third :—If the inundated area is large, and the discharge-capacity of the breach insufficient, the impounded water will be held up so long that it may not fall to low-water level before the tide again rises : the velocity of the current will be unduly high ; and these together will occasion more difficulty in the work than a greater length of closure made in water whose flow is less rapid and whose level more closely agrees with that of the tide. It is therefore almost always advantageous to widen to the requisite extent the opening above low-water mark, protecting its sides with fascine-work and its outlet and inlet with aprons. These latter, being at and below water level, will be best made by laying as foundation a mattress with strongly wattled compartments filled with sand-bags, sods, and stone: this, if properly done, should withstand any amount of wash to which it is likely to be exposed; and the overfall upon it will be but slight, since the water on the inside of the breach will rise and fall practically as fast as the tide.

From low-water level upwards, the closure will be made: *a*) By raising earthwork in layers in the breach: *b*) By forming a skeleton dam of piles, and planking and filling up: *c*) By an arrangement of sliding panels that can be simultaneously lowered so as to close the whole opening at once; or *d*) By forming an inset bank on the landward side of the breach.

*a*) The raising of earthwork in layers proceeds in much the same way as described for a new bank, so far as regards the supplying of material and its spreading and ramming. But since in the present case it will have to be commenced at low-water level, closure cannot be completed in a single tide: the slopes and top of the work will therefore require protection as the tide rises. The impounded water, increasing in depth as the closure proceeds, will probably cause some inconvenience in carrying on operations, but will be to some extent kept down by the sluices, so that the top of the work will not long remain awash after the tide has sunk below that level; and material for filling can be supplied by conveyance along the bank, or by barge.

*b*) A closure made by a dam of double planking secured to open rows of piles and brought up and filled-in by degrees in horizontal layers, will require a staging for the men in addition to the width of the dam itself. The piles must be well strutted on both sides, to sustain the pressure of the water. The planking and filling must be closely followed up by a backing of sacks filled with clay and sand puddled together, packed close against both sides of the dam and formed with a slope not less than 1½ to 1 and flatter if possible—this requirement of strutting and backing applies also to the work of closure in a new bank. It is questionable whether even in the latter case such a dam can always be brought up fast enough to close in a single tide: in that of a breach it almost certainly can not.

*c*) The arrangements for sliding panels, in closing the Middle Level drain for repair of the breach caused by failure of St. Germains sluice, are thus described. "Temporary piles were screwed into the ground in the first instance, and a platform was erected thereon, to form a staging for the pile-driving engines. When this was done, the permanent pile-work was commenced, by driving two rows of sheet-piling, 25 feet apart, transversely down the slope of the drain on each side. This sheet-piling extended from the centres of the banks to within about 20 feet of the bottom of the drain, leaving a space of 20 feet on each slope and of 48 feet (the bottom horizontal width of the drain), together equal to a central space of 88 feet of cofferdam to be completed. This portion of the dam was thus constructed:—Piles of whole timbers were driven on each side, so that when in place they would be in pairs, 7 feet 6 inches apart, from centre to centre. The piles in each pair were placed back to back, a space being left between them of 7 inches, this distance being preserved by a central piece 7 inches by 3 inches. These piles were driven separately, one of the piles, with the distance-piece attached, being first driven, and afterwards the second pile.

The grooves thus left were for the reception of sliding panels, to be used in order to fill up the spaces between these several twin piles. These piles could only be pitched during the few minutes of slack water. Waling pieces of whole timbers were fixed to the inside and the outside, both at the top, and also as near to the low water level as possible. As the piles were driven, proper struts and ties were inserted to stiffen and strengthen the dam, and strongly framed raking struts were fixed, abutting against the dam and against abutments, composed of piles backed with concrete, on the land. . . . The panels are composed of a series of timbers (7 inches thick, and of the length necessary to enable them to slide into the grooves), fastened together by bolts 1¼ inch diameter, and further strengthened and weighted by flat wrought-iron plates on one side, each plate being 6 inches wide by 1 inch thick. In order to put these panels in place, a frame was erected, from which they were suspended, and from which they could be lowered, and raised again if necessary, by pulleys." The panels were put-in in three tiers. Those "in the first, or lower tier were each 7 feet deep. They were pointed at the lower end, so that they could be driven down some depth into the mud; and when all those of the first set were driven, another set was put in. These latter were of variable depths, inasmuch as the first series could not all be driven to the same level, and the lengths of the second set were so arranged as to raise the panelling uniformly to the level of about low water of spring tides. Whilst the panels were being driven, and after they were down, the operation of throwing in sacks of clay and gravel, both on the inside and the outside of the dam, was persevered in." The top tier of panels was 12 feet deep, and its lowering into place occupied about twenty minutes. The backing was filled-in as fast as possible. "About 3,000 yards of clay with several hundred sacks of gravel and clunch were prepared for the operation, and 800 men were in readiness to put these materials in place, from several barrow-roads and waggon-roads; and so perfect were the arrangements, that the raising of the dam inside was kept in advance of the rise of the tide, and before high water the operation was completed."[160] This dam being across a drain embanked on each side, it would not have been possible to widen the opening; and the difficulty of the work was greatly augmented by the strong current, and an overfall sometimes amounting to 5 feet, due to the narrowness of the waterway, which was less than one-fourth of what would be given to a prearranged tidal opening, and even this was further reduced by the sheet-piling at the sides; so that during progress it was scarcely possible to maintain the aprons and backing, which were continually being broken up and washed away.

The requisite piles having been driven through the mattressing and filling whereby the bottom of the breach has been brought up to low-water level, its surface should be covered with a layer of puddled clay and sand 2 feet or 2 feet 6 inches thick, in which is sunk, well bedded and stanched, a bottom tier of the sliding panels, their top standing some 2 feet 6 inches above low-water level; the aprons being made up nearly to this height. The impounded water will be thereby raised, but its head will be so small as to occasion no trouble, and the panels thus fixed will form a good junction for the tier above. The top and bottom of all the panels should have a bevelled edge so as to make a tight joint. The length of the upper panels will depend upon the range of tide: if this is so great as to render them too heavy or difficult to handle, they can be in two or even more lengths (the fewer the better); but arrangements must be made for completion of the panelling to its full height in one operation, and sufficient men and materials provided to follow-up with the backing on the inside in advance of the rise of tide. When the dam is securely closed, the filling and slopes must be completed with the least possible delay.

*d*) An inset bank affords in some cases the easiest means of stopping a breach, especially where a sluice has been destroyed and, in order to avoid interference with the existing drains, or for other reasons, it is desired to reinstate it as nearly as possible in its former situation.

The sluice, if one be required in the inset bank, is first constructed, a cofferdam for the purpose being so placed as not to reduce the width of the breach, whereof however, the original width need not be increased unless dangerously rapid scour or other serious injury is taking place. The inset bank is then built, returned into the main bank at each end so as to shut off between the breach and the inundated area, an opening in it being left of sufficient width to reduce the speed of the tidal current to a working rate; and when all is ready, this opening is shut up in the ordinary manner. The area enclosed being small, no injury is likely to be occasioned to the sides of the breach by inflow and outflow when the inset bank is completed; but as a safeguard against wave-action they should be protected by strong fascine-work. The danger to be apprehended is that of the silting-up of the sluice. For avoidance of this risk, and as a general principle, the preferable procedure is to form a cofferdam on the inside and outside of the main bank, leaving room between the cofferdam and the breach for the return of the inset bank into the main bank so as not to include the sluice; and to put-in the sluice through the bank so as to discharge on the outside as the former one did. The sluice thus placed may so reduce the tidal current as to allow the breach to be closed direct. If not, an inset bank can then be built; and when the tide is thus excluded from the inundated area, there should be no difficulty in closing the breach and restoring the main bank to its original condition: after which the inset bank is no longer needed.

The repair and restoration of old and wasted sea-banks proceeds upon the same principles and in the same manner as in the foregoing pages described for the construction of new works : there does not appear to be anything in procedure differing from that already set forth, or needing special notice. There is in fact in the case of the former a particular advantage, inasmuch as what remains of them serves as an already established framework or skeleton whereon to build up and close in the new work.[161]

## CHAPTER VI.

### *WARPING.*

THE alluvial and other matter held in suspension in river-water, and in that of the sea near the shore, is in general of a high degree of fertility; and warping—or the accumulating of those substances by subsidence upon the land while temporarily covered by the water, is a matter of very considerable importance as a means of raising the surface and improving the soil of an area embanked or to be embanked for reclamation and of the foreland belonging to it. Two modes of procedure are in use for the purpose:—groyning; and letting-in warp-charged water to settle.

The water of rivers being more highly charged with warp, and that of more fertile nature, than is the case with sea-water, warping on a tidal river goes on more expeditiously, and with more profitable result to the quality of the land; while at the same time, owing to the comparatively sheltered situation of the site operated upon, with much more ease, than when dealing with the sea. The amount by which land can be raised by warping depends upon its original level, as the surface of the warp when completed cannot be higher than that of the tide at high-water; and where the land in its original state lies but a foot or so below this, the warp will of course be very shallow. The process of river-warping has been well described by Mr. T. C. Smith-Woolley, F.S.I., and is briefly as follows:—

The river being shut out from the area to be warped, a sluice is put into the river-bank, of a size proportional to the area to be covered and the distance of the furthest point. It differs in no essential respect from a sluice for drainage, and most warping sluices are used as drainage sluices when their original purpose has been fulfilled.

The area is next divided into compartments; and the one intended to be warped first is banked in, the top of the bank being made of uniform level throughout. The ground is roughly levelled, and hillocks are removed and thrown into the hollows or else used for the banks. Judgment has to be exercised in levelling, because when the ground rises to a considerable height within a compartment, the cost of removing it will sometimes be too large, if the material is in excess of that required for the embankment and no part of the area lies much below high-tide level. In such cases, it is usual to leave in their natural condition the hills which rise above high-water mark, and they may often with advantage be planted with larch, Scotch fir, or other trees. Where at the margin of the compartment the land rises rapidly above high-tide level, it serves the purpose of a bank, which at that place need not be constructed.

The compartment being embanked, the beginning of the main drain is cut from the sluice, supposing, as is usually the case, that the first compartment does not immediately adjoin the river, but that there is between them an interval of land not requiring warping. The sluice gates are then opened and the tide admitted. There are usually two or more openings to the sluice, and at first it is best to open only one of them, so as to prevent injury to the newly-made banks. It is a mistake to suppose that, when the tide has been admitted, the gates ought to be shut to keep it there for a considerable time in order to let the warp settle. A single tide in its natural flow and ebb deposits so large a proportion of what it brings, that it does not pay to lose tide No. 2 while tide No. 1 is taking time to settle. The water should therefore be retained no longer than will leave time for it to run off before the next tide is ready to run in.

While land adjacent to the sluice is being warped, all tides may be let in; but when the operation is being carried on at a distance (some warping drains are five or six miles long), it is necessary to shut out the neap-tides, because, their flow of water being but small, their power of doing good is out of all proportion to their power of doing harm—namely, by leaving their deposit in the main drain, where it is an unmitigated evil. The same objection does not apply to the spring-tides, as they have sufficient force to clear out the drain themselves during the ebb.

The disposition of the warp over the land requires great nicety. Were the water allowed to flow anyhow, the result would be that a large portion of the land would be when completed scarcely any more worth than it was originally, the tendency of the water being to deposit the valueless material it contains at the place at which it begins to spread out over the land, while the lighter and more valuable portions are carried to the farthest limits of the flow. Hence arises the necessity for "inlets" or little embanked channels, by which the water is conducted over different parts of the land. These are altered from time to time; and it is in their due adjustment so as to leave the land, when warped, of uniform value throughout, that the skill of an experienced warper is found to be invaluable. Very low land lying at a distance from the sluice is under a great disadvantage, for the water often does not begin to get off until that in the river has ebbed and begun again to flow.

It consequently is often necessary to shut out a tide, sometimes more than one, in order that the confined water which had not time wholly to escape may pass out through the sluice as soon as the water of the second tide in the river has ebbed to a sufficiently low level.

The first compartment of an area being completed, the banks of the main drain are carried right through it or along its side, to the next compartment, which in turn is subjected to the process, and so on until the whole area is finished; after which, unless required for drainage purposes, or for the conveyance by boat of the produce of the warped land, the main drain is allowed to warp itself up, which if left to itself it will very soon do. Should it be again required for the warping of still more distant lands or for any other purpose, a small channel is cut through the warp; when the spring-tides being allowed to flow in and out (neap-tides being excluded), the bed of the drain will soon be effectively scoured and in as good a condition as ever.

In river-warping, it is the practice to exclude the tide-waters when the river is in flood, the deposit brought down by freshes being always of very inferior quality to the ordinary warp, and sometimes utterly worthless.

The cost of river-warping varies greatly according to circumstances; but as a rule the larger the scale of operations the less the cost per acre, owing chiefly to the very great outlay required in building a sluice, and the difference between one to warp 100 and one to warp 500 acres being comparatively trifling. Wooden sluices, though much less expensive, are not desirable except in cases where the area capable of being warped is small; because a timber sluice cannot be expected to last more than ten years or so, whereas, if the area to be warped is very large, the sluice may be required for a much longer period, or perhaps even permanently. The making of the main drain, also, forms a very heavy item in the necessary expenditure. One of 30 feet bottom, the banks rising to a height of 6 feet above the surface of the water and 12 feet above the bottom of the drain, with slopes of 2 to 1, would cost about £1,200 per mile for labour alone: the banks in the case contemplated would be about 9 feet wide at the top, and the earth dug from the drain would be exactly the quantity required to form them.[162]

The process of sea-warping embanked land differs in no essential particular from that of river-warping. It is however, in some cases desirable to warp-up the surface before embanking; and the procedure is then different.

A salt-marsh has a general tendency to extend seaward; but, if not assisted by artificial means, the process of accretion is practically stationary after a certain distance from the shore. The oldest salt-marshes in the Wash are about half a mile in depth, beyond which there is nothing but bare sands. The cause of the accretion not extending beyond a certain point is easily explained. The tidal water, carrying matter in suspension, spreads over the foreshore up to the banks bounding the marsh, and for the short time during which there is a period of quiet, the matter in suspension is deposited. The siliceous particles of silt and sand, having the greatest specific gravity, are deposited first, the warp or loamy particles being carried back with the ebbing current. Gradually, as the marsh rises, the silt is deposited before the water reaches the banks, the warp alone being carried to the upper part and there deposited. As samphire and grass respectively grow, this process is hastened, the vegetation holding the warp and filtering it from the receding water. For the deposit of this light flocculent matter, a state of quiescence in the water is necessary, agitation keeping it in suspension. After a certain breadth of marsh has been formed, the body of water flowing off the marsh on the recession of the tide becomes so great as to form a current sufficiently strong to carry with it the siliceous as well as the argillaceous particles held in suspension. After a time, from the action of the forward and backward motion of the wavelets of the ebbing tide, a marked and broken line or steep, from one foot to two feet in height, appears at the edge of the newly-formed marsh, up to which the neap-tides reach, and beyond which the marsh ceases to grow. The existing marsh is then covered by spring-tides, but continues to rise slowly until covered by only the few spring-tides which rise above the average height. When the marsh is enclosed by a bank, the strong seaward flow of ebb off it no longer takes place: accretion recommences, and in the course of a longer or shorter time—sometimes a few months only—according to the amount of suspended matter brought up by the tide, the sand is covered with warp; then follows a growth of samphire, succeeded by grass, and in a few years a marsh is formed outside the recent enclosure, which rises by the accession of warp, through which the grass grows, until for a foot or more in depth the soil is a mass of the finest warp mixed with roots of grasses and decayed vegetation. This process, extended over a series of years, makes some of the most valuable and fertile soil in the country.[163]

Where no bank has yet been built, the backward flow of water off the marsh and over the foreland has to be retarded and controlled, so as to promote accretion on the foreshore and thereby enable further outward growth of the marsh. Grips should be cut in the surface of the lower or seaward half of the marsh, across the line of flow, and led into the creeks. Where they discharge into a creek it should be bushed; and, to prevent it from being scoured out by the additional current turned into it, brushwood or bushes should be laid in its channel, the branches or top ends turned landward, and secured with stakes as may be requisite. Rows of brushwood set in the marsh near to and parallel with its outer edge, help to break up the overflow from it. On the foreland, rows of stakes filled in with brushwood, or wattled, are placed parallel with the shore-line, at short intervals Sods, fascines, seaweed, and the like, placed on the foreland and secured with stakes, straw ropes, or other fastening, are also serviceable. These devices, or such of them as circumstances render possible and expedient, will in almost all cases contribute to the end desired; and watchful attention will soon detect any need of additions to or modifications of the means employed.

A curious feature connected with warping is, that under some favourable circumstances, worthless land above high-water level may by proper arrangements be brought into a condition for profitable cultivation. Certain parts of Thorne Waste, a large peat-moss near Goole, formerly above high-water level, have been so lowered by drainage as to be now below it; and a considerable portion of the higher part has been subjected to an experiment of the same kind. The peat, which is some 20 feet in depth, had in 1877 been already lowered 3 feet, and needed only lowering another yard to make the enterprise a success. The almost valueless nature of this land in its natural state would lead to its being chosen for improvement before land of finer quality, but this is not the only reason why it should be selected; for this moorish peaty soil becomes, when warped, land of extraordinary fineness.[164]

The length of time requisite for warping land into a condition fit for enclosure; the depth of warp obtainable in a given period; the cost; and in fact all particulars of the like description, have been variously stated. It is said that silt foreshores outside a newly-erected enclosure become grass marsh in about 10 years, after which 20 to 25 years should elapse before they are enclosed. In 15 years, a foreshore of bare sand became grassed all over: of this, 300 acres were enclosed 13 years, and 800 acres 24 years, later. River-warped lands become fit for enclosure in from 14 to 30 years. Some land below the Cross Keys embankment warped up 7 feet and became good grass marsh in 12 years. From 20 to 50 years is said to embrace the ordinary limits of such reclamation periods.[165] Of river-warping it is said that ten or twelve tides covered an area of 10 or 15 acres to an average depth of 2 feet; and that in seven months 160 acres were warped-up to a depth of from 1 to 3 feet.[166] "No enclosure should be made until the land is ripe for it. The growth of accretion is extremely slow, extending from 25 to 100 years." [167] The foregoing statements (with exception of the last, to which no local reference is given) all relate to examples on the estuary or affluents of the Humber; and the conclusion to be drawn from them—and indeed from any similar estimates—amounts to this: that the rate of deposit, and the time requisite before enclosure can be profitably undertaken, are matters wholly dependent upon local situation and conditions. So must be accounted also the cost of the process, variously stated at from £10 to £40 per acre. Bearing in mind the rich quality and abundant quantity of the Humber warp, the idea of ultimate benefit in a less-favoured locality would seem to connote also that of a lapse of time not less considerable than indefinite.

## CHAPTER VII.

### *THE CULTIVATION.*

THE rules and maxims laid down by Mr. Wiggins for cultivation—or, as he terms it, reclamation—of an embanked area, although in some minor details they may possibly be found to admit of modification in accordance with theory and practice of the present day, are of so plain and practical a nature, that it is desirable to reproduce them here: the more so because, this branch of the subject being wholly agricultural, its treatment by writers on the general question (with exception of the account of Holkham Reclamation, *infra* p. 245) is meagre in the extreme.

"We are now," Mr. Wiggins says, "to contemplate an intake securely and completely embanked, together with sluices of sufficient capacity to take off the water falling or coming from other lands on the surface of the intake, and these sluices having a sufficient run to seaward, to carry off those waters down to 18 inches below the general level of the surface of the intake, in sufficient time to prevent injury to vegetation. These are essential conditions, on which alone the work of reclamation can be commenced with any hope of success, and these conditions being strictly fulfilled, we may proceed to agricultural operations according to the nature of the soil, which may be classed into *clayey*, *sandy*, and *loamy*, each of which will require a somewhat different treatment in some respects, though in other matters they may be treated in the same manner, or nearly so; thus, for instance, in the first agricultural operation,—viz. that of enabling the soil, which has so lately been supersaturated with salt water, with all its chemical combinations, to part with so much of its saline and other particles as may be in excess for the purpose of vegetation; or, in other words, to *freshen* the soil sufficiently for land plants to thrive upon it: the process will be the same upon all these soils, and this process consists in forming a series of surface drains, grips, or channels, by which the downfall and other waters may run off, carrying with them such portion of the saline and other particles as they may have been enabled to dissolve, and take up or absorb. . . .

"The next operation is to divide it into marshes of such convenient size as may be judged most judicious; and this size will be partly governed by the soil, clayey soils parting with their salt most reluctantly, and sandy soils most easily. It will also be more strictly governed by the size most convenient for occupation in the particular locality, and also by the desire to save expenses; but in general sandy marshes may be considerably larger than other soils, and there may even be some advantages in leaving the interior of the level for some time without subdivision, since it will be by no means wise to hasten the process of freshening by any kind of washing or sudden saturation, but, on the contrary, to allow a considerable period of time to elapse before any thought of cultivation is entertained, and during that period to allow the level to remain sodden, only leading the surface waters away gently into the circular dykes already described [*ante*, p. 170], so as to prevent any pools of stagnant water; and it may be very judicious to fill up the nearest of such hollows or 'pans,' as they are called, with the stuff out of the circular dyke. This soddening, or stagnation of the soil in a watery state, is considerably more applicable to sandy soils, and to such of those as have before embankment been covered by every tide, than to clayey soils, and will be quite unnecessary in such high fringes or salts as have only been occasionally covered by the tide. But the benefits of allowing the soil to remain for a length of time under the influence of stagnant fresh water are great, since it affords time for the decomposition of such animal and vegetable matter as the sea may have deposited in it,—macerates and dissolves the calcareous, shelly, and other such matter, and even reduces the silicious matter into a state of subdivision resembling clay; and it amalgamates all those heterogeneous particles, takes off their crudities, promotes or prepares them for chemical combination, and reduces them to a state fit for the purposes of fresh-water vegetation. But such effects as these are not likely to happen by the too powerful action of water that might, and probably would, wash away the fertile or fertilizing particles, and reduce the soil to a state of infertile sheer sand, or sharp sand, and prove most injurious to future fertility of the level; we therefore disapprove any attempt at suddenly freshening the soil, and consider that even the soddening process recommended should be conducted with great care and caution, always gradually, but neither allowing the water to remain too copiously nor too long, nor suffering it to run off too quickly; for this purpose, therefore, cuts or channels should be made from the lowest spots of the level into the circular dyke, so that no water should remain absolutely stagnant if it could be got off, but that at the same time it should only be drawn off gradually: thus, supposing the whole level could be gripped, or channelled from the pans to the circular dyke, within the first year after shutting out the sea, and this was done only 12 inches deep, these grips should be allowed to remain at that depth a full summer and winter at least, before deepening them another 6 inches, bringing them to the ultimate depth of 18 inches; gradual freshening and maceration being essential to future fertility, and this requiring a longer time in proportion to the quantity of saline matter, and the crude state of that matter, with reference to vegetation, at the period of its embankment.

"Thus we have brought the level into this state; viz., it has a marsh dyke or water-fence surrounding it, and very numerous grips throughout its surface, leading the waters into the marsh dykes to the depth of 18 inches below the general surface, but of course lower where elevation of surface occurs. In forming the principal grips, care should be taken that they be cut in such places as to fall in with, and promote, the ulterior design of laying out the level into conveniently sized marshes; and it will also be proper to consider which way the ridges and furrows will lie, in case of these marshes being ploughed, and to lay the grips parallel thereto if possible, recollecting that the nearer the ridges lie to north and south the better.

"The depth of the soil, we may now suppose, has been somewhat increased by the soil arising from the grips being spread about. By this time several brackish plants, partly of a maritime, and partly of fresh-water nature, will have appeared, and partially covered the surface in places: these may be grazed to advantage, and as the surface soil freshens, it may be harrowed, and Dutch clover and ray grass may be sown and rolled in, wherever the absence of other plants may allow of them; first, however, bestowing but a small quantity of seed by way of experiment, and increasing this as success may encourage from time to time. In a period varying from three to seven years, according to the tenacity of the soil, and its height above the tide, the level will be fit to bear corn and pulse. If its surface be coarse and uneven, and its soil tenacious and stubborn, or what is called marsh clay, it may be judicious to dig it over and level it at the same time, preserving however the grips already dug; taking in the first instance a crop of coleseed (rape), which might judiciously constitute the first crop, and may either be saved for seed or fed off, and be succeeded in either case by oats, then beans, and then wheat; but even after the digging of such soils, they will require much tillage, so as to thoroughly mix and pulverize them, and the bean crop should be repeatedly well hoed and weeded. With good treatment, however, such soils bear heavy crops of wheat and beans in succession, and when some degree of exhaustion calls for a relaxation of cropping, the course of fallow, oats, clover, wheat, beans, will give all the produce that can reasonably be expected from any land; the crops very commonly grown on good soils of this kind being 8 to 10 quarters per acre of oats, 4 to 6 quarters per acre of wheat, and about the same of beans. This produce, however, must not be reckoned on as over the whole surface ploughed and sown with these crops; for at least one-eighth to one-fifth thereof will consist of 'lows,' 'rills,' and 'pans,' where the clayey soil will be still too crude, too salt, too wet, or too stubborn, to bear perhaps any crop, or at most but one-fourth of what is borne by the best parts. This drawback, together with the expenses of cultivating this description of land, soon points out that grass, not tillage, is its most profitable ultimate destination, and accordingly it is found expedient to prepare it for the true and legitimate purpose of an intake, viz. grazing. But we must not fall into the error that because this is the last, it may also be the first, destination of the level, a course of tillage being requisite for a time upon all the *argillaceous soils*, in order to mix and incorporate them, and to pulverize the soil, so as to bring it into a fit state for the production of the better kinds of grasses; otherwise the coarser will predominate, and the value of the ground be much deteriorated. The necessity of this course of tillage is demonstrated on a piece of silty loam-salts, near Fossdyke, in Lincolnshire, which the late Sir Joseph Banks, with his habitual consideration for the public good, ordered to be left untouched, in the state in which the whole intake was when embanked, and after a lapse of nearly thirty years the maritime salt plants still remain, and the land plants but feebly strive to establish themselves. In proportion, therefore, as the course of tillage is perfect without being continued to exhaustion, and as the levelling and surface draining are well performed, so will be the productive value of the grazing marsh which succeeds the tillage. Nor are these operations sufficient in stiff clayey soils; such will require to have their tenacity subdued or lessened, their working rendered easier, and their pulverization or admixture of parts more effectual, by the application of chalk rubbish, *i.e.* soft chalk, to the land, after the rate of at least ten tumbril cart-loads per acre, which will usually cost about ten shillings per cart, including carriage. This supply of calcareous matter will also act as a manure, and will not only increase the quantity of wheat, but also tend much to improve its quality, to stiffen its straw, so as to prevent or check its lodging, and the consequent deterioration of the grain. In these various ways, an expense of £5 per acre thus incurred will soon be repaid, whilst its beneficial effects on the soil will last at least twenty years even under a succession of cropping, but in grass would be permanent.

"The more silicious soils, whether sandy or loamy, require less chalk, if any; and as their texture is apt to be rather too open than too close, lime is often much better adapted to them, if any manure be at all needful, since an intake of soils of this kind generally abounds with shelly fragments, enough to supply the requisite quantity of calcareous matter. It may, however, be well worthy of consideration, whether a supply of lime would not be advantageous in setting to work that calcareous matter, and consolidating the texture of the soil.

"There are several reasons why any course of tillage should not continue long upon an intake level, one amongst which is, that even under the misfortune of a breach of bank but little harm ensues to grass marshes, provided the tidal waters be again excluded within a few months, because the saline particles, not being in excess, are rather fertilizing than otherwise; but the chief reason is, because the intake cannot advantageously continue many years without suitable farm-buildings, which require a great outlay of capital without adequate return, since a more profitable appropriation of the land can be made without them; and besides, if the natural fertility of these lands is exhausted by a succession of corn crops, it will be vain to look for their becoming rich grass lands afterwards. The period of tillage, therefore, should be limited to such a space of time as may be sufficient, according to the nature of the soil, to bring it into a fit state for the best grasses to grow to perfection. This, on *stiff clay* lands, may be reckoned as 1, oats,—2, beans,—3, wheat,—4, beans,—5, wheat,—6, clean fallow,—7, oats;

and lay this crop down with grass seeds, or what would be better, either sow it down on the fallow with grass seeds, and about half a seeding of coleseed, feeding off the same in a dry part of October, or otherwise inoculate it with the roots of sward from some good grass marshes in the neighbourhood,—a process in which a machine is used, constructed for the purpose of shaking apart, or otherwise separating, the grass roots, and then sowing them on the ground by hand, and rolling them down, by which means a good sward is obtained much sooner than by seeds alone, though both should be resorted to.

"But on the good *silty loams* of an intake, a different mode and duration of cropping may be adopted. Upon such lands, along the coasts of Norfolk and Lincolnshire, the usual course of cropping is 1, beans,—2, oats,—3, wheat, and they get better wheat after the oats than before, the straw being less bulky and less liable to 'go down.' But even in the case of such soils, if the argillaceous particles are in such abundance as to produce an unctuous texture or slipperiness under the feet when rather wet, they may judiciously be subjected to the rotation prescribed for clays, and treated similarly.

"There must, however, be a very great difference of treatment with regard to those light, loose, sandy soils, of which some spots of the intake level will be found to consist, when taken from the low slobs of a sandy shore which has been covered by every tide. Such loose sands, if *blowing when dry*, should be fixed as soon as possible by any feedable grass, that can be made to grow upon them, until a better sward can be produced. On such loose spots the *agrostis maritima* or *sea-side fiorin* has grown luxuriantly, especially when the *stolones* have been planted in a wet sod of bog turf, and that trodden into the sand. The shoots from these sets have been extremely vigorous, the cattle have sought and eaten them with avidity, and the treading thus induced has fixed the sand, whilst the droppings of the cattle, containing the undigested seeds of other grasses, have soon brought up a good sward wherever the drainage was sufficient for its establishment.

"In such cases of loose sand, no tillage need to be, or perhaps can judiciously be, contemplated. Such soils are already sufficiently open to part with their excess of saline particles, and are generally sufficiently homogeneous not to require admixture by stirring, unless it be by harrows on the surface, to let in the Dutch clover seeds that may with propriety be sown thereon, when that brought by cattle shall be permanent enough to show an aptitude in the soil for that plant. These seeds, after being thus sown in moist still weather, should be rolled down, and if the soil has been well drained and freshened, it is more than probable that a good grazing marsh will be established, at less expense, and in less time, than could be effected by any other means; since if the clover thrives, the cattle will lie so constantly on those spots as to enrich them more than any others.

"The cultivation of rape for seed has been much relied upon with reference to these newly acquired lands, as the first crop thereon; but it should be recollected that the price of this seed is much reduced by importation; that such crops on new grounds generally come very unequal; that it is a crop very liable to injury by frosts on low grounds; that the climate of this country does not admit of any good chance of saving any very *large* breadth of this crop; that the straw is valueless; and that it occupies the ground for two years, although on this latter point there is a remedy in a species of rape formerly grown on the Lincolnshire Wolds, which ripened the same year as sown. The merits of rape, however, are that it will grow on crude and not perfectly prepared land, and costs little for seeding, and if the land be clean, is not a bad forerunner of wheat.

"Mustard is another of those crops, which, being somewhat more valuable than common corn crops, are reckoned on as a means of returning some portion of the great outlay incurred upon an intake. The brown mustard taints the land worse than any weed, as is instanced in Canvey Island, Essex, where it is harvested with the beans, and is sometimes the best crop of the two. The white mustard has not the property of lying in the land, but requires a finer tilth and better soil than the brown sort, and an intake would require a lapse of time to prepare it for this crop, or for any other of the seed crops usually cultivated as extra valuable on the rich soils of Essex or Kent.

"Woad and other dye plants are also valuable, but require so much accommodation of buildings and machinery as to be quite inapplicable to the general circumstances of an intake. Chicory might do on deep sands when quite freshened.

"The benefits of irrigation have been much reckoned on with reference to some recent intakes which afford a command of water, and as an ultimate means something of this kind might be applicable to the higher portions of a level. When, however, it is duly considered that irrigation is only applicable to cases admitting of complete and quick drainage, and that the greatest difficulty in almost all intakes is timely to get rid of superfluous water, it will appear that this mode of augmenting value can but seldom be relied on to any great extent; nor does the farming system of marshes, whether in tillage or grazing, at all assimilate to that in which water meadows are valuable auxiliaries.

"To sum up this head of our discourse; the great and leading points for the guidance of the adventurer, in reclaiming his intake, are the following:

1. To freshen gradually;
2. To drain effectually;
3. To cultivate perfectly;
4. To crop moderately;
5. To look to grazing ultimately;
6. To lay down to grass carefully;

and in proportion to the perfect accomplishment of these points, will be the value of his land; *i.e.* it will, in the case of neglect or imperfect execution of them, become only coarse pasturage for young stock . . . ; or in the case of their perfect accomplishment, the lands will come, as near as their soil will admit, to those grazing lands of intakes in Sussex, which carry a fatting ox of 130 stone (8 lbs.) per acre, . . . or to those of Kent, which carry six or eight large sheep per acre; or even to some more favoured spots in Lincolnshire, which used to fat *ten sheep per acre to* 40 lbs. *per quarter, clipping* 14 lbs. *of wool each;* or others in that county, which carry a large ox per acre and several sheep besides." [168]

Mr. James Oldham, M. Inst, C.E., writing in 1862 respecting a Reclamation at Sunk Island in the Humber, whereof mention has already been made, gives the following brief account of its treatment for farming purposes. The local conditions are different from those contemplated by Mr. Wiggins, whose remarks apply more especially to the treatment of lands reclaimed from the sea itself: the situation of Sunk Island, on the estuary of a large river bringing down great volumes of fresh water, seems to have rendered unnecessary the operation of freshening the soil—a view deriving corroboration from the plenteous growth, shortly after the shutting-out of the salt water, of clover, its seed probably washed down by the river; a feature strongly contrasting with the case cited by Mr. Wiggins of sea-washed land left to itself after being embanked.

"The freshwater door" [of the sluice], says Mr. Oldham, "is used for the purpose of holding up fresh water in the drains, and for flushing and scouring the sluice and outfall, which is liable to be silted, in the summer, or when but little fresh water is running out. In very dry seasons, the sluice is used for taking in a quantity of tidal water, to fill or charge the fence ditches, and the cattle are thus prevented from straying; for the fields are generally only divided by ditches, and as the subsoil is of a sandy and porous nature, the water in them rapidly disappears.

