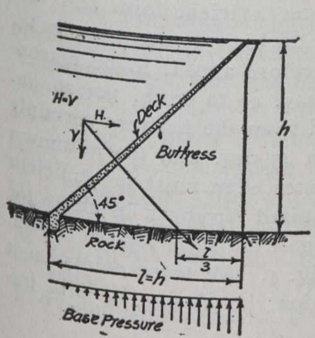
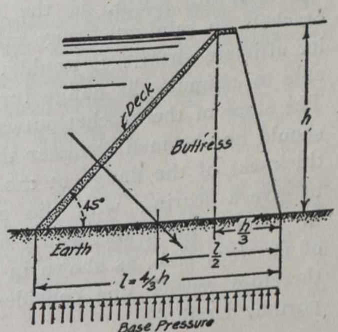
water cushion must be formed for low heads, possibly by slightly extending the base of the dam and placing a small barrier dam at its downstream edge, or a complete rollway, with or without an apron to prevent scour, must be used.

Construction.—The usual method is similar to that employed in the construction of masonry dams, but the required cofferdam is usually far less costly and of a more temporary character. The foundation and lower sections of the bulkhead are first constructed, and the entire flow of the stream is allowed to pass through this partially completed section while the upper parts of the buttress and slab are being erected and the remaining portions of the dam completed. The final closure is usually made as shown in Fig. 1, without employing any expensive cofferdam. This method is patented. The procedure in the erection, field joints, and forms will be discussed further on.



- Fig. 2 -



- Fig. 3 -

Slope of Deck and Shape of Buttress.—The deck slope is generally made 45 deg. The reason for this becomes clear by reference to Figs. 2 and 3. Fig. 2 represents a dam on a rock foundation where the resultant base pressure may be allowed to take the triangular form, i.e., the resultant may cut the base at or inside the middle third. This result must be obtained at the least cost. Neglecting the weight of the dam itself, and drawing the buttress with a vertical downstream face, which will evidently be the minimum practical form, it may be easily shown that a 45 deg. slope for the deck just satisfies this condition. A steeper slope would result in a little saving in the deck but would require an addition to the buttress on the downstream side to keep the resultant within the required limit. A greater slope would result in an increased slab and buttress. The relation, base equals height, therefore represents the economical proportions for this type of dam on a rock foundation.

On some foundations it is evident that it will be advantageous to have a practically uniform distribution of loading over the base. A brief consideration will show that this can best be obtained by applying an additional downstream section to the buttress, as shown in Fig. 3, giving a total bottom width equal to 1⅓ h. The uniform distribution of pressure could have been obtained, it is true, by decreasing the slope of the deck, but this would result in increasing the vertical component of the resultant water pressure and thus also the intensity of the base pressure, a condition not desired. It is therefore clear that the slope of the deck may be made 40 deg. for all conditions and, in softer material, the buttress may be given a downstream slope of between 0.25 and 0.33 of its height; this will bring the centre of pressure about the centre of the base, when the weight of the dam is considered in conjunction with the vertical component of the water pressure.

The top width of the buttress may be zero, but will generally be made 3 or 4 feet, to provide additional strength for ice thrust, where such is liable to occur, or to carry a walk across the top of the dam to facilitate inspection, etc. Where no ice is expected the walk may be carried on brackets, as shown in Fig. 2.

Buttress Thickness.—The buttress may have a tapering section, varying from a minimum thickness of 12 in. at the top to dimensions determined by the allowable pressure on the concrete, and shear at the different depths. The tapered section is, however, not so advantageous from the constructor's standpoint as a vertical section, increasing by offsets at intervals of 10 or 12 ft.; this plan offers a support for the bottom of the forms for each "lift." The minimum section should therefore be of 12-in. thickness for not over 10 or 12 ft., and should be increased in thickness 2 in. for each additional 10 or 12 ft. of depth, or as required by the working stresses in the concrete. A 1:3:6 concrete is commonly used for the buttresses, the allowable compression on which may be taken at 300 lb. and direct shear at 75 lb. per sq. inch.

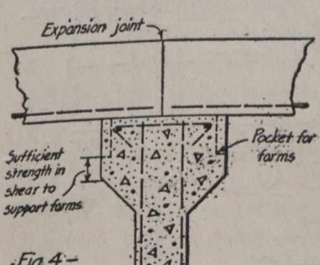
Struts.—These should be introduced at suitable points to brace the buttresses transversely. They should be placed a distance apart not over 15 times the thickness of the buttress and, to facilitate construction, should be placed at the levels where the offsets in the buttress occur. Their least dimension should not be less than 1/15 the distance between buttresses, and they should be reinforced to act as columns and carry their own weight as beams.

Spacing of Buttresses.—This will usually be between 14 and 18 ft., depending on the height and unit costs. As the distance, centre to centre of the buttresses is decreased, the span of the deck slab is decreased, and hence a saving in its cost results. More buttresses will be required, however. It is therefore clear that there must be some spacing which results in the greatest economy.

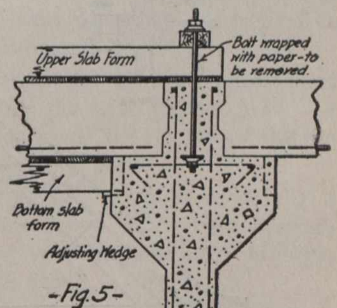
This economical spacing may be determined by the formula:

$$l^2 = \frac{370 + 17.5\,h}{\sqrt{\frac{h}{2}}}$$

in which h represents the average head and l is the spacing of buttresses. This formula can be readily derived by finding the volume of concrete and steel, and the area of form



- Fig. 4 -



- Fig. 5 -

work in the deck, buttresses and foundations in terms of h and l; applying to the same certain assumed unit prices and taking the first derivative of the total cost with respect to l. By equating this result to zero the value of l as above is found to satisfy the conditions of minimum cost under the units assumed. The unit prices will, of course, vary with local conditions but it will be found upon analysis of the formula that even under considerable variation in the unit prices the value of l will not change much. The prices assumed in this case include only the items affected by a variation in the buttress spacing, and were as follows: