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DESIGN AND CONSTRUCTION OF AN EMBANKMENT DAM IN NEW SOUTH WALES, AUSTRALIA

Nor Hamiza Zackaria and Robin Fell
Civil Engineering Programme, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia
E-mail: norhamiza_zackaria@petronas.com.my

ABSTRACT: Dams are built for several reasons such as to create reservoirs that capture water from streams and store the water to be used throughout the year and during drought years. Dams also provide irrigation water, drinking water, hydropower, and flood control. Many reservoirs provide recreational activities like fishing, boating, and other water sports. Embankment dams are one of the most common types of dams in Australia. Designs of embankment dams usually relate to the degree that seepage is controlled within the dam by provision of filters and drains, by the use of free draining rockfill in the embankment, and the control of foundation seepage by grouting, drainage and cutoff foundation. There are several types of embankment dams depending on what material is used most in the dams. The most common ones are earthfill dams, which are made mostly of soil, and rockfill dams, which are made mostly of rocks. The selection of dam type to be used at a particular site is affected by the availability of construction materials (earthfill, rockfill and filters), foundation conditions, climate, topography and relation to other structures (spillway, river diversion outlet works, etc.), staged construction and time for construction. In design, embankment dam zoning system is used where each zone has its function and typical construction materials. Two types of foundation treatments are adopted i.e. general excavation and cutoff excavation. This paper aims to provide some insights into the design and construction methods of an embankment dam situated in New South Wales, Australia as practiced by the geotechnical engineers in the country. The paper will discuss the available dam options before selecting the best for the site and elaborate the construction method of the selected dam type.

Keywords – design and construction method, embankment dam zoning system

1. INTRODUCTION

The site of the embankment dam is Southern Highlands of New South Wales Australia, which is just over 1 hour from southwest Sydney on the freeway, and 1 1/2 hours from the nation's capital, Canberra. It lies atop the Great Dividing Range, over 700 metres above sea level, from where the land falls away to the level plains of the inland. The embankment dam to be designed crosses steep valleys on the highlands lying above sandstone, clay and volcanic soils. The dam is designed to satisfy the topographic and foundation conditions at the site and to use available construction materials.

2. DESIGN DATA

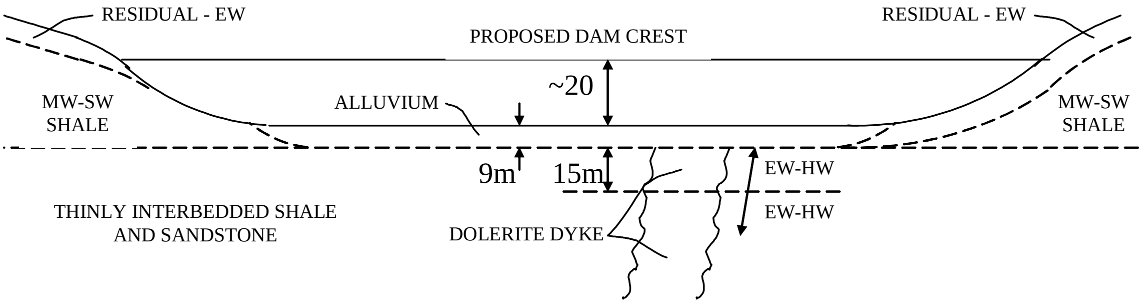


Fig 1. Simplified longitudinal section of proposed dam and types of soil and rock underlying it

Table 1. Characteristics of soil and rock underlying the dam

Types of Soil/Rock	**Descriptions**	**Permeability**	**Comments**
RESIDUAL - EW	Residual to Extremely Weathered Shale	~ 10^{-6} m/s	fissured, firm to stiff
Alluvium	same	10^{-6} m/s	clayey gravel
		at base, 10^{-5} m/s	minor sandy and clayey gravel at base
MW-SW SHALE	Moderately Weathered to Slightly Weathered Shale	2-10 lugeons	1 lugeon = 10^{-7} m/s
Thinly Interbedded Shale and Sandstone	same	10-40 lugeons in first 20m depth, <5 lugeons in remaining depth	clay seams and possible bedding shears
EW-HW Dolerite Dyke	Extremely Weathered to Highly Weathered Dolerite Dyke	<5 lugeons in first 15m depth	
MW-FR Dolerite Dyke	Moderately Weathered to Fresh Dolerite Dyke	20-50 lugeons in remaining depth	

Table 2. Available construction materials on site

No.	**Construction Materials**
1.	CH clay (inorganic clay of high plasticity), dispersive, over shale in reservoir.
2.	Ripped sandstone and shale from required excavation.
3.	Very limited filter materials available (major environmental constraints on quarrying). ASSUMPTIONS: Good quality filter materials and quarried sandstone rocks for rip-rap (refer *Table 6*) are available within economic distance.

