Revised Report on Dam at Africa School of Missions

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Background

In the floods of 2000 the right flank of the earth embankment dam on the premises of Africa School of Missions was breached, and was subsequently rehabilitated by the Department of Agriculture according to a design done by BKS.

At the invitation of Mr Geoff Malan, the principal and director of the Mission, the writer carried out an inspection of the dam on 30/07/2003.

This consisted of an estimate of its storage capacity, a walk across the embankment, an inspection of the downstream toe for seepage, measuring the elevation of its crest, measuring the upstream and downstream slopes, measuring the slope of the spillway along the centreline of the spillway channel, measuring the slope of the spillway's berm in a longitudinal sense, and finally determining the width and height of the spillway at a few critical sections.

Mr Malan gave the writer copies of the engineer's drawings, and reference is made to these in this report.

Context

The drawings indicate that the height of the crest of the embankment above the underlying foundations is 9,1m. The full supply level (FSL) is shown to be 3m lower, implying that the water level is only 6,1m above foundation level when the dam is full. The length of the embankment is approximately 200m, and the length of the reservoir along the path of the riverbed is estimated to be 300m at FSL, assuming a 2% upstream inclination at the location of the dam (judging from the topographical drawing). The shape of the reservoir is approximately triangular in plan. The capacity of the reservoir at FSL is estimated at 79000m^3. Since this capacity exceeds 50000m3, and since the height of the wall exceeds 5m, the dam is classified as a category 1 dam and in terms of the dam safety regulations in the Water Act of 1998 it should be inspected every 5 years by a profession engineer.

However, it should be observed that the capacity and height only marginally exceed the minimum below which no safety inspections are required. This, coupled with a relatively small catchment of approximately 6,3km^2 (determined from a 1:50000 topographical drawing) implies that failure of the embankment, while undesirable, is not likely to have catastrophic implications.

Dam Functionality

A storage dam should satisfy three important criteria. Firstly its embankment should be structurally stable, secondly it should not leak, and thirdly the spillway should have sufficient capacity to allow flood waters to pass through without causing damage.

These three aspects will now be considered in more detail and comments on the adequacy of the existing structure will be made where appropriate.

1 **Embankment Stability**: The embankment should be structurally stable in the sense that it should retain the water without being pushed downstream, without overturning, and without bursting. In an earth embankment dam, this is achieved by ensuring that the downstream and

upstream embankments are not too steep for the type of material used to construct the dam and with due consideration to the material on which the embankment is founded. Furthermore the downstream embankment should be sufficiently drained to increase its stability.

BKS have specified slopes of 1 in 2,5 and 1 in 3,5 for the downstream and upstream embankments respectively. These are relatively flat slopes and failure is therefore very unlikely unless poorly compacted inferior materials (e.g. low shear strength, excessively permeable throughout cross section), or unless the ground upon which the dam is founded has inadequate bearing and shear strength or is too permeable.

The design appears to make adequate provision for the drainage of the downstream embankment (see stripdrain and chimney drain details in the engineer’s drawing, and the call for well compacted semi-permeable soil on the downstream embankment). The absence of surface seepage on the downstream embankment indicates that the drainage measures are effective.

There is however one part of the embankment where the upstream slope was noticeably less than 1 in 3,5 (at CH 40 on dwg H1540-01-270-01-A-00). Here a slope of 1 in 2,5 was measured. Moreover this point coincides with the lowest downstream elevation of the toe of the embankment. However, providing that the material has adequate shear strength and was sufficiently compacted, a 1 in 2,5 slope for a dam with a relatively small embankment does not constitute grounds for undue concern. *It is however recommended that this be brought to BKS’s attention, since this is not noted on their ‘as built’ drawings.*

2 **Embankment Impermeability**. While no earth embankment is ever 100% impervious, it appears that the measures taken to ensure that the embankment does not leak are effective, given that there is no sign of seepage on the downstream embankment. These measures include the presence of a 3m wide clay core in the centre of the embankment, a vertical sand filter chimney drain immediately downstream of the clay core, the stripdrains beneath the downstream embankment, and finally the fact that the downstream embankment is presumably constructed of compacted ‘semi-pervious’ soil.

There does not appear to be any standing water in front of the toe of the embankment other than where water was let through the valve. However the presence of reeds in front of the toe indicates that the strip drains are conveying a slight amount of water that is either getting through the clay core, or seeping through the foundation, and that the design is thus serving its purpose.

3 **Spillway Capacity.** The spillway should have sufficient capacity to allow flood waters to pass through without causing damage to the various elements of the dam. In the case of a dam that has an earth embankment this is especially important so that water never goes over the top of the embankment – which may result in the dam being breached. The spillway should also have enough length to discharge the water well beyond the toe of the downstream embankment.

The aspects that determine a spillway’s flow carrying capacity are its slope, depth, width and roughness.

BKS have specified a spillway with a slope of 1 in 1000, a width of 14,5 m at the base, sloping up 45 degrees on either side. The length of the channel beyond CH0 is approximately 120m.

