Finishing works 9

9 Finishing works

9.1 INTRODUCTION

When the embankment has been constructed, and all major outlets and drains installed, the dam can then be finished off. It is quite important that the training banks along the spillway sides are well established with grass cover and protected with other erosion prevention measures before the spillway is to be used. Rains on an unprotected embankment and water flow through an incomplete spillway can, at the least, cause minor rills and gullies and, at worst, destroy the structure altogether. Therefore, when most of the heavy earthmoving and other work has been done, it is vitally important not to neglect the minor finishing touches that, if delayed, can negate much or all of the work already performed.

Even when finishing works have been carried out properly, and at the right time, minor problems with erosion and settlement are commonplace. Because of this a programme of regular inspection and maintenance has to be instigated to ensure that no major hazards arise.

The remainder of the site should not be ignored. Areas used for storage, accommodation or the access and parking for plant and equipment should be restored as much as possible to their original condition. Topsoil and grass reserved at the beginning of the works can be spread on such areas to allow vegetation to re-establish itself and erosion risks of exposed soils to be minimized. Borrow pits and other areas used to excavate materials should also be filled in as much as possible (using any leftover or unused materials) and then grassed unless they can be converted to water-storage ponds.

9.2 INSPECTION REQUIREMENTS

At the time of siting the dam it should have been made clear to the local community/dam owner that to maintain the dam in good condition and to prolong its life as a sound, useful water resource, competent and timely inspection and maintenance are going to be required.

All dams must be inspected at least annually. In dry season climates the best time to carry out this work is before the beginning of the rainy season, when most of the dam and its reservoir area can be seen. Time after the inspection (and before the rains begin) must be allowed for to complete any remedial or repair work.

All dams with grass spillways must be visited after every heavy rainstorm and flood. This is most important at the beginning of the rainy season when, because of limited grass cover, erosion risks are highest.

All new dams that have not completely stabilized and settled require frequent visits and, again, the beginning of the rainy season is an important time, especially if a grass cover has not been established. After the first year or so, a more routine inspection programme can commence. Initially visits (which will vary from site to site) should not be less than twice a month and after every rain or flood.

9.3 TRAINING BANKS

Training banks are required along one or both sides of the spillway to keep floodwater away from the downstream toe and shoulder of the embankment and within the channel. Training banks are often constructed without a core, but often will use the same slopes as the main embankment. However, the design can vary according to site conditions and crest widths and heights can be reduced as required. In construction, care should be taken to avoid traversing the spillway and no earth should be removed from the channel bed for this bank unless cut is required to form the spillway.

Concrete or stone pitching at the end of the main embankment and along the inner sides of the training banks may be advisable.

9.4 OTHER WORKS

In finishing the main embankment, the crest should be given a slight downward slope towards the reservoir so as to encourage runoff towards the reservoir and the less erodible upstream section of the embankment. The accumulation of water on and in the downstream shoulder must be avoided.

Tidying up, cosmetic work and other minor works can often be left to the farmer/dam owner/community rather than the contractor. These activities prove unnecessarily costly if heavy plant is to be used. Such finishing work should include the following:

- Grass planting (spillway, outfall and embankment)
- Sodding spillway (cut sections) and around stone-pitched areas
- Stone pitching spillway (low rainfall areas)
- Finishing trickle flow outlet and the outfall pipe arrangements
- Digging seepage drains
- Fencing
- Fertilizing and irrigating grassed areas
- Stone pitching training bank and embankment
- Concreting high erosion risk areas

Last, if gauges at the spillway, or other outlets or reservoir depth indicators are required these should be installed at this time (when they cannot be damaged by plant and traffic associated with the construction). Similarly, signboards and any safety advice notices should be considered at this time.

9.5 MAINTENANCE PROCEDURES

A farm dam is usually to be found in its best condition immediately after construction. To keep it in good order it is very important that maintenance is carried out regularly.

Preparation of a check list of activities to be completed annually (or more frequently) should be prepared and maintained as record of maintenance activities and works carried out.

This check list should include the following:

9.5.1 Grass cover

It is essential that a good creeping grass type (i.e. kikuyu, couch or star grass) is established on all bare earth surfaces as soon as possible after construction and preferably before the first heavy rains. At the time of construction all topsoil removed from the site (i.e. for foundation or spillway excavation work) should have been stockpiled and the latter used to finish off the dam with a good last layer (50-75 mm deep) of soil. This can then be mixed with manure or fertilizer (300 kg/ha of nitrogenous based fertilizer) and planted to grass. Where water is available, irrigation will greatly assist the establishment of a grass cover which will reduce erosion and related problems to a minimum.

