PAPER XI.

Revetments or Retaining Walls. By Lieut.-General Sir John Burgoyne, Inspector General of Fortifications.

Revetment is a term used in Fortification, and usually comprehends other requisites besides that of merely sustaining the bank of earth: the following memoranda have only reference to the latter quality, and therefore the subject is to be considered as of *retaining walls.*

Elaborate treatises, founded on abstruse mathematical reasoning, have been published on the pressure of earth, and the proportions to be given to retaining walls under different circumstances; they are proper elementary studies for every engineer, and may be consulted in framing projects for very great works; but a few simple rules, easily retained in a note-book, or even in the memory, will be very useful for ordinary practice and observation: of this kind are the data given by General Fanshawe, in the First Number of the "Corps Papers," namely, for a medium thickness of a retaining wall, of brick, to multiply the height by ·25 where there is a batter of one-sixth, and by ·31944 (say ·32) when the wall is vertical in its exterior face and countersloping within; or, what might be more easily remembered, take one-fourth of the height for the mean thickness of wall with the batter, and one-third very nearly for the vertical; always assuming the backing of earth to be of the same height as the wall, and no more.

This calculation is full and secure, provided the foundation, the material, and workmanship be good; but it is worthy of consideration, whether such rules are to be adhered to rigidly in all cases, or whether under a variety of circumstances and arrangements, the proportions might not be reduced without risk.

Very precise data from *facts* are much wanted; records of failures with minute particulars would be most interesting, but are not to be obtained; experiments have rarely been made,* except on small models, which latter are anything but satisfactory; these models are made of one rigid substance (wood), cut into the shape of the entire wall, and being loaded at the back with sand, bullets, or small shot, are proved as to the relative weight or force required to turn them bodily over on a pivot at their toe. Many useful analogies may be drawn from such trials, but as the action on a wall loaded with earth is very different, they might in some cases mislead, and cannot be considered in any as quite conclusive.

Under this impression, when Chairman of the Board of Public Works in Ireland, I took a favourable opportunity that presented itself at Kingstown, of entering upon a series of experiments on actual walls, which, unfortunately, circumstances did not admit of being continued to the extent contemplated; the first made however are interesting, as far as they go, and are exhibited in the Plate which accompanies this paper. Four walls were constructed of equal length, height, and mass, but of different figures, and then loaded at the back with

* A few were made by Lieut. Hope, Royal Engineers, at Chatham, under the orders of Colonel Sir Frederic Smith, reported in vol. vii. Professional Papers, and are interesting.

earth, as nearly as could be under the same circumstances; a medium thickness of one-sixth of the height was taken as a minimum, that would afford a chance of observing the relative order and manner in which each would successively give way, without contemplating that any would entirely resist, as it proved that one (the leaning parallel figure) did.

The intention was to have made further trials on those which had failed, by increasing their solidity in an uniform degree, when probably, at one-fifth mean thickness, the wall (of that peculiar description and weight of stone) with a batter would have been found to have sufficient stability, and in succession that with a counterslope would have shown its advantages over the parallel vertical wall.

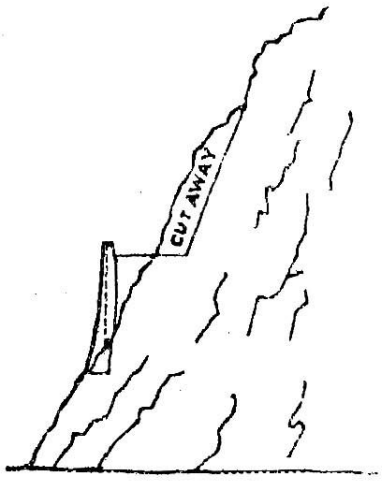
It was also in contemplation to try the effect of applying counterforts, as part of the mass of masonry.