"Soon after the exclusion of the tidal water from the surface of newly-embanked land, the marine grasses and vegetation begin to die and decay, and in the course of a year, or two years, fresh-water grasses appear. After the lapse of about three years, a tolerably good surface of pasture is naturally formed, and it is capable of sustaining a considerable number of cattle. But that which is most surprising, is the spontaneous appearance, and the growth, on the inclosures of Sunk Island, of an entire covering of white clover, which presents itself within three years, or four years of the date of the exclusion of salt water. . . .

"After the completion of the embankment, and the subdivision of the land, a selection is made as to what portion shall remain as pasture, and what shall be worked by tillage. Some trifling labour devolves on the farmer, in levelling irregular places on the surface; he then ploughs and prepares for a crop, and generally the first on the land is rape. This is sown about the third year or fourth year after the inclosure, and the produce is usually of extraordinary quantity and vigour. The following season oats, or beans may be sown, and then wheat, and perhaps, of all the districts in England, the largest and best crops may be found on Sunk Island, for the tenants admit that the land produces upwards of six imperial quarters of wheat per acre. Flax also is produced of a fine and valuable quality, and in large quantities. The producing power of this description of land is not limited to the growth of cereals, or fibrous products, but the finest roots, such as potatoes, turnips, mangold wurzel, &c., are successfully cultivated."[169]

The land reclaimed on Wexford Harbour received a treatment somewhat different from either of the foregoing.

"For the first three years after the reclamation on the north side was completed, the land was put under corn crops, with very slender success, many parts being perfectly barren. Where crops did grow well, there was a considerable admixture of sand or gravel in the mud. The limeing recommended by Professor Sullivan was resorted to, to the extent of twenty barrels (of 280 lbs.) to the acre, with very encouraging results, converting barren into productive land. Later on the limeing was increased to from forty to fifty barrels per acre, by which means luxuriant crops, particularly of wheat and barley, were grown. Green crops, clover and grasses, answered admirably, and the pasture improved in fattening qualities. The drainage, up to the present [1862], is still deficient, the water never having been more than 3 ft. below the surface; but when, with the assistance of the new machinery, the water is kept down 5 ft. or 6 ft., the value of the land will rise from 25 to 30 per cent. The experience of nine years in the management of the north side, together with some experimental farming on a very small scale on the south side, and an analysis indicating somewhat better land, justifies the conclusions that it requires the same treatment. The land should be turned up deeply by steam ploughing, for which it is peculiarly adapted, left to lie fallow for a year, and then heavily limed. After such treatment abundant crops may be certainly expected. Fortunately there is an abundant supply of limestone on the south side; it is brought to the limekilns, at a very low rate, by small sailing lighters." [170]

The intake at Holkham, on the north coast of Norfolk, is a sea-reclamation of 580 acres, embanked in 1856-58. Of the 580 acres, more than 200 acres adjoining the old grass-marshes were a strong clay loam; 170 acres strong blue clay or clay-loam, buried beneath the sand to a depth of from 6 inches to 3 feet; and 130 acres were either shingly stones, or sea-sand, to an unknown depth. Upwards of 370 acres were therefore good land. The following description of its treatment, given in 1867 by Mr. Shellabear, the steward of the owner, is specially instructive in details relating to the subdivision of the land and the actual work of setting out drains &c.

"In the autumn of 1859 the land was laid out for division into fields. One road was formed, passing through the entire length, and crossed at right angles at intervals of about 500 yards by two others. These roads are each 30 feet wide, and are bounded on each side by a ditch. The lands between are again divided by a ditch into fields, varying in extent from 10 to 20 acres. Every field, therefore, has access to a road and is square—two very important advantages with steam-cultivation.

"In bringing it into cultivation the next operation was to fill up the large creeks throughout the farm, sand being brought from a distance where necessary by means of a portable tramway worked with horses, or moved from the adjoining lands, where available, by barrow roads: in either case the creek was ultimately brought to the level of the land on each side by a coating of soil of similar quality. In the same way the small creeks which appeared only in the stiff lands were filled up, or else by digging,—and thus reducing the level of the adjoining land. By the summer of 1862, a large breadth of this land had been brought into cultivation; coleseed, peas, wheat, and oats were grown upon it, and a further portion was sowed with wheat—when the sea again came over it. Up to this date the crops were better than they have been at any time since, and it seems probable that the cultivated lands, especially those which had been subsoiled, became more strongly impregnated with the salt than when in their original state. The damage done to the watercourses and roads was inconsiderable; but the land had become so thoroughly saturated as to be incapable of bearing horses until late in the spring, and the roots of autumn-sown corn were destroyed by the wet and salt in the land.

"Underdraining, which had been done partially before, was now systematically commenced, and up to the present time [1867] about 230 acres have been drained with $1\frac{3}{4}$-inch pipes, at a distance of 12 yards in the clay and 24 yards in the sandy subsoils—nearly all the drains emptying into the ditches. The fields being all flat, considerable difficulty was experienced in maintaining a regular and proper fall in the drains, the slightest dip causing the drain-pipes to silt up in the sandy lands. The plan now adopted is to set out the level of the outlets in the ditches, and a point 4 feet above the bottom of the drains to be cut across the centre of the field, with a spirit-level, adding the rise to be allowed in the drains. From these two points given him, the foreman is enabled to give an even fall to the bottom of the drain throughout its length, by placing a T staff 4 feet long upon the level point at the outlet, and having a similar staff moved up and down the drain, aligning it upon the level given him in the centre of the field. Four levels only are given in each ditch, and four across the centre of the field, the remainder being put in with the T staves in the same manner. By this means the work is satisfactorily done, and the foreman is able to superintend the whole, check the levels of every drain, and assist a second man in laying the pipes in the drains, of which about 16 to 18 chains are cut every day from April to August, the work being impracticable in winter.

"Four hundred and twenty acres of the land have been cropped, but only 340 are at present under cultivation; the remaining fields are being treated as follows: Some of the heaviest clay lands are being sanded to a depth of 3 or 4 inches by means of the portable tramway (two horses drawing a load of from 4 to 6 tons), 8 or 10 inches of sand being taken from the sandy fields for this purpose, and to bring the clay beneath within reach of the steam-plough. In other fields where the clay is at a greater depth, pits are sunk, and the clay is barrowed upon the land to a depth of 5 or 6 inches (when solid), the surface-level having been previously reduced by barrowing the sand into the last pit sunk ; in other parts where the clay is from 12 to 16 inches from the surface, or where the sand is not required for the heavy lands, the ground is trenched, and from 8 to 10 inches of the clay brought to the surface : but in these cases, from the frequent occurrence of creeks in the clay below, the sinking of a pit is often necessary to complete the field and make the soil equally good throughout.

"With respect to cultivation but little at present can be said. Good crops of wheat, oats, barley, coleseed, turnips, mangold-wurzel, and clover have been grown upon the land, both before and since the winter of 1862 ; but it was not until the summer of last year [1866] that the land can be said to have recovered, to any extent, from the flooding of that time. As soon as the fields have been drained, they are broken up with Fowler's steam subsoil plough to a depth of 16 inches, allowed to lie the winter, and put under crop the following year." [171]

# CHAPTER VIII.

## *EXAMPLES, VALUES, AND RENTS.*

The chief objection to adducing particular instances as examples of Reclamations consists in this: that before any such instance can be regarded as a truly typical and trustworthy guide in similar undertakings, a vast amount of detail respecting it needs to be ascertained and specified, without which it is illusory and misleading so far as concerns its applicability to the special case contemplated by the inquirer. These details however, in their entirety are not and probably can not be known. For this reason, caution must be exercised in drawing and applying conclusions: indeed it is not too much to say, that only in respect of conditions and facts which can be beyond doubt ascertained to be exactly parallel to those of the contemplated case, can any conclusion with reference to it be safely drawn from an example. With this qualification, the following works of reclamation may be given. It is to be premised that, early and old Reclamations being even less instructive than recent ones, those here presented have been selected from works executed since 1840, and that they, in common with those noticed at pp. 243-248, are worth attention chiefly with respect to certain particulars concerning execution and subsequent treatment.

"Some embankments have taken place under 1 and 2 Vict., chap. 87, a special Act for that purpose, along the shores of Lough Foyle, in the county Derry, Ireland, which seem likely to prove but the commencement of similar, or perhaps more important undertakings, in that highly improvable country. About 3,500 acres have been excluded from the sea on the south side of this Lough, and as the soil in general affords every indication of the highest fertility, great ultimate returns are expected. Two different modes have been adopted by different parties in this undertaking; one having raised his bank by barrows and planks with the soil of the shore on the spot, which is a sandy silt or sea-mud drying into a whitish shelly sand composed of very minute particles; the other party having run out his earthy material and stone from the shore, upon tram-roads and waggons, drawn both by horses and locomotive engines. The whole face of the bank from foot to top is *pitched* with stone 18 inches deep, set edgeways, with a slope of about 4 to 1 more than half-way up, and then somewhat steeper to the top, which is 4 feet wide. The spring tide here rises 9 or 10 feet, but the outbursts are great, and the top of the banks will be, say 16 feet above the low-water line.

"Both parties have experienced those accidents to which these undertakings are subject, viz. very high tides before completion washing away material, leading to the conclusion that it is better to make up the bank to its full height at once as it proceeds, and also the conclusion that sufficient *height* is the one thing needful, and that the want of it is the rock upon which all these kinds of works are most likely to split." [172]

"In 1843 a bank or 'cop' was built by the joint efforts of the Hon. E. M. Ll. Mostyn, and J. P. Eyton, Esq., called the Bychan embankment, situated between Llanerchy-mor smelting-works and Mostyn colliery in Flintshire, being on the western estuary and near the mouth of the river Dee. Its dimensions are, base 87½ feet, height 16 feet, sea-side slope 59½ feet, of which 42 feet from the foot were stoned, landside slope 32¾ feet, and 2 feet wide at top, giving the following section.

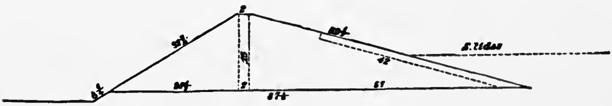


Fig. 28.—Bychan Bank.

"The length of the bank is 1,974 yards, or rather more than one mile and an eighth. The cost was £4,500, less the barrows and planks which were used in making up the bank with the sea-sand on the spot, and might be worth £50 when completed. The cost therefore would be £4,000 a mile, or as nearly as possible sixpence per cubic yard for the whole, including stone, which however was not placed over the whole face. When first laid on, the stones were thrown promiscuously on a layer of straw, gorse, or brushwood, which was put on the face of the sand, but the winter tides brought a part of the stones down to the base, and it was found expedient to replace them edgeways, paving them regularly and smoothly on the surface, in which process it is found that the larger the upper stones are, the better. The distance the stone had to be carried was about a mile and a quarter, and the cost was 13d. per ton, viz. 4½d. quarrying and 8½d. drawing; the total cost was reckoned at 3s. per square yard. The part not stone-faced was covered with sods in two thicknesses, each being about eight inches thick; but where stone was used, the sods from them to the top of the bank were only $2\frac{1}{2}$ inches thick, cut with a push plough; the inside slope was cut $3\frac{1}{4}$ feet deeper than the level outside, so as to have a larger facing, and to put a cover to make it a cart-road. The highest spring tides on the sands outside of the bank do not rise more than 7 feet *on the bank*, if in a quiet state, but in stormy winds blowing into the estuary, the waves reach nearly to the top of the bank. The land obtained is about 70 acres, but it is in a situation which gives it great local value, and with a probability of coal beneath. The Chester and Holyhead Railway will pass through it. The back of the bank will be sown with lucerne, of which there will be $4\frac{1}{2}$ acres." [173]

The foregoing is an instructive example of the way in which circumstances affect the question of expenditure upon a work. The cost figures out to something over £63 per acre—an amount doubtless foreseen before the work was commenced: the expectation of finding coal, together with probably other considerations of which we know nothing, making it worth while to incur this large expense. Yet, take this rate of £63 per acre and put it into a statement, either of separate or of average cost, without at the same time specifying the whole conditions under which it was incurred—and of what value does it become as a guide in estimating the cost of a proposed work?

On a tidal Reclamation at Lough Foyle, probably—though this point is not material—of later date than the one first cited, shallow surface-drains were formed after the salt water had been excluded, and in about two years rye-grass grew pretty freely, but exceptional spots remained barren for some time. The grass was followed by oats, which improved as the salt left the soil. Deeper draining allowed the cultivation of flax and clover. Afterwards, on still deeper draining, all ordinary crops began to grow well,—wheat, beans, turnips, mangold, and carrots, but all requiring as much manure as any old upper land. These slob lands yield a great return for manure, but must have manure on the lower and damper portions. Fiorin grass grows well without manure. When the ditches have so far drained the soil as to allow of its becoming cracked and open to the air, the crops begin to increase in produce. But the full value of the soil is never known until thoroughly under-drained with tile or stone; it then yields excellent crops of almost any produce, clover and rye-grass for hay being perhaps the most profitable. Grazing the land does not answer, except from the middle of May to the beginning of September; after this the soil is too cold and damp for the beasts to lie down, and they begin to fail. The expense of these intakes on the Foyle may be taken at about £20 per acre to get them from the sea, and the expense of bringing the land into cultivation will come to at least £10 more, making a total of £30 per acre. The best lands were said in 1874 to be worth [in rent] from about 63s. to 50s. per acre, and the lowest and wettest parts perhaps not more than about 12s. 6d.—say 38s. as a fair average. To this has to be added the expense of keeping up the banks and pumping water. The above remarks may be held generally to apply to Reclamations made about the same time on Lough Swilly, and certainly do not present encouraging views as to these Reclamations regarded as a mercantile speculation.[174]

A portion of the land on Morecambe Bay enclosed by the Ulverston and Lancashire Railway in 1856 was grassed over, the remainder being sand without any vegetation on it. After it was levelled it was divided into fields by open ditches and iron fences. The ditches had to be made very wide at the top in order to get them to stand. The land was then drained with 3-inch pipes, each drain opening into the ditch on each side of the field. The tiles were embedded in peat moss, to act as a filter to prevent the sand from running into them. The sand is so fine that without this precaution the drains would have filled up very quickly. The drainage was the great difficulty, the pipes being very apt to fill up after every precaution had been taken. On the portion that was grassed over before it was enclosed, two crops of oats were first taken, and then it was green-cropped. It grew for a few years good crops of wheat, beans, and clover, as also Swedish turnips and mangolds, but though a great quantity of manure was used the crops fell off, and in 1874 it was nearly all in grass. The portion that was bare sand when it was enclosed was treated in the same way, except as to the first two crops of oats. It was green-cropped after it had been enclosed about two years. After the railway was made, there was no means of warping that portion of the enclosure which was sand : the tide was entirely kept out. Had it been admitted, the lands would have been much more valuable and much higher, with better drainage and a richer soil. The portion that was already grassed over at the time it was enclosed was still [1874] much the best.[175]

In the foregoing examples, some mention has been made of the rental and the purchase value of land. To this may be added some further particulars derived from various authorities.

*Warped land before enclosure.* Rent.—On the Humber the foreshores when they have grown into salt-marshes are useful for the grazing of sheep, and in 1876 were said to let at from 5s. to 6s. per acre. In the same district, it was stated in 1877 that [arable] land let at from 50s. to 60s.; some, owing to special advantages of position, fetching as much as £5 per acre: the average rental being about 60s. On the Swale, in Kent, saltings or accretions some time before the surface reaches a level fit for enclosure, afford good pasturage for sheep, and in 1883 realised rents varying from 2s. 6d. to 10s. per acre.

*Warped land before enclosure.* Purchase. — On the Humber, the sum of £20 per acre was taken as a fair standard for the value in 1876 of a salt-marsh fit for enclosure: some years previous, the value was from £18 to £20 per acre.

*Reclaimed land.* Rent.—On the Humber, large quantities of land were, between 1831 and 1876, let immediately after enclosure for 40s. to 60s. per acre: in 1876, land immediately after enclosure let at from 40s. to 50s. per acre. In the estuary of the Dee, some reclaimed land is reported in 1883 as returning a rent of from 20s. to 52s. per acre; some reclaimed land in Lincolnshire as being let immediately after enclosure at from 40s. to 60s. per acre; newly-reclaimed land on the Swale, 10s. per acre, and five years after enclosure 20s. per acre, as grazing land. At Faversham, newly-reclaimed land, worth in 1868 a rent of 6s., was in 1883 valued at 20s.

*Reclaimed land.* Purchase.—On the Humber, some of the land below the Cross Keys embankment, enclosed in 1842, sold in 1847 for £80 per acre. In the same district, recent enclosures were reported in 1876 as selling at the rate of £60 per acre; and newly-reclaimed land as being valued directly after enclosure at from £50 to £60 per acre. Some land in Lincolnshire, valued at £18 per acre in 1873 when first enclosed, was worth £40 in 1883, the best parts realising £80 per acre.[176]

An instructive supplement to these figures is the following :—

"In 1849 Mr. Clarke estimated the average [rental] value of the land in the Fenland at 40s. an acre.

"From a report, made by the Boston Branch of the Chamber of Agriculture, in January, 1895, it is stated that rents varied in that district, from 15s. to 30s. an acre, the average being 24s. or 25s. Since 1880, there has been a reduction of from 30 to 50 per cent. A large farm of mixed soil, rented at £1,600 in 1880, was now let at £800. . . . As regards profits made by the tenants, in 1880 they averaged about £1 an acre, whereas, at the time of the report, there were no profits, save in exceptional cases.