In harsher environments or where soils used as earthworks' material are likely to be susceptible to erosion the designer/engineer can adopt one of several short-term solutions:

- ➔ Cover soil with a layer of gravel or loose light stone pitching (rip-rap in wet or wave action areas) which, if there is any, the grass can grow through. Where gravel and stone is expensive or difficult to find such protection should be limited to steeper slopes. If these areas are lightly irrigated before the rains start, the material will be bound together by the growing grass.
- ➔ Plant a short-lived cover crop, such as rye grass, pigeon peas or similar, that will grow rapidly and provide limited protection to the embankment and spillway while a creeping grass establishes itself beneath. Cutting the crop before seeding takes place is necessary.
- ➔ Use a hemp or similar net-like fabric that can be pinned or anchored to slope faces and will provide some protection to newly emergent grass and the soil beneath when runoff is severe.

An expensive and often last resort is to adopt flatter slopes (3:1 or 3.5:1) at the design stage and thus reduce the velocities and spread of the runoff more evenly across the embankment.

Once a grass-cover has been established it should be maintained in a dense, short condition – this is obviously difficult in climates with long dry seasons but can be assisted by:

- ➔ Irrigation – where water is scarce reserve a supply for use when temperatures begin to rise and just before the rainy season begins. Either use an irrigation system or a water bowser to supply around 25 mm or more of water per week.
- ➔ Cultivation – do not burn off grass as this will encourage taller clumping varieties to grow at the expense of the preferred shorter, creeping type. Either cut the grass or allow limited but well-supervised grazing; being careful to avoid damage and tracking across the embankment or spillway.
- ➔ Fertilizer – a careful application of manure or fertilizer before irrigation or the start of the rains will prove helpful.

9.5.2 Fencing

This is vital to keep livestock, people and vehicles off sensitive areas such as the spillway, the outfall and the embankment. Good fencing will assist in maintaining the grass-cover, will minimize erosion and control access to the dam and reservoir area.

Most gullies in the spillway areas and on embankment slopes are started when rainfall and the subsequent runoff concentrate in depressions caused by footpaths, vehicle tyres or animal tracks.

Therefore, keep all fences in good order, check all posts during the annual inspection and inspect the wire whenever possible. The local community or dam owner should provide the fencing at the time of construction and must be made aware of the importance of maintaining it.

9.5.3 Settlement

However well the dam was built, it will always experience some settlement. Most dams settle out in the first year or so after construction. Invariably most settlement occurs at the highest point of the dam where mass is greater and other pressures highest.

At the time of construction a settlement allowance should have been incorporated on the top of the embankment. At every inspection the crest must be checked to ensure it remains horizontal and that no low spots have developed. All over-settlement must be attended to with backfill and additional monitoring. If this is neglected, and should either the crest level fall overmuch, or an exceptional storm lead to backing up of floodwater from the spillway, the dam will overtop, water will concentrate in the low spots and serious damage result.

Unusual settlement in an older dam can indicate foundation movement or removal of embankment material by seepage or erosion. Always seek expert assistance when this occurs.

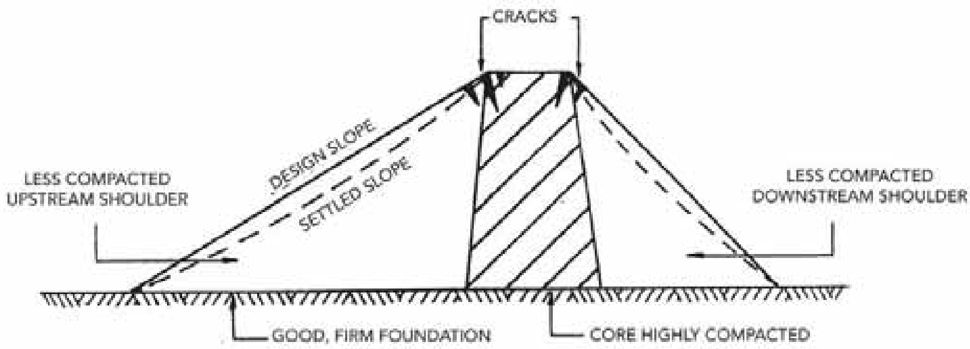
Another form of settlement can arise when, due to poor construction techniques, the core has been compacted comparatively more than other parts of the embankment. **Figure 13** illustrates this. The upstream and downstream sides or shoulders of the embankment settle more than the core as they are less well compacted and, as the foundation is firm (and it cannot fully absorb the differential settlement), cracks appear along the crest edges as the settlement takes place. These cracks do not represent a serious problem and can usually be treated by ramming in damp soil complete with grass as soon as they develop. It is important to prevent water entering such cracks (otherwise erosion and waterlogging will follow) and in the rainy season it may be necessary to sandbag the area to minimize runoff. When large, deep cracks appear on older dams (indicating foundation movement or slumping of either shoulder), the reservoir water level must be lowered and expert assistance must be sought without delay.