It may be observed, that as to the positive power of resistance, these experiments may be considered as having been somewhat trying. They were made in winter, the soil wet, and the weather unfavourable; the filling was of earth, thrown in loose and without any precaution of ramming or otherwise; the walling without mortar, and each portion of 20 feet in length, not connected or tied in at the ends to any other support; the only favourable circumstance was, being based on a thoroughly unyielding foundation—rock.

There are differences of opinion relative to the advantages of applying part of the masonry in the form of internal buttresses or counterforts, even as regards the stability of the wall; that is, independent of the military consideration of the resistance it may afford against being breached. The first matter for experiment and decision, however, is the best form of cross section for the facing of the wall. as that will not be affected by the question of the counterforts.

There are two points worthy of notice regarding the counterfort principle, that are not taken into consideration in mathematical reasoning, or in the trials with wood models; one is, the additional cost of the workmanship by the increase of surface lines to be worked to,—and the other, the tendency of the pressure to tear the facing from the counterforts; which, where the wall gives way, it always does more or less, showing a weakness in that point not exhibited in the models, which, on the contrary, produce an increase of power in that part, by the lengthened leverage of overhanging weight opposing the effort to overturn it.

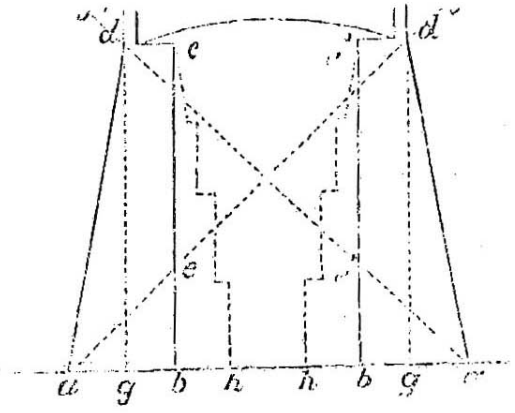
Independent of the reasoning on the abstract relative advantages of particular forms and dimensions for the section of a retaining wall, there may be peculiar circumstances of locality or nature of the work, that may lead to a deviation from any uniform rule; of which the following are examples:—



1. In Sir Henry Parnell's "Treatise on Roads," containing many valuable details of that magnificent work, the great Holyhead road, will be found a section descriptive of the mode in which it was carried along the side of a precipitous rocky mountain; in which it will be seen how a good rule for ordinary circumstances may be carried too far in special cases. Telford considered a curved batter and of certain dimensions a good form for a retaining wall, and this seems to have been followed here without reference to circumstances, for there can be no doubt but that a vertical wall, as

shown by the dotted line, would much sooner find its base, and with far less work and material, would have been quite as efficient; and very great strength of wall was the less necessary, as the filling must have been, not of earth, but of the pieces of excavated rock, giving no elastic pressure, but merely dead weight, and even that capable of being very much relieved by a little pains given to packing them.

2. In another case, a road in Ireland was to be carried across a ravine, by a high embankment with retaining walls; the road was required to be 21 feet wide between the fences, and 30 feet above the bottom of the valley. The retaining walls were planned on the ordinary rules, as *a*, *b*, *c*, *d*, in the figure, with an external batter of one-sixth; these, therefore, were calculated to resist a pressure of a filling included in the section *c*, *e*, *f*, *c'*, *e'*, *f'*, whereas it will be seen how much short of that bulk the real filling occupied, and which bore upon each wall; but by altering the shape, and adopting a wall vertical externally, and removing the front projection of batter to the counterslope in the interior, that is, to the lines *g*, *h*, *c*, *d*, it will be found that a great part of the *filling* would have been of the masonry, to a great saving of labour in filling, and of pressure on the walls; and a saving of land by the projection *g*, *a*, for their entire length.