Table 3. Additional data for the design

No.	Additional Data
1.	Dam is of high hazard category (refer *Table 4*).
2.	Full supply level is 3m below crest.

Dams in Australia are commonly rated as to their hazard, i.e. the potential for adverse consequences in the event of dam failure. The hazard rating of a dam is high, significant or low. These ratings are incremental flood hazard categories, which refer to incremental losses and effects due to dam failure. *Table 4* below describes the high hazard category for this dam.

Table 4. High hazard rating as per ANCOLD (Australian National Committee on Large Dams) 1986

Hazard Rating	Descriptions
HIGH	Loss of identifiable life expected because of community or other significant developments downstream. AND/OR Excessive economic loss such as serious damage to communities, industrial, commercial or agricultural facilities, important utilities, the dam itself or other storages downstream. AND/OR Dam essential for services and repairs not practicable.

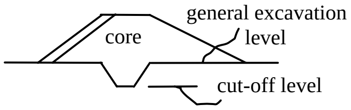
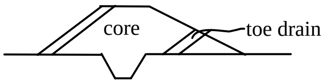
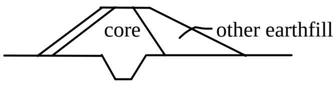
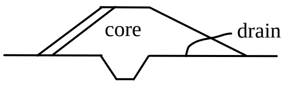
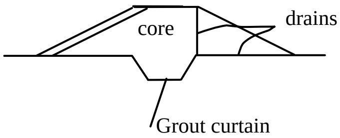
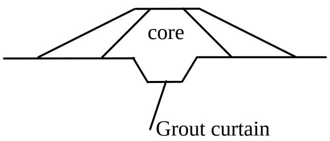
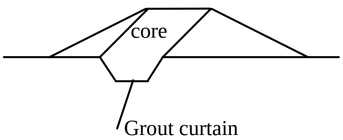
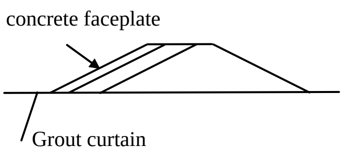
3. DESIGN METHOD

ANCOLD has specified eight types of embankment dams with typical cross section, details, features, advantages and limitations of each. They are homogeneous earthfill, earthfill with toe drain, zoned earthfill, earthfill with horizontal drain, earthfill with horizontal and vertical drain, central core earth and rockfill, sloping upstream core earth and rockfill and finally concrete faced rockfill. Some types have more in-built conservatism than others, therefore the hazard rating becomes the influencing factor in the choice of best dam type. A preliminary study on all eight dam types was carried out before selecting the best that suit the design data of this dam.

3.1 Preliminary study

The main criteria to be satisfied in this study are the high hazard category and dam height of 20m. Other criteria such as seepage and erosion control as well as availability of construction materials are also examined, as they are equally important.

Table 5. Preliminary study on embankment dam types

No.	Dam Type	Typical Section	Comments
1.	Homogeneous earthfill		Not good enough for high hazard category dam due to inadequate seepage and erosion control.
2.	Earthfill with toe drain		
3.	Zoned earthfill		
4.	Earthfill with horizontal drain		
5.	Earthfill with horizontal and vertical drain		Suitable for high hazard category dam up to 50m high. Have good seepage and erosion control in embankment. Have good under seepage control in foundation. Plenty of earthfill available i.e. shale and ripped sandstone.
6.	Central core earth and rockfill		Suitable for high hazard category dam up to 200m high but restricted space makes construction complicated for dams $\leq$ 20m high. Have good seepage and erosion control in embankment. Need free draining rockfill, which is unavailable, since sandstone and shale are low permeability rockfill. Environmental constraint on quarrying makes it difficult to get rockfill.
7.	Sloping upstream core earth and rockfill		Ok for high dams and high hazard category but restricted space makes construction complicated for dams $\leq$ 20m high. Have good seepage and erosion control.
8.	Concrete faced rockfill		Ok for high dams and high hazard category but for dams $\leq$ 20m high, the cost of the plinth and setting up of faceplate construction usually makes it uneconomic. Have good seepage and erosion control. Need free draining rockfill, which is unavailable, since sandstone and shale are low permeability rockfill. Environmental constraint on quarrying makes it difficult to get rockfill.