9.5.4 Seepage and drainage

All earth dams will leak to some extent and seepage only becomes a problem if it endangers the embankment – either by encouraging erosion in the downstream area or by causing waterlogging of the dam and thus affecting its stability. Dirty water seeping from the downstream face of any dam is cause for concern. As finer materials are eroded, and carried out of the embankment, this could lead to piping or slumping in the structure.

At the time of construction and, particularly if the dam does not have a dry, well-drained downstream foundation area, drains should be installed before the embankment is built. If this was not done and seepage has become excessive, the following may reduce the problem:

Figure 13 - Settlement cracks



- ➔ Minimize the seepage by sealing the upstream face and reservoir areas. This can take the form of a 500 mm thick clay blanket laid and compacted on the areas with highest water pressure and protected (from erosion and drying out) by topsoil or gravel. If the dam water level can be lowered, construct a new cutoff beneath the upstream toe. **Figure 10** illustrates an example where both a clay blanket and new cutoff have been installed. In both cases the most impervious clay available should be used and should be laid on the upstream face once it has its layer of topsoil removed and been disked or ploughed to encourage a good bond between the old and new surfaces. Once installed it is important to prevent damage to the new surface by deep-rooting plants or burrowing animals. Obviously, this work can only take place when the reservoir is dry.
- ➔ Trench into and beneath the downstream toe to relieve water pressure in this shoulder of the embankment – always ensuring that the excavation work is safe. Backfill the trenches with rock and gravel to allow continued drainage and restore the embankment to its original slope with a final layer of topsoil and grass. All drains should feed a central collector drain which is then taken to a safe, non-erosive discharge area further downstream. This work is best carried out during the dry season but can be done as required if the dam is in danger. In both cases, if possible, the water level in the dam should be lowered before these operations are completed to reduce risk.

9.6 TREES AND BUSHES

Do not allow trees, bushes or other deep-rooted plants to grow anywhere near the embankment, the spillway and its outfall. Keep all parts of the dam clean with a low grass cover to protect against erosion and assist inspection and maintenance.
Trees on the embankment do not help stabilize the soil and their roots will eventually reach to water. When dead and decomposed, pathways for insects, animals and water are then formed. Therefore, remove all trees and bushes before they become established. In a situation where large, old trees have been allowed to establish themselves on the embankment they should be removed when the upstream water level is low. The trees should be cut as low as possible and, if the stumps cannot be excavated, they should be soaked in petrol and burnt or treated with chemicals to

allow their rapid decomposition. All remaining material and roots must be removed and all excavation works backfilled, compacted and restored to the design slope with topsoil and grass cover.

Trees or bushes on the spillway will alter its hydraulic characteristics and can reduce its capability to safely carry away flood flows. Such flows are encouraged to concentrate in channels (and thus may lead to erosion) rather than to spread evenly over the full width of the spillway (thus maintaining lower velocities and avoiding turbulence). Again, tree roots do not assist the stability of the soil.

9.7 EROSION

This is a common problem on any dam where grass cover and fencing have not been maintained. If not rectified at an early stage gullies can form and soil can be lost to runoff and floods leading to stability and seepage problems.

The main causes of erosion are:

- ➔ Lack of suitable grass cover.
- ➔ Tracking by livestock and people on the embankment and spillway.
- ➔ Low flow channels developing on the spillway.

All erosion should initially be treated by restoring the affected areas to their design dimensions, (i.e. backfill, compact and grass all eroded sections) and re-fencing as required.

Low flow channels in the spillway are often associated with dams constructed on perennial rivers where, during the dry season, low flows are allowed to meander across and down the spillway (especially on spillways that have not been maintained) and have concentrated into small gullies. The best solution to this problem is to install an overflow pipe beneath the embankment at the time of construction with a protected inlet location just below spillway level. This will carry all normal river flows while the spillway is reserved for floods only. However, if such an overflow is not available it is unwise to excavate into the embankment once the dam has been built; therefore it is better to modify the spillway to cater for normal flows.Excavate and line a small channel with sufficient capability to carry the estimated volumes of water involved and ensure (as in any outlet) that it is taken to safe, non-erosive discharge.

A disadvantage of this is that after every flood these channels require checking and de-silting and, where such measures have been instigated, special attention must be paid to their condition at every inspection.

Where spillways have been damaged by flows, whether small or large, it is important to restore them to their design dimensions – backfill, compact and grass all low spots, protect eroded sides with stone pitching or masonry and ensure all outfalls (discharge areas) are safe with flat, broad slopes to allow non-erosive disposal of flood waters.

The construction of concrete sills at the entrance, and at regular intervals down a grass spillway, will ensure a horizontal surface is maintained for the channel bed, will limit erosion to within each section and act as energy dissipaters. Each sill should be a minimum of 0.3 m wide and 0.3 m deep and be well keyed to the sides and the bed of the spillway. Depending on the slope, they can be positioned at intervals of 30-50 m down the spillway. As gullies often develop first in the outfall area (usually the result of too steep slopes, restricted discharge area and poor maintenance), sills will assist in restricting erosion that may move back up the spillway if remedial work cannot be immediately undertaken.

9.8 TERMITES AND ANIMAL BURROWS

With a regular, competent inspection programme, ant or animal activity should never be a problem. Any ant workings found should be suitably treated with a recommended fumigant, dug out and the excavation backfilled in layers with good material and the careful use of a long-life insecticide. All slopes must be restored to their original design shape. If, the excavation required is large (usually because of no or poor inspection), always seek expert advice and never attempt to carry out the work in the rainy season or if the dam is full.

Repair work 10

10 Repair work

10.1 INTRODUCTION

Only carry out repair work that is simple, straightforward and falls within your capability. For difficult, large-scale or technically complex work always consult a qualified engineer. Poor repair work can be dangerous and lead to more serious problems developing later in the dam's life.

Before any repair work is begun always try and ascertain and rectify the cause of the damage so that the problem will not recur. Modes of failure can be attributed to four basic causes:

- ➔ Overtopping: can be counteracted by conservative spillway design, generous freeboard allowances, and avoiding areas where landslides could affect the reservoir.
- ➔ Slope failure: avoid by following correct design and construction procedures based on site investigations and materials' analyses.
- ➔ Spreading of the embankment base: minimize risk by avoiding poor foundations, the adoption of flatter side slopes and reducing the height of the dam.
- ➔ Piping: avoid the development of piping by following correct design and construction procedures, filling of cracks as they develop (normally after settlement of a new dam) and the introduction of drainage downstream through filters and toe drains should seepage become excessive.

Problems can develop from structural defects associated with poor design and construction and can often have catastrophic results when the dam breaches or collapses. Non-structural defects such as too small or too large catchments and spillways relate directly to faults in design. The major results of these defects are outlined below along with remedial measures that can be taken.

10.2 STRUCTURAL DEFECTS

These are all directly associated with the embankment and spillway and can be associated with foundation, materials used, design and construction techniques.

10.2.1 Slumping and sliding of the downstream face

Occasionally this may apply to the upstream side of the dam. It is usually the result of poor quality material, too steep side slopes, inadequate drainage and/or excessive seepage. If severe, the dam's stability can be affected and it is then very important to lower the reservoir water level as soon as possible.

Use of good material and well designed side slopes at the time of construction and following correct construction procedures will prevent these problems developing.

However, when serious problems do develop, especially in an old dam, major reconstruction work is the only solution and should include drainage relief measures in and underneath the downstream section, clay blankets upstream, the flattening of side slopes and reduction in reservoir water levels. The latter can be maintained by lowering the spillway or drop inlet levels.

Other factors, such as low strength soils, poor compaction and compressible foundations, also contribute to partial slope failures and can be very difficult to remedy.

10.2.2 Foundation slope movements

Movement of the embankment on its foundation can lead to complete failure of the dam. Usually associated with a poor choice of site and, with larger dams, movement of the embankment will lead to cracks appearing in the structure. They are most serious when they extend transversely across the embankment and below the water line. Reduce the water level immediately and fill all cracks with good material and plant to grass.

Earth dams can absorb some movement without suffering damage but if cracks continue to form, or suddenly appear in old dams, it is best to seek expert advice immediately.

10.2.3 Piping

This occurs when seepage establishes a tunnel or pipe through an embankment and in severe cases can lead to undermining and the eventual collapse of the dam. It is most serious in dams constructed of poorer soils with greater permeabilities.

To avoid this it is best to anticipate such problems at the design stage and construct drains beneath the downstream section before the dam proper is started. However, when piping is excessive, or not allowed for, measures already outlined to reduce seepage should be followed.

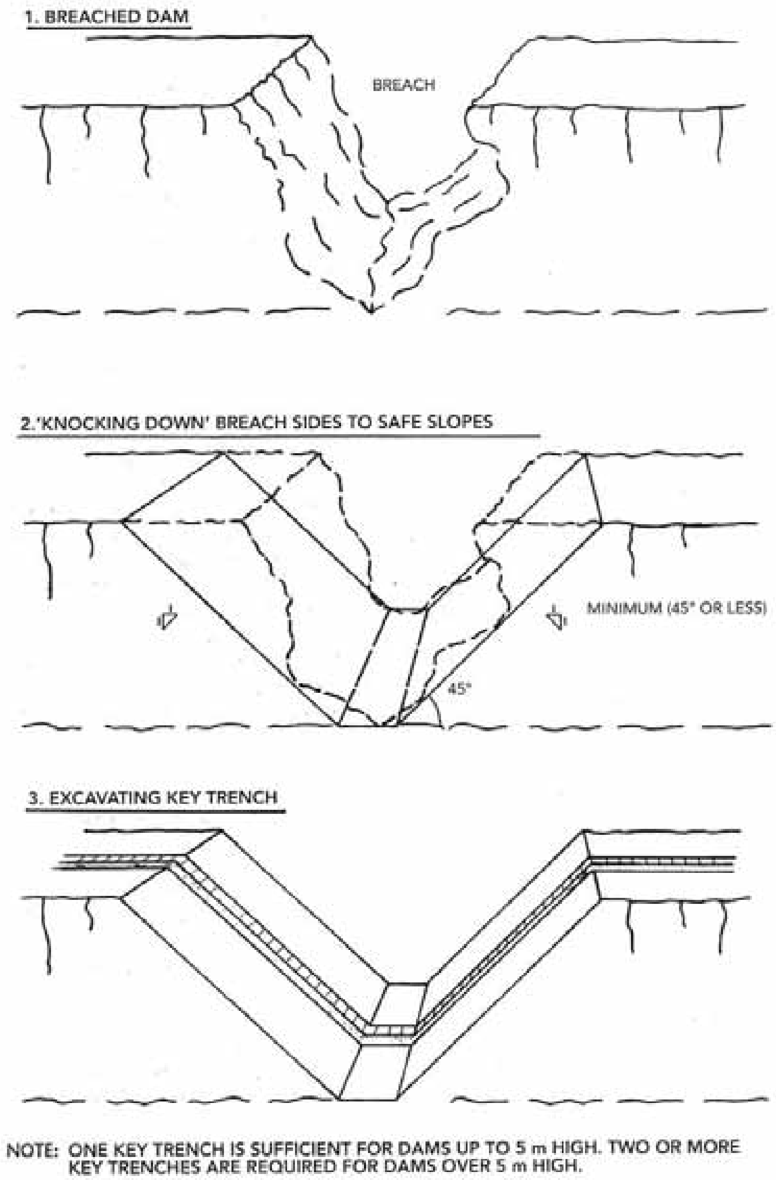
When brown, muddy water is seen to emerge from the downstream face of the dam or seepage starts to increase, this can mean serious internal damage is occurring. This may be associated with the development of whirlpools on the upstream side when most severe. Always reduce the water level and carry out repair and remedial works without delay.

10.2.4 Breaching

A dam breaches when a section of the embankment finally gives way and a hole appears that can cause complete failure. Unless caused by overtopping by an exceptional flood (or too small a spillway), breaching is usually the result of one of the problems outlined above developing into a major fault. Always investigate the cause of the breach before commencing permanent repair work and, once the problem has been solved, the breach can be filled and the dam restored to its design condition. However, to fill the breach, certain guidelines must be followed – referring to **Figure 14**, the following must be adhered to:

- ➔ Always carry out repair work in the dry season and ensure there is enough time to complete the repair before the rains start.
- ➔ Remove all loose and poor material from the sides and the floor of the breach and ensure excavation is carried to good foundation (i.e. subsoil, rock, firm well compacted embankment or core material).
- ➔ Cut back the sides of the breach to a relatively flat slope (1:3 minimum and 1:5 or less where possible). This ensures plant and machinery can pass up and down the cut slope (to back-fill and compact) rather than through the breach area and that, when the gap is plugged, the repaired area is securely founded on the old dam material.

Figure 14 - Repair of breached dams



- ➔ Excavate key trenches as required.
- ➔ Reconstruct the embankment (refer to Section 7) to the new design requirements ensuring all backfill is installed in layers and is well compacted.
- ➔ Check and inspect the repair frequently immediately after reconstruction and pay special attention to the area subsequently.

It is very important to ensure a good bond between the old and the new material. If the sides are not cut back, and the key trenches not excavated, the repair area can easily fail again. When the repair is done properly the area is better able to resist the pressure of water behind it and a slip surface between the old dam material, and the new is less likely to develop. A little extra care and attention at the time of repair is always preferable to a rushed, more general infilling of the breach.

A drawing illustrating a typical breach repair is provided in Annex 4.