3. Another cause of occasional failure in retaining walls, or of an excess of masonry to avoid it, arises from their being built almost universally under very unfavourable circumstances, that occasion a violent pressure on them of short duration; and that when they are in their weakest state: thus, these walls are usually constructed rapidly, and while green and their mortar unset, backed with earth, which for a period is gradually settling, and exerts a powerful effort on them; they consequently require to have a mass proportioned to resist these *temporary* disadvantages, whereas when the backing is well consolidated, and the wall dry, much smaller proportions would be ample. I have witnessed the case of a considerable retaining wall, of proportions somewhat less than the rules admit, which very soon after being backed with earth began to bulge, and showed signs of giving way, but was at once strongly shored up with timbers, which were left for several months, and then removed; since which the wall remained firm, and is standing to this day. The same of the two abutments of a bridge, of a single arch of 18 feet span, and immediately backed with earth; the walls in a similar manner began to yield, but being well strutted with stout timbers and plank for some months, until the whole was thoroughly settled, remained firm ever after.

A splendid instance of this kind of remedial measure, judiciously applied, may be seen in the cuttings near the Euston Square Station of the North Western Railway, where the walls were found to be insufficient to support the pressure of the London clay, probably as trying a substance as any in the world; and those fine curved cast-iron girders that may be now observed, were fixed from wall to wall spanning the entire road. I have no doubt, however, but that even that soil, after so many years of being cut through and sustained, will, with the walls, have acquired such a consistence, as not now to require that precaution; and as it is

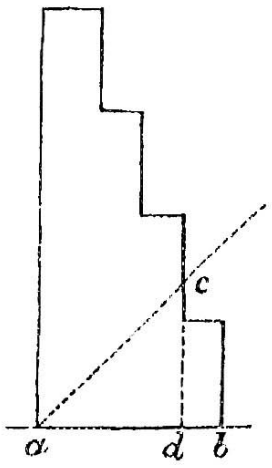
in some degree an eyesore, in interfering with the simplicity of the work, and would appear to be superfluous, it is to be expected that some day a single girder will be removed, and others in succession, and gradually in alternate order to try the effect, and that finally the whole will disappear.

The power of resistance of the leaning parallel wall has been long known, and that form might be generally applied instead of the ordinary batter given to the external face only, but for one great inconvenience, which is, the necessity for carrying up the filling behind it, at the same rate as the wall rises, in order to support it from falling *inwards*.

The results of the single trial at Kingstown may lead to a belief that the wall, vertical in its face and countersloped in rear, affords less resistance in proportion to one with the ordinary external batter, than is commonly calculated upon; and it would be a matter of peculiar interest to have decided by thorough actual experiment; at the same time it would still be in very many cases the better form to adopt, in consequence of the serious disadvantages and evils of the external batter, particularly in brick.

The internal counterslope is usually carried up by offsets, which (the courses being horizontal) are quite as easy in building, and they give a slight increase of resistance, and perhaps might give more, if by their means the greater thickness of wall was adjusted, on experiment, to the points where the pressure is greatest rather than by the usual regular gradation.

For instance, *a*, *b*, *c*, being within the angle of repose of the filling, has scarcely any pressure upon it, and consequently only serving as the base of the wall above, no extra thickness, as shown in the figure, need be given to it; but the line being brought down from the next offset above (as to *d*), the portion *d*, *b*, might be suppressed, and given to increase the strength of the wall above.

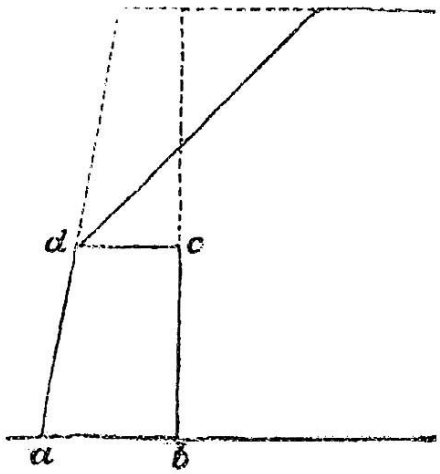


It may not be superfluous to add a reminder on two or three well-known circumstances, that never must be lost sight of in the construction of retaining walls:—

1. The absolute necessity of securing a thoroughly good foundation, as any yielding at the base will peculiarly influence the stability of such walls.