"Mr. Wilson Fox (Commission on Agriculture, 1895) gives the rents as averaging, in the Wainfleet District, 30s. to 50s. for marsh land, 25s. to 45s. for fen land, and 60s. to 100s. for toft, or early potatoe land; near Boston, for the very best land in small holdings, 60s. to 100s.; farms of about 60 acres, 40s.; Spalding District, 30s. to 40s. Some heavy clay land was let as low as 5s. an acre.

"There is a great demand for land suited for growing early potatoes, and from £4 to £5 an acre is given for this.

"Taking an average, in the neighbourhood of Spalding, the reduction of rents on small farms, of from 20 to 70 acres of good land, is estimated to be from 30 to 50 per cent. during the past 20 years; on farms of 70 to 250 acres of good land, 30 per cent.; on farms of 250 acres and upwards, 30 to 40 per cent.; and where the land is bad, 70 per cent.; in the neighbourhood of Grantham, 50 per cent.; and round Sleaford, 33 per cent. on good land, and 60 per cent. on land of bad quality.

"The Lincolnshire Chamber of Agriculture put the reduction at from 25 to 40 per cent. for good land.

"The following examples, taken from Mr. Wilson Fox's report, will show what the freehold value of land was when times were good, as compared with what it is now, in the depressed condition of Agriculture. An arable farm of 300 acres at Spalding, of fair quality, having mixed peat and clay soil, was purchased in 1876 for £19,000, or about £63 an acre; and in 1894 could not find a purchaser at £23 an acre. Another peat farm, in the same locality, of 100 acres, bought 18 years ago for £65 an acre, was sold in 1894 for £23 an acre. A farm of 461 acres, bought in 1885 for £65 an acre, was sold in 1892 at the rate of £13 an acre. A farm of 110 acres of good alluvial soil, at Kirton, bought in 1870 for about £74 an acre, could not be sold for £40 an acre in 1891. A farm of 118 acres, in Blankney Dales, bought in 1877 at the rate of £65 an acre, was sold for half this in 1894; and a farm of 92 acres, at Whaplode Drove, the original price of which was about £85 an acre, could not be sold for £40 an acre.

"The fall in the freehold and rental value of land is due to the unfavourable seasons and the low prices of produce. During the series of wet seasons, 1874-1882, the condition of the land became seriously affected, the pastures were deteriorated, and the manure washed out of the arable land and there was no opportunity of properly cleaning it. This resulted in a decreased yield and in rot in the sheep. On farms where 10 quarters of oats were grown to the acre, the yield fell to 7, and where 7 or 8 quarters of barley were grown, only 5 or 6 could be harvested. Following on the bad seasons, began a decline in prices, which has since continued. Between 1874 and 1894 the average price of wheat has fallen 60 per cent.; of barley, 53 per cent.; and of oats, 50 per cent.; the average price of wheat for 1874-1884 being 44s. 9d.; for 1894, 19s. 2d.; barley for the same period fell from 35s. to 20s. and oats from 22s. 4d. to 14s. 6d. Wool also has steadily decreased, the average for 1873-1877 being 40s. 2d. a tod; 1883-1887, 21s. 3d. and 1893-1894, 21s. 4d., a decrease of 46 per cent. Cattle have fallen in price during the 12 years, 1882-1894, from 28½ to 34 per cent."[177]

The picture thus presented is not encouraging to sanguine expectations of profit. And fortunately so, since this makes for safety. Highly-coloured statistics, while powerless to aid success, may bias the mind and unduly influence judgment. Thousands of acres still await reclamation and offer a fair reward to well-conducted enterprise. And modest—even under-stated, figures, *per se* ineffectual as absolute deterrents but inducing deliberate and diligent examination, may tend to promote the prosecution of undertakings unpromising at first sight, whose intrinsic soundness is shown up all the better through subjection to the ordeal of rigorous scrutiny.

Finally: as a consideration of paramount importance, the necessity of heedfulness cannot be too strenuously pressed upon him who purposes entering upon the business of Reclamation; and his attention is earnestly invited to the following precautions on no account to be omitted:—

First.—Let him ascertain the nature and quality of the soil or soils over the whole intended intake. A great deal of land has been reclaimed before it is fit: such land has no heart in it.

Second.—Let him learn what terms can be made with proprietors, frontagers, and others, as to their claims (if any) in the matter; and what provision will have to be made for legal and all other similar contingent expenses.

Third.—Let him obtain at the hands of a competent adviser, a design and inclusive estimate of cost for the works required.

Fourth.—Let him allow for interest upon the whole amount of money expended, unfruitful until cultivation is completed and returns begin to come in.

Such amounts, together with a margin of not less than 20 per cent. on construction and 10 per cent. on all other items of outlay (and as much more as the financial aspect of the affair will allow) for contingencies—will make up the equivalent of capital to be provided.

Fifth.—Let him then ascertain what is the actual present value of land of similar quality or qualities in the district, and take an average of the *lower* figures of that valuation.

If the result of all this shows a positive profit, or a rental sufficient to cover sinking-fund and satisfactory rate of interest:—in such case, let him decide for himself.

If, on the other hand, the result shows anything less:—in such case, let him hold aloof from the speculation.

## CHAPTER IX.

### Legal Requirements: The Parties to Works of Reclamation.

Before concluding this volume, some reference may be made to the preliminary negotiations and arrangements with adjoining landowners, and other persons or bodies interested in the lands to be affected by a proposed embankment, which will require the attention of the projectors before any such project can take a substantial form.

As regards the land sought to be reclaimed or inclosed, the present ownership of such land is necessarily the first fact to be ascertained. Where lands adjoin a river, the soil of one-half of the river, from the banks on either side to the middle of the stream, is presumed to belong to the respective owners of the lands adjoining the stream, except in the case of a *tidal* river, the soil whereof up to high-water mark belongs presumptively to the Crown. The Crown is also presumptively entitled to the sea-shore up to high-water mark of medium tides, although on many parts of the coast grants of portions of sea-shore have been made at different times to private individuals as well as to public bodies;[176] and it is well established that, where documentary evidence is not forthcoming, such grants may be presumed by proof of long-continued and uninterrupted acts of ownership.[177]

As to the ownership of the soil affected by changes in the flow of the sea, the legal position may be briefly stated as follows: A sudden irruption of the sea gives the Crown no title to the land thrown under water, although when the sea makes gradual incroachments the rights of the owners of the land to which the incroachments extend are as gradually transferred to the Crown; and in like manner, when the sea gradually retires, the rights of the Crown below the original high-water mark are as gradually transferred to the owners of the adjoining coast-land. But a sudden dereliction of the sea will not deprive the Crown of its title to the soil.[179]

The charge and management of the rights and interests of the Crown in foreshore lands is now (under the Crown Lands Act, 1866) vested in the Board of Trade, with whom it rests to make grants of the foreshore, where required for useful works which can be carried out consistently with the public welfare. Such grants are made either in perpetuity, or for a term of years.

If it happen that any proposed works of embankment will involve the inclosure of adjoining common lands, or other interference with rights of common, application will be necessary also to the Board of Agriculture, with whom (under the Commons Act, 1876) now rests the administration of the several provisions of the Inclosure Acts, 1845 to 1882. Should the proposed interference with common rights be such as to require confirmation by means of a Provisional Order under the Act of 1876, the persons making application to the Board of Agriculture in that behalf must represent at least one-third in value of the interests proposed to be affected, and consents to the Order must be given by persons representing at least two-thirds in value of such interests, and by the Lord of the Manor; but inasmuch as the Provisional Order will itself require confirmation by Parliament, the case may be one in which the projectors would do well (as is often, for various reasons, found to be necessary) to proceed by way of a Private Act of Parliament authorising the proposed works, and granting them all necessary powers. It may be assumed, however, that no authority would be given by Parliament to inclose any common land, or to vary or diminish rights of common, without reference to the attitude of the Board of Agriculture, who, therefore, in any case affecting common rights, would have to be reckoned with by projectors.

Further, where the inclosure of a common is proposed, the Commons Act, 1876, now requires that special information shall be furnished to the Board of Agriculture as to the reasons why an inclosure is "expedient when viewed in relation to the benefit of the neighbourhood," so that it may be taken for granted that no inclosure will be sanctioned in future unless shown to be of "benefit to the neighbourhood," as well as to those legally interested in the common itself. Where the freemen, burgesses, or inhabitant householders of a borough have rights in a common, the consent of two-thirds in number of such freemen and burgesses as are resident in the borough, or within seven miles thereof, or of such inhabitant householders, is required for any inclosure under the Act.

It may further be noted, that under the Local Government Act, 1894, District Councils are empowered to aid in preventing the extinction of rights of common, and to regulate the use of common lands.

Should the proposed works involve interference with existing highways, the powers of the District Council will again be called into exercise, the Local Government Act, 1894, having imposed on the Councils the duty of protecting all public rights of way and preventing their closure or obstruction, and of preventing any unlawful encroachments on roadside wastes.

Under the same Act, the Rural District Councils exercise the functions originally conferred upon vestries of adopting or initiating proceedings for the stopping-up or diverting of highways, under orders to be made by Justices at quarter sessions under the Act 5 & 6 Will. IV. c. 50.

As pointed out by Mr. Wiggins,[180] in almost all cases where the embankment of a large space or extent of sea frontage is contemplated, several frontagers, or adjoining proprietors, will have to concur in the measure, in addition to the representatives of the Crown, or other person or body in whom are vested rights of foreshore; and if, as often happens, only some of the parties whose concurrence is requisite are in a position to give such consents as shall be legally binding on their successors, it becomes, in many cases, absolutely necessary to seek Parliamentary powers. For this purpose application may be made by the projectors to Parliament, as soon as they have obtained sufficient consents, in number, of the parties concerned, and a sufficient proportion in value, to enable a Parliamentary Committee to entertain the Bill. The provisions of such a Bill will have for their object, on the one hand, to secure to the public, the frontagers, and all other interested parties, *either* a continuance of the enjoyment of all their property, rights, privileges, and conveniences, *or* a compensation for the loss of them; and, on the other hand, to secure to the projectors the fullest means of carrying their project into effect, and the fullest enjoyment of it when effected.

As opposition to a Bill necessarily increases the cost of proceedings before the Parliamentary Committee (without whose approval of its provisions the Bill cannot receive further consideration in Parliament), the true policy of the promoters is to disarm opposition as much as possible before coming to Parliament, by concluding agreements wherever practicable with the various interested parties, and thus lessening the chance of defeat before the Parliamentary Committee by predisposing that tribunal in their favour. Even at the best a contested Bill must be a matter of some cost, which may be substantially lessened by previous consents.

According to Mr. Wiggins,[181] *one-tenth of the land embanked* has been mentioned as the probable expectation of the frontager, in consequence of that proportion having been given in some considerable cases of the kind; and this, over and above such pasturable verges or grassy fringes as have already been subject to acts of ownership and occupation on the part of the frontager. But one-tenth (he says) is a larger deduction than almost any intake will allow, so as to leave the adventurers a sufficient chance of adequate remuneration for their enterprise.

Still, the frontager must be compensated, since he loses conveniences and easements of value—such as the feedage of the pasturable verges; he loses also something from having the sea further removed from his upland, and if he gets manure from the shore, the embankment will in this respect be some hindrance; further, he loses the opportunity of making the same speculation as the adventurers.

In discussing the extent of compensation properly allowable to a frontager, Mr. Wiggins points out that in the case of the inclosure of the waste or common of a manor, the lord of the manor would commonly receive from one-twelfth to one-sixteenth of the commonable land in respect of his manorial rights—namely, his absolute right to the soil and a portion of the herbage, and his right of granting portions of the soil to copyholders. The lord has also a right not only to all the timber growing on the waste, but to all timber on a copyholder's lands, although he cannot come upon the lands to cut his timber, or to work the minerals on and under the soil, without the leave of his copyholder, and his claim to the timber is on some manors commuted by custom for a one-third or other defined share thereof. Yet to a lord of a manor, the actual share of waste lands allotted upon inclosure has seldom been more than one-sixteenth, sometimes one-twelfth, and in some cases only one-twentieth, although the lord is undoubtedly in the enjoyment of actual rights of property to a greater amount than any frontager to seaward in foreshore lands, where slobs or mud-banks are covered by every tide.

Another case cited by Mr. Wiggins is that of mines or quarries, where the accustomed royalty, seignorage, or groundage varies, according to circumstances, from one-eighth to one-twelfth, one-sixteenth, or one twenty-fourth; and he arrives at the conclusion that *one-fifteenth* may be reasonably taken as the fair share of an intake to be rendered to the frontager, in lieu of rights in and over such surfaces as are covered by every tide.

As to the pasturable fringes, Mr. Wiggins further observes that it would be very disadvantageous for the projectors not to secure them, since the great disadvantage of the kind of property created by an embankment is the uniformity of its nature, and the absence of the "shift"—in other words, of that change of soil, of aspect, of herbage, of crop, and of all local circumstances—which is found so requisite to successful farming.

Now the only alleviation of this disadvantage of an intake is to be found in the higher levels of land constituting these fringes, or pasturable verges (called on the eastern coasts of England "salts" or "saltings"). On some portions of the coast, the verges consist of shingly or sandy dunes or downs, which are very seldom covered by the tide even at outbursts, and which not only afford the only approximation to a "shift," but also the only secure and healthy place of habitation, as well as place for the folding of cattle for shelter.

On the other hand, it should be recollected that the frontager will be relieved from all future expense of defence against the sea, and of repairing damage which the sea may possibly occasion to his property; and in consideration of these advantages he should in fairness class his verdant frontages with the other lands to be embanked.

Any proposed arrangement with a frontager should, therefore, include the frontager's verges up to the present sea-defences, if he has any, and if not, up to the high-water mark.

It may, however, be more convenient to a frontager, instead of an allotment of a defined portion of the land to be embanked, to have a money rent reserved on the land to be gained; and it then becomes a question what this rent should be per acre. To settle this question, two points have first to be determined: (1) What would be the fair proportion of land to be rendered; and (2) The value of that land when embanked, and *before* any of the operations of drainage or reclamation have been commenced. These points settled, the amount of rent to be reserved is a matter of calculation only.

In estimating, on the one hand, the probable benefits derivable from an intake, and on the other hand the cost of the undertaking, Mr. Wiggins[182] gives (as applicable at the time of writing) the following statement " as the result of good management, attended by such a share of good fortune as might reasonably be expected " :—

| | | |
|---|---|---|
| Say 1,000 acres, of the value when embanked and drained of £40 per acre . . . . . | | £40,000 |
| Cost of embanking and draining . . | £20,000 | |
| —— of 1s. 6d. per acre for $\frac{1}{15}$th . . | 1,500 | |
| —— of occupation roads, gates, etc. . | 1,500 | |
| —— of Parliamentary and professional expenses . . . . . . | 1,000 | |
| —— of extra works, etc. . . . . | 1,000 | |
| | | 25,000 |
| Yielding, at £40 per acre, a profit of . . . | | £15,000 |
| —— at £35 per acre, a profit of . . . . | | £10,000 |
| —— at £30 per acre, a profit of . . . . | | £5,000 |

These figures (and any figures which may be substituted for them in view of altered values, whether of land or of works, at the present time) will be subject in every case to deduction for loss of interest on money sunk, from the commencement of operations to their conclusion.

A promoter or projector of a proposal for reclamation of land on any extensive scale, who canvasses for consents to such a project, must in some cases be prepared to encounter extravagant demands on the part of frontagers, some of whom will consider that the projectors are about to get rich at their expense or by their means. Any such unreasonable demands may be best met by a full and frank statement of the case as it presents itself to the promoters, and of the manner in which they propose to deal with existing interests. This statement may be conveniently circulated amongst the several persons whose co-operation or consents will be requisite. With this statement, there may also be circulated a draft of the Bill proposed to be submitted to Parliament, accompanied by a sufficient map or plan showing the ground proposed to be embanked, the line of embankment, and a section of the bank intended, with such other particulars as may be necessary to furnish adequate particulars of the works in contemplation. The adjacent rivers and streams, and other features of the country, should be sufficiently indicated on the map, as well as the roads intended to be carried out, and the drainage to be made or continued. There should also be a report from the engineers engaged by the projectors specifying the data on which the proposed works are founded, particularly the rise of the highest tides and of the greatest outbursts, and estimates showing the cost of the undertaking.

The reception given in any particular case to the proposals of the projectors, as thus formulated, will serve to guide them as to their subsequent proceedings; and will enable them to judge whether it be advisable to avail themselves of the provisions of the Lands Clauses Consolidation Act in framing their Bill to be submitted to Parliament. That well-known Act (8 & 9 Vict. c. 18)—the provisions of which may be incorporated with a private Act—was passed in 1845 to furnish (as it has been expressed) "a general code regulating the manner in which lands, or interests in land, may be taken under the authority of Parliament, and compensation made for injury occasioned by what may be thus legalised by the Legislature." [183]

No enlargement is necessary here upon the wisdom of thus endeavouring by a frank and open policy to secure provisionally beforehand the consents required to the undertaking. The promoters, before actually applying to Parliament, will then be in possession of the sentiments of those concerned, and be enabled to judge what amendments, if any, may be advisable in the details of their project, and enabled also to estimate the probability of carrying their Bill against any threatened opposition. An open and candid policy at the outset is not only likely to dispose frontagers and others to give better terms, or to be content with less expensive accommodations, but will also have its due effect before the Parliamentary Committee in favour of the promoters.

It is unnecessary to enter in detail upon the further steps to be taken, and the formalities observed, with a view to obtaining the authority of Parliament for the proposed works by means of a private Act. With this object in view the projectors will have to rely on the guidance and assistance of their legal advisers, acting in conjunction with a professional Parliamentary agent. Here it will suffice to say that, as arrangements for Parliamentary business are necessarily made well in advance, when application is intended to be made for an Act in the coming session, a copy of the Bill representing its provisions—whether intended to be introduced in the first instance in the Lords or in the Commons—must be deposited in the office of the Clerk of the Parliaments on or before the 17th of December. Notice must also be given by advertisement once in the *London Gazette*, and in the local papers once in each of two successive weeks (with an interval of at least six clear days between) in the preceding October or November (but the last of such notices must be not later than 27th November), of the intention to make application for the Bill, with such particulars of its provisions as are required by the Standing

Orders. These Orders provide (among other things) for the deposit with the Board of Trade, at the Private Bill Office, and with local authorities, on or before 30th November, of plans, books of reference as to any properties proposed to be taken, and other particulars, to be open to public inspection; and copies of the Bill must also be deposited in the Private Bill Office, and in certain other public offices, on or before 21st December, for public inspection. On or before 31st December estimates of the expense of the undertaking, and particulars of the constitution of the body by whom it is proposed to be carried out, must be furnished to the proper Parliamentary officials. A deposit in cash, equivalent to four per cent. of the amount of the estimated outlay, will also have to be made.

In the course of the ensuing January the Bill comes before the Examiners, whose duty it is to certify whether the Standing Orders have been complied with, and to report the Bill to the Select Committee on Standing Orders. That Committee, in their turn, report to the House whether any non-compliance with Standing Orders certified to them should or should not be waived; and in the event of any non-compliance which is not waived, the Bill will be lost, as far as the coming session is concerned.

It is subsequently to these proceedings that the Bill is formally presented to the House in which it is introduced, and has to pass through the various stages of first, second, and third readings in the two Houses. In the course of this progress it comes before the Parliamentary Committee upon whose approval or non-approval of its preamble its further progress depends, and before whom appear (besides the promoters and assenting parties or public bodies) the parties, if any, by whom the passing of the Bill is opposed.

The preamble being held by the Committee to be "proved," they then proceed to consider its provisions clause by clause, to hear objections, to discuss proposed amendments, and (should occasion require) to add new clauses found to be necessary in order to meet objections, or more completely answer the objects of the Bill. The Bill is eventually reported to the House in which it was introduced, and (unless re-committed) comes up there for third reading, afterwards going to the other House to pass through its several stages of first, second, and third reading.

It is manifest, from what has been already said, that clear and well-defined notions are necessary on the part of promoters of works of reclamation as to the actual rights of all the parties concerned, and as to the best means whereby these are to be provided for. In this respect Mr. Wiggins[184] has some observations, the substance of which may be given here.

1. First, he says, the *rights of the public* are involved in all such projects by reason of the propriety and necessity of continuing to them the conveniences and accommodations which they have hitherto enjoyed—namely, of roads to the sea-side, navigation of the sea and of the rivers, and that general species of drainage which such rivers, together with the smaller brooks and streams, may have hitherto afforded.

With this view, therefore, all *public roads* should be continued across the embanked lands to the sea; and this according to ascertained dimensions and defined rules as to quantity and disposition of materials, and under proper arrangements for drainage and for future maintenance.

As to *rivers* also, the avoidance of any obstructions to their discharge into the sea should be secured by their embankment on each side across the slobs or shores to be gained; and the lines of these banks should be laid down with an ample degree of divergence, so that the river waters may have a due space for their outfall and escape to seaward. The height and dimensions of these banks should also be specified and fixed, so as to secure their being of such elevation and strength, that neither the tide itself, nor tide and floods together, may be able to overtop or break them; and yet that the land-flood waters may not be impeded so as to drown the lands situated above the intake. These points as to rivers ought not to be left to the projectors only, who may not be aware of the quantity or force of waters coming down a river, or of the liability of that river to flood the grounds near its mouth, or of the lowness of such grounds upon some part of the course of such river. It would therefore be expedient that a qualified Engineer should certify on the part of the public, as well as of the proprietors of lands adjoining such river, that the proposed river-banks will be good and sufficient for all these purposes; and hence, among other reasons, the necessity (as already suggested) of the Engineer's original report specifying the height of tides and other particulars or data.

These points being secured, that of the navigation of the rivers should also be protected. It is sometimes of great consequence to a tract of country that either the actual power of navigating to a certain point up the river, or at least the capability of rendering the river navigable to such point, should be preserved; but this is in great danger of injury or annihilation when embanked, by reason of the accumulation of detritus brought by the stream down from the upper country. Any alteration of the stream, therefore, becomes of great importance in a river where such detritus is abundant; and the width at which the banks should be set, their direction, and the degree of their divergence, are matters of equal importance; since the natural bias of the projectors will be to place the river-banks as close as possible, in order to avoid diminishing the area of the intake, whilst the danger of their being too close is, not only want of sufficient *space* for tide and flood, but such an accumulation of detritus as to leave an insufficient *depth* for tide and flood, and totally to destroy navigation.

To obviate these difficulties, it may be requisite to deal with the rivers far above the bounds of the intake, and to deepen, widen, and embank them, so as to secure them against every mischief to which they may be liable in consequence of the works of the intake; but as this ought to be done by, or at the expense of, the promoters of the scheme, it may be best that such matters should be left to be finally determined in detail by some authority or tribunal to be named in the Act; and should any works done by the projectors, beyond those necessary for the embankment, be greatly beneficial to the public, the district reaping the advantages of such works should be required to contribute towards the cost in manner to be prescribed by the Act.

As in matters of *drainage*, also, the public may be injured by the projected embankment, care should be taken to secure the complete drainage of the lands embanked, so as to prevent malaria, or any unhealthful effects of stagnant waters, as well as to prevent any stoppage of such drains as have hitherto carried the upland waters to sea. On the other hand, waters may be lowered, roads improved, and bridges rendered unnecessary by the proposed new works, in which case also contributions to the cost should be forthcoming from the district so benefited.

In the case of *navigation seaward*, the public will necessarily be driven to a greater distance from the usual landing-places on the shore, and any disadvantage in this respect should be compensated by commodious landing-places, conveniently situated with respect to the roads that are to cross the intake.

In the case of quays or wharfs to be built by the projectors, powers should be taken to charge tonnage or other dues within limits to be specified by the Act.

The public also ought to have reserved to them the customary power of collecting such substances as the sea affords on many parts of the coast—such as shingle, sand, boulders, sea-weed, shells for manure, sea-mud, etc.; but as the unlimited exercise of those powers as hitherto enjoyed might be injurious to the embankment, it ought to be limited within a certain distance of the foot of the bank, by way of compensation facilities for the free landing of such substances should be provided.

II. Secondly, Mr. Wiggins proceeds to say, the due provision to be made for the rights of the *proprietors* of adjoining land, who may be affected by these projects of embanking lands from the sea, and those especially who have been denominated frontagers, will require the fullest consideration; and any Bill proposed to Parliament with the object of reclamation of lands from the sea, whilst it gives powers to the promoters sufficient to carry out their project, must also carefully guard against abuse of those powers by invasion of or injury to existing property without ample compensation.

The property actually taken away will chiefly, if not entirely, comprise that which has been previously described and estimated as share of frontage and pasturable fringes, which should be wholly vested in the undertakers in fee, when the sea has been shut out by them. But in case of the final abandonment of the project for any reason, as it would be hard on the frontager to lose his slob and fringes, provision should be made that if the sea again break in, and the breach made thereby remain open, and the reserved rents thereof remain unpaid for, say, three years, then the slobs and fringes should revert to their original proprietors.

It might be provided, also, that any buildings may be removed within one year after expiration of the three years, but the materials of any roads should not be removed.

If these stipulations be thought too specific for the clauses of an Act of Parliament, they might be embodied in an agreement specifically referred to and allowed by the Act.

III. Thirdly, as regards the consideration of what is due to the *projectors* of an intake or embankment of lands from the sea, the general principles are, that every possible facility and encouragement should be afforded to the projectors, consistently with the rights of the public and of the proprietors or frontagers.

The projectors, accordingly, should have power to enter upon lands, and to take materials fit and proper for their purpose; also to make roads for the conveyance thereof, and to make catchwater drains, and to erect temporary buildings, and for all other purposes that the prosecution of their work may require, subject, of course, to every reasonable restriction necessary for the interests and convenience of the proprietors, without too much reducing the powers of the projectors.

The projectors should also be enabled at a future period to embank any further portion of the shore than that laid down as their exterior line of bank; and the extent of their rights over such portion as remains unembanked should be clearly defined by the Act; saving to the public and to the frontage proprietors, until embanked, such rights and privileges as they have been hitherto accustomed to enjoy in, on, and over such unembanked shores.

They should also be allowed to enjoy all the advantages which their bank may afford, towards promoting trade thereon by landing-places, wharfs, quays, warehouses, etc., without hindrance from the frontagers, but under conditions specified in the Act.

Any public roads made by them should afterwards be maintained and kept up in the same manner as other public roads are kept up in the district.

It would be reasonable, also, that the lands embanked should be declared free from all rates and taxes for a defined period—say for the first seven years, to be computed from the day of the commencement of the year of any assessment next after the final shutting out of the sea.

The projectors having executed the works of embankment and drainage, the several distinct intakes, or embankment enclosures, may be erected into *levels*, bearing such denominations as may be prescribed by the Act, and provision made for the due maintenance and repair of the said banks and sluices by the appointment of Trustees for each level respectively.

The Trustees (who may be owners of lands within the level, or their nominees) should have power to levy an acreable rate to any needful amount—such rate not to be uniform and even over the whole level, since some of the lower lands will require more draining than others which are higher, whilst all the lands will equally require the protection of the bank; but there may be an equal acreable rate for the support of the bank, with a separate rate for drainage levied according to the situation of the lands. These may be distinguished into, say, *high lands*, *medium lands*, and *low lands*, and the drainage rate levied accordingly. This principle of classification in the expense of drainage has always been recognised as equitable in the case of reclaimed lands.

The interests involved in any large scheme of reclamation, and the necessary incidents of the completion of the work, being thus of so varied and complex a nature, it will be readily understood that the authority of Parliament, to be secured by a Private Act, is in many cases found necessary for the carrying out of the project.

In the case of works on a smaller scale, which yet involve the appropriation of any portion of foreshore, a grant by the Board of Trade of so much of the shore as is required to be taken or dealt with may be sufficient for the purpose in view.

The procedure for obtaining such grants is very simple, but no grants are made without security being taken, by means of such covenants (to be entered into by the grantees) as the Board may deem necessary, for the purpose of reserving to the public all existing rights of walking, bathing, boating, landing, fishing, etc.; and it is also the practice to insert where necessary in the deed of grant, clauses and covenants for the protection of navigation, similar to those of the Railway Clauses Act, 1863 (ss. 13-19).

In simple matters, upon sufficient particulars being furnished by the applicants for a grant, the Board may dispense with any official survey of the shore-land proposed to be dealt with; but before considering any application, it is the practice of the Board to make inquiry as to the existing user of the foreshore. A communication is therefore addressed to the Officer commanding the nearest Coast Guard division, requesting information as to the use at present made, or which has hitherto been made, of the shore in question, either by fishermen, boatmen, or the public generally; and as to whether the shore is or has been used by the public for walking, bathing, boating, landing, fishing, gathering seaweed, etc., or any other purpose; and inquiring also whether the use of the shore contemplated by the applicants will interfere with or abridge its present use and enjoyment by the public. Communications are also addressed to every owner and occupier of the land adjacent to the foreshore in question—and if the shore is in a harbour, to the Harbour Authority—inviting their observations upon the proposals of the applicants. When the result of these inquiries is known, if the view of the Board is favourable to the desired grant, public notice of their intention to make it is given in the locality before the grant is made absolute.

The grant may be made either by way of sale, in consideration of the payment of a sum of purchase money, or for a term of years on lease at an annual rent: the terms in either case being adjusted by reference to a valuation made for the purpose under the direction of the Board.

Subjoined (pages 279-282, and 283-287) are the forms in which conveyances and leases of the rights of the Crown in foreshore lands are usually made by the Board of Trade; but it will be understood that not all the clauses given in the forms are applicable to every case of grant. Omissions are made of such clauses as do not apply to a particular case, and it may be that in certain cases additional clauses will need to be inserted.

## I.—FORM OF CONVEYANCE OF FORESHORE IN FEE.

THIS INDENTURE, made the day of 1 , between THE QUEEN'S MOST EXCELLENT MAJESTY of the 1st part, THE BOARD OF TRADE, acting in exercise of such of the powers conferred by the Crown Lands Act, 1829, and the Crown Lands Act, 1852, or any other Act, as were transferred to the Board of Trade by the Crown Lands Act, 1866, of the 2nd part, and
hereinafter called the grantee , of the 3rd part, WITNESSETH, that in consideration of the sum of
by the grantee paid to the Assistant Secretary, Finance Department, Board of Trade, the receipt whereof is hereby acknowledged, the Board of Trade, on behalf of Her Majesty, and with the consent of the Commissioners of Her Majesty's Treasury, signified by their warrant dated the day of 1 , do by these presents grant unto the grantee and h heirs
ALL piece of land being part of the foreshore and bed of the below high-water mark situate opposite to
in the parish of in the county of and extending
which said premises hereby granted are intended to be delineated in the plan annexed to these presents and to be therein coloured .

*Except* nevertheless and always reserving to the Queen's Majesty, Her Heirs and Successors, out of this present grant full and free right for Her and them, and for all persons by Her or their permission (which permission shall be assumed to have been granted unless the contrary be shown), to ride, drive, walk, or otherwise pass to and fro, over, and to fish and bathe upon, and to gather sea-weed and ware from the premises hereby granted and to land thereon goods and passengers from vessels and boats, and to embark therefrom goods and passengers in vessels and boats, but so that erections or works constructed or placed on the said premises, with the consent and approval of the Board of Trade as hereby provided, shall not be prejudiced or interfered with by reason of the aforesaid exception and reservation.

And also except and always reserving as aforesaid all rights of way and access to and over the premises now existing by means of any public road, footpath, bridge, or other means, or by means of any road, footpath, or bridge shown on the said plan hereto annexed, as made or intended to be made.

And also except and reserving to the Queen's Majesty, Her Heirs and Successors, and to the Board of Trade, and any other body or person duly authorised in right of the Queen's Majesty, Her Heirs and Successors, full right to enter on the premises hereby granted, and remove therefrom all buildings, works or erections which may have become dilapidated or abandoned, or which may have been constructed without the consent or approval hereby required thereto, or which may, in the opinion of the Board of Trade, be injurious to navigation or the public interest, and to restore the site to the former or proper condition thereof, and to erect or construct any buildings or works which may, in the opinion of the Board of Trade, be required for the purpose of navigation or the public interest.

TO HAVE AND TO HOLD the premises hereby granted unto and to the use of the grantee , h heirs and assigns for ever.

YIELDING AND PAYING unto the Queen's Majesty, Her Heirs and Successors, the yearly rent of *one shilling* on the first day of January in every year, if demanded.

And the grantee do hereby for h self h heirs and assigns, covenant with the Queen's Majesty, Her Heirs and Successors, in manner following; that is to say, THAT the grantee , h heirs and assigns, will not, without the consent in writing of the Board of Trade first obtained, erect or place on the premises hereby granted any building or work.

AND ALSO will, in case the Board of Trade shall consent to any building or work being erected or placed on the premises hereby granted, erect, place and construct the same according to such plan and under such restrictions and regulations as may be approved of in writing by the Board of Trade, and not otherwise.

AND ALSO will not, in case any such building or work shall have been so erected or placed on the premises hereby granted, at any time alter or extend the same without the like consent and approval of the Board of Trade having been first obtained.

AND ALSO will not, without the consent in writing of the Board of Trade first obtained, place any materials, or do any other act on the premises hereby granted, which may, in the opinion of the Board of Trade, prejudice or obstruct navigation, or be or become injurious to the public interest.

AND ALSO will at all times keep the premises in a good and proper state of repair, and in proper condition, free from all defects injurious to navigation or the adjacent lands or the public interest.

AND ALSO will, during the whole time of constructing, altering or extending any work upon the premises hereby granted, and also after the completion thereof, exhibit and keep burning every night from sunset to sunrise such lights (if any) as the Board of Trade shall from time to time require.

AND ALSO that it shall be lawful for the Queen's Majesty, Her Heirs and Successors, and the Board of Trade, and any persons duly authorised by Her or them, from time to time, and at all reasonable times, to enter into and upon and inspect the premises hereby granted, and the state and condition thereof, and of any want of repair or of any defect to give notice, and to place such notice in some conspicuous position upon the said premises, and that the grantee , h heirs or assigns, will on receipt of any such notice, or upon any such notice being placed in some conspicuous position on the premises hereby granted, forthwith, and within three calendar months from the giving or placing of such notice, restore the premises hereby granted to a proper state and condition, and substantially and properly execute the repairs and amendments, and remove the defects specified in such notice.

AND ALSO that it shall be lawful for the Queen's Majesty, Her Heirs and Successors, and the Board of Trade, and any persons duly authorised as aforesaid, at any time to enter upon the premises hereby granted, and to remove therefrom and abate all buildings, works, or materials which may have become dilapidated or abandoned, or which may have been constructed without the consent or approval hereby required thereto, or which may, in the opinion of the Board of Trade, be injurious to navigation or the public interest, and to restore the site to the former or proper condition thereof, and to erect or construct any buildings or works which in the opinion of the Board of Trade may be required for the purpose of navigation or the public interest.