Whenever a dam has suffered from a major problem like this, always ensure that the water level is not allowed to rise and fall rapidly. It should be kept below the maximum for a few years to assess the effectiveness of the repair and to enable the repaired section to settle. This section should be given special emphasis at times of inspection and monitoring.

10.2.5 An eroded spillway

Spillway erosion and the inability to carry flood flows are the main reasons behind many earth dam failures. Once erosion on a grassed spillway or a friable rock spillway has started, it is very difficult to prevent it recurring without continual maintenance and remedial procedures. Normally this signifies that solid rock should have been used for spilling flood water.

If a trickle flow has not been constructed, a lined channel in the spillway should be excavated and, to reduce risks, another second spillway may be built on the other end of the dam wall. Careful placement of sand bags or stop logs can then allow the alternating use of spillways to enable the maintenance of one or the other to be initiated. Stone pitching and concreting of the spillways and embankment are expensive solutions, which may have only partial success, if concrete is laid on earth it can easily be undermined and eroded. Simpler measures, such as increasing the available spillway width; the construction of a concrete sill at the spillway entrance (to prevent erosion in a sensitive area and dissipate some energy); the generous grassing of the spillway bed and protection (stone pitching, loose rock or gabions) of the sides including the outlet into the river or stream where the gullying will usually start; as well as continual inspection and maintenance in the flood season, will always minimize risks.

Where flood flows far exceed spillway capacity, the backing up of water in the reservoir can attain a level where it overtops the embankment. The correct assessment of anticipated flood flows and the maximizing of safety factors such as spillway width and freeboard, especially where hydrological information is insufficient, are absolutely vital. A spillway that is too wide is not a problem but one that is too narrow can, at worst, result in the loss of the dam and, at best, in further expenditure that could easily have been avoided.

10.2.6 Wave action

Wave action on the upstream face can cause erosion, which can increase the slope angle to an undesirable steepness or establish ‘beaches’ on the slope that could lead to the slumping of this section. If this is allowed to continue, it can reduce the crest level to below the full supply level. This is often exacerbated by poor grass growth and erosion from animal tracks and, as a result, it may become necessary to reconstruct the entire upstream area to reduce slopes and allow for the laying of rip-rap in the most susceptible areas. For large dams with high fluctuations in water level, the works involved can become quite expensive.

10.3 NON-STRUCTURAL DEFECTS

A dam that does not fill with water has failed just as much as one that suffers from the problems of embankment and spillway failures. Basically, non-structural defects result in the dam not meeting its design capabilities and usually this leads to a reduction in available water storage. Two main reasons can be identified:

10.3.1 Dam reservoir fails to fill up

The dam may be too large for the catchment. This problem can be prevented at the design stage[17] by correctly assessing the catchment yield (i.e. average runoff per hectare or square kilometre in a 1 in 10 year (or as the designer/dam owner requires) rainy season including taking other dams and water uses into consideration). Reservoir inflow can be increased by constructing storm and contour drains to enhance runoff and channel water from the surrounding catchment if considered economic.

Where the yield is known to be satisfactory, it may be that the water is by passing the dam to such an extent that the reservoir cannot fill up. Often, as water pressure builds up, permeable material beneath the core or faults extending into the reservoir, can act as seepage drains. Water may re-appear downstream or contribute to groundwater recharge making identification and rectification of the problem difficult.

The careful monitoring of excavation at the time of construction of the cutoff trench to ensure it is dug deep enough, and that no permeable layers are likely to be beneath it (i.e. old stream beds or slate/schist type bedrock), will minimize the risk of such problems arising. The investigation of the river bed upstream of the dam at the feasibility study stage to locate swallow holes will also help. In order to ensure that borrow areas in the reservoir maintain water tightness under pressure, they should not be completely excavated of clay material.

Where leaks are suspected, the possible source area can be sealed by puddling clay in the reservoir immediately upstream of the embankment (especially where the water is deepest) and/or excavating a new cutoff trench to an impervious layer beneath core level, in the upstream section of the embankment. The latter may prove most economic if a large reservoir area has to be layered with impermeable material.

10.3.2 Dam silts up

This is usually a long-term problem that can be avoided if dams are not constructed on rivers that carry heavy sediment loads. If undetected at the feasibility study stage, certain remedial measures can be taken:

- → The local catchment land practices can be improved by better crop rotation, reduced stocking rates and by introducing conservation methods.
- → The vegetation cover in the catchment can be maximized, especially in dry season type climates where early rains lead to high erosion levels. Deforestation should be minimized throughout the catchment and the practice of establishing gardens for fruit and vegetables close to the reservoir or river (to facilitate hand irrigation), common in many locations, should be discouraged.
- → Where the latter does occur, improved cultivation practices such as contour ridging and ploughing, maintaining a band of uncultivated land close to the

17 Refer to section 5.5.

river and reservoir and conserving waterways can reduce runoff and erosion.

