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Canadian Society of Civil Engineers.

INCORPORATED 1887.

TRANSACTIONS.

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NOTES ON RETAINING WALLS IN MONTREAL.

By H. Irwin, M.Can.Soc. C.E.

(To be read Thursday, October 25th, 1894.)

Having obtained some information as to the complete or partial failure of some retaining walls in Montreal during the last few years, the writer thinks that it may not be altogether uninteresting to bring this information under the notice of the members of this Society, in order that it may, if possible, induce some of them to give the results of their experience in the construction of walls, particularly of those that have proved too light, as the failure of a structure generally teaches more than its success.

Before taking up the subject, however, the writer thinks it only fair to state that neither the Chief Engineer of the Railway on which he is employed, nor the writer himself, was in any way responsible for the design of any of the walls herein alluded to as having failed.

The various cases will be taken up in the order of the numbering of the figures.

The wall shown in section by Fig. 1 is of dry masonry, built of stones from three feet to eight feet in length, by from ten inches to fourteen inches thick, the beds of the stones being fairly flat, but the back of the wall, in some places, seems to be rather poor, the stones being too small; the top front course was built with large, flat stones from five feet to eight feet six inches in length, but the writer has not been able to find out what proportion of through stones were used. The filling behind the wall is principally clay, a small proportion being earth and sandy clay, and was dumped from cars running on a temporary trestle.

The bank on which the filling rests has an average slope of about $2\frac{1}{2}$ to 1, and was not benched before the filling was begun; at the temporary trestle must have largely helped to keep the embankment from sliding, as it was built for a double track and was well braced longitudinally.

Indeed, possibly, this trestle, so far as it went, was better than benching, as the greasy clay would easily slide from one bench to another, unless the benches were cut down very deep; however, no doubt it would have been better to have benched the part of the slope below the trestle.

The bank under the filling is of gravel, which absorbs the melting snow in the spring very quickly, so much so that the catchwater ditch on the upper side of the slope seldom has any water in it, and there is never any sign of water passing down between the original slope and the clay filling.

The wall at the foot of the slope was built with a face batter of 1 in 12, the batter of the back being 1 in 4; and shortly after the filling was finished it pushed the wall gradually forward till the top overhung the base by about 1 in 12, the embankment rising behind the wall.

wall should have been strong enough to resist overturning, but that, at the ground level, the horizontal component of the thrust would be 4,500 lbs., per foot run, while the vertical component of the resultant pressure, divided by 2 to give the frictional resistance to sliding, was 4,790 lbs., without taking the vibration caused by trains into account. Had the wall been built of the dimensions given above as derived from "Trautwine," it would have appeared to be quite strong enough, according to Weyrauch's theory, to resist the extra thrust from vibrations.

It seems also that this wall would have been quite strong enough to retain the filling behind it, had it been of good material such as would stand at a slope of $1\frac{1}{2}$ to 1.

The wall shown in Fig. 3 was also of dry rubble, built of the same class of stones as No. 2, the embankment behind it being of the same nature as that in Case 2.

The filling was made in the winter by train on a temporary trestle. The wall failed completely early in the following summer, and a part of the same wall, which gradually stepped down to a height of only two feet, was pushed down for part of its length, and the lowest part was so completely covered by the filling that no attempt was made to dig the stones out, as an extra strip of land was bought to give additional room.

Unfortunately the writer did not see any part of this wall until after it had given way entirely; but in a part of the wall left standing the writer noticed a large flat bedded stone which had been eight feet nine inches below the top of the wall, and which had been pushed forwards four inches beyond the course below it. This, together with the fact that the wall, when it failed, was completely buried by the filling, seems to shew that the stones were pushed forward and fell over each other, rather than that the wall failed by overturning, especially as a wall immediately adjoining it and built in cement (shewn in Fig. 4), which was a little higher and not quite so thick, did not fail altogether, though it was built with a vertical face. The courses of this wall, built in cement mortar, could not, of course, slide over each other before overturning.

The sliding noticed in this case, as well as that mentioned in Case 1, seems to contradict the statement to be found in Mr. M. A. Howe's book on retaining walls, edition of 1886, page 48, that "experience "and theory prove that if the resultant cuts the base within the "*middle third*, the wall is perfectly stable, and will not yield either "by sliding or bulging, and also that the wall has a factor of safety of "at least 2."

This statement has, however, been omitted in the edition of 1891, and the writer has concluded that Mr. Howe must have found that it was not correct for dry walls, at least when they were subject to the vibration from passing trains.

Shortly after the failure of this wall the slope of the bank was found to be from $1\frac{3}{4}$ to 1 to 2 to 1 at a place where the bank had completely covered the wall.

In digging away the debris, at a place where no extra land could be acquired, considerable masses of snow were found quite hard and fresh in the months of August and September. The clay in the bank was also quite damp and greasy, and required very strong timber to retain it while the new wall was being built.

The writer noticed in one place that a $6'' \times 15''$ stick fifteen feet long, with its greatest depth against the bank which was about eleven feet high against it, was badly cracked.

This stick was well braced at the foot and at a point about eight feet up from the foot, and carried a length of seven feet of the bank. Unfortunately the writer was so busy with other work that he had no time to take proper notes of the shoring of the bank.

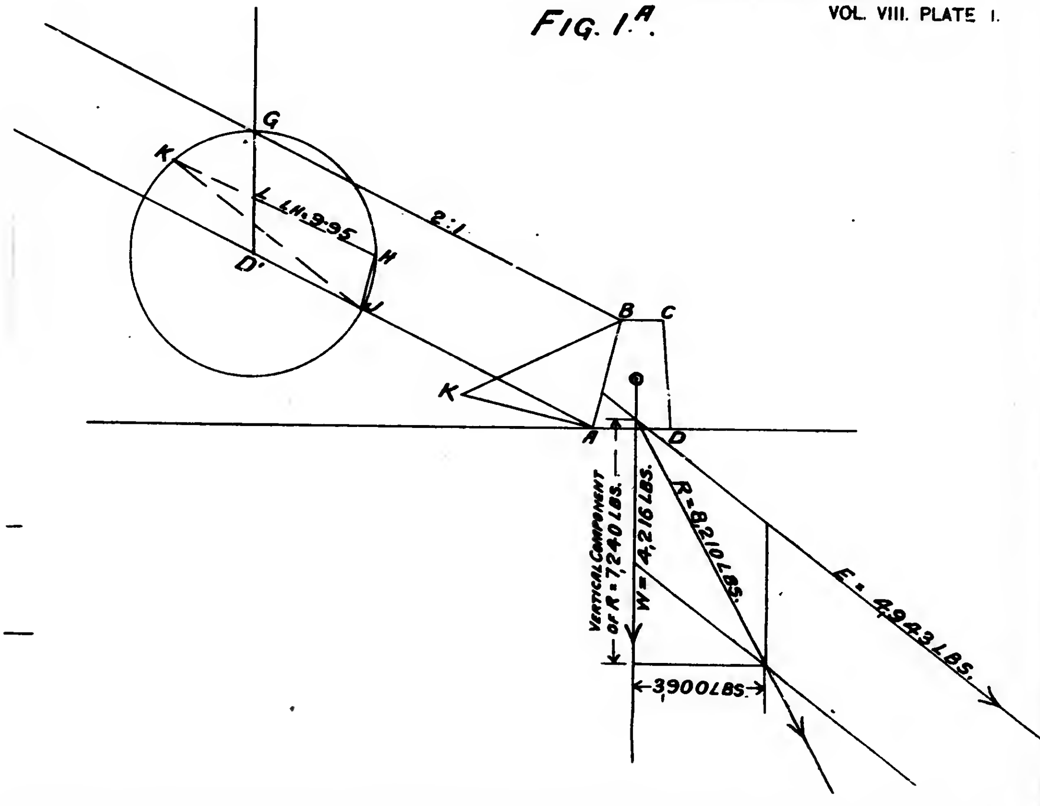
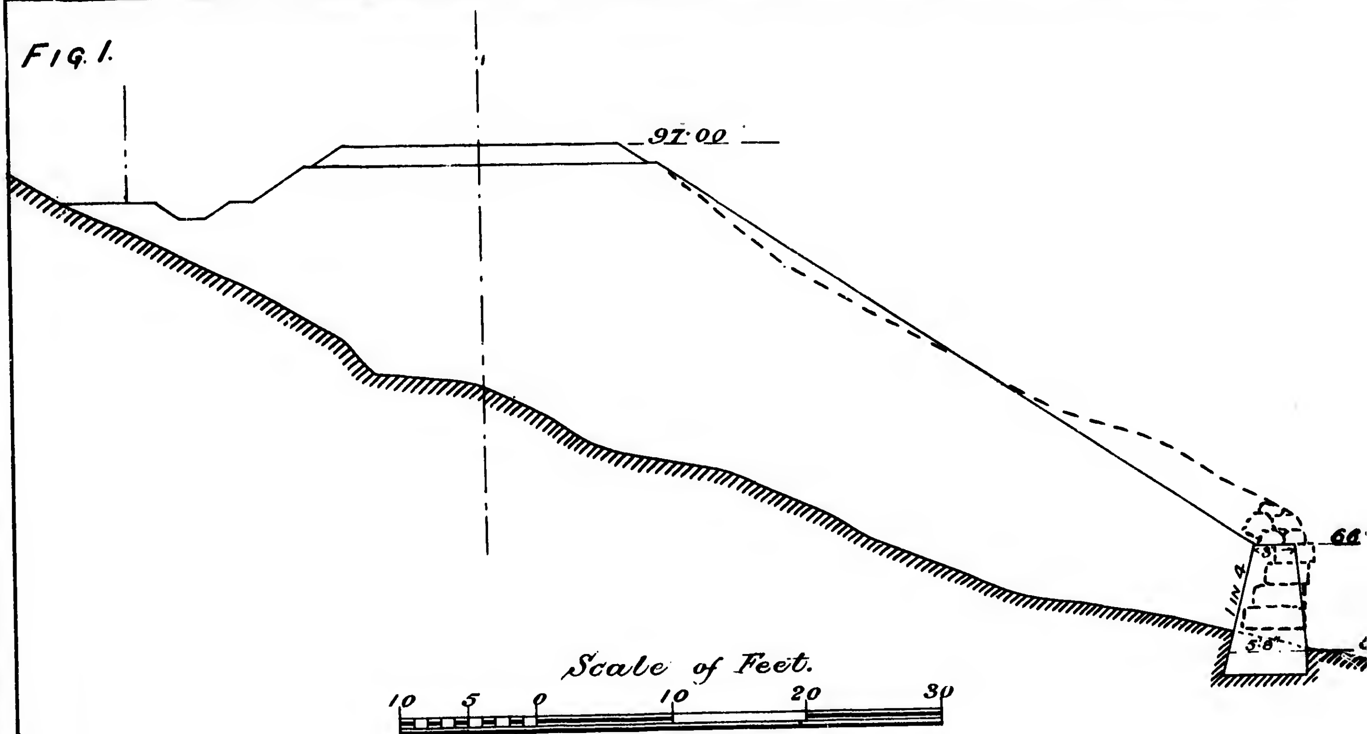