3.2 Selection of embankment dam type

From 3.1 above, only one dam type satisfied all criteria i.e **earthfill with horizontal and vertical drain**, thus selected for the site. This dam is usually constructed from clay, sandy clay, clayey sand and gravel-sand-clay soils with a horizontal and vertical drain composed of high permeability sand, or sand and gravel. The vertical drain intercepts seepage through the dam and, provided both drains have sufficient flow capacity, the earthfill downstream of the vertical drain will remain unsaturated. This control is independent of the kH/kV ratio (horizontal permeability to vertical permeability ratio) for the earthfill. If the drains are designed to act as filters to the earthfill, internal erosion is also controlled.

The horizontal drain also acts to intercept seepage through the dam foundation and control pore pressures in the embankment due to the under-seepage. If the drain is designed as a filter to the foundation material it will also control erosion of the foundation. This is particularly important for dams constructed on permeable soils (sand, sand-gravel and clayey soils with permeable structure), or on weathered permeable rock, which is potentially erodible.

3.3 Embankment dam zoning system

The zoning system is used in the design where each zone has its function and typical construction materials. There are two types of earthfill available on site, i.e shale and ripped sandstone, where the latter is coarser. Shale forms the embankment core, Zone 1, while ripped sandstone is placed downstream of the vertical drain forming Zone 3. The vertical drain acts as filter, Zone 2A, intercepting seepage through the earthfill core, Zone 1, and controlling internal erosion. The horizontal drain acts as filter, Zone 2A and 2B, under the earthfill downstream, Zone 3, intercepting seepage through the erodible alluvium foundation, controlling pore pressures in the dam due to under-seepage and controlling erosion of the foundation. *Fig 2* and *Fig 3* show the cross sections of the dam in the valley and at the abutments respectively. Both sections comprise of six main zones in the dam where the descriptions, functions and construction materials of each zone are detailed in *Table 6*.

