The Design and Construction of Small Earth Dams

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Dams or reservoirs are widely used to preserve surplus rainfall. They can be constructed with a variety of materials and in many different ways. Usually it is reckoned to be a highly technical and expensive job, but this need not necessarily be so. However, it must be remembered that a body of water is a potential danger if the dam breaks and therefore construction should not be undertaken light-heartedly.

Many farmers and others with a minimum of technical knowledge have built useful dams. A dam could be constructed following these instructions carefully. The basic resources available will differ dramatically according to the country, its rainfall, geology, topography and its people. In Great Britain it would be stupid to start building a dam using hand labour; similarly in Tanzania or rural India it would be inappropriate to use heavy machinery.

I have had experience in building small earth dams in Kenya, where hand tools and wheelbarrows are used effectively. In fact, one can get better consolidation using bare feet and hand rammers, than from a bulldozer's giant tracks – and even better are the feet of cattle or donkeys! Oxen with dam-scoops can be used to enormous advantage.

Earth *is* a suitable material with which to contain water, but you must choose the *right sort* of earth and this might take some time as samples from alternative sites must be compared.

A simple way of comparison is to rub a sample of sub-soil between the hands and then wet a small amount of it in one palm and spread it over thinly, then let it dry before trying to brush it off. (See Note 1 for more detail on soils). Another comparison test is to make a ball of soil from each site and place them in moving water and observe the disintegration of each ball. While making the balls one can also get an idea of the soil's plasticity.

Choosing the Site

The most favourable site for a dam is usually in a valley, where high ridges on either side drop fairly steeply into the valley. Preferably the wall should be built where the valley narrows and the storage area is as wide and as long as possible. (see Fig. 1).

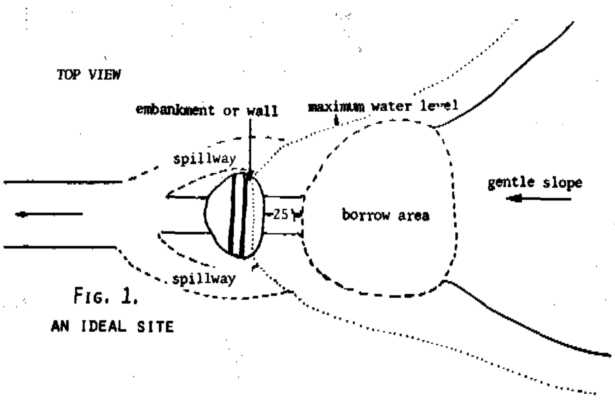


FIG. 1.
AN IDEAL SITE

The 'borrow area' is the area from which the earth is removed for building the wall. It should also increase the holding capacity of the dam.

The spillways are extremely important and should be carefully designed to take away the maximum likely floodwater. (See Note 2 for more details). When a suitable-looking site is found, consider where the floodwater will go once the dam is full.

Earth walls are usually about five feet higher than high water level. Water must *never* flow over an earth dam wall, as it does in the case of a concrete weir; the principles are entirely different and are not within the scope of this article (see footnote).

Having found a good site in a suitable place, check carefully that there is no pervious sand or gravel layer on the sides of the valley or under its floor by digging a test pit. Take note of the catchment area and bear in mind the need for an adequate spillway. (The greater the catchment area, the bigger the spillway needs to be, so it may be better to have a dam near the head of the valley).

Test that the soil is adequate for the type of wall you want to build. (The homogenous embankment is the easiest – see Fig. 4.) Be sure that all the necessary tools, finance and labour are available, and choose the right time of the year. (It is disappointing to have half a wall washed away by a sudden storm and it may upset the budget!).

Construction

1. Clear the site of trees, bush, grass and roots.
2. Collect top soil and pile in a heap out of the way.
3a. Peg out site as indicated in Fig. 3.
3b. Rip up the whole area onto which the embankment is to be built and dig small ditches parallel to the foundation trench, so as to help prevent the wall slipping. In a swampy area it is wise to make French drains to carry water away from the foundation ditch, to below the downstream toe line. These will help to prevent the lower part of the wall becoming waterlogged, especially if no rock toe is incorporated.
4. Remove all sand and gravel to the lower side of the foundation ditch (trench) – any stones can be heaped up at the toe. (See Figs. 2, 4 and 5).
5. Dig the foundation ditch down to a hard impervious 'seat' throwing the earth on the lower side of the valley below the site and spreading it out in thin layers and consolidating it well.