G
K
L 14.9.95
2:1
H
D'
J
B
C
K
A
D
VERTICAL COMPONENT OF R = 7,240 LBS.
W = 4,216 LBS.
R = 8,210 LBS.
E = 4,943 LBS.
3900 LBS.

FIG. 1A.

FIG. 1.



TRANSACTIONS CAN. SOC. C. E.,
VOL. VIII. PLATE I.

FIG. 1.A.

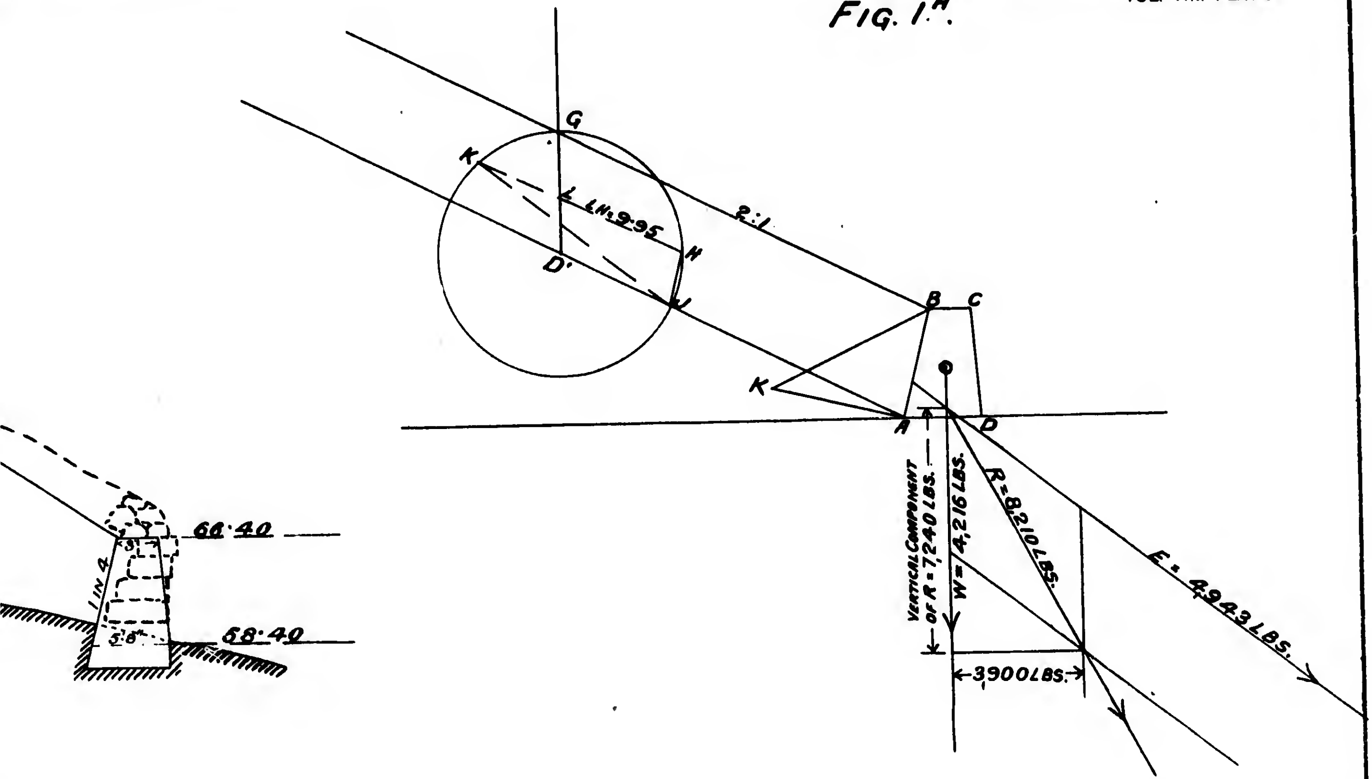


FIG. 2

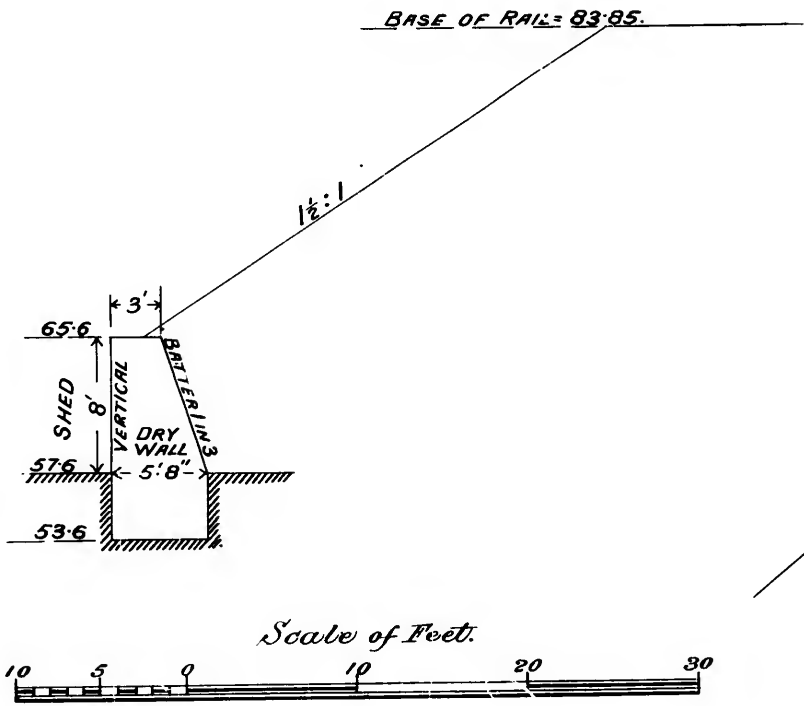

BASE OF RAIL = 83·85.
1½ : 1
3'
65·6
SHED
8'
VERTICAL
BATTER 1 IN 3
DRY WALL
57·6
5'8"
53·6
Scale of Feet.
10
5
0
10
20
30

FIG. 2A

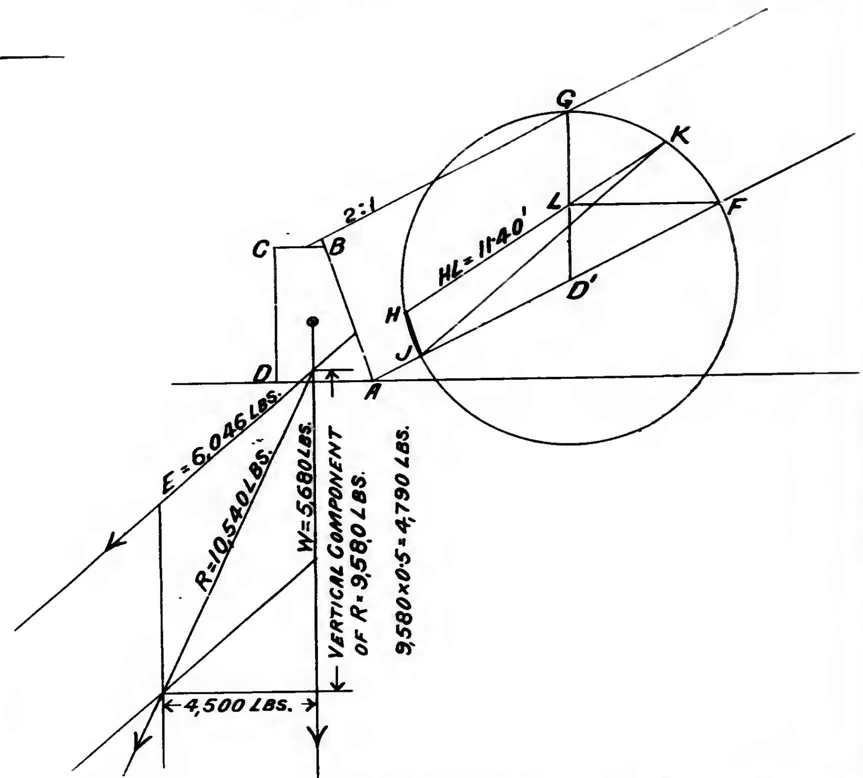

G
K
L
F
2:1
C
B
HL = 11·40'
D'
H
J
D
A
E = 6,046 LBS.
R = 10,540 LBS.
W = 5,680 LBS.
VERTICAL COMPONENT OF R = 9,580 LBS.
9,580 × 0·5 = 4,790 LBS.
4,500 LBS.

