OPTIMAL HYDRAULIC / GEOTECHNICAL DESIGN FOR AN EARTH FILL RESERVOIR: CASE STUDY

OUR EXPERIENCE ON TARHUNA - WESHETATA EARTH FILL RESERVOIR

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ABSTRACT

There are various parameters controlling the design of earth fill Reservoir constructed in zones of arid climate. The prime parameters are reservoir's required capacity and the assigned inlet and the outlet levels. These important parameters are dominating reservoir dimension selection. The other equally important factors are the surveying data, and the geotechnical site investigation results, which identify reservoir's foundation supporting level. Reservoir filling material is also a parameter that need to be fully utilized to minimize costs. The remaining parameters such as emergency facilities and surveillance system should also be thought of. This article presents an optimal design for an earth fill reservoir aims at maximizing the use of local materials, and the full utilization of site topography, and geological conditions. It highlights our case study experience in designing Tarhuna-Weshetata Earth Fill Reservoir.

Keywords: Earth Fill, Reservoir, Dam, Optimal Design.

INTRODUCTION

In order to meet the demand of the 280 farms, of 2000 hectares total area, in the vicinity of Tarhuna - Weshtata agriculture project, an Earth Dam Reservoir is planned to be built. The dam will store water received form the Great Man Made River. The Reservoir should comply with the following: used for seasonal storage, having a capacity to store half a million cubic meter over two weeks period, and allow for a maximum outlet discharge of 50,000 cubic meter per day.

The article is divided into 4 sections. The first section reviews the available topographic, and geological data. Criteria for system selection are listed in section 2. Section 3 presents optimization parameters considered in the study. The outcome of the first three sections are transformed to a full engineering design structure, as illustrated in section 4.

1. Site Condition

- **Topography**

The proposed Earth Reservoir location falls within the international coordinates (3570678N,261222E), (3570678N,260872E),(3570854N,261047E), and (3570505N,261047E),with latitude ranges from 13 41 40 degree, to 13 34 00 degree. The Reservoir is approximately 1.6 kilometers south the Great Man Made River.

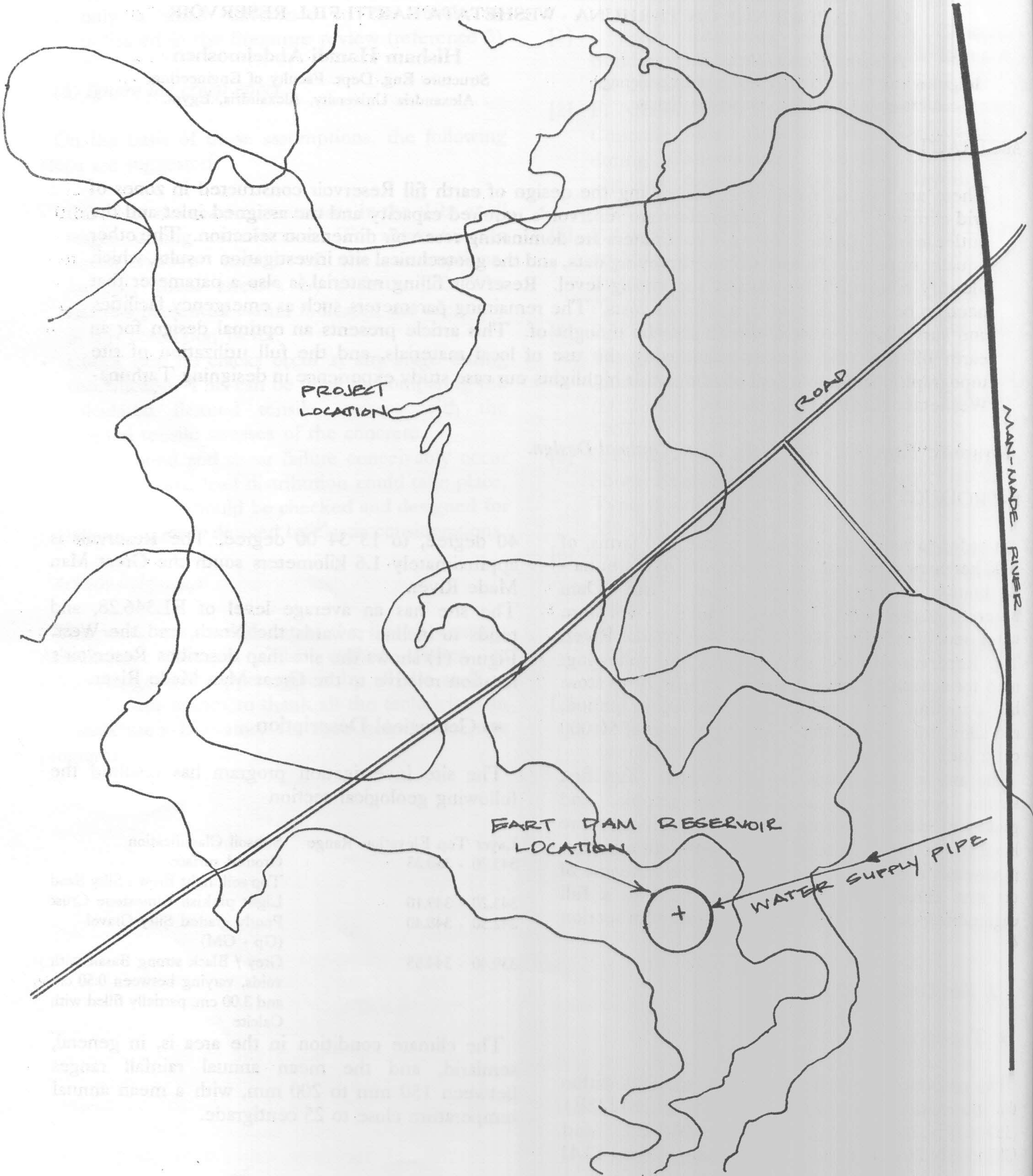
The site has an average level of EL346.28, and tends to incline towards the North, and the West. Figure (1) shows the site map describes Reservoir's location relative to the Great Man Made River.