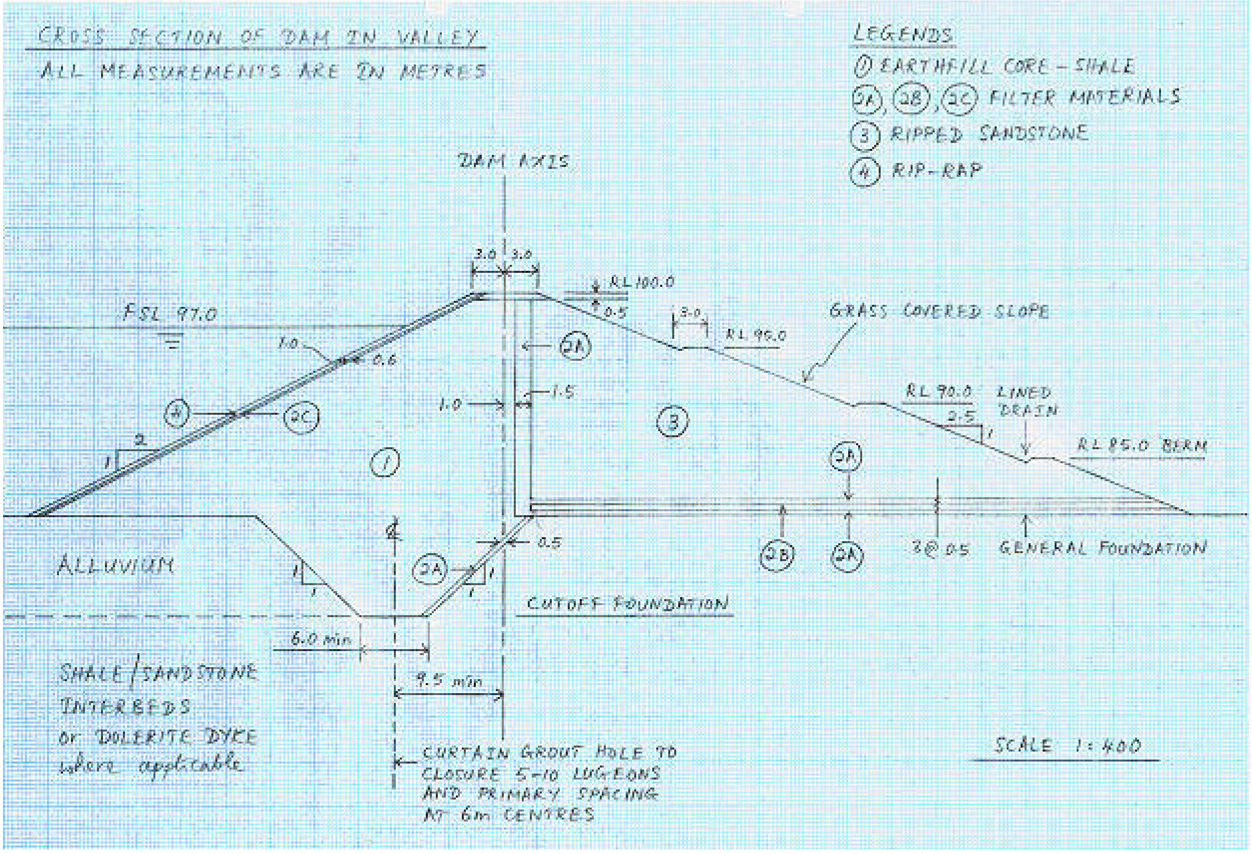


Fig 2. Cross Section of dam in valley

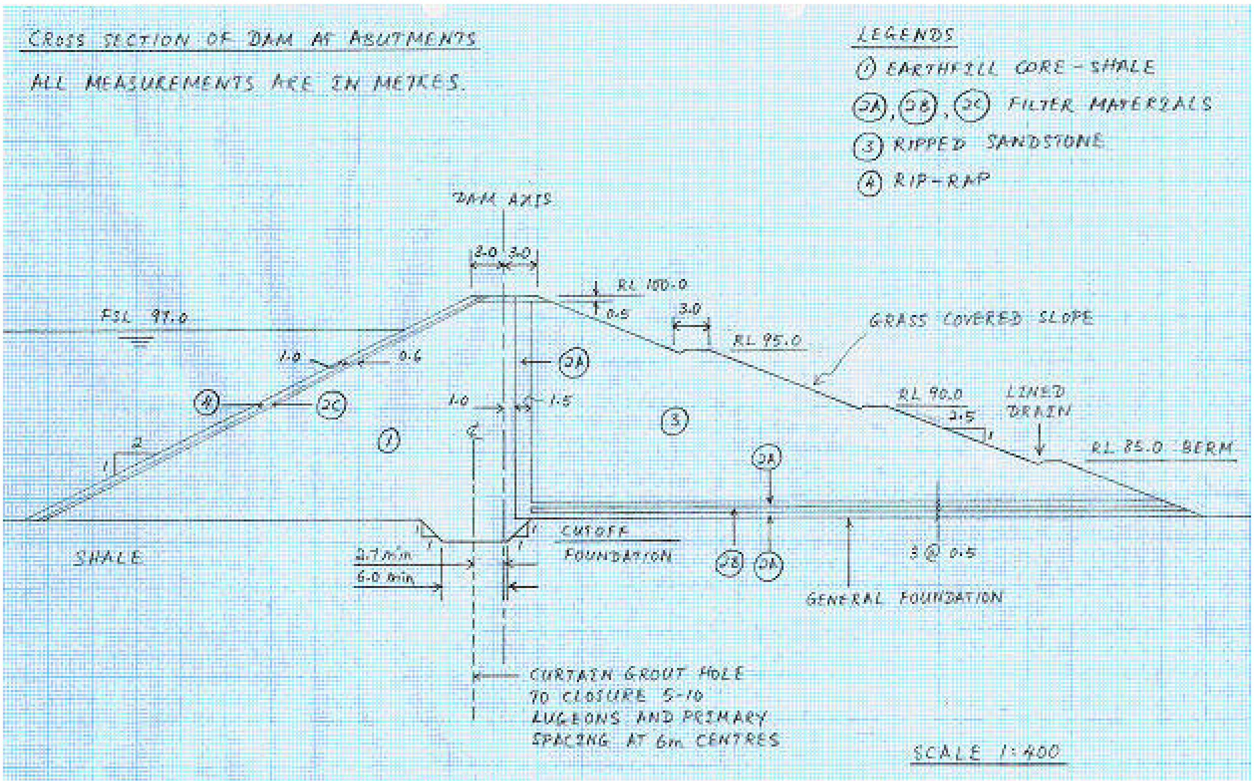


Fig 3. Cross Section of dam at abutments

Table 6. Embankment dam zone descriptions, functions and construction materials

Zone	Description	Function	Construction Materials
1	Earthfill core	Control seepage through the dam	Shale compacted to 150mm thick layers by a sheepsfoot roller to give sufficiently fine material where >15% (preferably more) passing 75μm
2A	Fine filter drain	Prevent erosion of Zone 1 by seepage water where used as vertical drain, prevent erosion of the alluvium foundation where used as horizontal drain and inclined drain on the downstream side of the cutoff trench	Sand or gravelly sand, with <5% (preferably <2%) fines passing 75μm and fines should be non plastic. Manufactured by crushing, washing, screening and recombining sand-gravel deposits and/or quarried rock
2B	Coarse filter drain	Discharge seepage water collected in vertical or horizontal drain	Gravelly sand or sandy gravel, manufactured as for Zone 2A. Note: Zone 2A and 2B are required to be dense, hard durable aggregates with similar requirements to that specified for concrete aggregates. They are designed to strict particle size grading limits to act as filters.
2C	Filter under rip-rap	Prevent erosion of Zone 1 through rip-rap	Sandy gravel or gravelly sand, well graded, 100% passing 75mm, <8% passing 75μm, fines non plastic. Usually obtained as crusher run or gravel pit run with a minimum of washing, screening and re-grading. Relaxed durability and filter design requirements compared to Zone 2A and 2B.
3	Earthfill downstream	Provides stability by allowing discharge of seepage through and under the dam	Ripped sandstone compacted to 400mm thick layers by 4 passes of 10-ton steel drum vibratory roller or by a sheepsfoot roller. Coarser than shale.
4	Rip-rap	Prevent erosion of upstream face by wave action	Selected dense durable rockfill sized to prevent erosion by wave action. Constructed from quarry run rockfill.

4.3 Embankment dam details