FIG. 3A

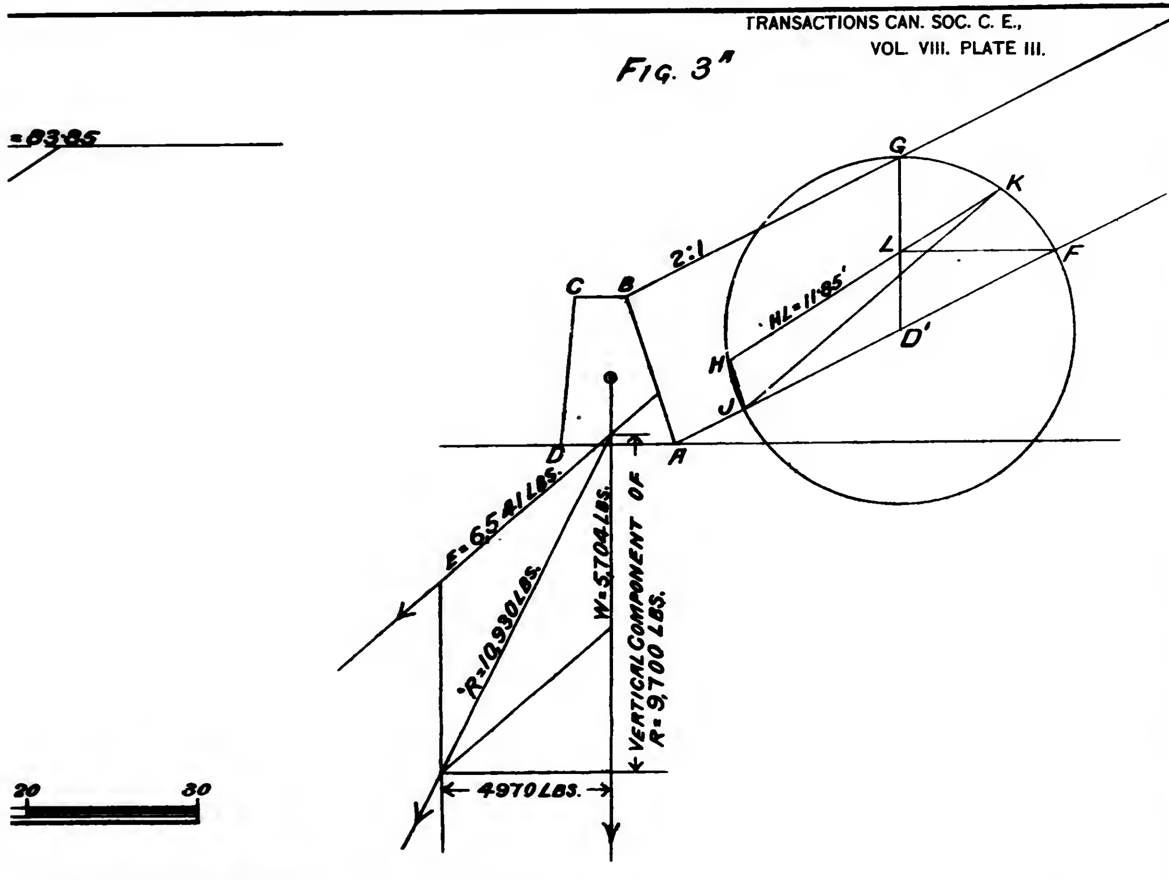

=83·85
G
K
L
F
2:1
C
B
HL=11·85'
D'
H
J
D
A
E=6,541 LBS.
R=10,930 LBS.
W=5,704 LBS.
VERTICAL COMPONENT OF
R=9,700 LBS.
4970 LBS.
20
30

FIG. 3.

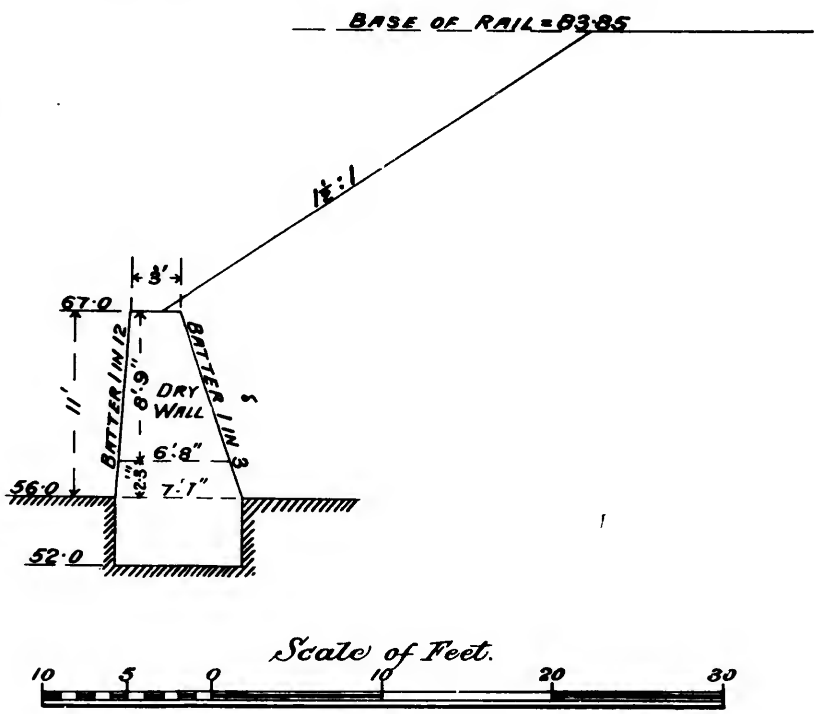

BASE OF RAIL = 83·85
1½:1
3'
67·0
11'
BATTER 1 IN 12
BATTER 1 IN 3
8'9"
DRY WALL
6'8"
2'3"
7'1"
56·0
52·0
Scale of Feet.
10
5
0
10
20
30