The measurements taken indicate that the slope of the channel approximates 1 in 1000 for the first 80m, after which the slope steadily increases. The width of the channel exceeds that given in the drawings and is at a minimum at point about 80 m away from CH0, where it is approximately 18m wide (with relatively steep sides), and at this point the spillway has a depth of approximately 1.25m below the crest of the adjacent berm.

Substituting the values of n = 0.02, b = 18m, d = 1,25 and i = 1/1000 into Manning's equation the flow in the channel may be calculated as 38m^3/s.

Note that while the channel has a depth of 3m adjacent to the embankment (at point CLB in the engineer's dwgs), its berm has a downward slope of approximately 2,3% along the length of the channel, while the floor of the channel only has a slope of 0,1%. This explains why the height of the berm is only about 1,25m at the point 80m from CLB. It will be seen that this has the effect of compromising the capacity of the spillway.

In determining the inflow into the dam use has been made of the concept of the regional maximum flood (RMF) which is an empirically established upper limit of flood peaks that can be reasonable expected at a given site. The method is described in the document TR137 'Regional Flood Peaks in Southern Africa' published by the Department of Water Affairs and Forestry. The method is based on maximum flood peaks recorded since 1856 at more than 500 sites in Southern Africa. RMF compares favourably with the results obtained by other methods, and flood peaks in the 50 to 200 year recurrence interval can be estimated from RMF.

The RMF can be instantly calculated if the geographic position of the site and its effective catchment area are known, as is the case in question. It is evident from the 1:50000 topographical map '2531AA Kiepersol' that the catchment area is relatively small, approximately 6,3km^2. Applying the method described in TR137 a RMF of 140m^3/s has been determined.

Note that the flood value of 140m3/s obtained using RMF correlates reasonably well with the Engineer's 125m3/s flow based on a 1:200 year flood. (For a 1 in 150 year flood the engineer has determined a 75m3/s flow). However, given the steep topography of the catchment and its consequent rapid and concentrated response to a major storm, the use of the higher RMF as an alternative design tool is probably not unrealistic.

Whichever of these flood values are used, they are clearly *more than the spillway channel's capacity of 38m3/s*. In order to support the engineer's 1 in 150 year design flow of 75m^3/s the channel depth should be at least 2m for the first 80m (where its slope is 1 in 1000), and to support the alternative 1 in 200 year design flow of 125m^3/s the channel depth should be 2,7m.

Crest of Embankment: For the spillway to operate at its maximum capacity, it stands to reason that the elevation of the crest of the embankment must equal or exceed the elevation of the water flowing down the spillway, especially at the mouth of the spillway. This does not seem to be the case. Relative to the writer's datum point used in his survey (approximately at or near point CH0 - see engineer's dwg) *virtually the whole length of the embankment is lower*, by as much as 700mm in places, compromising the specific head. In a serious flood event there will thus be an overspill over much of the embankment before the spillway reaches its capacity. This will lead to the onset of erosion of the embankment, although a complete breach is unlikely from one event, given the small catchment area, the limited capacity of the reservoir, the relatively long length of the embankment, and the fact that the downstream embankment is well grassed.

The engineer's drawings are enlightening. The recommended construction height is '102.1' and the design height is '101,9'. Assuming the *construction* height was achieved by the contractor, then as much as 550mm of consolidation had occurred by August 2002 when the levels were taken by the Department of Agriculture, Conservation and the Environment (see documented elevations on the engineer's drawings). It is therefore not difficult to imagine that over the next twelve months further consolidation occurred resulting in the settlement values I obtained.

Erosion: For the first 80m along the centreline of the spillway from CLB the slope approximates to 1 in 1000 (as per the design). In the next 20m the slope increases to 2.3%. In the following 20 m the slope increases to about 5%, and this will result in velocities approaching 9m/s, resulting in erosion in this region. Consideration should be given to *building the 'drop structure' or packing the area with rocks* as originally suggested in the engineer's drawings.

Conclusion and Recommendation

The general impression gained of the embankment is that it is soundly engineered and constructed. However the height of the spillway's berm is inadequate for much of its length, and the spillway therefore does not have sufficient capacity for a major flood. It is also likely to suffer some erosion in its lower reaches. The embankment appears to be very stable except that its upstream slope is relatively steep at one point. There appears to have been significant consolidation in the embankment or foundations to the point where water will now go over the embankment's crest before the spillway has reached its design capacity.

It is recommended that either BKS or the contractor responsible for building the dam be contacted so that corrective measure may be taken. Note that the material required to raise the embankment and the berm are insignificant in relation to the total volumes used in the construction.

Disclaimer

I do not accept responsibility for statements made here which may later be shown to be incorrect. Nor I do not accept any responsibility for the safety/stability/performance of the dam, which rests with the contractor and the consultant. My recommendations are made purely to bring various observations to the attention of ASM, the user, who it is assumed will inform the contractor and the client - in doing so ASM is at liberty to forward this report. The final decision to act upon these recommendations rests entirely with the user, the consultant and the contractor.

Yours faithfully

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