FIG. 2.
CROSS SECTION OF EMBANKMENT FOR A SMALL EARTH DAM ON A ROCK BASEMENT

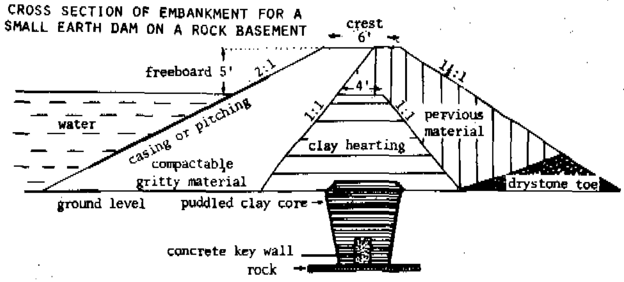


FIG. 3.

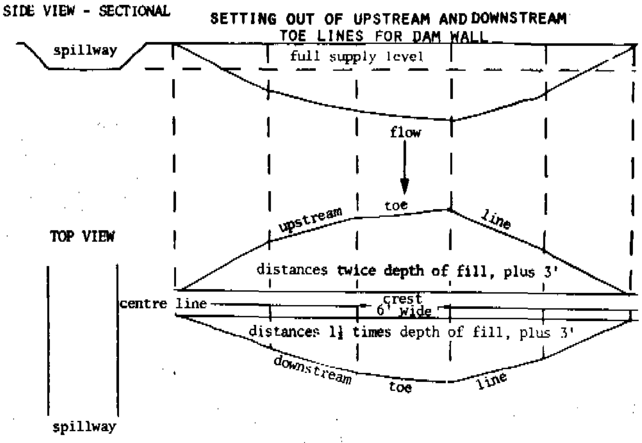
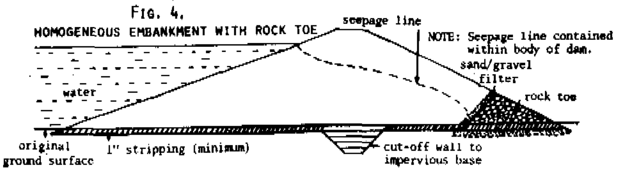


FIG. 4.



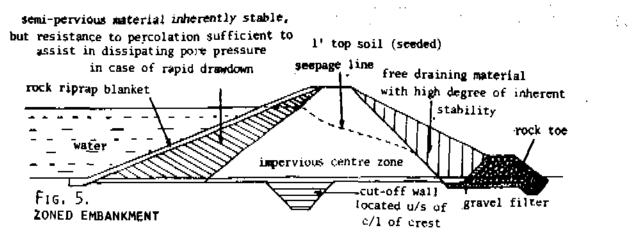


FIG. 5.
ZONED EMBANKMENT

6. The ditch should extend sideways as far as possible and 'key' in to the valley sides.
7. Choose the best earth/clay and spread it in thin layers in the foundation ditch and consolidate it very well. Use water if necessary. This is called a puddle-core and in some cases a puddle wall (or clay hearting) is extended above it, as the wall proceeds upwards, thus giving the embankment (wall), a clay core. This may be necessary in bigger dams or where the earth is semi-pervious. (See Figs. 2 and 5).
8. When the ditch is filled, start building up the upper side, layer by layer, right across the whole site from side to side and from back to front, consolidating each layer of 3" to 6" as you go. This work seems never ending to begin with, but speeds up as work continues and the wall gets narrower. The earth should be free from clods, large stones, roots, etc., and should be well watered if it is dry. (See note).
9. Bevel the valley sides if they are steep so as to obtain a good bonding of the embankment to side slopes.
10. Work on the spillway(s) can be done at the same time as the embankment is being built, as excavation is involved and that material is then used for the embankment.
11. As the embankment nears completion, often it is extended sideways to form the side wall(s) of the spillway(s).
12. The top or crest of the embankment should slope slightly towards the upstream side so as to facilitate drainage.
13. The top and lower side should be spread with top soil and planted with grass if this is possible. Otherwise it can all be covered with a thick layer of pebbles/stone to stop erosion. This is needed especially on the upper (water) side to prevent damage from small waves that lap against the wall.
14. The bottom of the spillways may need to be paved with stone and the sides protected in the same way from erosion. The 'outfall' area needs particular attention – this should be well below the embankment.
15. It is possible to place a pipe in position when or before you begin to build the wall. However, this can bring problems and a syphon pipe exit is probably easier to deal with. PVC piping is ideal. (You can start the water flowing initially by pumping up water from below the wall).
16. A cattle trough can be built at a convenient place below, also a standpipe for drinking water for human consumption.
17. The whole dam, or only the wall, can be protected, with a fence, to keep out livestock etc.
18. The embankment may be useful for carrying a road, but then the crest must be made wide enough (min. 10 feet) and care is needed so as not to obstruct the spillway. Also erosion must be controlled.