2. To provide weep holes through the wall, to allow the water, as it drains from the filling, to escape freely.

3. To allow in the calculations for the strength of wall, for the nature of the material employed, its specific gravity, &c.



4. To avoid (what is the cause of many failures) the not proportioning the retaining wall to the height of the earth which it has to support, instead of merely to that of the wall; thus *a*, *b*, *c*, *d*, being the lower portion of a wall calculated to the full height of the embankment, will be the section required to support the foot of it.

Escarps in fortifications are frequently given a form and strength exceeding the dimensions required of them, as retaining walls only, and at considerable more

expense, in order to obtain a prolonged resistance from the effect of an enemy's breaching batteries; but this precaution may be carried too far; if applied generally to the whole contour of the place, it will add very importantly to one of the most costly items of expense, and will be superfluous on every part but those that present the greatest facilities of approach to a besieger.

In general it will be more advantageous to adapt the escarps to a system of masonry, that will in the most economical manner retain the mass of earth behind them, reserving the extra means for adding to the difficulties of being breached—for any part that may be peculiarly liable to be attacked, and making that as strong as possible by arches carried through to the external face, in the manner designated by the French engineers as *en décharge*. On many occasions, this valuable accessory for defence may be obtained without extra expense, by making these arches part of the necessary bomb-proof cover for the accommodation and use of the garrison.

Whatever reasonings may be held out for reducing the dimensions of retaining walls, that are not confirmed by actual experience or trial, must be received with caution.

The old rule of making everything stronger than strong enough, must be particularly attended to by our military engineers; at the same time let us anxiously look out for every possible improvement, that will tend to stability in the first instance and to economy in the second.

J. F. B.

REFERENCE TO PLANS AND SECTIONS OF REVETMENT WALLS.

The masonry of the leaning wall, section A, and the earth falling at the rear, commenced 20th of October, 1834, and proceeded, *pari passu*, until the wall was carried to its full height. At this date (31st of December) the wall remains unaffected by the lateral pressure of the earth filling, although kept to its full height, from time to time as subsidence occurred.

The masonry of the sloping wall, section B, commenced on the 20th October, 1834, and was carried to its full height on the 27th of the following November. The earth filling in the rear was begun on the 20th of November, and completed on the 6th of December. The deficiencies from subsidence, in the filling, were made good from time to time, as in the preceding case. Since the completion of this section the slope in front is diminished $2\frac{1}{2}$ inches, and there are some slight fissures in the face of the wall indicative of instability.

The masonry of the counter sloping wall, section C, was commenced and completed concurrently with section B. The earth filling in the rere was commenced on the 20th of November, and on the 6th of December, when the filling attained the height of 17 feet, the wall was overturned. The overseer reports—"at one o'clock, P.M., the counter-sloping wall fell, the filling 17 feet high behind the wall; it overhung 10 inches, was greatly convex on the face, and rending in every direction; it overhung five inches in the first 5 feet of its height. In falling it burst out at about 5 feet 6 inches from its base, and two-thirds of the wall from the top, downwards for its full length, kept in an upright position, until it reached and was crushed on the ground." See diagram C, fig. 2.

The masonry of the rectangular wall, section D, was built at the time sections B and C were erected. The earth filling in the rear was commenced on the 20th of November, and on the 6th of December, when it attained the height of 17 feet, this wall was also overturned. The overseer reports—"at four o'clock, P.M., the rectangular wall fell, the filling 17 feet high behind the wall; it overhung 1 foot 6 inches, convexity on the face more than 4 inches; it fell like a board, having increased in the overhanging from 1 foot to 1 foot 6 inches, from half-past three till four o'clock, when it fell." See Diagram D, fig. 3.

The several walls were founded on solid rock.