Fig 2 and *Fig 3* also show the embankment details. The crest is 6m wide and covered with a 0.5m thick road pavement to allow two-way vehicle traffic. A vertical line passing through the centre of the crest becomes the dam axis that acts as reference line in dimensioning the dam. Reduced levels of the crest, the reservoir full supply and the berms are used rather than height. This is because the dam height varies across the valley and is not known at any section prior to construction since the general foundation level is unknown. Zone 2A, 2B, 2C and 4 are dimensioned as widths and not thicknesses normal to the slope since construction of these zones is in horizontal lifts. Upstream slope of 2H:1V and downstream slope of 2.5H:1V are adopted. The cutoff trench has 1H:1V left and right slopes set out from the top point of right slope as shown. In valley, it is cut through the total depth of the alluvium i.e. ~9m while in abutments; it is cut through a smaller depth of shale for reasons explained in next section. The cutoff trench centerline is at 9.5m minimum width in valley and at 2.7m minimum width in abutments from the dam axis. It has a width of 6m minimum specified for low permeability rock foundation such as shale, sandstone and dolerite dyke. The width is dimensioned at the cutoff foundation. Minimum widths are used in dimensioning the cutoff trench to cover the situation where the depth of excavation to cutoff foundation is deeper than anticipated. All the dimensions shown in the details are those commonly adopted for this dam type. A curtain grout hole is drilled through the cutoff foundation with primary spacing of 6m centres and grouted to closure of 5-10 Lugeons. The grouting details are explained in next section and shown in *Fig 4*.

4. CONSTRUCTION METHOD

Construction of the dam starts with the foundation treatment. There are two types of foundation treatment namely general excavation and cutoff excavation. The description of each foundation treatment is shown in *Table 7*. Once the foundation is ready, earthfill and filters are placed.

Table 7. Embankment dam foundation treatment

Item	Description
General excavation	Excavation of compressible and low strength soil and weathered rock as is necessary to form a surface sufficiently strong to support the dam and to limit settlement to acceptable values.
Cutoff excavation	Excavation below general excavation level to remove highly permeable soil and rock

The details of each foundation treatment in different areas of the dam and placement of earthfill and filters are explained below.

4.1 Preparation and cleanup for general foundation under earthfill

In valley, alluvium is left in since it is quite deep i.e. approximately 9m. Furthermore, the alluvium comprises of clayey soils, so liquefaction is not expected to occur. Weak and compressible soil is removed by having the surface proof rolled with a steel drum or tamping foot roller to assist in locating the soil. It is not necessary to roll to a specified compaction requirement. The surface should be cleaned of loose soil and rock prior to placing earthfill, e.g. with a grader, backhoe or excavator. Intensive cleanup is not generally required. It may be desirable to scarify and moisten the surface prior to placing the first layer of soil to assist in 'bonding' the embankment.

In abutments, residual soil, fissured (open) soil and weak compressible soil are removed. Where residual lies beneath alluvium, e.g. in right abutment, both are removed. Adequate foundation is identified by near blade refusal of a small bulldozer or excavator. The surface should be cleaned of loose soil and rock prior to placing earthfill, e.g. with a grader, backhoe or excavator. Intensive cleanup is not generally required. It may be desirable to moisten the surface prior to placing earthfill to maintain adequate moisture in the earthfill for compaction.

4.2 Preparation and cleanup for general foundation under horizontal filter drains

In valley, alluvium is left in since it is quite deep i.e. approximately 9m. Furthermore, the alluvium comprises of clayey soils, so liquefaction is not expected to occur. Weak and compressible soil is removed.

In abutments, residual soil, fissured (open) soil and weak compressible soil are removed. Where residual lies beneath alluvium, e.g. in right abutment, both are removed. Adequate foundation is identified by near blade refusal of a small bulldozer or excavator. Slope modification is carried out where necessary.

In all areas, the surface should not be rolled prior to placing the filter. Rolling will destroy the soil structure and reduce the permeability, making it difficult for seepage water to flow into the filter drains. It is desirable for the foundation seepage to flow into the filter drain so erosion is controlled, rather than being forced to emerge downstream of the toe of the embankment in an uncontrolled manner. Trafficking with earthmoving equipment will continuously break up the surface, necessitating final cleanup with an excavator or backhoe working away from the cleanup area. Once cleaned, the filter should be dumped on the cleaned up surface and spread onto the surface without equipment trafficking directly onto the foundation. The surface should be cleaned of loose dry and wet soil and rock immediately before placing the filter. This may necessitate intensive work using light equipment and hand methods. Final cleanup should involve an air or air-water jet to 'blow' away loose materials.

4.3 Preparation and cleanup for cutoff foundation

In valley, alluvium is removed by excavating to rock. Where alluvium in the sides of cutoff trench displays coarse layers, these should be filled with shortcrete or other concrete to prevent erosion of earthfill into them. Otherwise filter 2A should be placed on the downstream side of the cutoff trench. In the floor of the cutoff exposing shale-sandstone, clay seams and bedding surface shears are filled with concrete or grout and dental concrete respectively. This is to avoid erosion of the seams and bedding shears allowing seepage to bypass the earth core and filters. EW rock in the base of cutoff exposing dolerite dyke is removed.

Fig 4. Cutoff trench

In abutments, rock with open joints and with other fractures leading to a highly permeable structure is removed. Rock with clay infilled joints (important for dispersive clay), roots etc., which may erode under seepage flows is also removed to yield a high permeability rock. Where the exposed shale is susceptible to slaking by wetting and drying or breakdown under trafficking, it should be covered with cement-sand grout, pneumatically applied mortar or concrete. This should be done immediately the shale foundation is exposed or after a second cleanup immediately before placing the earthfill core. If cement-sand grout is used, it may crack under trafficking of equipment placing the earthfill, thus should be removed prior to placing the earthfill. Where open joints or other features are displayed in the floor and sides of cutoff trench, which would allow erosion of earthfill into them, it should be cleaned of loose material and covered by a cement-sand grout, pneumatically applied mortar or concrete. This is particularly critical on the downstream side of the cutoff trench. If there are only a few of such features, they might be treated dentally. No rolling is required on the cutoff surface since it will only disturb the rock leading to a higher permeability material.

In all areas, all loose soil and rock, and other debris are removed from the surface, using light equipment and with an air or air-water jet. Hand cleanup may be necessary. Surface should be moistened prior to placing the earthfill so as to maintain earthfill moisture content. Curtain grout is adopted throughout the foundations with a single row of holes to closure of 5-10 Lugeons and primary spacing of 6m centres.