Dimensions

1. *The length* of the embankment depends on the distance between the sides of the valley or depression.
2. *The height* is governed by the nature of the site, the required capacity of the dam and the finance available.
3. *The width* is proportional to the height. A 10 foot wall will have a minimum of 40 feet at the base and 5 feet at the top. A minimum of 4 x the height makes rough calculations very easy, thus making a 2:1 slope on the water side and a 1½:1 slope on the lower side, with a crest width of ½ height. If the soil available is of poor or doubtful quality for the job, increase the proportions to 3:1 and 2:1 up to a maximum of 6 x height. (Remember, this increases the work and therefore the expense). These larger proportions are also recommended for embankments over 20 feet high. However, 20 feet should be the maximum height for an 'amateur' attempt as there are many finer points that an engineer would look into carefully before constructing a larger dam. I have heard of a 65' high dam and there are undoubtedly larger ones than that.
4. *The capacity of the dam* The simplest way to calculate this is to multiply the surface area by ¼ of the maximum depth of the water, then multiply by 6¼ gallons, e.g. surface area is 48,000 sq.ft. x 5 ft. (¼ of 20') x 6¼ = 1,500,000 gls.
5. *The volume of earth in the embankment* Multiply the cross-sectional area of the embankment at the deepest point by the top length of the wall (6' + 76' ÷ 2 x 20' = 820 sq. ft.) Divide by 2 where the valley slopes are gentle or by 3 where the slopes are steep, e.g. a wall that is about 20' high and 400 ft. long with a gentle valley slope:

   Volume = 820 sq.ft. x 400 ÷ 2 = 164,000 cu.ft.
6. It is worth *relating the size* (volume) of the embankment to the storage capacity of the dam; this will vary enormously with the different sites (N.B. the examples in

4 and 5 are of different dams) and will be an important factor to consider when choosing your site.

7. The cut-off wall, or clay core, is built in the foundation ditch, which varies enormously according to the site. However, it should be a minimum of 4' across the base with well sloping sides. In Fig. 2 the sides are rather steep.

Other considerations

1. There is a *small stream* running in the valley you want to dam. Either wait for the dry season when it dries up, or divert it, or build the embankment on each side of the stream and have an all-out effort to close the gap, (not so easy as it sounds and it can lead to seepage later). Alternatively, culverts can be laid which will later be blocked up. Great care should be taken to prevent seepage.
2. *Seepage* A small amount is to be expected. See seepage lines on Figs. 4 and 5, thus a rock toe is highly recommended. If severe seepage occurs it may be due to piping. This is particularly serious if soil particles are seen in the water: every effort must be made to block it, preferably on the water side of the embankment. When tree roots rot, piping can occur. A small amount of water can be lost through seepage into lower stratas under the dam. The loss of up to 1" in a week should not be considered unreasonable.
3. *Evaporation* This is considerable in hot, dry areas, when up to ½" of water is lost every day. So, the larger the surface area of the dam, the greater the loss of water. Thus a large, shallow dam will dry up sooner than a smaller, deeper dam.
4. *Silt* This is a hazard, especially in the arid areas, and is an important factor to consider when choosing a site. It may be possible to build silt-traps up-stream from the dam. Overgrazing of the catchment area should be avoided if at all possible. It must also be remembered that the presence of water will bring more livestock into the area of the dam.
5. *Legal Aspects* There are probably fairly strict Government regulations that pertain to the building of dams and these should be adhered to. Although it may not be easy to discover who knows about them – persevere.
6. *Grants or Subsidies* These may exist to help you. There may also be a government Dam Construction Unit or Advisory Service.
7. *Alternative Plans* Don't become 'fixed' on the dam idea. Consider other potential sources of water: borehole; well; protected spring; steam jets; pipe-line; etc., then carry out a cost-benefit analysis.
8. *Sub-surface dams* are another, often natural, source of water. Barriers can be constructed across seasonal rivers, below the surface of the sandbed. The sand will hold water to the extent of about a quarter of it's volume.
9. *A bulldozer* if used alone, is not a very suitable machine for dam building – a scraper is far better. Used with care. a dozer can build a dam to contain up to 6' of water. Poor consolidation is the problem.

