so that the resultant is still ·03 feet outside the middle third; and if that is not considered near enough another inch added to the width of base will make it so.

The following table of walls shows a comparison of a variety of conditions, h = 6 feet and 12 feet, rectangular and battered, calculated for cohesion with the different values above described, and also without allowance for cohesion, in the usual text-book method. The table graphically sets out the very great economy obtained from an allowance of even 25 pounds per square inch ultimate cohesive strength of the mortar, which allowance, as is seen, reduces the walls to about half the size of those computed in the manner usually advocated, notwithstanding a factor of safety of about 19 to 29 for cohesion, as against the cohesive strength of cement mortar (240) in the walls for working conditions.

A few other points of interest may be seen in the table. It may be observed that the rectangular form of wall is an absolute source of weakness. Taking the diagram condition walls, it will be observed that those with backs battered are actually of less width on the base than those that are rectangular (compare 2 with 4 and 6 with 8), and the factor of safety of the rectangular walls against overturning only is merely a trifle in excess of the smaller walls with batters, notwithstanding that the rectangular walls contain nearly twice the quantity of material. Material more properly placed gives almost the same strength as nearly double the amount in unsuitable form, with very little difference in cost of labour at that. This is accounted for by the relative positions of the centre of gravity, and the extra material in the upper portion of the wall merely gives rise to a tendency to make the wall top heavy; it is not only a waste of material, but it is a waste that is positively detrimental to the stability.

When proposing a new factor such as cohesion, in view of the fact that the proposal results in considerable reduction of dimensions, as shown by the table, it is necessary to consider to what extent other actions causing tendency to failure are affected thereby. So far, it is seen that the walls scheduled with dimensions for diagram condition are sufficiently secure against overturning, but the horizontal effect of the force P also induces a tendency on the wall to slide horizontally on its base or other joints. With a wall resting only, and without cohesion, on an horizontal foundation, such tendency would be resisted by friction; but since the walls are not in the least likely to be built so as to depend upon friction alone, that excessively uncertain quantity need not be considered in detail. When the element of the cohesion of the mortar is added, the resistance becomes shearing strength of the mortar. Whether

BRICK IN CEMENT WALLS.

One Part Portland Cement to Three Parts Sand.

S.G. of Brickwork taken as 1·8.
200 lbs. per square inch. Ultimate Tensile Strength of the Mortar under Laboratory conditions.
100 ,, ,, ,, ,, Adhesive ,, ,, ,, ,, Favorable ,,
50 ,, ,, ,, ,, ,, ,, ,, ,, ,, Average ,,
25 ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, ,, with allowance for "Fatigue."

Walls subject to full Hydrostatic Pressure, *i.e.*, depth of water equal to height of wall.
Walls No. 2, 4, 6, 8, are safe against Crushing or Sliding (Shearing).

Wall Number.	Height of Wall = Depth of Water.	Assumed Ultimate Value for the Adhesive Strength of the Mortar.															
		Nil.				25 lbs. per square inch. c = 3,600 b				50 lbs. per square inch. c = 7,200 b.				100 lbs. per square inch. c = 14,400 b.			
		b. Width of Base.	Factor of Safety.	Section of Wall.	Position of R on Base.	b. Width of Base.	Factor of Safety.	Section of Wall.	Position of R on Base.	b. Width of Base.	Factor of Safety.	Section of Wall.	Position of R on Base.	b. Width of Base.	Factor of Safety.	Section of Wall.	Position of R on Base.
	ft.	feet.			feet.	feet.			feet.	feet			feet.	feet.			feet.
1	6	2·58	1·0	Rectangle	At Toe	1·03	1·0	Rectangle	At Toe	0·75	1·0	Rectangle	At Toe	0 55	1·0	Rectangle	At Toe
2	6	4·45	3·0	,,	At M/3	1·8	3·0	,,	At M/3	1·31	3·0	,,	At M/3	0·95	3·0	,,	At M/3
3	6	2·84	1·0	9in. Crest Batter	At Toe	1·0	0·95	9in. Crest Batter	·03 outside Toe	0·75	1·0	9in. Crest No Batter	At Toe	—	—	Less than (see	9in. Crest No. 1)
4	6	4·25	2·62	,,	·04 inside M/3	1·75	2·86	,,	At M/3	1·3	2·95	9in. Crest Batter	·002 inside M/3	0·95	3·02	9in. Crest Batter	·003 inside M/3
5	12	5·2	1·0	Rectangle	At Toe	2·7	1·0	Rectangle	At Toe	2 05	1·0	Rectangle	At Toe	1·5	1·0	Rectangle	At Toe
6	12	9·0	3·0	,,	At M/3	4·67	3·0	,,	At M/3	3·55	3·0	,,	At M/3	2·62	3·0	,,	At M/3
7	12	6·0	1·0	9in. Crest Batter	0·03 inside Toe	2·75	0·99	9in. Crest Batter	0·01 outside Toe	2·0	0·93	9in. Crest Batter	0·075 outside Toe	1·5	0·98	9in. Crest Batter	0·016 outside Toe
8	12	8·75	2·1	,,	0·09 inside M/3	4·5	2·61	,,	0·03 outside M/3	3·5	2 82	,,	At M/3	2·5	2·7	,,	0·03 outside M/3

friction or shearing stress, considerable additional resistance is afforded by laying the bed-joints at right angles to the back batter or slope, when a lifting resistance, due to the inclined plane, is added to the sliding resistance; but it is preferable to consider the shearing strength alone as affording the resistance required, partly because the lifting resistance is proportionately small at ordinary inclinations, as compared with the shearing strength of the cement, and partly because it would be difficult to determine to what extent such lifting resistance would come into action prior to fracture of the mortar, whilst after that fracture the weight of the mass would have to act alone, and would, of course, be insufficient, or the fracture could not have occurred.

The smallest 12-foot wall in the table is that in the C = 14,400 b division, with base 1·5 foot wide, with factor of 1 against the horizontal force of 4,493 pounds; allowing the same factor 1, since that wall has 216 square inches of area of mortar per foot run of the wall, it is necessary that the mortar should have an ultimate resistance to shearing of 21 pounds per square inch. It is stated that the ultimate shearing strength of 3 to 1 Portland cement mortar, under the same (favourable) conditions, may be safely taken at 35 pounds per square inch; hence this wall has ample excess in that direction. The smallest diagram factor wall (12 feet high) has width of base 2·5 feet, and presents 360 square inches of resistance, so has a factor of about 2·8 against shear, or about the same as the factor for stability; hence all the larger or safe working condition walls are amply strong in resistance to "shear" or horizontal sliding.

Next there is resistance to bulging, which might take place in one of two ways, either in some part of the length of the wall as a kind of "beam" strain between supports, or in some part of its height. The latter event does occasionally occur whilst the mortar is green; it has been known to occur to a certain extent, and then to cease altogether, probably owing to temporary removal of stress with subsequent or more complete setting of the mortar.

Such a wall is not a beam suspended between the ends; it is supported all along the base line, which is the line of maximum pressure; and this support is carried up in parallels with lessening pressure through the other course joints of the masonry to the crest, where the pressure is nil. Any propensity to "bulge" is closely analogous to shearing strain at the foundation; it appears to occur most frequently at the position of the centre of pressure in weakly-constructed walls, and it becomes a shearing strain at that point. But if the wall be designed (as it must be designed) so that each course is of sufficient width to withstand the stress of the full "head" above it, each course will have a ratio of strength corresponding to the strength of the base course.

Hence it may reasonably be contended that the tendency to bulge is only a form of tendency to shear or slide, taking place in joints other than those of the base; and that if the wall be of strength sufficient to withstand the one, it will be similarly so with regard to the other.

There now remains resistance to crushing stress. With the wall standing free from lateral pressure, the resultant obviously lies along the centre of gravity points of the different courses, and the weight of the wall, resting upon its base evenly to an equal distance on each side of this line, needs only special consideration in the case of very high walls, and certainly in none of those of the table.

When, however, the lateral pressure P is applied, the resultant is pushed over towards the toe of the wall. If f = 1, the resultant crosses the base line at the toe, and then the total pressure is theoretically concentrated, and practically nearly concentrated upon that point, when, if the resultant stress be in excess of the crushing strength, the toe must crumble and the wall will fail.

When the resultant passes through some point of the base line inside the toe, the greatest pressure falls upon that point whilst a portion of the aggregate is distributed between that point and the toe, and the remainder between the same point and another at equal distance upon the other side, the amount theoretically diminishing with distance from the resultant, so that the further point, the heel, would be in the position of receiving none; but this feature is modified by the distributing faculty of the molecules of the material.