Fig 5 shows the simplified longitudinal section of the dam with the foundation treatments.

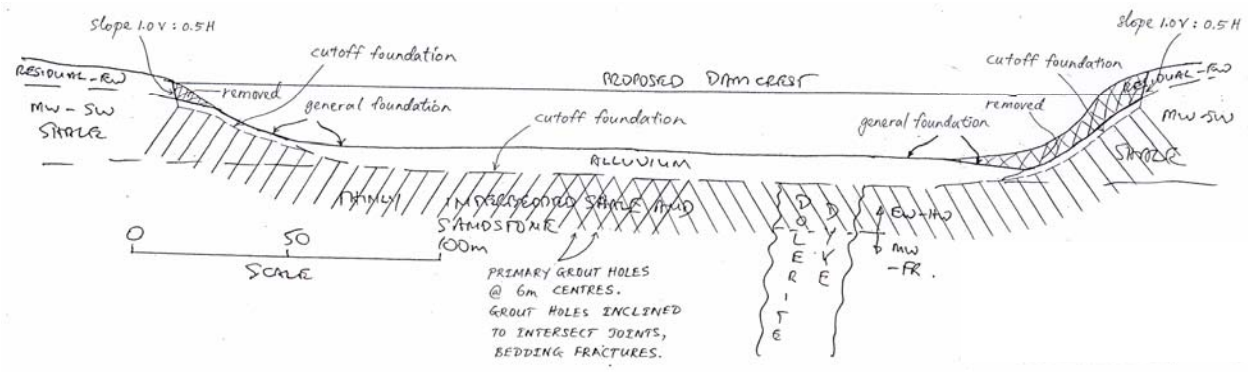


Fig 5. Simplified longitudinal section of the dam with the foundation treatments

4.4 Placement of earthfill and filters

The earthfill is constructed upwards in a series of thin layers. For each layer, the fill material is transported to the dam by trucks and dumped there. Then bulldozers are used to spread the material in a thin layer. The thickness of the layer depends on the material being used. Shale, the earthfill core, is constructed in 150mm thick layers by compaction using a sheepsfoot roller. Ripped sandstone, the earthfill downstream, is constructed in 400mm thick layers by compaction using 4 passes of 10-ton steel drum vibratory roller or a sheepsfoot roller.

The filter widths of the dam are small, thus a spreader box shown in Fig 6 is used to spread the filters. The filter materials are dumped off the truck into the spreader box, which spreads the filter out of its base as it is pulled along by a small bulldozer.

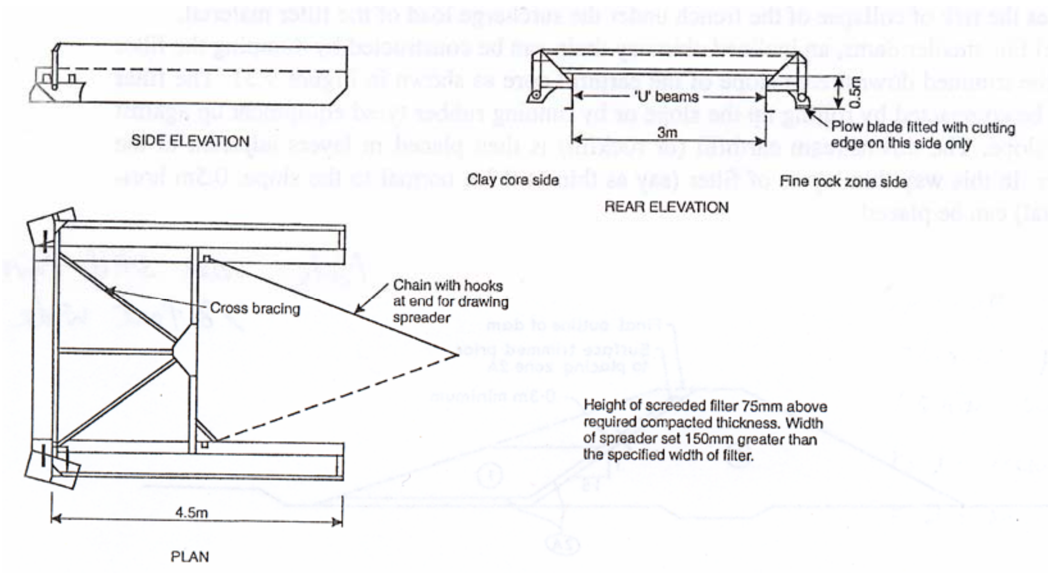


Fig 6. Typical spreader box and screed

The vertical filter is constructed by placing the earthfill for up to 2m over the filter layer, and then excavating through the earthfill with a backhoe or excavator to expose the filter, as shown in *Fig 7*. Careful cleanup of the surface of the exposed filter is necessary, and the filter is compacted with small vibrating sleds or other compaction equipment. The depth "h" is best limited to say 1m to reduce the risk of collapsing of the trench and allow access of men into the trench.