FIG. 3ª

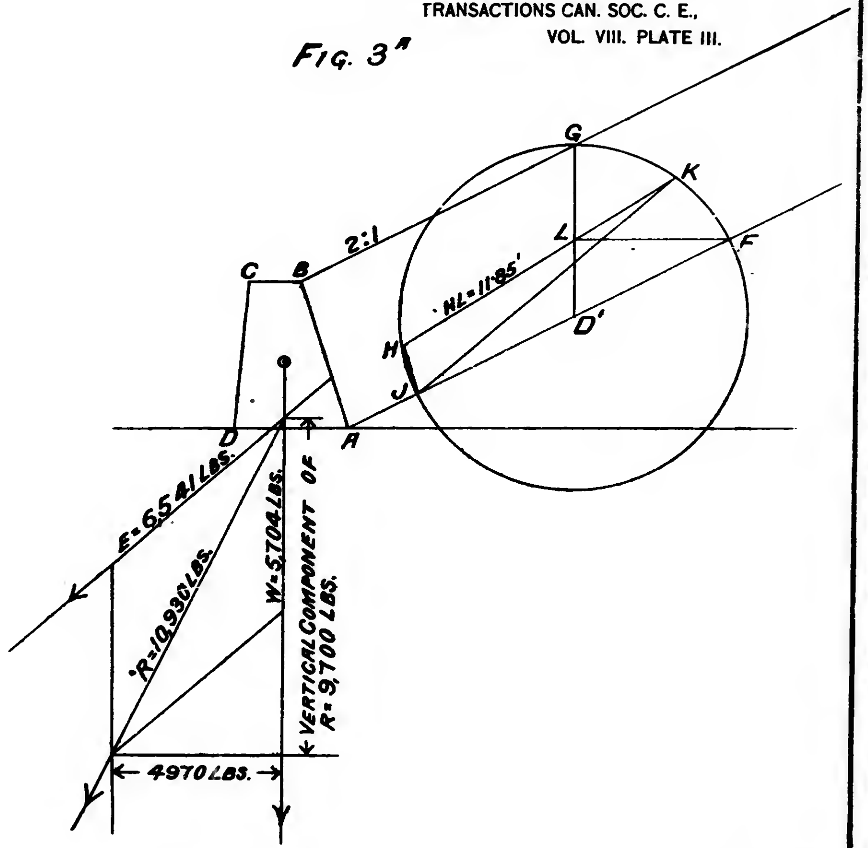
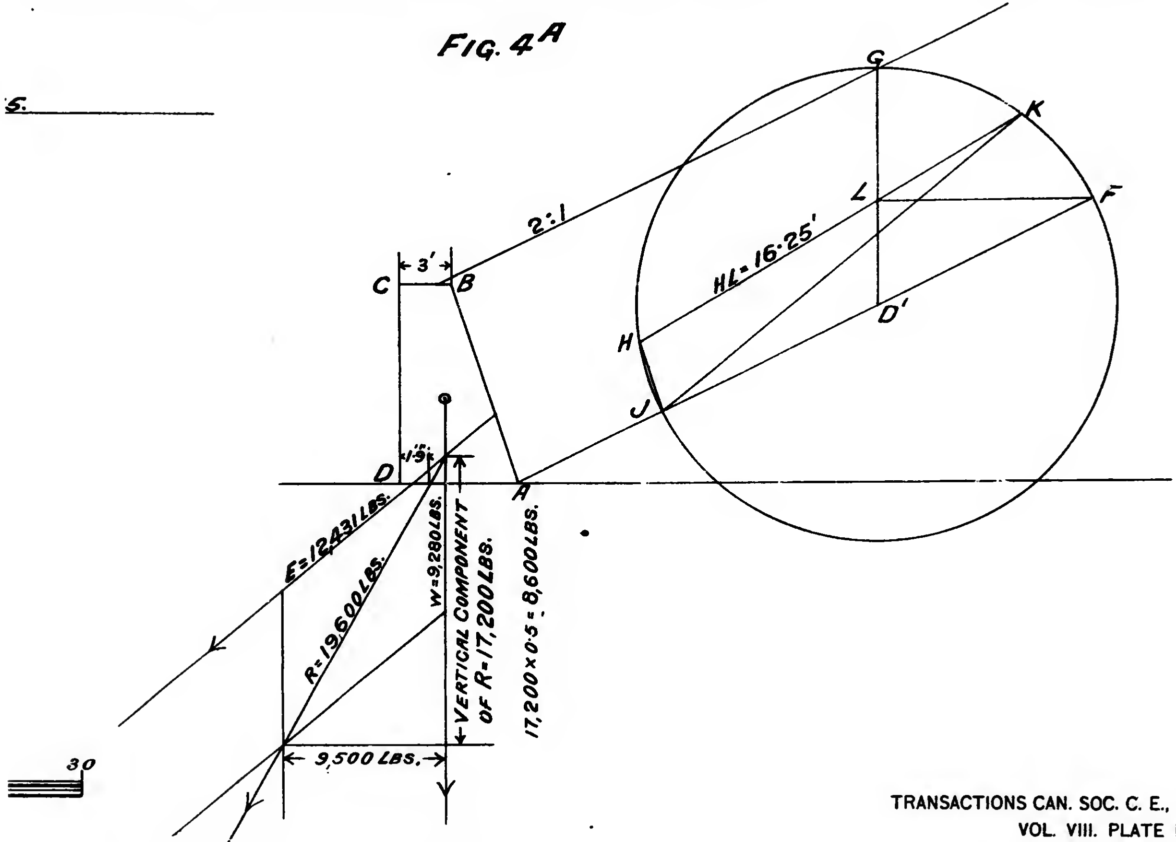

G
K
L
F
2:1
C
B
HL = 11·85'
D'
H
J
D
A
E = 6541 LBS.
R = 10,930 LBS.
W = 5704 LBS.
VERTICAL COMPONENT OF R = 9,700 LBS.
4970 LBS.

FIG. 4A



S.
G
K
L
F
2:1
HL = 16·25'
C
3'
B
D'
H
J
D
1·5'
A
E = 12,431 LBS.
R = 19,600 LBS.
W = 9,280 LBS.
VERTICAL COMPONENT OF R = 17,200 LBS.
17,200 × 0·5 = 8,600 LBS.
9,500 LBS.
30

FIG. 4.

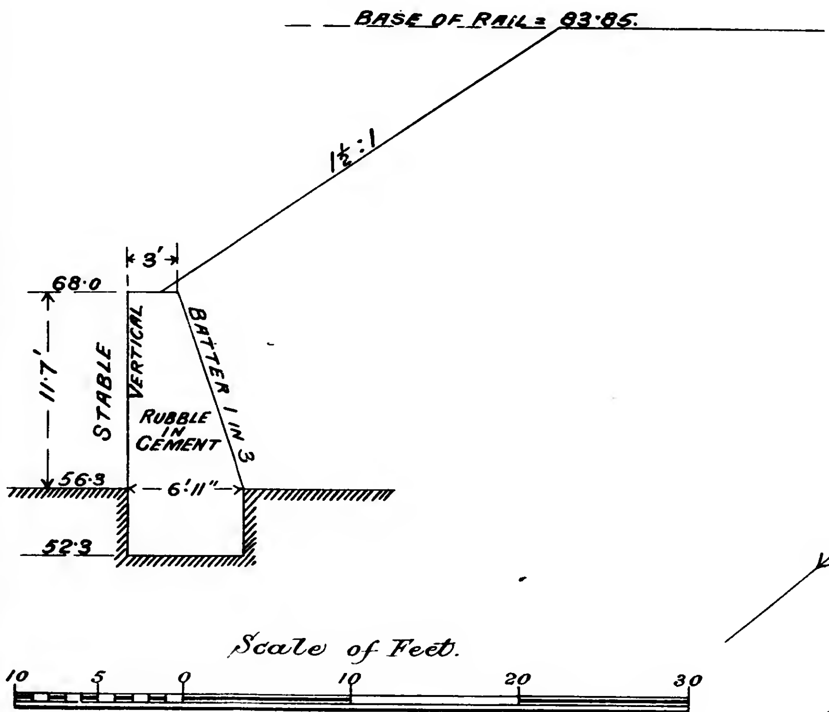

BASE OF RAIL = 83·85.
1½ : 1
3'
68·0
11·7'
STABLE
VERTICAL
BATTER 1 IN 3
RUBBLE IN CEMENT
56·3
6' 11"
52·3
Scale of Feet.
10
5
0
10
20
30

FIG. 4^A

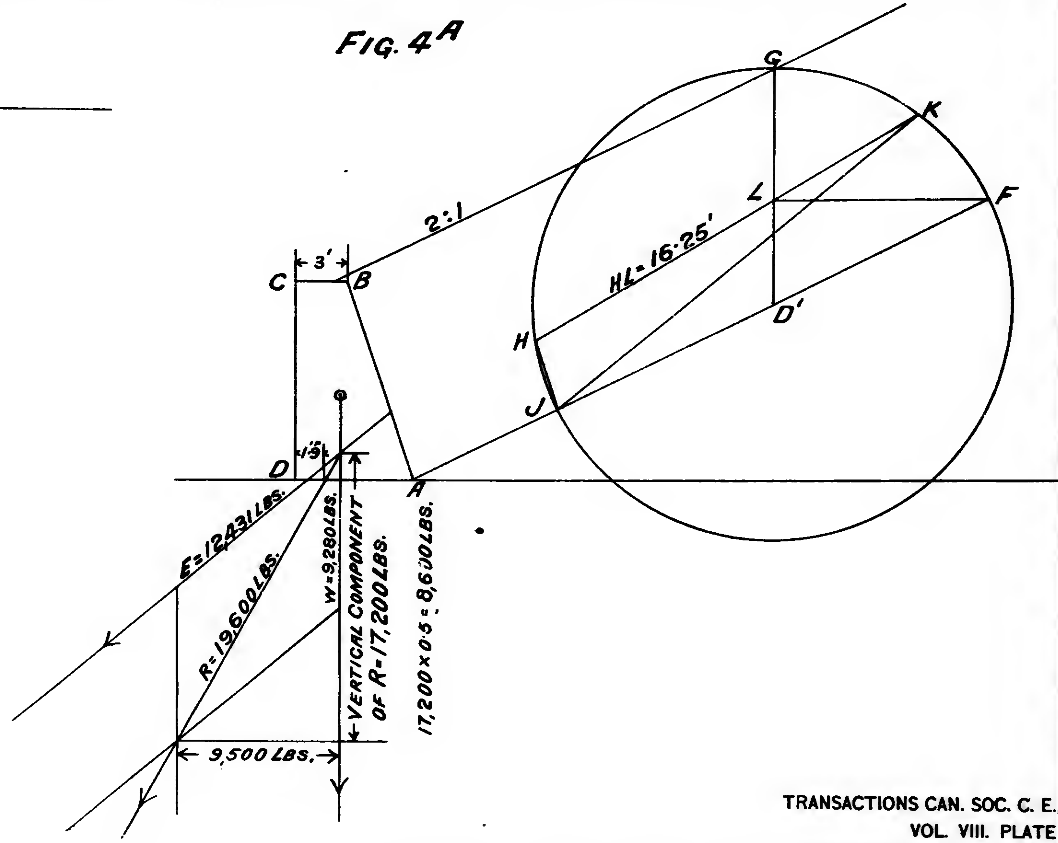
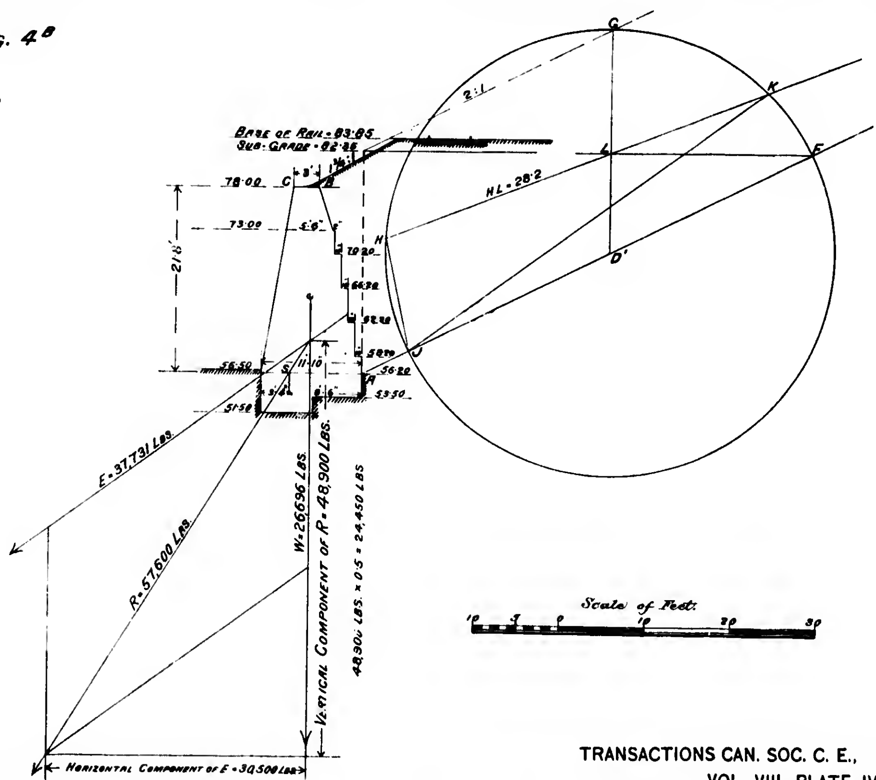