Practically the pressure on the base of the wall may be regarded as concentrated upon that portion of the base that lies between the toe and the resultant, and an equivalent width on the opposite side of the resultant; and for all practical purposes the molecular properties of the material may be considered as causing uniform distribution of the total stress over that portion. Hence, in a wall three feet wide, if the lateral pressure be such as to throw the resultant over to a point one foot inside the toe (the middle third condition), the whole of the pressure represented by the resultant may be regarded as evenly distributed over the two-thirds of the base on the toe side. The assumption is on the side of safety, because the one-third on the heel side will certainly receive some of the load, the amount depending upon the characteristics of the material.

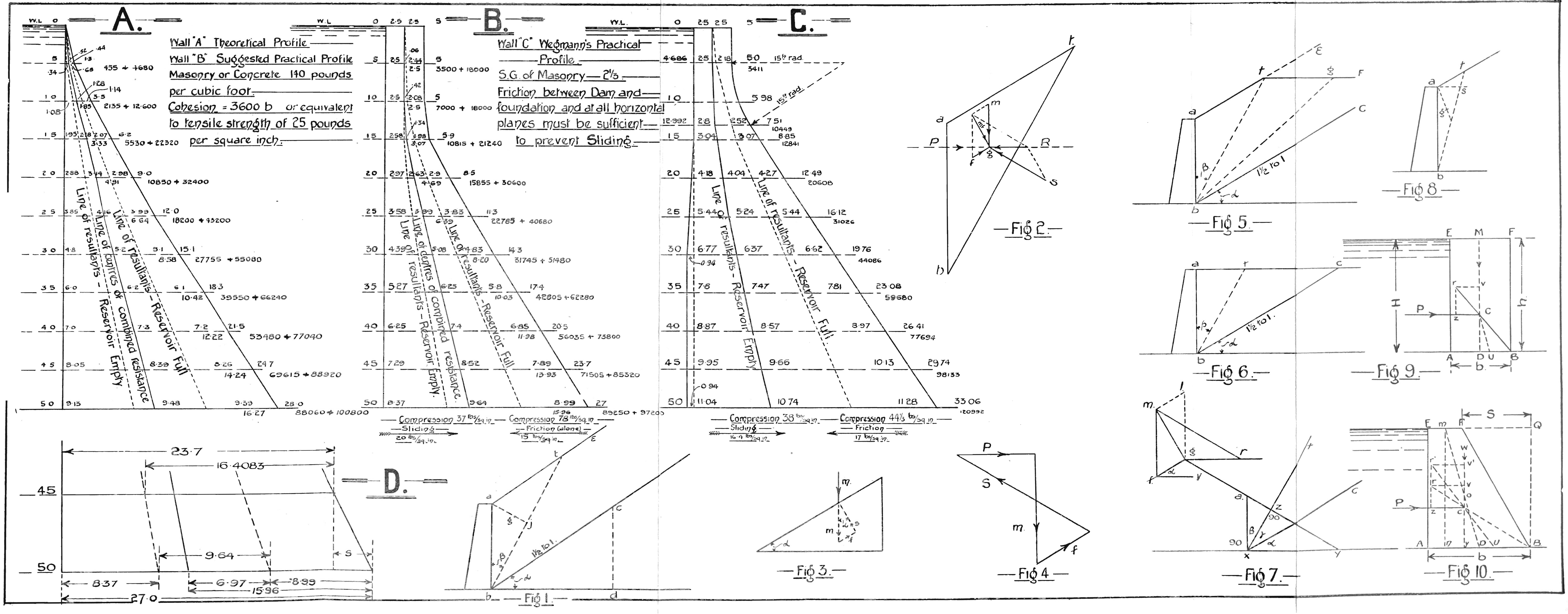
Wall No. 8, of the table of the $c = 14,400$ b section, is the most heavily stressed in this direction. The value of the resultant or total crushing stress is 28,422 pounds on a width of $2 \times 1 \cdot 17 = 2 \cdot 34$ feet of the base, giving 85 pounds per square inch of compression. The ultimate compressive strength of the mortar is probably about 1,000 pounds per square inch, and that of the brickwork in cement may safely be regarded as having a working or safe resistance to crushing of 180. or certainly 150 pounds per square inch.

It may now be considered as established that all the walls in the table are stable against the various stresses to which they are liable, to at least the value of the factor placed against each; and also that those scheduled as calculated to the middle third condition are safe working construction under the conditions set forth. It may also be reasonably concluded that those calculated to middle third condition, under $C = 7,200$ b, can be accepted as sufficient dimensions, when special care is taken to ensure excellence of material and workmanship; whilst those similarly calculated with $C = 3,600$ b are safe working walls for quite ordinary construction under full hydrostatic pressure.