- ➔ Gullies and other high runoff areas must be reclaimed or at least stabilized.
- ➔ Silt traps upstream of the main dam can be constructed. Small dams or sumps collect a major proportion of the silt before it reaches the reservoir. These are usually temporary, often expensive and require regular de-silting and therefore should be regarded as stop-gap measures while methods to reduce the silt at source are initiated.

Where a reservoir is severely silted, it is not normally economic to excavate the reservoir. Moving and safely dumping huge quantities of wet silt can prove difficult. The preferable alternative is to raise the dam once the sediment inflow has been reduced by the measures above. This will increase the storage capacity at the expense of a relatively small increase in earthworks' volume.

For dams being constructed on rivers with high levels of silt, the construction of an embankment with a wide crest will facilitate the raising of the dam in subsequent years.

Bibliography and further references

British Standard 1377, London, UK, 1990 nine standards: references 1377-1-1990 to 1377-9-1990 inclusive and including later amendments at www.bsigroup.com.

Food and Agriculture Organization. 2001. Small dams and weirs in earth and gabion materials, AGL/MISC/32/2001. FAO Land and Water Development Division, Rome.

Food and Agriculture Organization. 2006. Simple methods for aquaculture – Manuals from the FAO training series, CD-Rom set. FAO Inland Water Resources and Aquaculture Service.

Hudson, N.W. 1975. Field engineering for agricultural development. Oxford, UK, Clarendon Press.

Ministry of Agriculture and Cooperatives of Swaziland. 1990. Repair and maintenance of small earth dams. Field Support Guide 109, Swaziland.

Ministry of Agriculture and Cooperatives of Swaziland. 1992. Handbook on dam design and construction.

Nelson, K. 1997. Design and construction of small earth dams. Australia, Inkata Press. Third edition.

Schwab, G.O., Fangmeier, D.D., Elliot, W.J.T. and Frevert, R.K. 1981. Soil and Water Conservation Engineering. New York, John Wiley & Sons. Third edition.

Sherard, J.L., Woodward, R.J. and Gizienski, S.F. 1964. Earth and rock dams. New York, John Wiley & Sons.

Stephens, T. 1991. Handbook on small earth dams and weirs – A guide to siting, design and construction. Bedfordshire, UK, Cranfield Press.

Terzaghi, K. and Peck, R.B. 1967. Soil mechanics in engineering practice. New York, John Wiley & Sons. Second Edition.

United States Bureau of Reclamation (USBR). 2006. Design of small dams. Water Resources Technical Publication Series. Washington, DC.

World Bank, Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development. 2009. Gender in agriculture sourcebook. Washington, DC.

Glossary

Atterberg limits	They are a basic measure of the nature of a fine-grained soil. Depending on the water content of the soil, the soil may appear in four states: solid, semi-solid, plastic and liquid. In each state the consistency and behaviour of a soil is different and so are its engineering properties.
Backfilling	The on-site filling of a trench or other excavation with either material originally excavated from the same excavation or using material imported from elsewhere.
Berm	A horizontal bench or terrace-like area on an embankment slope, included for stability or where a change of gradient is required.
Borrow pit	A source for earthworks' materials for embankment construction. Best located within the reservoir area to improve storage and avoid the need for restoration measures after the dam has been completed.
Breaching	Complete removal of a section of the dam by the reservoir water breaking through the embankment. Can be induced by erosion, foundation movement or overtopping.
Catchment area	This is the area upstream of the dam that takes in all the streams and rivers that supply the dam.
Catchment yield	The estimated total runoff from a catchment area for a certain period; usually one year.
Compaction	The compression, by mechanical means of a soil material, in embankment construction, to improve its stability and load-bearing characteristics.
Core	The central section of a zoned dam, constructed of highly impermeable material to seal the embankment from seepage. The below ground section of the core is referred to as the cutoff.
Crest	This is the top of the embankment. The spillway crest is the level at which water will begin to flow in the spillway.