AND ALSO will pay to the Queen's Majesty, Her Heirs and Successors, all expenses incurred by the Queen's Majesty, Her Heirs or Successors, or the Board of Trade, or any persons duly authorised as aforesaid, of and incidental to a survey of the premises hereby granted, preparatory to the erection or construction of buildings or works or of or incidental to any consent or approval hereby required to be given thereto, or which may be incurred in removing buildings, works, or materials which may have become dilapidated or been abandoned, or which may have been constructed without the consent or approval hereby required, or which may, in the opinion of the Board of Trade, be injurious to navigation or the public interest, and all other expenses incurred in restoring the premises hereby granted to the former or proper condition thereof.

AND ALSO will not in any way hinder or obstruct the due exercise and enjoyment of any other right or privilege excepted and reserved out of the grant hereby made.

AND ALSO will duly observe and perform all the stipulations and provisions contained in the Schedule hereto.

Provided always, that if the rent hereby reserved shall be unpaid for the space of twenty-one days after the same shall have become due and been legally demanded, or in case default shall be made in observance or performance of any covenant or provision herein contained, and on the part of the grantee , h heirs or assigns to be observed and performed, or in case the
then and in any of such cases it shall be lawful for the Queen's Majesty, Her Heirs or Successors, into and upon the premises hereby granted, or any part thereof in the name of the whole, to re-enter, and put an end to the grant hereby made, and thereupon the grant hereby made shall become void accordingly, without prejudice to any remedy of the Queen's Majesty, Her Heirs and Successors, under any covenant by the said grantee herein contained.

Provided always, and it is hereby declared, that nothing in this deed shall be deemed to extend to or affect any beds, seams, or veins of coal or stone, or any metallic or other mineral substance, or any mines or quarries thereof referred to in Section 21 of the Crown Lands Act, 1866, and further that nothing in this deed contained shall affect any of the rights or powers mentioned in Sections 22, 23, or 24 of the same Act.

Provided also, and it is hereby agreed and declared, that if the Queen's Majesty, Her Heirs or Successors, or the Board of Trade, shall at any time be desirous of purchasing the premises hereby granted, then the grantee , h heirs or assigns, shall sell the same to the Queen's Majesty, Her Heirs or Successors, at such price as shall be agreed upon, or, if not agreed upon, as shall be ascertained by arbitration under the provisions of the Lands Clauses Consolidation Act, 1845, with respect to the purchase of lands otherwise than by agreement, and on payment of the purchase money so ascertained the premises shall be re-conveyed to the Queen's Majesty, Her Heirs or Successors.

Provided also that this deed shall be deemed sufficiently enrolled by the deposit of a duplicate thereof in the Office of Land Revenue Records and Enrolments, and the filing or making an entry of such deposit by the Keeper of the said Records and Enrolments.

And the grantee hereby declares that accepts the grant and conveyance hereby made as effectual only to the extent of such estate, right or interest in the premises as may be vested in the Queen's Majesty at the date of these presents.

In witness whereof one of the Secretaries or Assistant Secretaries of the Board of Trade and the grantee have hereunto set their respective hands and seals the day and year first above written.

The SCHEDULE above referred to.

## II.—FORM OF LEASE OF FORESHORE.

THIS INDENTURE, made the day of 18 between THE QUEEN'S MOST EXCELLENT MAJESTY of the 1st part, THE BOARD OF TRADE acting in exercise of such of the Powers conferred by the Acts 10th George 4th, Chapter 50, and 15th and 16th of Her Majesty, Chapter 62, or any other Act, as were transferred to the Board of Trade by "The Crown Lands Act, 1866," of the 2nd part, and
hereinafter called the lessee , of the 3rd part, WITNESSETH, that THE BOARD OF TRADE on behalf of HER MAJESTY, and with the consent of the Commissioners of Her Majesty's Treasury, signified by their warrant dated the day of
18 , do by these presents grant and demise unto the lessee
ALL piece of land being part of the foreshore and bed of the below high-water mark opposite to .
in the parish of in the county of and extending
which said premises hereby demised are intended to be delineated in the plan annexed to these presents and to be therein coloured .

*Except* nevertheless and always reserving to the Queen's Majesty, Her Heirs and Successors, out of this present grant and demise, full and free right for Her and them, and for all persons by Her or their permission (which permission shall be assumed to have been granted unless the contrary be shown), to ride, drive, walk, or otherwise pass to and fro over, and to fish and bathe upon, and to gather sea-weed or ware from the demised premises, and to land thereon goods and passengers from vessels and boats, and to embark therefrom goods and passengers in vessels and boats, but so that erections or works constructed or placed on the demised premises, with the consent and approval of the Board of Trade as hereby provided, shall not be prejudiced or interfered with by reason of the aforesaid exception and reservation.

And also except and always reserving as aforesaid all rights of way and access to or over the demised premises now existing by means of any public road, footpath, bridge, or other means, or by means of any road, footpath, or bridge shown on the said plan hereto annexed, as made or intended to be made.

And also except and always reserving to the Queen's Majesty, Her Heirs and Successors, and to the Board of Trade, and any other body or person duly authorised in right of the Queen's Majesty, Her Heirs or

Successors, full right to enter on the said demised premises, and remove therefrom all buildings, works, or erections which may have become dilapidated or abandoned, or which may have been constructed without the consent or approval hereby required thereto, or which may, in the opinion of the Board of Trade, be injurious to navigation or the public interest, and to restore the site to the former or proper condition thereof, and to erect or construct any buildings or works which may, in the opinion of the Board of Trade, be required for the purpose of navigation or the public interest.

TO HAVE AND TO HOLD the said hereby demised premises unto the lessee , h executors, administrators, and assigns, for the term of years from the day of 18 ,

YIELDING AND PAYING therefor during the said term unto the QUEEN'S MAJESTY, Her Heirs and Successors, the yearly rent of pounds, to be paid to the Assistant Secretary for the time being of the Finance Department of the Board of Trade at the office of the Board of Trade in London by equal half-yearly payments on the day of and the day of in every year, free from all deductions on account of present or future landlords' or tenants' taxes, rates, charges, or impositions, except landlord's property tax, the first yearly payment to be made on the day of 18 , and the payment of the rent for the last year of the said term to be made on the day of next preceding the expiration of the said term.

And the lessee do hereby, for executors, administrators, and assigns, covenant with the Queen's Majesty, Her Heirs and Successors, in manner following; that is to say, THAT the lessee , h executors, administrators, and assigns, will duly pay the yearly rent hereby reserved, at the times and in manner hereby provided.

AND ALSO will pay the land tax, and all other present and future landlords' and tenants' taxes, rates, charges, and impositions, except landlord's property tax, payable in respect of the demised premises, or by the landlord or tenant on account thereof.

AND ALSO will not, without the consent in writing of the Board of Trade first obtained, erect or place on the demised premises any building or work.

AND ALSO will, in case the Board of Trade shall consent to any building or work being erected or placed on the demised premises, erect, place, and construct the same according to such plan and under such restrictions and regulations as may be approved of in writing by the Board of Trade, and not otherwise.

AND ALSO will not, in case any such building or work shall have been so erected or placed on the demised premises, at any time alter or extend the same without the like consent and approval of the Board of Trade having been first obtained.

AND ALSO will not, without the consent in writing of the Board of Trade first obtained, place any materials, or do any other act on the demised premises which may, in the opinion of the Board of Trade, prejudice or obstruct or tend to prejudice or obstruct navigation, or be or become injurious to the public interest.

AND ALSO will not commit or suffer any waste, spoil, or destruction on the demised premises.

AND ALSO will, at all times during the term hereby granted, keep the demised premises in a good and proper state of repair, and in proper condition, free from all defects injurious to navigation or the adjacent lands or the public interest.

AND ALSO will, during the whole time of constructing, altering, or extending any work upon the demised premises, and also after the completion thereof, exhibit and keep burning every night from sunset to sunrise such lights (if any) as the Board of Trade shall from time to time require.

AND ALSO that it shall be lawful for the Queen's Majesty, Her Heirs and Successors, and the Board of Trade, and any persons duly authorised by Her or them, from time to time and at all reasonable times, to enter into and upon and inspect the demised premises and the state and condition thereof, and of any want of repair or of any defect to give notice, and to place such notice in some conspicuous position upon the demised premises, and that the lessee , h executors, administrators, or assigns, will, on receipt of any such notice, or upon any such notice being placed in some conspicuous position on the demised premises, forthwith and within three calendar months from the giving or placing of such notice restore the demised premises to a proper state and condition, and substantially and properly, and to the satisfaction of the Board of Trade, execute the repairs and amendments, and remove the defects specified in such notice.

AND ALSO that it shall be lawful for the Queen's Majesty, Her Heirs or Successors, and the Board of Trade, and any persons duly authorised as aforesaid, at any time to enter upon the demised premises, and to remove therefrom and abate all buildings, works, or materials which may have become dilapidated or abandoned, or which may have been constructed without the consent or approval hereby required thereto, or which may, in the opinion of the Board of Trade, be injurious to navigation or the public interest, and to restore the site to the former or proper condition thereof, and to erect or construct any buildings or works which, in the opinion of the Board of Trade, may be required for the purpose of navigation or the public interest.

AND ALSO will pay to the Queen's Majesty, Her Heirs or Successors, all expenses incurred by the Queen's Majesty, Her Heirs or Successors, or the Board of Trade, or any persons duly authorised as aforesaid, of an incidental to a survey of the demised premises preparatory to the erection or construction of buildings or works, or of or incidental to any consent or approval hereby required to be given thereto, or which may be incurred in removing buildings, works, or materials which may have become dilapidated or been abandoned, or which may have been constructed without the consent or approval hereby required, or which may, in the opinion of the Board of Trade, be injurious to navigation or the public interest, and all other expenses incurred in restoring the demised premises to the former or proper condition thereof.

AND ALSO will not in any way hinder or obstruct the due exercise and enjoyment of any other right or privilege excepted and reserved out of the demise hereby made.

AND ALSO will not assign or underlet the demised premises or any part thereof without the consent in writing of the Board of Trade first obtained.

* AND ALSO will cause all assignments of the demised premises or any part thereof made with such consent as aforesaid, and all probates and letters of administration affecting the same premises, to be, within six calendar months after the date thereof, entered and enrolled in the Office of Land Revenue Records and Enrolments, in the Consolidated Record and Writ Office, Chancery Division of the High Court of Justice in Ireland.

AND ALSO will duly observe and perform all the stipulations and provisions contained in the Schedule hereto.

AND ALSO will, at the expiration or other sooner determination of the term hereby granted, deliver up the demised premises to the Queen's Majesty, Her Heirs or Successors, in good and substantial repair and proper condition, having regard to the erections and works to be authorised pursuant to the provisions of these presents.

Provided always, that if the rent hereby reserved shall be unpaid for twenty-one days after any day hereby appointed for payment thereof, whether legally demanded or not, or in case default shall be made in observance or performance of any covenant or provision herein contained, and on the part of the lessee , h executors, administrators, or assigns, to be observed and performed, or if any act shall be done or suffered whereby the demised premises or any part thereof shall, without the assent of the Board of Trade first obtained, become vested in any person other than the lessee , or other than any of the following persons, namely, an assignee becoming such with such assent

* Omit words which do not apply.

as aforesaid, or an executor, or administrator, or legatee of the lessee , or of any such assignee, or in case the

then and in any of such cases the term hereby granted shall cease without prejudice to any remedy of the Queen's Majesty, Her Heirs or Successors, under any covenant by the said lessee herein contained.

Provided always, and it is hereby declared, that nothing in this deed shall be deemed to extend to or affect any beds, seams, or veins of coal or stone, or any metallic or other mineral substance, or any mines or quarries thereof referred to in section 21 of "The Crown Lands Act, 1866," and further that nothing in this deed contained shall affect any of the rights or powers mentioned in sections 22, 23, or 24 of the same Act.

Provided also, and it is hereby agreed and declared, that if the Queen's Majesty, Her Heirs or Successors, or the Board of Trade, shall at any time be desirous of purchasing the demised premises for all the residue of the term hereby granted, the then lessee , h executors, administrators, or assigns, shall sell the same to the Queen's Majesty, Her Heirs or Successors, at such price as shall be agreed upon, or if not agreed upon as shall be ascertained by arbitration under the provisions of "The Lands Clauses Consolidation Act, 1845," with respect to the purchase of lands otherwise than by agreement, and on payment of the purchase money so ascertained the demised premises shall be surrendered to the Queen's Majesty, Her Heirs or Successors, to the intent that the term hereby granted may merge and be extinguished.

*Provided always, that this deed shall be deemed sufficiently enrolled by the deposit of a duplicate thereof in the Office of Land Revenue Records and Enrolments, and the filing or making an entry of such deposit by the Keeper of the said Records and Enrolments in the Consolidated Record and Writ Office, Chancery Division of the High Court of Justice in Ireland, and the filing and making an entry of such deposit by the clerk of the Records and Writs.

And the lessee hereby declares that accepts the grant and demise hereby made as effectual only to the extent of such estate, right or interest in the premises as may be vested in the Queen's Majesty at the date of these presents.

In witness whereof one of the Secretaries or Assistant Secretaries of the Board of Trade and the lessee have hereunto set their respective hands and seals the day and year first above written.

The SCHEDULE above referred to.

* Omit words which do not apply.

# NOTES AND REFERENCES.

☞ *The figures in heavy type denote the consecutive number of the note; those in old-face type immediately following, refer to the page of this volume on which the note occurs.*

**1.** 1.—*Reports on the Paris Universal Exhibition* 1867, iv. 322.

**2.** 2.—Surveyors' Institution, *Transactions*, xv. 299.

**3.** 2.—*Embanking Lands from the Sea*, 54.

**4.** 2.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 467-468.

**5.** 3.—*Ib.* xxiii. 183.

**6.** 3.—*Ib.* xxi. 468.

**7.** 3.—Royal Agricultural Society, *Journal*, 2nd. S., iii. 665.

**8.** 3.—Institution of Civil Engineers, *Minutes of Proceedings*, xlvi. 77.

**9.** 4.—*Ib.* xlvi. 72.

**10.** 4.—A, C-F, H, J-L, P, Q, Surveyors' Institution, *Transactions*, xv. 306: B, G, I, O, U, Wiggins, *l.c.* 173-186: M, N, R, V, Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 463, 485; xxiii. 182: S, T, Institution of Civil Engineers of Ireland, *Transactions*, vii. 103-105.

**11.** 6.—*L.c.* 54, 174.

**12.** 7.—D. Stevenson, *Reclamation and Protection of Agricultural Land*, 24.

**13.** 9.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 480, 481.

**14.** 11.—Condensed from J. F. W. Johnston, *Lectures on Agricultural Chemistry*, 2nd. ed., 443-445.

**15.** 11.—The mode of examining with the view of naming soils, as above, is very simple. It is only necessary to spread a weighed quantity of the soil in a thin layer upon writing paper, and to dry it for an hour or two in an oven or upon a hot plate, the heat of which is not sufficient to discolour the paper—the loss of weight gives the water it contained. While this is drying, a second weighed portion may be boiled or otherwise thoroughly incorporated with water and the whole then poured into a vessel, in which the heavy sandy parts are allowed to subside until the fine clay is beginning to settle also. This point must be carefully watched, the liquid then poured off, the sand collected, dried as before upon paper, and again weighed. This weight is the quantity of sand in the known weight of *moist* soil, which by the previous experiment has been found to contain a certain quantity of water.

Thus, suppose two portions, each 200 grs., are weighed, and the one in the oven loses 50 grs. of water, and the other leaves 60 grs. of sand,—then the 200 grs. of *moist* are equal to 150 grs. of *dry* soil, and these 150 grs. of dry soil contain 60 of sand, or 40 in 100 (40 per cent.). It would, therefore, be properly called a *clay loam.*

The determination of the lime, when it exceeds 5 per cent., is attended with no difficulty. Thus,

To 100 grs. of the *dry* soil diffused through half a pint of cold water, add half a wine glass full of muriatic acid (the spirit of salt of the shops), stir it occasionally during the day, and let it stand over night to settle. Pour off the clear liquor in the morning and fill up the vessel with water, to wash away the excess of acid. When the water is again clear, pour it off, dry the soil and weigh it—the loss will amount generally to about one per cent. more than the quantity of lime present. The result will be sufficiently near, however, for the purposes of classification. If the loss exceed 5 grs. from 100 of the dry soil, it may be classed among the marls, if more than 20 grs. among the calcareous soils.

The method of determining the amount of vegetable matter, for the purposes of classification, is to dry the soil well in an oven, and weigh it; then to heat it to dull redness over a lamp or a bright fire till the combustible matter is burned away. The loss on again weighing is the quantity of organic matter.

*Summary.*—The several steps, therefore, which are necessary in examining a soil with the view of so far determining its composition as to be able precisely to name and classify it, will be best taken in the following order:—

1°. Weigh 100 grains of the soil, spread them in a thin layer upon white paper, and place them for some hours in an oven or other hot place, the heat of which may be raised till it begins slightly to discolour the paper. The loss is water.

2°. Let it now (after drying and weighing) be burned over the fire as above described. The second loss is organic, chiefly vegetable matter, with a little water, which still remained in the soil after drying.

3°. After being thus burned, let it be put into half a pint of water with half a wine glass full of spirit of salt and frequently stirred. When minute bubbles of air cease to rise from the soil on settling, this process may be considered as at an end. The loss by this treatment will be a little more than the true per-centage of lime, and it will generally be nearer the truth if that portion of soil be employed, which has been previously heated to redness.