A TABLE

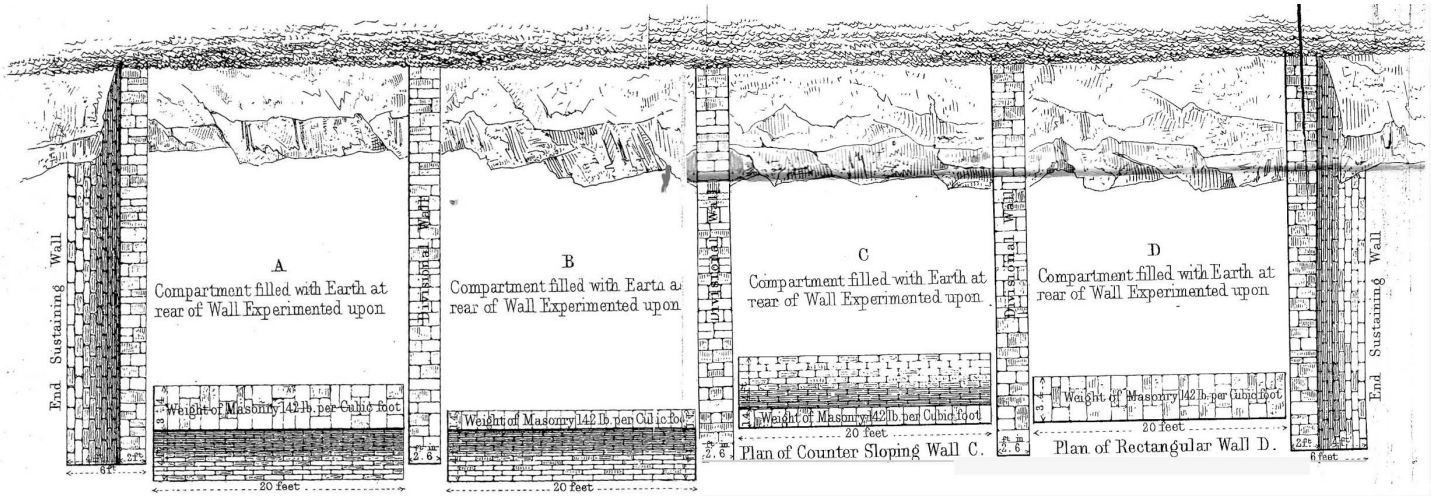
SHOWING THE HEIGHT TO WHICH THE CLAY-FILLING WAS CARRIED EACH DAY DURING THE PROGRESS OF THE WORK.

ALSO A DIARY OF THE WEATHER.

Dates, 1834.	A		B		C		D		State of the weather.
	Morning.	Afternoon.	Morning.	Afternoon.	Morning.	Afternoon.	Morning.	Afternoon.	
Commenced 20th Oct.	F. In.	F. In.	F. In.	F. In.	F. In.	F. In.	F. In.	F. In.	
November 7 ..	..	5 0	..	..	..	..	..	..	Dry.
,, 8 ..	..	7 0	..	..	..	..	..	..	
,, 19 ..	..	11 0	..	..	..	..	..	..	Rain.
,, 20 ..	..	14 0	..	..	..	..	..	..	
,, 26 ..	..	..	2 6	2 10	4 0	6 4	4 0	5 6	Dry.
,, 27 ..	..	..	3 0	4 9	7 0	7 6	6 0	7 0	
,, 28 ..	..	..	6 0	8 0	7 9	8 0	7 0	8 4	
,, 29 ..	..	..	8 0	11 0	8 0	9 9	8 4	8 4	
,, 30 ..	..	..	10 8	..	9 6	..	8 8	..	
December 1 ..	..	..	10 8	11 6	9 8	10 2	8 8	9 9	Much rain during night.
,, 2 ..	..	20 0	11 9	12 0	10 4	11 4	10 2	10 6	Rain during night.
,, 3 ..	..	..	12 0	13 0	11 4	11 0	10 6	13 0	Dry.
,, 4 ..	..	..	12 9	12 6	11 0	13 8	12 6	13 8	
,, 5 ..	..	..	12 6	13 6	13 3	14 4	14 8	15 4	
,, 6 ..	..	..	15 6	20 0	15 3	17 0	15 3	17 0	
,, 7 ..	20 0	..	20 0	..	Fallen.		Fallen.		Much rain during night.