The obvious objection to the practice of construction, on the principle of allowing value for the cohesive strength of the mortar, is the difficulty of fixing the value of that strength. For instance, if a wall be built to resist an hydraulic pressure, and that pressure be applied before the mortar has had time to set, obviously the wall will not have its proper quota of assistance from the cohesive property, and in the case of a very thick wall, it may occupy weeks, and even months, before that wall is anything but green; though, of course, a very thick wall will take a long time to build, and its points of maximum pressure will be completed first and have the longer time to set.

In most cases the period required for setting can be arranged for. A dam may be completed early in the dry season, or some months before it is actually required to stand stress. A retaining wall may be built and dry backing placed behind it with ample provision of seepage holes in the base, and during the setting period, some little care may be taken to divert drainage from the new work. In most cases of retaining walls for embankments the full computed stress will not come into action prior to the occurence of some phenomenal season, if at all.

In the case of retaining walls, it must be recognised that each case can only be considered on its merits, and much must depend upon the judgment of the designing architect or engineer; but it is certainly an unpleasant alternative to incur two or three times the cost of a wall to provide a source of


A.
B.
C.
D.
Wall "A" Theoretical Profile
Wall "B" Suggested Practical Profile
Masonry or Concrete 140 pounds per cubic foot.
Cohesion = 3600 b or equivalent to tensile strength of 25 pounds per square inch.
Wall "C" Wegmann's Practical Profile.
S.G. of Masonry — 2⅓.
Friction between Dam and foundation and at all horizontal planes must be sufficient to prevent Sliding.
Line of resultants – Reservoir Empty
Line of centres of combined resistance
Line of resultants – Reservoir Full
Compression 37 lbs/sq in
Sliding 20 lbs/sq in
Compression 78 lbs/sq in
Friction (alone) 15 lbs/sq in
Compression 38 lbs/sq in
Sliding 16.4 lbs/sq in
Compression 44½ lbs/sq in
Friction 17 lbs/sq in
15ft rad.
1½ to 1
Fig 1.
Fig 2.
Fig 3.
Fig 4.
Fig 5.
Fig 6.
Fig 7.
Fig 8.
Fig 9.
Fig 10.

strength that is only of service for a few weeks, or at most months, and then is never again required. In most cases it is less expensive to make arrangements to admit of the setting of the mortar than to pay the high cost of the mere gravity wall.

Returning once more to the table of walls, it may be observed that the No. 8, 12-foot wall in the C = 3,600 b section, is 4·5 feet wide at the base, and that the No. 4, corresponding 6-feet wall, is only 1·75 foot wide at the base, or considerably less than half of the former; hence it is evident that the requisite width of base is not directly proportional to the height; also that if the batter of the 12-feet wall be built in a straight line from the toe to the crest, there will certainly be waste of, or unsuitably placed materials. That wall would be 2·6 wide at the middle, whereas No. 4 shows that it only needs to be 1·75 at that point. On the other hand, it does not follow that the wall could safely be constructed 1·75 wide at 6 feet height and 4·5 at the base, for the loss in weight in the upper portion would need some compensation in the leverage. Still, notwithstanding, an accurately designed wall must have a profile, which will partake more or less of the form of a curve. This is better exemplified by inspection of the figures A, B, and C.

Figure A represents a theoretical profile under the practical conditions of the proper factors of safety, as against overturning, sliding, or crushing, but starting from a point, at the water level, to show the conformation of the various curves when calculated upon the basis of an allowance for cohesion of C = 3,600 b in the cement, with which the particles are bound together. Figure B represents what may be termed a practical profile under similar conditions, but allowing a width of crest of 5 feet for convenience, and access to fittings, such as sluice valves, etc. Figure C is a copy of the Wegmann dam practical profile, for the same hydrostatic pressure, introduced for the purpose of comparison. The three walls are calculated for practically the same conditions, though the advantage is slightly in favour of the Wegmann wall, which is based upon S.G. $2\frac{1}{3}$ for the material, or 145·6 pounds per cubic foot, whereas the walls of Figures A and B are computed for material weighing only 140 pounds per cubic foot, so that the difference between the systems is slightly greater than appears from the figured dimensions.