- **Geological Description**

The site investigation program has resulted the following geological section

Layer Top Elevation Range	Subsoil Classification
343.20 - 350.35	Ground surface Top soil, light Brown Silty Sand
343.20 - 349.10	Light pinkish Limestone Crust
342.50 - 348.40	Poorly graded Silty Gravel (Gp - GM)
339.40 - 344.55	Grey / Black strong Basalt with voids, varying between 0.50 cm and 3.00 cm, partially filled with Calcite

The climate condition in the area is, in general, semiarid, and the mean annual rainfall ranges between 150 mm to 200 mm, with a mean annual temperature close to 25 centigrade.


PROJECT
LOCATION
ROAD
MAN-MADE RIVER
EART DAM RESERVOIR
LOCATION
WATER SUPPLY PIPE

2. CRITERIA FOR SYSTEM SELECTION

The following criteria are the bases for the system selection adopted in the study:

1. Full use of the local available material
2. Utilize the presence of the impervious Basalt layer close to the ground level
3. Observe the provided site location
4. Strictly satisfy the provided maximum Reservoir water level
5. Utilize the site topography
6. Full use of the Geotechnical available data
7. Full control over the minimal / unexpected water leakage within, and underneath the Reservoir
8. Protection against unexpected environmental variations
9. Emergency facilities and surveillance
10. Cost versus efficiency
11. Easiness in maintenance, and repairing operations.

3. SYSTEM OPTIMIZATION

Hydraulic Design Parameters for each structure item are as follows:

Reservoir

- Maximum capacity not less than 500,000 cubic meter
- Variable Charging flow
- Discharge flow per day is 50,000 cubic meter
- Controlled evaporation rate
- Maximum Reservoir water level is about EL347.00 (to comply with the existing Hydraulic System)
- Low Reservoir water level is about EL342.00
- Maximum water depth is about 5.50 m

Inlet Structure

Variable Discharge

Outlet Structure

Discharge capacity = 50,000 cubic meter /day

Spillway

- Maximum discharge is about 33,000 cubic meter per day

4. SYSTEM LAYOUT [REFERENCES 1 - 4]

■ Site Preparation

The whole site is to be totally excavated down to EL341.50. The excavation is carried out in sections with equal radial angles, to form a circular shape with 205.0 meter radius. The four meter layers below EL 341.50 are either weathered Basalt(at the east portion of the site), or (GP-GM) silt /gravel / sand mixed to various percentage. These layers shall be grouted for impermeability improvement. Reservoir embankment is formed starting from EL341.50, and up to the crest level. The same local GP-GM material is used, mechanically compacted to the maximum relative density, similar to Reservoir foundation. Compaction layers are 0.30 meter in thickness. Pneumatic operated tampers with rise not less than 0.20 meter is employed for compacting zones located above, and in the vicinity of hydraulic structures crossing embankment's body.