PLANS AND SECTIONS
OF
REVETMENT WALLS
OF
VARIOUS DESIGNS OF EQUAL MAGNITUDE
But under Particular
MODIFICATIONS OF STRUCTURE
Experimented upon at
KINGSTOWN HARBOUR
By Order of the
BOARD OF PUBLIC WORKS.

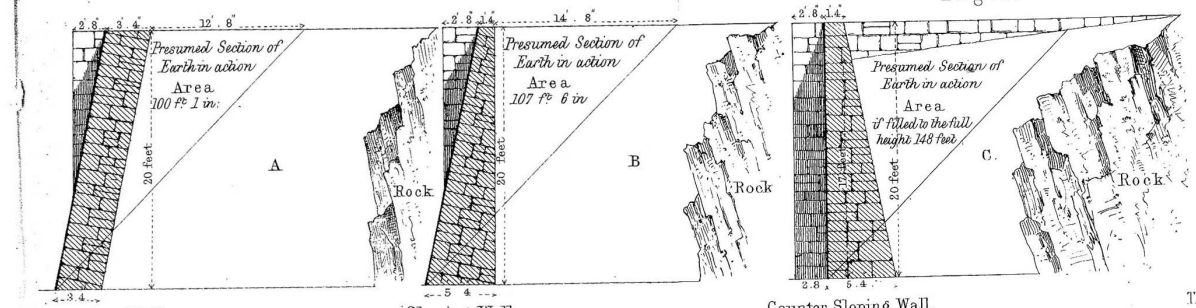
Note. *The natural Angle of Repose of the Earth filling is assumed to be 45° or one foot base to one foot perpendicular, The Earth employed in this filling was loose Mould which imbibed the Rain and Moisture readily, its Weight, when put in equaled 87 lbs. per Cube foot.*
The walls were of Granite, roughly squared without mortar and of the description shewn in the Sections.



Plan of Leaning Wall A. Plan of Sloping Wall B. Plan of Counter Sloping Wall C. Plan of Rectangular Wall D.

SECTIONS.

Fig. 1.

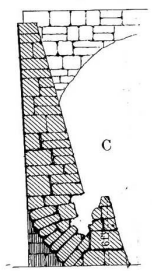


Leaning Wall.
Opposite Sides equal and parallel
Thickness 3/5 of the height
Lean or Slope 3/5 of Ditto.

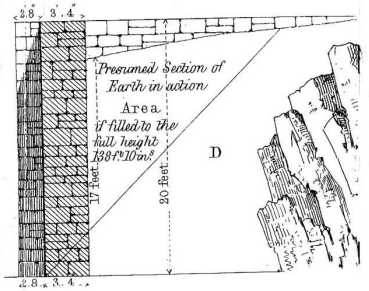
Sloping Wall.
Mean thickness 3/5 of the height
Slope in Front 3/5 of Ditto

Counter Sloping Wall.
Mean thickness 3/5 of the height
Slope in rear 3/5 of Ditto.

Fig. 2.

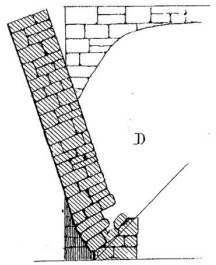


This Diagram exhibits the Form the Counter Sloping Wall assumed when falling.



Rectangular Wall.
Thickness 3/5 of the height.

Fig. 3.



This Diagram exhibits the form the Rectangular Wall assumed when falling

SCALE