With all due respect to a generally recognised authority, the design of the Wegmann wall appears to be somewhat illogical, for it is laid down as a condition of the design that friction, to prevent sliding on the base (or horizontal joints), is assumed. The wall is otherwise calculated purely upon the basis of gravity as against overturning moments. Friction, to prevent sliding on the base, might well be provided by dove-tailing the base into the foundation, but what is going to provide this friction on the other horizontal joints? They might all be dove-tailed, too. It would not be impossible, but it would be expensive certainly beyond anything, we will venture to say, that is contemplated in the design that is labelled "Practical Profile"; yet, what else, if not cohesion? Thus it is fairly evident that Wegmann assumes a cohesive strength in the mortar as against sliding, but will not allow for the same factor of resistance as against overturning moment. A high co-efficient of friction is necessary, to resist horizontal sliding upon any horizontal plane (that is a self-evident fact), yet the force which enhances or produces the same effect throughout the mass is totally ignored in the consideration of overturning moments, and, as illustrated by comparison of B and C, it is quite an important factor in the economy of the wall.

With regard to Figure A, no further comment is necessary; it is merely an illustration of the path of various curves commencing from the point at which both stress and strain $= 0$.

Figure B.—Here the compression arising from the "reservoir full" resultant line only amounts to 78 pounds per square inch, and allows a factor of nearly 2 against even the *safe* working allowance for the material, which is taken as Portland cement concrete. The centre of gravity or "reservoir empty" line lies slightly outside the middle third—a few inches outside of it—but the resulting compression only amounts to 37 pounds per square inch, which is trifling. Referring to Fig. C, it will be noted that Wegmann seems to lay some stress on adjusting this line so that it shall lie within the middle third, and with that object, specially constructs an offset of nearly a foot on the heel side; but apart from the aspect of general conformity with an abstract principle, there seems to be absolutely no purpose served by the provision, and the price is too high for the mere effect of conformity to abstract principle.

Upon the base area of Figure B alone the stress to induce sliding amounts to $\frac{78{,}000}{27 \times 144} = 20$ pounds per square inch; whilst the friction co-efficient taken at two-thirds the weight (for masonry) amounts to $\frac{2 \times 89{,}250}{3} = 59{,}500$, on 3,888 square inches, or 15 pounds per square inch, leaving, therefore, only 5 pounds for the stress to be resisted in the form of shearing strength, and at the lowest computation the shearing strength may be set down at one-quarter of the tensile strength. Taking the latter at the very moderate value of 50 pounds, there is available $12\frac{1}{2}$ pounds per square inch, whilst the said shearing strength is set down by some authorities as *safe* at 35 pounds. But this is not all, for it is based on the unassisted strength of the base course alone, whereas before the wall can slide, it must also break the vertical joints. It might be that two such vertical joints would have to be fractured, but certainly there must always be one and a portion of another. The vertical joint upon one side only of the figure amounts to 91,800 square inches, which allows for less than one pound per square inch shearing strength, without including anything for friction on the base course. Including the latter resistance, there is only one-fifth pound per square inch to be counteracted by shearing strength, so that against mere "shear" there is a very great factor of safety, unless it be contemplated that the shear is to take effect at the shallow ends of the dam; in that case the stress would practically amount to overturning moment, the factor against which in this wall is $2\frac{1}{4}$.

In Figure C, again taking the friction co-efficient at two-thirds the weight, the Wegmann wall has frictional resistance just about equal to the sliding stress on the base course, or a factor of 1 in this particular, and practically the same in the courses above. The wall is therefore in condition of unstable equilibrium on the basis of calculation adopted (unless dovetailed throughout), so that evidently the design is dependent for its safety upon a factor which is refused place in the other calculation.

It therefore appears that for the sake of ignoring as an asset a force which certainly exists, with substantial value, in order to obtain a mathematical factor of 2, or thereabouts, against overturning, and only 1, even then against shearing, if the same factor be still ignored, Wegmann advocates the employment of some 36 per cent. excess of material and cost over and above the quantity that is necessary to obtain concordant results when employing that factor, which, although ostensibly ignored, is equally essential to his design for the maintenance of stable equilibrium throughout—equally in principle, if not to the same extent, as in the design of Figure B.

Upon reference to Figures A and B, it will be observed that there are three interior curves shown. The left-hand one is the line of centre of gravity of the mass, and is therefore, of course, the resultant line of the condition "reservoir empty." The right-hand line represents the incidence of the combined forces (resultant) at the various sections, under the condition "reservoir full." The full line between these two represents the position of the centre of action of the combined forces, gravity and cohesion, and its situation depends upon the moment of each at each horizontal layer. Perhaps the best manner of