G
K
L
F
2:1
3'
C
B
HL = 16·25'
D'
H
J
D
A
E = 12431 LBS.
R = 19,600 LBS.
W = 9,280 LBS.
VERTICAL COMPONENT OF R = 17,200 LBS.
17,200 × 0·5 = 8,600 LBS.
9,500 LBS.

FIG. 4B



G
K
2:1
BASE OF RAIL = 83·85
SUB-GRADE = 82·35
L
F
78·00
C
B
HL = 28·2
73·00
5·6"
H
21·8'
D'
56·50
11·10
J
56·20
S
A
53·50
51·50
E = 37,731 LBS.
W = 26696 LBS.
VERTICAL COMPONENT OF R = 48,900 LBS.
48,900 LBS. × 0·5 = 24,450 LBS
R = 57,600 LBS.
Scale of Feet.
10
5
0
10
20
30
HORIZONTAL COMPONENT OF E = 30,500 LBS.

TRANSACTIONS CAN. SOC. C. E.,
VOL. VIII. PLATE V.

FIG. 5A.

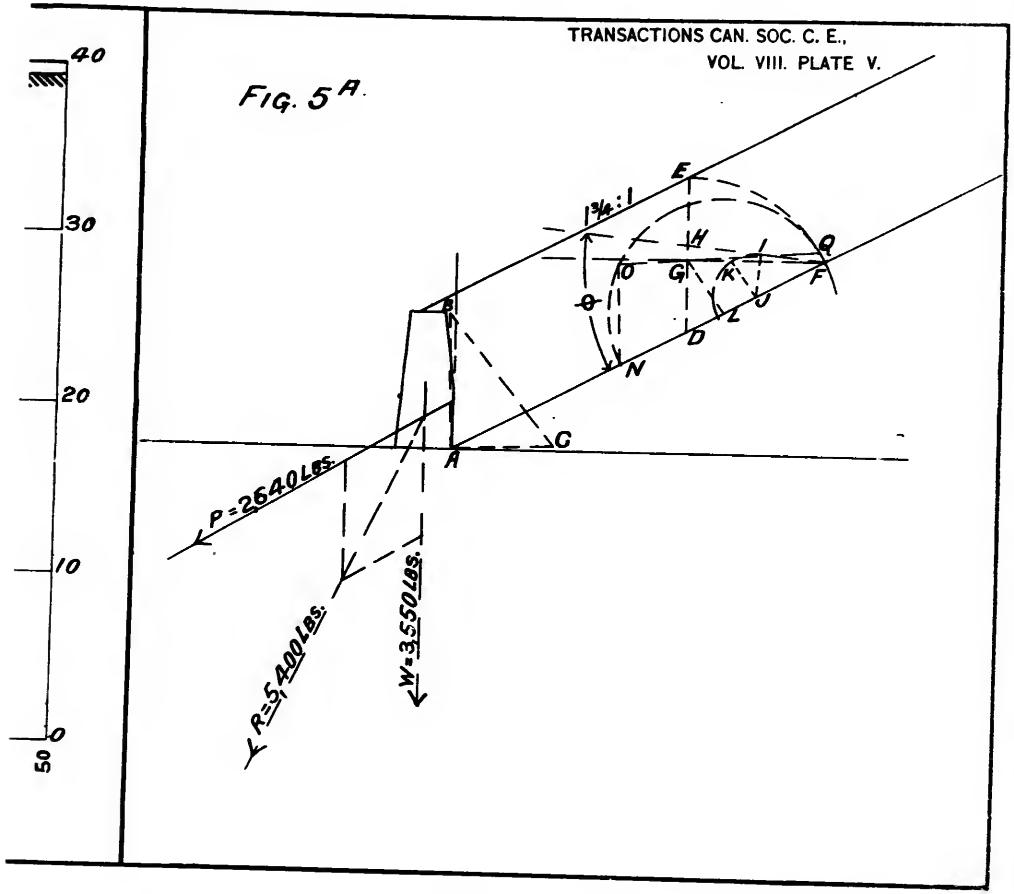
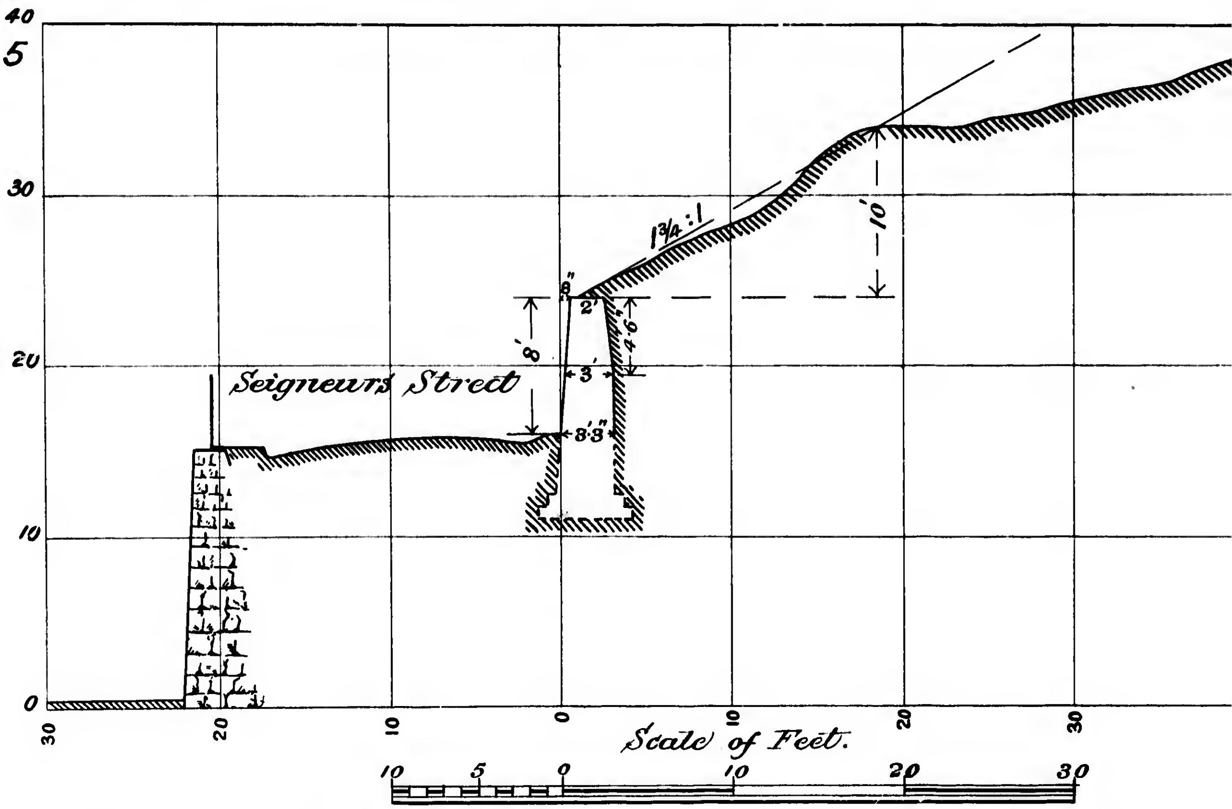


FIG. 5



40
30
20
10
0
Seigneurs Street
1¾ : 1
10'
8'
8"
2'
3'
4'6"
8'3"
30
20
10
0
10
20
30
Scale of Feet.
10
5
0
10
20
30

TRANSACTIONS CAN. SOC. C. E.,
VOL. VIII. PLATE V.