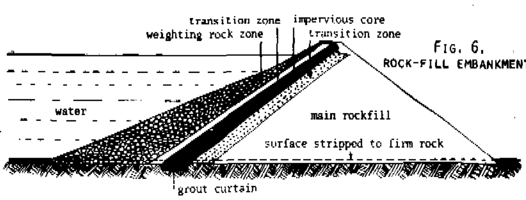


FIG. 6. ROCK-FILL EMBANKMENT

A typical small earth dam built by the author in Kenya.

This article has dealt with the details of choosing a suitable site, and constructing the embankment which creates the dam. The embankment and spillway design is all-important and can be summarised as follows:

1. Embankments must be stable under all conditions of saturation and loading.
2. The foundations should have adequate bearing capacity.
3. Embankments should be sufficiently watertight and the percolation of water through, under and around the sides should not exceed safe limits.
4. Sufficient spillway capacity should be provided to maximum estimated floods, while maintaining a dry freeboard of at least 2' between maximum reservoir water level and embankment crest level.
5. Anti-erosion and other protective measures, particularly in the spillway, should be adequate to ensure long-term stability and safety, with a minimum of maintainance.

Long, low dams are safer and cheaper than high dams, but evaporation is relatively high in shallow reservoirs.

Notes

1. *Soils* Engineers talk of 'soil mechanics' and soils are analysed and tested to give an indication of their 'engineering characteristics', but don't lose heart!

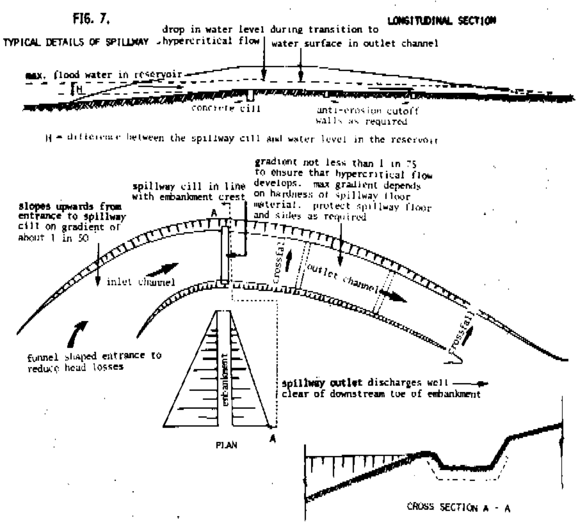
For the homogenous embankment you need a fairly coarse graded soil containing 20%–40% silt and clay. If you have a sample of well-sieved soil in a clear glass jar, shake it up with water and let it settle, you will see the bands of different materials: sand; silt; clay. A spoonful of cooking salt will facilitate the process. Sometimes soils can be mixed to achieve the desired proportions.

For a variety of reasons you should avoid using the following types of soil:

1. Sodiac Soils – they are very unstable
2. Calcitic Clays – they are stable, but porous
3. Humic Soils – are porous and become unstable
4. Schists and Shales – can slip when wet
5. Heavy Clays – can crack and cause piping
6. Fine silts – are unsuitable on their own

'Pore pressure' is a factor to be reckoned with, especially if a dam is to be emptied quickly. Pore pressure disequilibrium can lead to earth slips.