4°. A fresh portion of the soil, perhaps 200 grains in its moist state, may now be taken and washed to determine the quantity of siliceous sand it contains. If the residual sand be supposed to contain calcareous matter its amount may readily be determined by treating the dried sand with diluted muriatic acid, in the same way as when determining the whole amount of lime (3°.) contained in the unwashed soil.*

* The weighings for the purposes here described may be made in a small balance with grain weights, sold by the druggists for 5s. or 6s., and the vegetable matter may be burned away on a slip of sheet iron or in an untinned iron table spoon over a bright cinder or charcoal fire—care being taken that no scale of oxide, which may be formed on the iron, be allowed to mix with the soil when cold, and thus increase its weight. Those who are inclined to perform the latter operation more neatly, may obtain for about 6s. each—from the dealers in chemical apparatus—thin light platinum capsules from 1 to 1½ inches in diameter, capable of holding 50 or 100 grs. of soil, and for a few shillings more a spirit lamp, over which the vegetable matter of the soil may be burned away. With care, one of these little capsules will serve a lifetime.

*Example.*—Along the outcrop of some of the upper beds of the green sand . . . occur patches of a loose friable *grey* soil mixed with occasional fragments of flint, which is noted for producing excellent crops of wheat every other year. . . . I select a portion of this soil . . . for my present illustration.

1°. After being dried in the air and by keeping some time in paper, it was dried for some hours at a temperature sufficient to give the white paper below it a scarcely perceptible tinge: by this process 104½ grs. lost 4 grs.

2°. When thus dried it was heated to dull redness. It first blackened, but gradually assumed a pale brick colour, the change, of course, beginning at the edges. The loss by this process was 4⅓ grs.

3°. After this heating, it was put into half a pint of pure rain water with half a wine glass of spirit of salt. After some hours, when the action had ceased, the soil was washed and dried again at a dull red heat. The loss amounted to 3 grs.

4°. Washed with water by decantation 100 grs. of the soil left 70 grs. of very fine sand, or 104½ grs. would have left 73 grs.

The soil, therefore, contained—

| | | |
|---|---|---|
| Water . . . . . . | 4 grs. | 3·9 per cent. |
| Organic matter, (less than) . | 4⅓ ,, | 4·1 ,, |
| Carbonate of lime, (less than) . | 3 ,, | 3·0 ,, |
| Clay . . . . . . | 20⅙ ,, | 19·0 ,, |
| Sand, (very fine) . . . | 73 ,, | 70·0 ,, |
| | 104½ | 100 * |

* Some of these numbers differ by a minute fraction from those in the previous column: this is because they are calculated from the more correct

decimal fractions contained in my own note book. The organic matter is said to be *less than* the number here given, because by simple drying, as here prescribed, the whole of the water cannot be driven off—a portion being always retained by the clay, which is not entirely expelled till the soil is raised nearly to a red heat. Hence the loss by this second heating must always be greater than the actual weight of the organic matter present. The lime is also *less than* the number given, because the acid dissolves a little alumina as well as any carbonate of magnesia which may be present.

This soil, therefore, containing 70 per cent. of sand, separable by decantation, is properly a *sandy loam*. (J. F. W. Johnston, *Lectures on Agricultural Chemistry*, 2nd ed. 443-447.)

At p. 1073-1092 are given methods of more minute analysis; but these are outside the scope of Engineering investigation save in cases where the services of an analytical chemist are not obtainable.

**16.** 12.—*Lectures on Agricultural Chemistry*, 2nd ed. 524.

**17.** 12.—Royal Agricultural Society, *Journal*, 2nd S., iii. 668.

**18.** 12.—Etatsraad Trapp, cited in Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 435.

**19.** 12.—*Reclamation and Protection of Agricultural Land*, 23.

**20.** 12.—Royal Agricultural Society, *Journal*, 2nd S., iv. 34.

**21.** 13.—*Embanking Lands from the Sea*, 75-80.

**22.** 15.—*Ib.* 73.

**23.** 16.—*L.c.* 31.

**24.** 16.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 454.

**25.** 18.—J. Wiggins, *Embanking Lands from the Sea*, 83.

**26.** 19.—D. Stevenson, *Reclamation and Protection of Agricultural Land*, 13.

**27.** 19.—J. Wiggins, *l.c.* 84.

**28.** 20.—J. Linehan, *The Drainage Engineer*, 107.

**29.** 20.—Institution of Civil Engineers, *Minutes of Proceedings*, xxvii. 234.

**30.** 20.—*Ib.* xlv. 94.

**31.** 20.—*Rivers and Canals*, 2nd ed. i. 13.

**32.** 21.—D. Stevenson, *Canal and River Engineering*, 3rd ed. 130.

**33.** 21.—W. H. Wheeler, *Drainage of Fens and Low Lands*, 9.

**34.** 22.—J. Wiggins, *l.c.* 80.

**35.** 23.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 468.

**36.** 23.—*Ib.* xiv. 249.

**37.** 25.—American Society of Civil Engineers, *Transactions*, xxvi. 568, 569.

**38.** 25.—*L.c.* 48.

**39.** 26.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 441.

**40.** 28.—*Ib.* xxi. 469.

**41.** 30.—J. Wiggins, *l.c.* 70-72.

**42.** 31.—"The Engineering of Holland," in Weale's *Quarterly Papers on Engineering*, vol. ii.

**43.** 31.—*L.c.* 68.

**44.** 34.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 467.

**45.** 34.—Royal Agricultural Society, *Journal*, 2nd S., iii. 664.

**46.** 36.—Institution of Civil Engineers, *Minutes of Proceedings*, vi. 480.

**47.** 37.—*L.c.* 21.

**48.** 38.—Royal Agricultural Society, *Journal*, 2nd S., iii. 666.

**49.** 39.—Institution of Civil Engineers, *Minutes of Proceedings*, ii. (1842) 129.

**50.** 39.—Royal Agricultural Society, *Journal*, 2nd S., iii. 659.

**51.** 39.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 440, 461.

**52.** 39.—*Ib.* xiv. 242, xxi. 482.

**53.** 40.—*Ib.* vi. 122, 97.

**54.** 40.—*L.c.* 13 *et seqq.*

**55.** 44.—Institution of Civil Engineers, *Minutes of Proceedings*, i. (1841) 141.

**56.** 44.—*L.c.* 20.

**57.** 45.—*Ib.* 23, 18.

**58.** 45.—"The Engineering of Holland," in Weale's *Quarterly Papers on Engineering*, vol. ii.

**59.** 46.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 440, 491.

**60.** 46.—Institution of Civil Engineers of Ireland, *Transactions*, vii. 105.

**61.** 47.—Institution of Civil Engineers, *Minutes of Proceedings*, xxviii. 503.

**62.** 47.—*Ib.* vi. 477.

**63.** 48.—*Ib.* xxi. 462.

**64.** 48.—Institution of Civil Engineers of Ireland, *Transactions*, vii. 104.

**65.** 50.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 431, 438-442.

**66.** 52.—"The Engineering of Holland," in Weale's *Quarterly Papers on Engineering*, vol. ii.

**67.** 53.—Institution of Civil Engineers, *Minutes of Proceedings*, vi. 96, 91.

**68.** 56.—*Ib.* xxi. 472, 473.

**69.** 69.—*L.c.* 24-46.

**70.** 70.—Institution of Civil Engineers, *Minutes of Proceedings*,

vi. 136 *et seqq*. The subjoined extract shows the useful character of the Table referred to.

TABLE of the LENGTH, PERIOD, and VELOCITY of the TRANSMISSION of WAVES of the Second Order.

Column A, length of Waves in Feet.
,, B, period of Waves in Seconds.
,, C, calculated Velocity of Waves in Feet per Second.

| A. | B. | C. | A. | B. | C. |
|---|---|---|---|---|---|
| 2 | ·748 | 2·672 | 50 | 3·74 | 13·36 |
| 4 | 1·058 | 3·778 | 100 | 5·29 | 18·89 |
| 6 | 1·296 | 4·628 | 200 | 7·48 | 26·72 |
| 8 | 1·496 | 5·334 | 300 | 9·16 | 32·73 |
| 10 | 1·670 | 5·975 | 400 | 10·58 | 37·78 |
| 20 | 2·366 | 8·45 | 500 | 11·83 | 42·25 |
| 30 | 2·90 | 10·34 | 1,000 | 16·70 | 59·75 |
| 40 | 3·34 | 11·95 | 2,000 | 23·66 | 84·5 |

**71.** 72.—*Ib.* xlvi. 65. The cost of conveyance to the work (4s.) is probably somewhat exceptional in the case cited, the distance having been about 5 miles, and the boats only able to navigate the river on the tide.

**72.** 77.—*Ib.* xli. 161-164.

**73.** 77.—"Sea Coast Protection," in *The Engineer*, 19 May, 1899, p. 483.

**74.** 78.—American Society of Civil Engineers, *Proceedings*, xxii. 36-117, giving full details of construction and cost: the cost in recent years of mats fixed in place, seems to be at the rate of about 2s. 5d. per square yard. It is scarcely needful to remark that the conditions under which such work is executed in a river differ immensely from those of work on a sea-shore, and greatly in favour of the former.

**75.** 79.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 443.

**76.** 82.—De Luc, *Geological Travels*, cited by J. Wiggins, *l.c.* 202.

**77.** 82.—*L.c.* 41.

**78.** 84.—Institution of Civil Engineers, *Minutes of Proceedings*, xxiii. 168-179.

**79.** 85.—*Ib.* xxi. 468.

**80.** 86.—*L.c.* 52. And at p. 61 he gives his reasons for preferring several openings to a single one.

**81.** 89.—Institution of Civil Engineers, *Minutes of Proceedings*, xxiii. 180. Aprons are also made of bags of sand or ballast, staked down.

**82.** 91.—American Society of Civil Engineers, *Transactions*, xxvi. 572.

**83.** 91.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 440.

**84.** 92.—American Society of Civil Engineers, *Transactions*, xxvi. 570.

**85.** 92.—*Ib.* xxvi. 571.

**86.** 94.—*The Engineer*, 30 Oct. 1868, p. 328. The result of experiments with this invention does not appear to have been published.

**87.** 95.—Institution of Civil Engineers, *Minutes of Proceedings*, vi. 99. But cf. what is stated at p. 152-153 of our text.

**88.** 96.—*L.c.* 59-61.

**89.** 98.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 463. This settlement amounts to about one-seventh of the height to which the bank was raised. Mr. Wiggins allows from one-eighth to one-fifth. The allowance in Dutch practice is said to be from one-seventh to one-twentieth.

**90.** 100.—J. Wiggins, *l.c.* 112.

**91.** 101.—*Ib.* 212.

**92.** 101.—Mr. W. H. Wheeler, M. Inst. C.E., to the Author.

**93.** 102.—American Society of Civil Engineers, *Transactions*, xxvi. 578, 579.

**94.** 103.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 463.

**95.** 104.—*L.c.* 50-52.

**96.** 105.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 480.

**97.** 106.—*Ib.* xxi. 177-178.

**98.** 107.—J. Wiggins, *l.c.* 18, 62.

**99.** 110.—*Ib.* 19, 213. The term "flood-flanking" in this sense seems to be purely local. Mr. Wheeler informs me that there was an expression used by navvies in embanking, "flood-fanging," which meant the bringing-up of the bank to the height needful for excluding the tide (not its full ultimate height). When the water was thus shut out from the intake, the bank was "flood-fanged."

**100.** 112.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 478, 479.

**101.** 114.—*L.c.* 52-54.

**102.** 115.—Surveyors' Institution, *Transactions*, xv. 316, 317.

**103.** 120.—*L.c.* 57.

**104.** 122.—*Ib.* 218-220.

**105.** 123.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 471, 472.

**106.** 124.—*L.c.* 42.

**107.** 125.—*L.c.* 221.

**108.** 125.—American Society of Civil Engineers, *Transactions*, xxvi. 584.

**109.** 127.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 441. It is remarked, however, that by some of the Danish Engineers stone facing is considered a dangerous mode of defending a bank, as its weight causes a depression at the foot of the facing.—The peculiar character of the shore (cf. *ib.* 430, 435), its firm upper layer of sand or clay resting on soft material below, probably accounts for this objection.

**110.** 128.—*L.c.* 37-39.

**111.** 128.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 482.

**112.** 130.—J. Wiggins, *l.c.* 40, 45, 210.

**113.** 130.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 470.

**114.** 131.—"The Engineering of Holland," in Weale's *Quarterly Papers on Engineering*, vol. ii.

**115.** 131.—It may be doubted whether a more polyonymous vegetable is to be found in English nomenclature. Besides the names mentioned in the text, it bears or bore the botanical designations of *Ammophila arundinacea, Psamma arenaria, Psamma arundinacea;* and the English ones Maram, Marrum, Common Marum, Bent-grass, Mat-weed, Sand-reed, Sand-rush, Sea-bent, and Sea-mat, all existing in print; besides probably others in popular if not literary use. A passage quoted in the *New English Dictionary* mentions it as "known to the Highlanders by the name of Muran, and to the English by that of Bent-star."

**116.** 131.—Institution of Civil Engineers, *Minutes of Proceedings*, vi. 117; xxviii. 503.

**117.** 136.—W. H. Wheeler, *Tidal Rivers*, 400, 211; and additional particulars communicated by him to the Author.

**118.** 137.—Institution of Civil Engineers, *Minutes of Proceedings*, xlvi. 65. In the discussion on his Paper, Mr. Wheeler (p. 79) adds:—"For £1 per foot many estuaries might be trained in which the cost of stonework would entirely preclude improvement."

**119.** 138.—*L.c.* 54.

**120.** 138.—Institution of Civil Engineers, *Minutes of Proceedings*, xlvi. 74.

**121.** 139.—*Tidal Rivers*, 213.

**122.** 141. Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 441 ; xxviii. 499.

**123.** 142.—*Ib.* vi. 99.

**124.** 143.—*L.c.* 232-234.

**125.** 143.—Institution of Civil Engineers, *Minutes of Proceedings*, li. 206.

**126.** 145.—*Ib.* li. 207-210.

**127.** 147.—Institution of Civil Engineers of Ireland, *Transactions*, xii. 13.

**128.** 151.—*Ib.* xv. 70-75, 82.

**129.** 156.—"Sea Coast Protection," in *The Engineer*, 14 April, 1899, p. 354.

**130.** 157.—Institution of Civil Engineers, *Minutes of Proceedings*, vi. 99, 117.

**131.** 157.—American Society of Civil Engineers, *Transactions*, xxvi. 584.

**132.** 158.—*Reclamation and Protection of Agricultural Land*, 61, 64.

**133.** 161.—W. H. Wheeler, *Drainage of Fens and Low Lands*, 8, 9.

**134.** 162.—*L.c.* 90.

**135.** 162.—Mr. Smith, of Deanston, quoted in Dempsey & Clark, *Drainage*, 3rd ed., 79, 88.

**136.** 163.—*Drainage of Fens and Low Lands*, 10, 43.

**137.** 163.—Dempsey & Clark, *l.c.*, 84.

**138.** 164.—*L.c.* 90.

**139.** 170.—*Drainage of Fens and Low Lands*, 10-26.

**140.** 171.—*L.c.* 94.

**141.** 171.—Institution of Civil Engineers, *Minutes of Proceedings*, vi. 98.

**142.** 171.—*Delf* appears to be etymologically the more correct ; but the latter form is preferable as being distinctive from the earthenware so called. In relation to drainage, it is defined in the *New English Dictionary* as a trench, or ditch, and as "specifically applied to the drainage canals in the fen districts of the eastern counties." Although noted as being "now only *local*," it is worthy of general adoption as a term to denote the particular water-channel described in the text. In this sense it is invariably employed by Mr. Wiggins.

**143.** 172.—Institution of Civil Engineers, *Minutes of Proceedings*, vi. 98.

**144.** 173.—*L.c.* 46.

**145.** 186.—*Drainage of Fens and Low Lands*, 27-33. Another example is also given. For the sake of illustration, the several data are here changed so as to make them correspond with those of the example given in the text:—

A sluice, with pointed piers, and doors fully open, allowing a free discharge of the water, having three openings of 16 feet each, with depth of water 9 feet, and a head of ·0927 foot, would discharge (4 per cent. being allowed for friction) 1,010 cubic feet per second.

Area $= 16' \, 0'' \times 9' \, 0'' \times 3 = 432' \, 0''$.
Velocity $= 8 \sqrt{\cdot 0927} \times \cdot 96 = 2{\cdot}338$ feet per second.
Discharge $= 432 \times 2{\cdot}338 = 1010$ cubic feet per second.

If the water approached the sluice with a velocity of 1·50 feet per second, allowance would require to be made for the head due to this, then:—

$$\text{Head due to this} = h = \left(\frac{1{\cdot}50}{8 \times \cdot 96}\right)^2 = \cdot 0381.$$

Adding this to the head through the sluice, the head $= \cdot 0927 + \cdot 0381 = \cdot 1308$, which gives a velocity of 2·778 feet per second, and a discharge of $432 \times 2{\cdot}778 = 1200$ cubic feet per second.

In the Appendix, two useful Tables are given for facilitating calculation of tides and tidal sluices, here with slight modification reproduced.

### Table A.

*To find the quantity of water due to 24 hours' rainfall to be discharged in a limited time owing to the sluice being closed by the tide.*

| No. of Hours Sluice Doors Open each Tide. | Multiplier. | No. of Hours Sluice Doors Open each Tide. | Multiplier. |
|---|---|---|---|
| 12 | 1· | 6 | 2· |
| 11 | 1·09 | 5 | 2·4 |
| 10 | 1·20 | 4 | 3· |
| 9 | 1·33 | 3 | 4· |
| 8 | 1·50 | 2 | 6· |
| 7 | 1·71 | 1 | 12· |

Multiply the given discharge per hour, minute, or second, by the multiplier opposite the number representing the hours the sluice doors are open each tide.