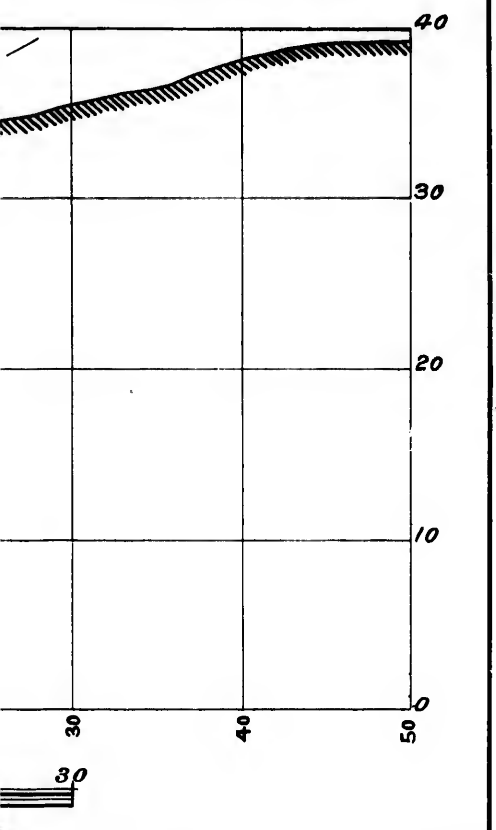
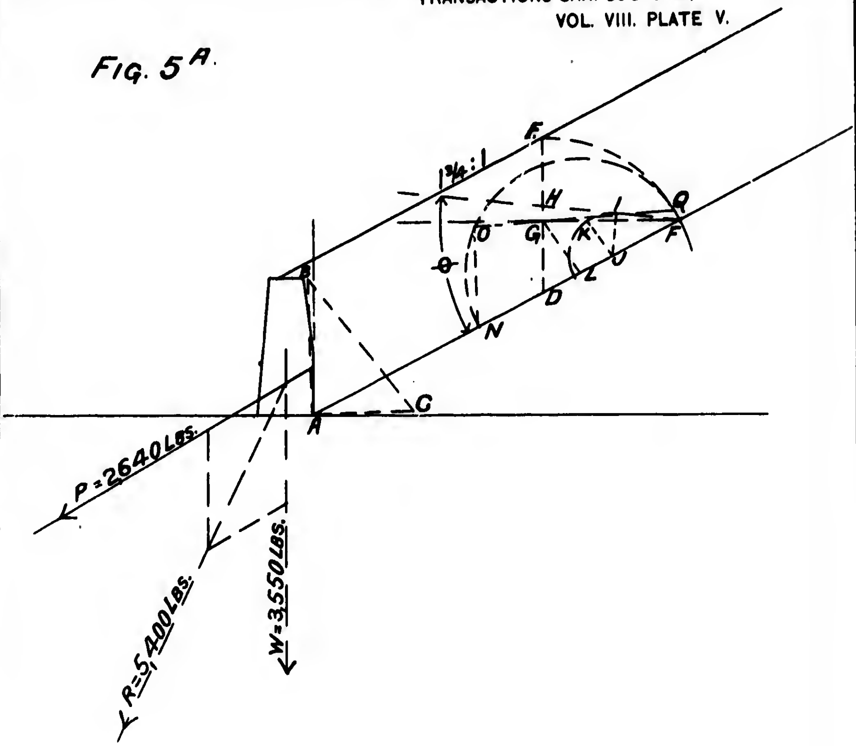


FIG. 5A.



TRANSACTIONS CAN. SOC. C. E.,
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FIG. 6.

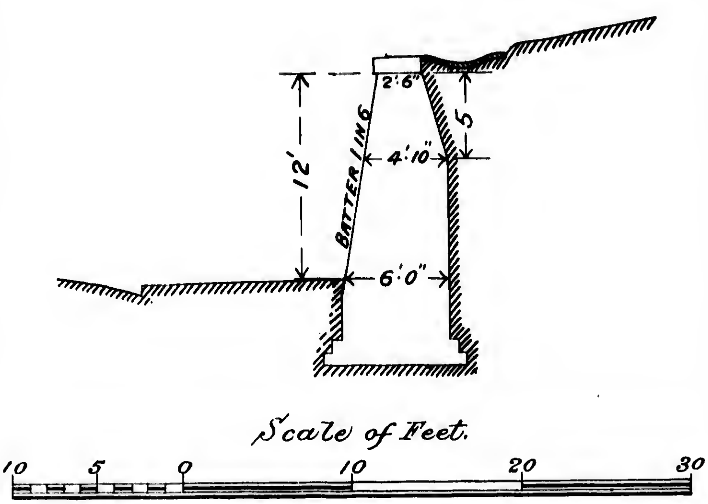


FIG. 7A.

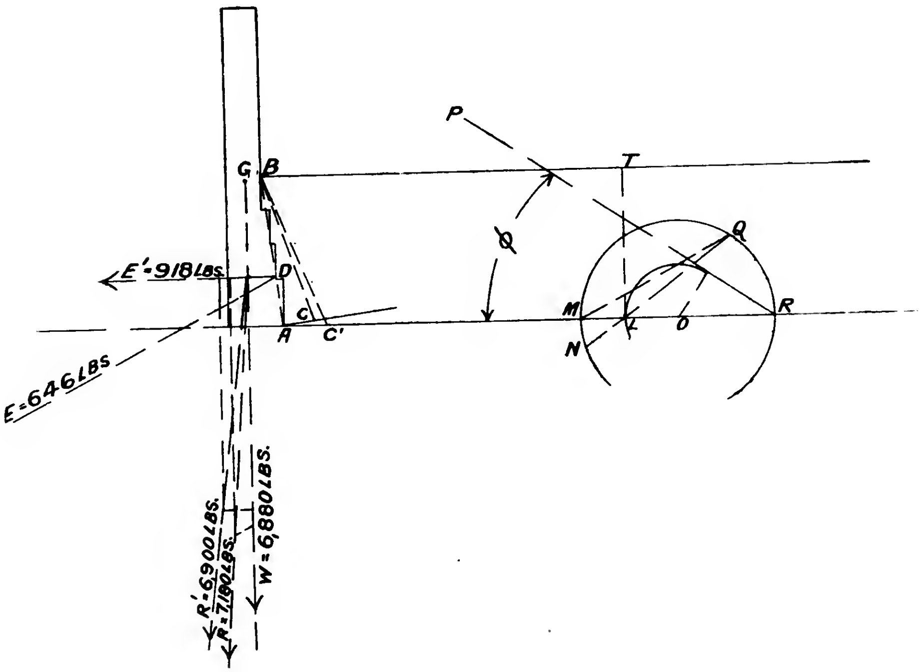

P
T
G
B
Q
φ
E'=918 LBS.
D
M
R
C
A
C'
K
O
N
E=646 LBS
R'=6900 LBS.
R=7180 LBS.
W=6,880 LBS.

FIG. 7.

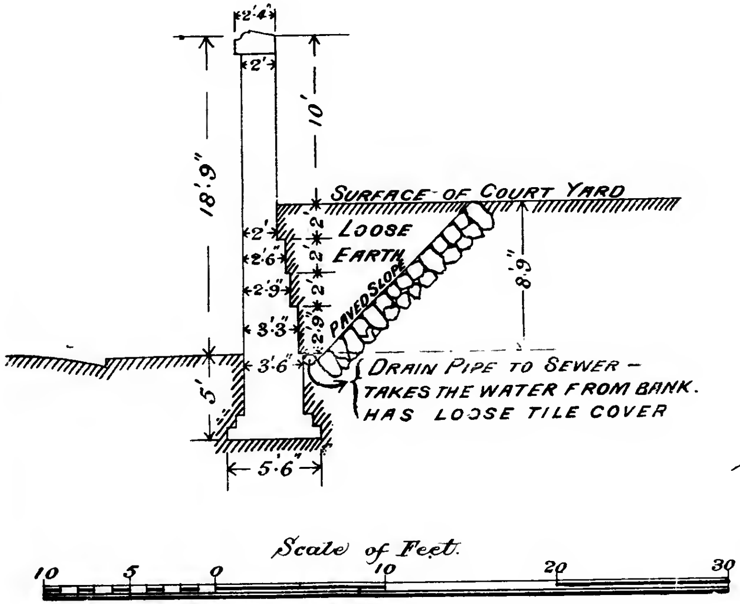
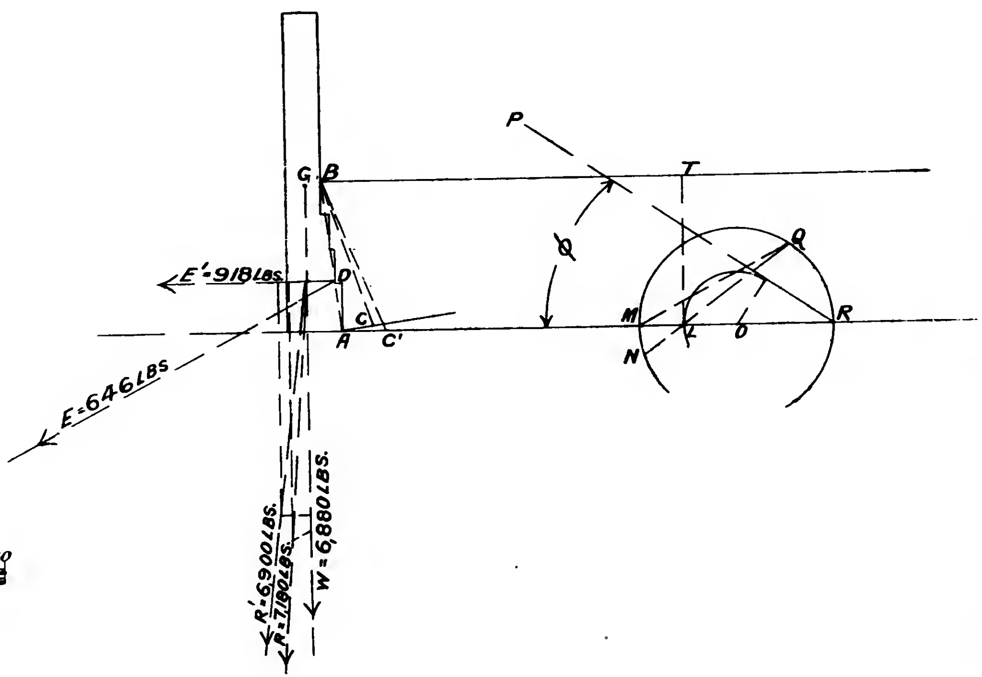

2'·4"
2'
10'
18'·9"
SURFACE OF COURT YARD
LOOSE EARTH
PAVED SLOPE
2'
2'·6"
2'·9"
3'·3"
3'·6"
8'·9"
DRAIN PIPE TO SEWER – TAKES THE WATER FROM BANK. HAS LOOSE TILE COVER
5'
5'·6"
Scale of Feet.
10 5 0 10 20 30

FIG. 7A.


G B D C C' A
E'=918 LBS
E=646 LBS
R'=6900 LBS.
R=7180 LBS.
W=6880 LBS.
P T Q R M N L O
φ

According to "Trautwine," this wall, if built with the same batter on front and back, should have a thickness of ten feet one inch at the base and five feet six inches at the top, instead of seven feet seven inches at the ground level and three feet at the top, as it was actually built, and Trautwine's dimensions are based on the assumption that the filling behind the wall would be of good material such as would stand at a slope of 1½ to 1.

Considering that the filling would not stand at a steeper slope than 2 to 1, while moist, the writer thinks that, according to "Trautwine," the wall should have been at least ten feet seven inches at the base and six feet at the top, or about fifty per cent. thicker than it was built, and that it would have been better to have built a wall in cement mortar about ten per cent. thicker than the wall which failed.

The diagram 3 A shows that, if the wall had been built according to Trautwine's dimensions, it should have had, by Weyrauch's theory, a factor of safety of one and a half against the stones sliding on the course above mentioned as being eight feet nine inches below the top of the wall; but this theory makes no allowance for vibration caused by trains.

Diagram 3 A is drawn for the wall as it was actually built and for the course above mentioned.

As the wall was made with extra large stones, its weight is taken at 0.82 of solid stone, or 135 lbs. per cubic foot, the clay filling being taken at 120 lbs. per cubic foot, and being assumed to come only to the top inner corner of the wall.

The diagram shows that the horizontal component of the thrust is 4,970 lbs. per foot run of the wall, and that the vertical component of the resultant pressure is 9,700 lbs., which, divided by 2 to get the frictional resistance to sliding, gives 4,850 lbs. for this resistance, therefore, according to the theory mentioned above, the stones at this joint should have been just about ready to slide without the help of vibration.

As this wall did not fail till early in the summer after the filling was finished, when the clay was getting thawed out, it is probable that it would have been just about strong enough had the filling been of good material, deposited in layers and properly rammed behind the wall.

In view of the fact that the clay in the bank was still quite plastic and contained some snow, which might be expected to melt out gradually and make the clay still worse, and bearing in mind that a failure of the wall might derail a train and send it down the bank, and that, if the wall gave way, heavy claims for damages would have to be met, it was decided to rebuild the wall of a very heavy section, almost the same as that shown in Fig. 4 B, which was adopted in rebuilding the wall shown by Fig. 4, the new walls in both these cases being much higher than those which failed so as to allow the bank to be widened out.

Fig. 4 B, drawn according to Weyrauch's theory, shows that the resultant pressure cuts the wall at ground level seven inches outside the middle third; this would leave the wall stable enough theoretically, as the foundation was good.

The diagram shows the horizontal component of the thrust to be 30,-500 lbs. per lineal foot of the wall, and the vertical component of the resultant pressure to be 48,900 lbs., which, divided by 2 to get the frictional resistance of dry stone, would give only 24,450 lbs., as the resistance to the horizontal pressure; but as the wall was built with Portland cement mortar, there would be no danger of the courses sliding on each other.

In drawing this pressure diagram the weight of the wall was taken at 160 lbs. per cubic foot, the weight of the filling was taken at 120 lbs. per cubic foot, and an additional 2 feet was added to the height of the bank to make allowance for the train load being so close behind the wall.

According to "Trautwine," a wall of the height shown in Fig. 4 B, with the given surcharge, with the face batter transformed by Trautwine's method, which, in this case, adds 2 inches to the face at ground level and takes off 3 feet 5 inches from the top width in front, and with the back changed to the batter shown, which is 2½ inches per foot for the lower part, and leaving the same quantity of masonry at the back, would be 14 feet 3 inches in width at the base and 5 feet 5 inches in width at the top.

These dimensions were considered excessive as they are about 35 per cent. greater than the standard which was used for fillings level with top of wall, and it was decided to build the upper 5 feet of the wall of the same thickness as the standard, but to give the wall a face batter of 2 inches per foot instead of 1 inch, according to the standard, thus making the wall 16 inches thicker at the ground level than the standard.

Weep holes were left in the new walls at intervals of about 6 feet, and the back of the wall was packed with small stone and spawls to secure good drainage behind the wall.

The wall shown in Fig. 4 was built to retain a portion of the same bank as No. 3. Being rather higher than the highest part of the dry wall just dealt with, and as it was to be built with a vertical face because it adjoined a property line and abutted against a brick stable, it was built with cement mortar.

It was pushed forward gradually for some months before and after the failure of the wall No. 3, and would probably have failed altogether in the course of a year.

It was pushed forward about 5 inches at the top, when it was decided to take it down and replace it by the wall shown in Fig. 4 B, which has been already discussed.

The reasons for taking it down were firstly to secure more space by building a higher wall, and secondly to avoid the possibility of damages caused by a total failure.

According to "Trautwine," a good rubble masonry wall of the surcharge shown in Fig. 4, and with the same batter at the back, should be 9 feet 5 inches thick at the base and 5 feet 6 inches thick at the top, instead of 6 feet 11 inches at the base and 3 feet at the top, as the wall that failed was actually built, and it seems certain that if Trautwine's dimensions had been adopted the wall would not have moved.

The thickness of 5 feet 6 inches at the top required for a wall with a vertical face might have been reduced to 4 feet 6 inches without weakening the wall if the front face had been given a batter of 1 inch per foot.

In the case of the new wall, with a front batter of 2 inches per foot, the neighbouring proprietor was allowed to run the roof of his stable back, and to connect it with the face of the wall, so as to keep snow and rain from getting into the V shaped space between the two walls.

Fig. 4 A, drawn according to Weyrauch's theory, shews that the resultant pressure cuts the base at one-fourth of its width from the front corner, and the vibrations caused by trains should throw it still nearer the front corner, so that it is possible that the small forward movement of the wall was due to excess of pressure on the foundations. The horizontal component of the thrust is about half the vertical component of the resultant pressure; but the courses could not have slipped on each other, as the wall was built in Portland cement mortar.

The new wall shown in Fig. 4B has shown no signs of failure.

It is true it is even thicker than the standard C.P.R. retaining wall, which may at first sight, as it did to the writer, seem too thick. It must be borne in mind, however, that this standard was designed not simply to retain an earth bank, but to carry and stand the thrust and vibrations of a heavy train running close up to it, either on tangents or sharp curves; and it has done this for many years and in a variety of places without any failures that the writer ever heard of.

The wall shown in Fig. 4B has however to stand a surcharge of 1.27 to 1, and the thrust of a soft clay bank, so that the writer thinks it is fairly proportioned.

Fig. 5 shews the old retaining wall on Seigneurs street between St. Antoine street and Dorchester street, where it runs diagonally up the face of the hill.

The dimensions were taken by the writer while the wall was being taken down a short time ago, and seem rather too small considering the amount of surcharge, yet its partial failure seems to have been due to the want of proper care. Had the joints been all well raked out and filled with good cement mortar, it would doubtless have stood as long as it was wanted.

The writer understands that it was removed to make way for the widening of the street which entailed the building of a much higher new wall.

When the old wall was removed and the bank cut back, its face stood perfectly well at a slope of about ¼ to 1, apparently almost vertical, the material of the bank being mostly compact fine gravel and sand, which would stand at a very steep slope so long as it was undisturbed and protected from the weather; in fact, it looked firm enough to require a very thin wall if proper precautions were taken to prevent water from lodging behind it, and if the filling replaced at the back of the wall were well rammed so as to prevent any movement of the old bank behind.

It will be noticed that the bank retained by this wall is of a totally different nature from those already alluded to; the former is an old solid undisturbed gravel bank, the latter new clay fillings dumped from cars with no attempt to spread the material in layers or consolidate it behind the walls.

The writer hopes that the City Surveyor will furnish the Society with a section of the new wall on Seigneurs street, giving the profile of the bank for some distance back from the wall.

According to Trautwine, a rubble masonry wall with a surcharge similar to that shown in Fig. 5, and with the given batter, should be 5 feet 5 inches thick at the ground line and 3 feet 9 inches at the top, instead of 3 feet 3 inches at the base and 2 feet at the top; however, it must be borne in mind that Trautwine's dimensions are given for a bank of clean dry sand which would exert far more pressure than the bank in question, the surface of which above and behind the wall was covered with the old sod and bound together with the roots of trees, and the material of the bank was, as already stated, very compact.

The Fig. 5A is drawn according to Weyrauch's theory for a surface surcharge sloping back at the same angle as the natural slope and for material standing at a slope of 1½ to 1. The weight of the bank is taken at 110 lbs. per cubic foot and of the wall at 160 lbs; and the bank is assumed to come within a foot of the front of the wall.

The diagram shows that the resultant pressure cuts the base at about one-third of its thickness from the front corner, so that the wall should have been safe from overturning. The horizontal component of the thrust is 4,600 lbs. per foot run, while the vertical component of the resultant pressure, divided by 2 to get the frictional resistance, is 4,830 lbs.; but as the wall was built with mortar, there would be sufficient resistance to sliding of the joints—indeed, in this case, as the stones were small and not built in regular courses, the tendency for the stones to slide on each other should have been small.

Fig. 6 is a section of the wall in front of the Archbishop's Palace on Lagauchetière street, from dimensions given to the writer by the contractor, who built it about 30 years ago, and repaired the portion from the entrance easterly to Mansfield street, a length of about two hundred and twenty feet, about nine years ago.

The writer was enabled to get this information through the kindness of Mr. A. Robert, the accountant at the Palace.

The portion of the wall from the entrance westerly to Cathedral street, a length of about 57 feet, has not been repaired since it was built, but bulges out at the top 4 inches at the middle of its length. The ends of this portion are well tied in by the wall on Cathedral street and by the return at the entrance, so that the unsupported length is under 50 feet.

The wall is all built in common lime mortar, and, so far as the writer remembers, the part repaired only had the front stones taken out and replaced with new mortar; the stones seemed to have been pushed out by the freezing and thawing of water lodged behind them.

There are no weep holes in the eastern part, but it has one drain behind at the centre which discharges into the street sewer. The contractor said that he wished to have put more drains behind, but was not allowed to do so; and also said that he considered such drains much better than weep holes, which are liable in this country to get frozen up in the spring from the cold of the inner part of the wall, and that they let the frost into the body of the wall.

The writer hopes some members will give their opinion on this point.

There is no drain behind the shorter western part, but there is one weep hole at the street corner. If the dimensions given are correct, the wall is fully thick enough, and if built in cement and properly drained behind, should never have moved.

There is a thin cement catchwater drain behind the eastern portion, as shown in Fig. 6, which takes away the surface water from behind the wall.

Fig. 7 is a section of the wall on the west side of Bleury street and just above Dorchester street.

It failed by bulging out on the face, and was taken down and rebuilt last year.

Through the courtesy of the Rev. F. X. Renaud, Superior of St. Mary's College, the writer was permitted to get the dimensions of this wall, and other information as to its construction, from the architects who designed it.

It appears that the architects at first advised the building of a 4 foot stone wall, similar to that which carries the present new building, which could be used for a future extension along Bleury street; however, the proprietors did not wish to go to so much expense, as they did not think of building any further in the future, and wished to reduce the cost of the wall as much as possible.

It was therefore decided to pave the slope as shown, build as light a wall as possible, and fill the V shaped space between the slope and the wall with light material, not rammed, so as to allow the water falling in the yard to percolate through the filling and run off through the drain at the foot of the slope, the drain being covered with flat tiles laid with open joints.

The wall was let by contract to the lowest tenderer, not the contractor for the new building, and the price was only sufficient to leave him $1.50 per cubic yard for the rubble backing.

The writer was allowed to see the specification for the wall. It was carefully drawn up, and provided for an ample number of headers, which were to be through stones wherever the wall was 2′ 6″ or less in thickness. It also called for 2 to 1 Portland cement mortar, made with White's or as good cement. It does not seem that the pressure of the earth filling was the cause of the bulge in the wall for which the Building Inspector had it taken down; for when it failed, the filling was not saturated with water, and there had been no time for frost to affect it.

It will be seen that the wall was about thick enough to retain the filling, for 8′ 9″ multiplied by 0.4 gives 3′ 6″ for the thickness at grounds level, while the actual thickness of the wall was 3′ 3″, and the vertical pressure of the extra 10 feet in height would have been more than enough to ensure the stability of the wall, providing it were properly built.

In fact, the wall bulged out in one place where there was no filling, at all behind it.

The greatest bulge was at a height of 6 or 8 feet above the level of the sidewalk, or almost as high as the top of the filling, and this seems too high to have been caused by the lateral pressure, since the greatest bulge should be about the centre of pressure.

The failure seems to have been due entirely to bad mortar, want of proper headers, and through stones and excess of mortar in the backing.

The writer examined the wall carefully after it had been almost all taken down, and could find no trace of a through stone or of a good header at all, and the wall seemed to have parted in two, the cut stone front separating from the backing.

The face was built of cut stone with a bed of only about 8 inches in depth, and the backing was of small stone with altogether too much mortar in the joints. The mortar was made of very fine dirty sand with too little lime in it, and what little there was no doubt of the useless fat lime now exclusively used in Montreal, because it is cheaper than good lime made from the black limestone which takes more fuel to burn it.

The consequence was that the upper 10 feet of the wall compressed the mortar in the backing, while the cut stone front, with its thin joints, would scarcely compress at all, and the front was forced out.

The writer has brought a sample of the mortar for inspection.

The architects protested against the way in which the walls were being built, and notified the proprietors not to pay for it; it was taken down not long after completion, and rebuilt with the money retained.

The writer believes that this wall would have stood perfectly well if a sufficient number of headers and through stones had been used, and if the mortar had been made of good cement and sand, in accordance with the specification; but thinks that it would have been better to have arranged to set the upper 2 foot portion 4 inches back from the face of the part below.

The diagram down in Fig. 7A. drawn according to Weyrauch's theory, shows that the wall would be in no danger of overturning and that the courses would not slide on each other.

In drawing this, the masonry was taken at 160 lbs. per cubic foot and the loose earth at 80 lbs. per cubic foot.

It may be added that a part of the wall which bulged slightly is still standing.

The writer regrets that the various cases referred to in this paper are unimportant works, but thinks that, in describing them as fully as possible, the results may prove useful.

They seem to shew that Weyrauch's theory, *intelligently applied*, would be a good check on empirical rules.

This theory assumes that the filling is without cohesion, and that its free surface slope would be a plane surface.

This seems to be the worst condition that a filling could assume, and that is what is to be guarded against in the case of embankments made by dumping from trains on a trestle.

In the case of a wall intended to retain a natural bank, part of which is to be cut away, nothing but experience and good judgment will be proper guides in determining how far theory may be departed from, and these would require to be supplemented by a thorough knowledge of the nature of the bank.

A natural bank, like that at Seigneurs street, only requires to be properly drained, and to have the material replaced behind the wall well rammed, so that the new face may not gradually loosen and press forward till at last there will be as much pressure against the wall as from a new bank ; if these precautions are carried out, a very light wall might be used.

The writer is well aware that such an eminent authority as Sir Benjamin Baker, whose practical rules are so good, seems to think that theory is entirely at sea with regard to retaining walls, if one may judge from his book on the lateral pressure of earthwork published by D. Van Nostrand in 1882.

With all due deference to this distinguished engineer, the writer thinks that he is a little hard on theory.

Many of the failures mentioned in his book were due to bad foundations ; such cases as these require quite different treatment from those where the foundation is solid, and should be kept quite separate.

Without attempting to criticise the book above mentioned in full, the writer may mention that on pages 26 and 34 Sir Benjamin obtains the pressure against two walls by calculating the moment of stability of the walls after they had been pressed forward considerably. Surely this is not fair to theory, since the force requried to start a wall and push it out of plumb would be much greater than that finally required to push it down when leaning ; and, besides, it is reasonable to assume that the pressure would be relieved by the forward movement of the wall, unless the filling had no cohesion, and unless it were kept up to its original level.

Again, on page 49, referring to cracks in clay over tunnels, the cracks being probably along the line of least resistance, he assumes this to be Coulomb's line of least resistance, and argues against his theory because the cracks had a slope of $\frac{1}{4}$ to 1.

There does not seem, however, to be any very good reason for doing so since Coulomb's theory did not take into account the cohesion of the clay ; and, besides, the writer thinks that the case of a mass of clay over a tunnel is not quite the same as that of a bank against a retaining wall with a plane face.

In conclusion, the writer would ask his fellow-members to bear in mind that this paper has been written rather too hurriedly for proper consideration, and trusts that they will give as much information as they can on the subject.