Crumb test	Is a simple, quick method for identification of a dispersive clay soil.
Cutoff	This is the area excavated, below ground under the core and through any permeable material to reach a more impermeable stratum, and to be backfilled (and compacted) with highly impermeable material to seal the foundation against seepage.
Desilting	The excavation of silt or other material from a dam reservoir to improve storage capacity. It may be more economic to raise the height of the embankment to achieve an increase in storage than to desilt a large basin area.
Earthworks	All the soil material to be used in the construction of a dam will comprise the earthworks.
Embankment	This is the dam wall.
Erosion	The removal of soil and rock by natural agencies such as rainfall, river flows, seepage or slumping. Often accelerated by people or animals by overgrazing or by the formation of paths and tracks.
Fetch	The maximum unobstructed distance, at full supply level, that the wind can travel across a reservoir to raise waves that will impact on the embankment.
Filling	The embankment construction. This is usually done on a layer-by-layer basis accompanied by moistening and compaction.
Flood flows	Above normal river flows following excessive rainfall.
Freeboard	The difference in height between the crest of the dam and the level of the spillway entrance.
Full supply level	The maximum water level the dam is designed for. For small dams this is the same as the spillway entrance level.
Gabions	A patented mean for erosion protection in the form of wire baskets or mattresses selectively filled *in situ* with rock.
Geotextile	A synthetic permeable fabric of varying thickness with filtering and drainage properties. When placed behind and beneath gabions, they limit the movement of soil material in suspension from the natural ground into the gabion basket or mattress.

Homogenous dam	An embankment constructed with one consistently similar soil material to produce an homogenous structure.
Modified homogenous dam	An embankment similar to an homogenous dam but with a filter zone in the downstream side to safely draw down the phreatic surface and then pass the drainage/seepage water out of the embankment.
Moisture conditioning	The wetting (but not waterlogging) or drying of a soil to assist compaction.
Outfall	The area at the end of the spillway where it discharges to a stream or similar. Erosion often starts here if the outfall has not been properly designed, protected or maintained.
Overtopping	This is where excessive flood flows pass over the embankment beacause of insufficient spillway capacity. Erosion always follows and, if severe, can lead to major damage.
Probable maximum flood	The peak flood from a catchment based (for the design of the dam and spillway) on a return period of 1 in X years.
Perennial flow	A stream that flows all year round is said to be perennial. The alternative, where a stream dries up periodically is said to be seasonal.
Permeability	Is a measure of the ability of a porous material (often, a rock or less consolidated material such as soil) to transmit fluids.
Phreatic surface	The top water level in any saturated zone of the embankment.
Piezometer	A small diameter observation well in the embankment equipped with a measuring device, to record water levels and in particular notify engineers of variations.
Piping	Piping occurs when hydraulic flows (seepage) through the embankment carry soil material in suspension causing pipes to develop in the structure and lead to internal erosion.
Planimeter	An instrument to measure area from a plan or map.
Proctor Test	A standard test, developed in the United States, for moisture and compaction control for cohesive soils.

Puddling	The use of clay to seal a surface by mixing the soil with water and layering it on a surface and then compacting it by machine or hand (historically by cattle trampling) to make it watertight.
Seepage	Water moving through or under an embankment is referred to as seepage. All dams will, to some extent, seep and, if small or controlled, such seepage is not considered a serious problem.
Settlement	The embankment, however well built, will settle to some extent. Provision for this should be included at the time of construction (settlement allowance) by raising the midpoint of the embankment and tapering this raised area off to the valley sides.
Shear strength	The resistance to deformation in soil by cohesion, usually increased by compaction at a certain moisture content.
Slumping	The movement of earth through erosion or waterlogging (especially on steep slopes) away from either face of the embankment. May also be referred to as slippage or sloughing.
Slush grouting	The filling in, with a plaster-like mortar, of cracks and fissures on a rocky surface in preparation for concrete work or backfilling.
Spillway	The overflow section of the dam, dependent not on the size of the dam but on the size of the catchment and its hydrological and other characteristics. It must be constructed to dimensions to safely carry away the design probable maximum flood (PMF) when the dam is full.
Stone pitching	The protection of a vulnerable surface by the placement of similar sized stones sometime bedded in a mortar. Often used for toe drains.
Storage potential	The maximum possible volume of water the dam can store when the reservoir is full.
Time of concentration	The time between a storm commencing on a catchment and the development of the maximum flood at the dam. Used in spillway design.
Turbulence	Rapid, irregular, highly erosive flow. To be avoided on grass or earth spillways by flat slopes and wide, shallow channels.
Training wall	The extension of the embankment, constructed to safely contain spillway flows and to prevent water

	affecting the downstream area of the dam. May also be referred to as the training bank.
Waterline	The level of water in the reservoir is referred to as the waterline or water level. The maximum water level possible is referred to as the full supply level (FSL).
Waterlogging	A soil completely saturated is waterlogged. The downstream section of the embankment can become unstable (especially as it usually designed with steeper slopes and more permeable materials) if allowed to become waterlogged. Free drainage is therefore important in this area of the embankment.
Zoned dam	An embankment, when constructed of varying soil materials, differentiated according to position and role in the structure, is said to be zoned.