A wider variety of soils can be used for the construction of zoned embankments, but more careful supervision is required. Soil will always 'settle' even in the best consolidated walls. Allow 1" in every foot for this.



2. *Spillways and catchments* Basically, the spillway(s) has to take the place of the former stream-bed, and should be of a similar capacity. However, it will probably have to be wider, so as to keep the 'high flood level' as low as possible, remembering the minimum free-board required (5' above floor of spillway – it can be less if the spillway is exceptionally wide).

The larger the catchment area, the bigger the spillway(s) should be. There are various other factors; the annual average rainfall, the intensity of storms, the rate of run-off etc.

The rate of run-off is a critical factor which is influenced by relief (percentage of slope), soil infiltration, surface storage (marshes, ponds etc.) and effective plant cover. To illustrate this, a 1,000 acre catchment area which slopes gently and has good plant cover needs a 40' wide spillway, whereas a 1,000 acre, poorly vegetated, hilly area needs a 100' wide spillway. Various formulae and graphs can be obtained to help the calculations.

The spillway slope should be 1:75 and often has a sill construction of rock, brick or concrete across its width, in line with the embankment crest. This leads to hypercritical flow which ensures that there is no 'backing up' of water in the dam. See Fig. 7 for further details.

3. If a suitable site is found in a rocky area, you consider a conventional concrete weir *or* a rock dam with a concrete or clay core. Alternatively, an impervious layer of earth/clay can be built on the upper face. (See fig. 6). For a small dam it may even be worth trying a layer of butyl rubber, as concrete is very liable to crack and thus spoil the dam.

4. Note that there is a definite relationship between the moisture content of a soil and the maximum density which can be obtained by compaction. For example, using the Proctor test, the maximum density of a particular soil sample was proved to be obtained when the moisture content was 13.5%. The density was less when the soil was both drier than this, and wetter.

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Making Paper By Hand

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Modern paper making is a notably capital intensive industry consuming acres of virgin forest and devoted to the supply of mass markets with standard products. Advanced paper chemistry and sophisticated automatic control systems have taken paper a long way from its simple beginnings and, some would say, a long way beyond the actual needs of most of its users. Yet paper machines have only a short history; the first was built in England at the start of the 19th Century from plans drawn by a refugee from revolutionary France and mills are still being built to house machines that do not differ in principle from that first design.

Paper has a longer history than this. It is said to have first been made in China in 105 AD and to have spread from this one source to the whole of Asia and Europe. It was first made in Europe, at Xativa in Spain, in about 1150 AD and there were working mills in most of the continent some 400 years later. Through all these years it was only made by hand, yet today, hand made paper is a rare and special material, exotic and costly when compared with machine made sorts and, one would suppose, no sort of model for an unsophisticated economy. If we are to look for fresh applications for this old craft we should remember that up to about 170 years ago hand made paper was used for newspapers and for packaging just as it was for legal documents and fine printing and we should perhaps draw lessons from the time when a substantial labour force was employed in hundreds of paper mills to meet the demands of an ever expanding market. It was above all in Europe and the United States that this expansion occurred and it is important to notice that the techniques described below are those developed by European paper makers working in a temperate climate. They, naturally, welcomed and adopted every possible mechanical aid but so long as the formation of the sheet of paper was itself a manual operation machines were largely confined to the preparation of raw material. In other parts of the world different methods and materials were adopted with a much greater dependence upon manual labour and the practice of Japanese and Indian paper makers is particularly worthy of study.

Wherever paper is made, by whatever method, it requires four things; a supply of vegetable cellulose fibre, water, power, and some form of sieve or straining device. The basic raw material must be cellulose fibre suspended in water because only cellulose in this form has the special property of forming fibre to fibre bonds by the exchange of hydrogen ions as the water leaves it, whether impelled by gravity, pressure or heat. This raw material may come to the mill as textile or other waste or as partly prepared virgin fibre and will first need to be separated from impurities and extraneous vegetable matter. This is usually accomplished by boiling under pressure with caustic soda but the universal practice in earlier days was to allow bacteria to work in heaps of wet rag, so that the necessary degradation was accomplished by a kind of controlled rot. Control is required because either method of preparation