*Example.*—The discharge from the rainfall of 24 hours over a given area is equal to 500 cubic feet per minute. This has to pass through a sluice, the doors of which are closed 5 hours each tide, or 10 hours out of the 24, consequently the discharge will have to be effected in 14 hours, or 7 hours each tide, and the quantity per minute will be

$$500 \times 1{\cdot}71 = 855 \text{ cubic feet.}$$

TABLE B.

*To ascertain the time the doors of a sluice are closed by the tide.*

| Falling Tide. Time after High Water. H. M. | Constant. Ebb and Flood. | Rising Tide. Time after Low Water. H. M. |
|---|---|---|
| 0· | 1· | 6· |
| 0·30 | ·96 | 5·30 |
| 1· | ·92 | 5· |
| 1·30 | ·84 | 4·30 |
| 2· | ·75 | 4· |
| 2·30 | ·63 | 3·30 |
| 3· | ·50 | 3· |
| 3·30 | ·38 | 2·30 |
| 4· | ·26 | 2· |
| 4·30 | ·16 | 1·30 |
| 5· | ·08 | 1 |
| 5·30 | ·025 | 0·30 |

Having ascertained the level of the sill of the sluice with reference to low-water in the sea or estuary into which the sluice discharges: *add* this to the depth of water in the drain if the sill is above low-water mark, and *deduct* if the sill is below low-water mark. Divide the sum (or the difference) by the range of tide for the day. The constant (in middle column of Table) nearest to the result will give in the right-hand column the time after low-water when the doors will close with the rising tide, and in the left-hand column the time after high-water when they will open again on the falling tide.

*Example.*—Suppose the range of tide to be 22 feet; the sill of the sluice to be 6 feet above low-water; and the surface of water in the drain 4 feet above sill (or $6 + 4 = 10$ feet above low-water mark), accumulating during tide-time to 8 feet above sill (or $6 + 8 = 14$ feet above low-water mark). Then 10 divided by $22 = 0·45$, which is nearly the mean between 2 hours 30 minutes and 3 hours in right-hand column. The doors will therefore close $2\frac{3}{4}$ hours after low-water, leaving $3\frac{1}{4}$ hours to high-water. Again: 14 divided by $22 = 0·63$, which gives in left-hand column the time for their opening as $2\frac{1}{2}$ hours after high-water. The doors will thus be shut for $3\frac{1}{4} + 2\frac{1}{2} = 5\frac{3}{4}$ hours each tide, or $11\frac{1}{2}$ in the 24. The drain must therefore be constructed to discharge in $12\frac{1}{2}$ hours the water due to the rainfall of 24 hours.

If the sill is 3 inches below low-water mark (the other conditions being as above), the surface of water in drain will be $4·0 - 0·25 = 3·75$

above low-water. $\frac{3 \cdot 75}{22} = 0 \cdot 17$, and the doors will close $1\frac{1}{2}$ hour after low-water, leaving $4\frac{1}{2}$ hours to high-water. Again: $8 \cdot 0 - 0 \cdot 25 = 7 \cdot 75$; and $\frac{7 \cdot 75}{22} = 0 \cdot 35$, which gives the time for their opening as nearly $3\frac{3}{4}$ hours after high-water; and they will thus be shut for about $8\frac{1}{4}$ hours each tide, or $16\frac{1}{2}$ in the 24. The drain must therefore be constructed to discharge in $7\frac{1}{2}$ hours the water due to the rainfall of 24 hours.

Table B enables one also:—

*To ascertain the height of the tide at any hour during the ebb and the flood.*

Multiply the range of the tide for the day by the constant (in middle column) opposite the time required. The result will give the height of the tide at that time.

*Example.*—Suppose the range of tide to be 22 feet. To what height will it have risen $2\frac{1}{2}$ hours after low-water? and to what will it have fallen $2\frac{1}{2}$ hours after high-water? For a rising tide, the constant opposite *2 h. 30 m.* is 0·38; and $0 \cdot 38 \times 22 = 8 \cdot 36$ feet, the height at $2\frac{1}{2}$ hours after low-water. For a falling tide, the constant opposite *2 h. 30 m.* is 0·63; and $0 \cdot 63 \times 22 = 13 \cdot 86$ feet, the height at $2\frac{1}{2}$ hours after high-water.

**146.** 186.—Communicated to the Author by Mr. W. H. Wheeler.

**147.** 188.—*The Windmill as a Prime Mover.* 8°. 1885. New York. p. 72.

**148.** 203.—*Drainage of Fens and Low Lands*, 50, 73-90.

**149.** 205.—The subjoined Table will facilitate calculation. To obtain the *exact* average daily rainfall, multiply the annual rainfall by ·00274. It is however best, as a margin of safety for exceptional fall on occasion, to multiply annual rainfall by ·0076 as recommended at p. 161, and to use the fractions of an inch so found, for ascertaining the multipliers. If it is desired to work to smaller fractions than tenths, hundredths can be found by shifting the decimal point of the multiplier one place to the left, thousandths by shifting it two places to the left, and so on. *Example* :—Required the cubic feet per minute per acre for a daily rainfall of ·136 inch. In the column of multipliers,

| | | | |
|---|---|---|---|
| | ·1 inch | = | ·2521 |
| | ·03 ,, | = | ·07562 |
| | ·006 ,, | = | ·015125 |
| Multiplier for | ·136 | = | ·3428 |

Acreage × ·3428 = Total cubic feet per minute.

TABLE C.

| Rainfall in 24 Hours. Decimals of an Inch. | Multiplier for Cubic Feet per Minute per Acre. | Multiplier for W. H. P. per Foot of Lift per Acre. | Rainfall in 24 Hours. Eighths of an Inch. | Multiplier for Cubic Feet per Minute per Acre. | Multiplier for W. H. P. per Foot of Lift per Acre. |
|---|---|---|---|---|---|
| ·1 | ·2521 | ·000477 | ⅛ | ·3151 | ·000597 |
| ·2 | ·5042 | ·000954 | ¼ | ·6302 | ·001194 |
| ·3 | ·7562 | ·001432 | ⅜ | ·9453 | ·001790 |
| ·4 | 1·0083 | ·001909 | ½ | 1·2604 | ·002387 |
| ·5 | 1·2604 | ·002387 | ⅝ | 1·5755 | ·002984 |
| ·6 | 1·5125 | ·002865 | ¾ | 1·8906 | ·003581 |
| ·7 | 1·7646 | ·003342 | ⅞ | 2·2057 | ·004178 |
| ·8 | 2·0167 | ·003819 | 1 | 2·5208 | ·004774 |
| ·9 | 2·2687 | ·004297 | | | |
| 1·0 | 2·5208 | ·004774 | | | |

**150.** 206.—*Drainage of Fens and Low Lands*, 58-69.

**151.** 206.—

| Name of Station. | Description of Pump. | Area. Acres. | Total Cost of Buildings and Machinery. | Cost per Acre of Land Drained. | Cost per W. H. P. Buildings. | Cost per W. H. P. Machinery | Cost per W. H. P. Total. |
|---|---|---|---|---|---|---|---|
| | | | £ | £ | £ | £ | £ |
| Lade Bank . | Wheel . . | 35,000 | 17,000 | ·49 | | | 80·37 |
| Dirtness . | Wheel . . | 10,660 | 8,887 | ·83 | | | 55·90 |
| Prickwillow | Centrifugal | 25,000 | 4,917 | ·20 | | | |
| Wexford (North) | Centrifugal | 2,489 | 4,575 | 1·84 | 54·10 | 37·00 | 91·10 |
| Upwell . . | Wheel . . | 9,000 | 2,680 | ·30 | 26·40 | 74·68 | 101·08 |
| Messingham | Centrifugal | 3,250 | 1,432 | ·44 | | | |
| Redbourne . | Centrifugal | 800 | 852 | 1·06 | 21·10 | 64·10 | 85·20 |
| | | | . Mean | ·74 | | Mean | 82·75 |

**152.** 208.—Surveyors' Institution, *Transactions*, xv. 308, 311, 313, 314.

**153.** 208.—It has already been seen that he commends the swarding of the bank with couch-grass on account of its distastefulness to cattle.

**154.** 210.—*L.c.* 225-227.

**155.** 210.—American Society of Civil Engineers, *Transactions*, xxvi. 579.

**156.** 211.—*Ib.* xxvi. 579-580.

**157.** 214.—*Ib.*, citing Dutch authorities, xxvi. 596-598.

**158.** 214.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 462.

**159.** 216.—*Ib.* xxi. 476-477, 491.

**160.** 220.—*Ib.* xxii. 500-503.

**161.** 222.—The maintenance of the Bank in sound condition and repair is of importance not only because of the great expense attending its restoration in the event of a breach occurring, but also on account of the disastrous consequences to the land of a flooding by sea-water. For a very thorough investigation into the far-reaching injury thereby occasioned to the soil see Messrs. Dymond and Hughes's excellent *Report on Injury to Agricultural Land on the Coast of Essex by Inundation of Sea Water*, published by the Essex Technical Instruction Committee, September 1899. See pp. 246 and 248 of our text, for damage similarly caused at Holkham.

**162.** 227.—Surveyors' Institution, *Transactions*, x. 40-47. The agricultural value of some warps will be readily appreciated upon examination of the subjoined analysis of two samples from Lincolnshire, given by Mr. Smith-Woolley:—

No. I.

| | | |
|---|---|---|
| Organic matters | | 6·927 |
| Soluble salts of river water, 1·473 | Chloride of magnesium | ·105 |
| | Chloride of sodium and potassium | ·939 |
| | Sulphate of magnesia | ·176 |
| | Sulphate of soda | ·313 |
| Carbonate of lime | | 8·177 |
| Carbonate of magnesia | | ·312 |
| Sulphate of lime | | ·104 |
| Alkalies from decomposed silicates | | ·469 |
| Lime | | ·677 |
| Magnesia | | 2·604 |
| Oxide of iron | | 5·052 |
| Alumina | | 8·177 |
| Oxide of manganese | | traces |
| Perphosphate of iron | | 1·040 |
| Silicic acid | | 9·062 |
| Sand, undecomposed silicates, &c. | | 55·866 |
| | | 100.000 |

No. II.

Mud taken in front of Sluice on the Lincolnshire Coast.

(At 300° F. the solid matter in this sample was 66·94, the moisture 33·06.)

| | |
|---|---|
| Organic matter, water of combination (containing Nitrogen ·11, equal to Ammonia ·12) | 3·96 |
| Oxide of iron | 3·41 |
| Alumina | 3·75 |
| Carbonate of lime | 9·69 |
| Magnesia | 1·92 |
| Potash and soda | ·58 |
| Chloride of sodium | ·04 |
| Phosphoric acid | ·12 |
| Insoluble matter (chiefly fine sand and fine clay) | 76·53 |
| | 100·00 |

**163.** 228.—Institution of Civil Engineers, *Minutes of Proceedings*, xlvi. 67.

**164.** 230.—Surveyors' Institution, *Transactions*, x. 40. From recent information obligingly communicated by Mr. Smith-Woolley, it appears that drainage has now so far lowered the surface as to render a considerable area capable of being warped.

**165.** 230.—Institution of Civil Engineers, *Minutes of Proceedings*, xlvi. 68, 69, 76.

**166.** 230.—Surveyors' Institution, *Transactions*, x. 45.

**167.** 230.—*Ib.* xv. 312.

**168.** 242.—*L.c.* 93-107. Mr. D. Stevenson, in 1874, at p. 33 of *Reclamation and Protection of Agricultural Land* (originally a Paper read before the Highland and Agricultural Society of Scotland), says:—"The treatment of reclaimed marsh or slob lands in order to fit them for the purpose contemplated by their enclosure, . . . has been very fully, and I should think judiciously, treated by the late Mr. John Wiggins, F.G.S., in his treatise on 'Embanking Lands from the Sea.' I therefore offer no apology for giving the following extracts from Mr. Wiggins' book":—which he proceeds to do at considerable length; a pretty good proof that experience during the twenty-two years then elapsed had not impaired the value of Mr. Wiggins's recommendations.

**169.** 244.—Institution of Civil Engineers, *Minutes of Proceedings*, xxi. 464-465.

**170.** 245.—Institution of Civil Engineers of Ireland, *Transactions*,

vii. 106. Four samples of the soil reclaimed, analyzed by Professor Sullivan, gave an average as follows :—

| | |
|---|---|
| Potash . . . . . . . . | ·083 |
| Soda . . . . . . . . | ·285 |
| Lime . . . . . . . . | ·220 |
| Magnesia . . . . . . . . | ·319 |
| Alumina . . . . . . . . | 4·312 |
| Peroxide of iron . . . . . | 2·194 |
| Protoxide of iron . . . . . . | 1·531 |
| Phosphoric acid . . . . . . | ·080 |
| Sulphuric acid . . . . . . . | ·420 |
| Hydrochloric acid . . . . . . | ·033 |
| Silica in combination, decomposable by hydrochloric acid . . . . . | 9·062 |
| Clay or silicates undecomposable by hydrochloric acid . . . . . . | 28·021 |
| Silicious sand . . . . . . . | 44·694 |
| Water not driven off at 212° and organic matter rich in nitrogen . . . . | 7·815 |
| Carbonic acid and loss . . . . . | ·931 |
| | 100·000 |

**171.** 248.—Royal Agricultural Society, *Journal*, 2nd. S., iii. 661-662.

**172.** 250.—J. Wiggins, *l.c.* 191-192.

**173.** 252.—*Ib.* 184-186.

**174.** 253.—Stevenson, *Reclamation and Protection of Agricultural Land*, 45.

**175.** 254.—*Ib.* 46.

**176.** 256.—Institution of Civil Engineers, *Minutes of Proceedings*, xlvi. 72, 69, 73: Surveyors' Institution, *Transactions*, x. 48, 59; xv. 307, 317.

**177.** 258.—W. H. Wheeler, *The Fens of Lincolnshire*, 2nd. ed. 418-420.

**178.** 260.—From Returns made to Parliament, it appears that from 1st January, 1867, to 31st December, 1891, grants of foreshore within the United Kingdom were made, either by way of sale or by lease for a term of years, by the Board of Trade to various individuals and corporate bodies, to the number of nearly 600. But only a small percentage of these grants would be made with a view to the reclamation of land as dealt with in this volume; the great majority being for the purpose of facilitating works of shore preservation, such as groynes, sea-walls, and the like; or for the construction of harbours, docks, landing-places, piers, etc.; or with a view to the protection of cliffs and the construction of public promenades; and in other cases for the laying of submarine telegraph cables.

**179.** 260, 261.—See *Williams on Real Property*, 17th ed., pp. 390-1, and the authorities there cited.

**180.** 263.—*L.c.* 133-136.

**181.** 264.—*L.c.* 136-140.

**182.** 267.—*L.c.* 142.

**183.** 268.—*Per* Blackburn, J., in *Regina* v. *Lord Mayor of London*, L.R. 2 Q.B. 292.

**184.** 271.—*L.c.* 147-167.

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**Note Supplemental to Chapter V.**—On 5th March a Paper was read before the Society of Engineers by Mr. R. F. Grantham, M. Inst. C.E., on *The Closing of Breaches in Sea and River Embankments*, containing some particulars of personal experience in three cases—those of a tidal opening in Brading Harbour, and of breaches at Northey Island in the Blackwater, and on the Swale at Grovehurst. The method adopted at Brading was that of forming a skeleton dam by driving piles, in two rows 15 feet apart. The piles were pitched at intervals of 12 feet, their heads left 5 feet above low-water, with timber ties securing the front piles to the back ones. A waling was bolted on the landward side of the back row, and wales along both sides of the front row; and the space between the wales on the front row was filled-in with sheet-piling, against which were thrown-in sand-bags and chalk, forming slopes of about 2 to 1 on each side of the dam. Piles, their tops 19 feet above low-water, were then driven on the landward side of the inner front waling, strutted to the back piles, planked, and backed with sand. The embankment was made up to its intended height and the sea shut out. The bank thus raised was, however, too low, and four months afterwards an unusually high tide overflowed and wrecked it. The dam was restored, and ultimately a bank 35 feet wide on top was permanently established. The breaches at Northey and Grovehurst were caused by the storm and high tide of 29th November 1897, and in each case occurred at a sluice—whether owing to the failure of the sluice itself, is not stated. The repairs at Northey were begun in July 1898, by which time the damage had become serious. At Grovehurst, some attempts at piling from the sides were made, and failed: the matter was ultimately put into Mr. Grantham's hands, and work commenced seventeen months after the disaster occurred. At Northey, and at Grovehurst, the method adopted was that of forming an inset bank and sluices, and in both cases ultimately proved successful: the bank at Grovehurst was not carried high enough, and was several times destroyed before being finally established. A noteworthy point mentioned in connexion with the building of the inset banks is, that the rush of tidal water was found not to cause any scouring of the surface of the marsh, the roots of the grass appearing to hold the earth together so that the current flowed over without abrading it.

The importance of height in a bank, of careful inspection and constant attention to maintenance, of promptly taking in hand all needful repairs, and of care in the foundation and construction of sluices, pointed out in the present volume, are well illustrated by the examples given in this interesting Paper.

# INDEX.

*** *The figures in old-face type refer to the pages of the volume; those in heavy type to the notes so numbered* (pp. 289-306).
*Some of the sub-heads appear also as principal headings, under which may be found further particulars respecting them.*

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