Figure (2) shows Reservoir System Layout. It composes of 10 various elements, which are discussed herein below.

■ The Reservoir

Figure (3) shows the Reservoir cross section. It comprises the upstream face, the crest, the downstream face, and the base. Reservoir diameter is 330.0 meter at the base, and increases to 367.50 meter at the crest level, allowing for a 2.5H:1V side slope.

- Upstream Face

The upstream face is sloped by 2.5H to 1.0V, and coated by three layers; the protection layer, the geomembrane layer, and the supporting base layer. The protection layer is made of Bituminous concrete. Geotextile is the supporting base material. More details are included herein below.

i. Bituminous Concrete

A 0.15 meter thick layer of hot - mix Bituminous concrete is prepared in two layers ; binder course (0.09 m) , and wearing course (0.06 m)

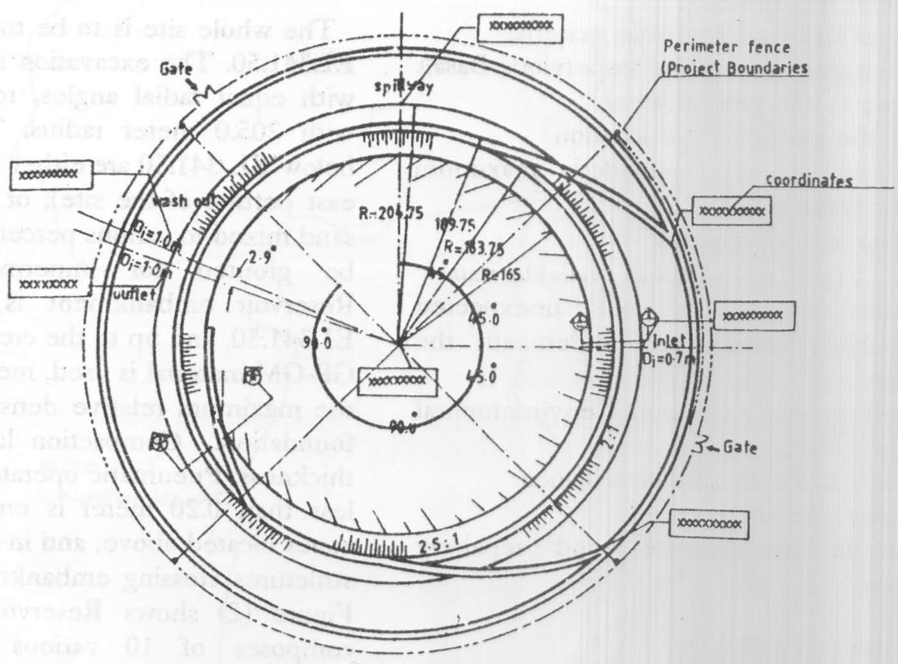


Figure 2. Schematic plan for the Reservoir.

ii - *Geomembrane Layer*

A 36 - mil (0.91 cm) thick reinforced sheets are used, commercially fabricated to 11.59 by 12.20 meters. Each sheet overlaps the adjacent down stream sheet by approximately 1.25 meter, to provide adequate protection for the compacted backfill, that anchors the down stream sheet. A minimum overlap of 0.60 meter is provided on the horizontal bed surface. Transverse joints between adjacent sheets, are not bonded, to prevent stress build up in one sheet from being transferred to another.

iii- *Geotextile Layer*

A 0.0025 meter thick layer of Geotextile sheets is placed on top of the earth fill surface to support the geomembrane layer.

- The Crest

The crest is 7.50 meter above Reservoir base level, having an elevation level of EL349.00. It is 6.00 m wide, allowing for transportation facilities around the Reservoir. The crest is sloped and paved to form the Belt road.

- Downstream Face

Its 2 : 1 sloped surface, and protected against erosion by wind, via a 0.30 meter thick local lime stone pitching .

- Toe Drain

Toe drain is provided to drain out any leakage through the Reservoir body, the crest, and the downstream face. The drain pipe runs around the reservoir perimeter, and inclines towards a drainage sump pit. Drain filter material complies with seepage properties of the Reservoir earth fill material.

- The Base

It is located at approximately EL341.50. The base is protected against water leakage using the same laying components similar to the upstream face. In addition, a 0.20 meter thick dense plain concrete slab is placed beneath the Geotextile layer for protection and leveling purposes.

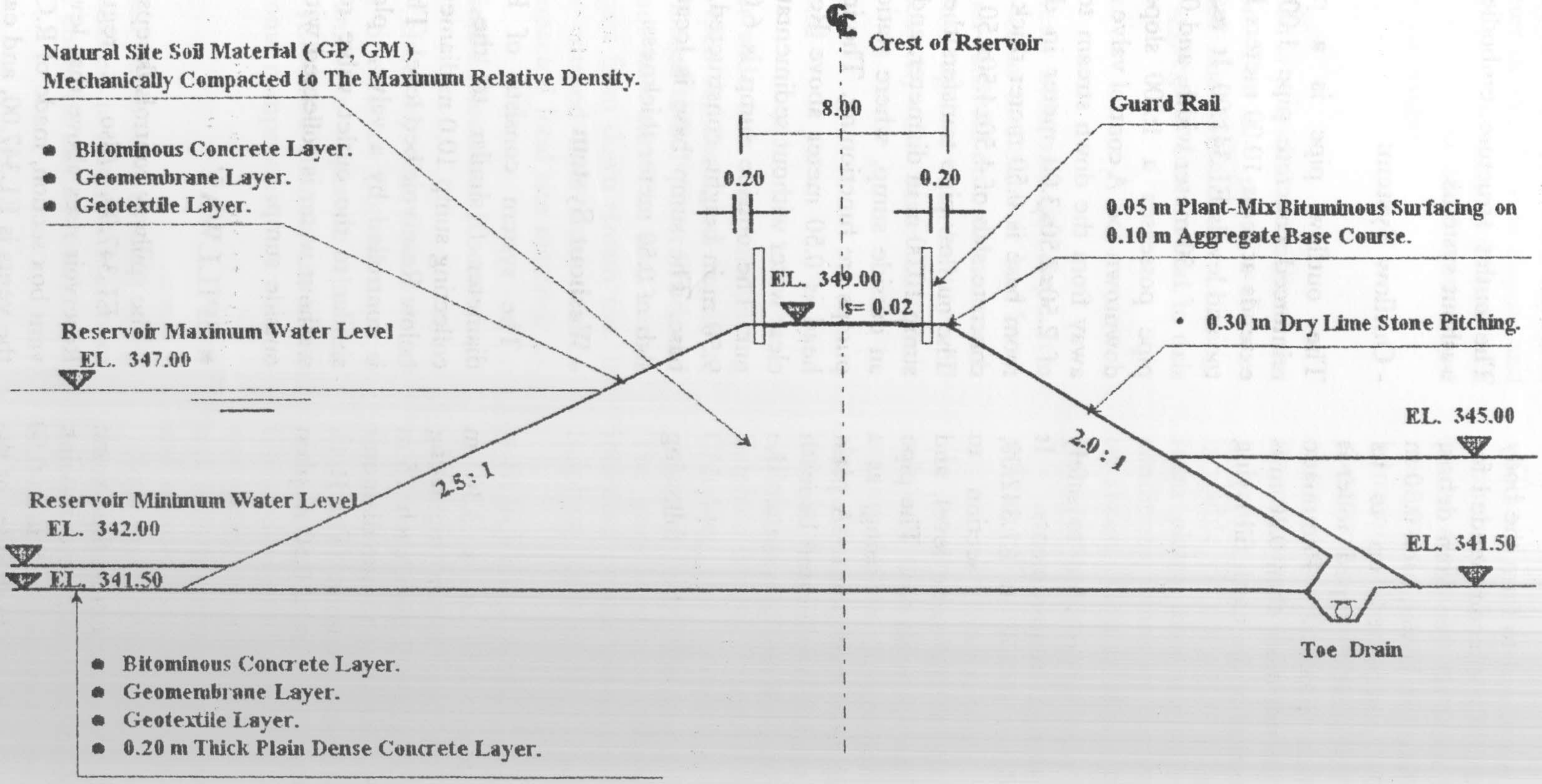


Figure 3. Reservoir cross section.