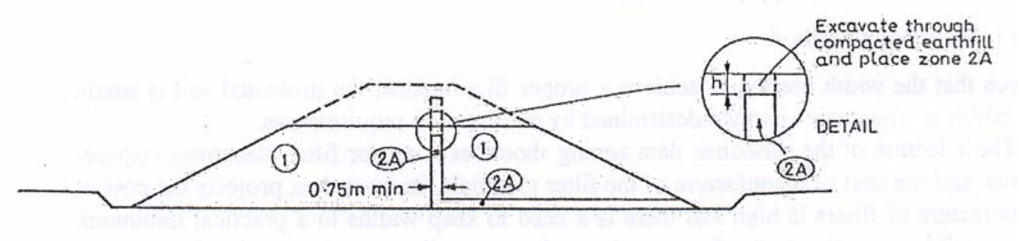


Fig 7. Construction of vertical filter drain by excavation through earthfill

Contamination of the filter during the placement can be reduced by spreading it from a movable steel plate placed adjacent the trench. This also reduces the risk of collapse of the trench under the surcharge load of the filter materials.

The horizontal filters are placed in minimum 150mm thick layers by compaction using a vibratory smooth steel drum roller. The inclined filters are constructed by dumping the filters on the trimmed slopes of the earthfill core. The filters are compacted by rolling up/down the slope or by running rubber tyred equipment up/down against the slope, where applicable. The rip-rap is then placed in layers adjacent to inclined filter zone 2C on the upstream face. It protects the dam against damage by waves, and sometimes provides waterproofing too.

4.5 Erosion control and slope protection measures

The previous section has explained the functions of all zones in the embankment dam in controlling erosion. In addition, erosion of the downstream face is prevented by:

i) establishing grass cover
The type of grass depends on local conditions, particularly climate and soil, and advice should be sought from local authorities. It is common to provide a layer of topsoil and seed the slope using bitumen hydro mulch, which provides initial protection against erosion before the grass is established. Low native bushes have also been successfully used. The grass will need to be watered at least until it is well established, and that reseeding and repairs will be necessary.

ii) providing berms to limit vertical distance over which runoff can concentrate
Berms are provided at 5m intervals vertically. In arid climates where this dam is subjected to, it is sufficient to provide a berm above the outlet of horizontal drains. This is necessary to prevent blockage of the outlet to the drain by the soil eroded of the embankment. Drains will often block with eroded soil before the grass is established necessitating regular inspection and cleanout. When grass is established, the drains should be maintained to ensure they function properly.

iii) providing lined drains on berms to catch runoff and carry it to the abutments
The drains on berms are extended along abutments for this purpose. Erosion at the contact between the embankment and the abutment is therefore controlled.

Fig 8.Construction of an outlet of horizontal drains

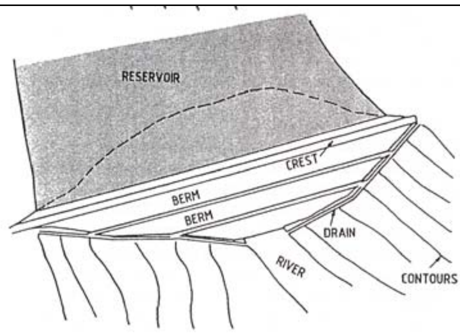


Fig 9. Berms and drainage for downstream slope

Fig 10.Completed dam

5. CONCLUSION

The dam designed in this paper is one of the most common types of embankment dams. It is designed to satisfy the particular topographic and foundation conditions at the site and to use available construction materials i.e. available earth and rocks on site. The ultimate factor in selecting a dam type is a structure that is adequately safe for the lowest total cost. Usually, the most economic design will be that using construction materials source close to the dam site, without excessive modification from the 'borrow pit run' or 'quarry run' materials.

6. REFERENCES

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