- The Earth Fill

Local available material is utilized to form the body of the Reservoir. Gp, and GM are recommended for that purposes. Material must be free from debris, and cobbles, and to be placed in layers, each 0.30 m thick, and mechanically compacted up to its maximum dry density. Pneumatic - typed roller is employed for compaction process. Pneumatic operated tampers with rise not more than 0.20 m is recommended for the portion of the earth fill laying over hydraulic structures.

■ Inlet Structure

A 0.70 m ductile steel pipe is provided to safely satisfy the hydraulic design requirements. It approaches Reservoir down stream at EL342.00, penetrates reservoir's embankment section to intersect the upstream toe at the same level, and extends 8.70 m beyond the upstream toe. The pipe is flared to a 1.40 m rectangular diffusing, at a distance of 3.50 m away from exit point. A plain concrete slab of 0.50 m thickness is located beneath the pipe for supporting purpose and to maintain the pipe designed level.

The Inlet Structure comprises the following components :

-- Non Regulating valve
-- Valve Room:

Constructed of 2.50 m x 2.50 m x 3.30 m dimensions, to house the non return regulating valve. It consists of R. C. wall, and base, each .25 m thickness, and reinforced by 5 steel 13 mm diameter bars per meter length in both directions. The R. C. base is laid over a 4.50 m x 4.50 m x 0.50 m plain concrete base.

-- Expansion joints:
-- Energy Breaker:

A layer of the local available natural crest lime stone blocks is placed in the vicinity of the pipe exit point. Block dimension could vary between 0.35 m to 0.50 m. The layer extends 5.00 m on both sides of the pipe center line.

■ Outlet Structure

The outlet structure embodies an outflow , and washout systems.

- Outflow System:

The outflow pipe is a pre-stressed pre-cast reinforced concrete pipe 1.00 meter in diameter, extends at least 10.00 meters beyond the upstream toe and levels EL341.00. It rests on a plain concrete slab of 1.50 meter width, and 0.50 m thickness. The pipe possesses a 1:200 slope towards Reservoir downtown toe. A control valve room is located 3.00m away from the down stream toe, and made of R.C. of 2.50x2.50x3.00 meter in dimension. The R.C. room base is 0.50 meter thick, and rests on a plain concrete slab of 4.50x4.50x.50 meter in dimensions. The outflow pipe transfers the water from an inside sump 10.00 m in diameter, and rests at EL341.00, to an outside sump, where station distributing lifting pumps are functioning. The inside sump's wall free head is 0.50 meter above Reservoir Bed, so as to clear water without sedimentation is allowed to flow out. The outside sump is 6.0 m in diameter, and 9.50 m in height, constructed from R.C. walls, and base. The sump base is located on plain concrete slab of 0.50 meter thickness.

- Washout System

The system consists of R.C. pipe 1.0 meter diameter (similar to the outlet pipe), and a collecting sump 10.0 m diameter, located 0.50 meter below Reservoir bed level. The flow inside the pipe is controlled by a valve, placed in a valve room, similar to the outlet valve room, and the outflow washout water is collected with the outflow water in outside sump.

■ SPILLWAY

The spillway controls /keeps /limits the water level to EL347.00. Also it regulates releases when Reservoir rises above that level. The spillway has 3 vent box section, made of R.C. The bottom level of the vents is EL347.00, and each vent is 1.00 by 1.00 meter in section. Excess water passes via spillway, through the embankment, and along the downstream face. The outlet channel is an open one, with 3.40 meter wide, 1.50 meter depth, 2:1 side slopes, and 1:10000 longitudinal slope. The channel is lined with Bituminous Concrete for its first 100.0 meters, and pitched for the rest of its length.

■ Belt Crest Road

A 6.0 meter wide road is provided to facilitate the maintenance operation. The road paved surface is 0.05 m thick plant-hot mix Bituminous surfacing, supported on 0.10 m aggregates base course.

■ Ramp Road

A ramp road is 6.0 meter wide, and 1:10 slope. It is included to facilitate access to Reservoir bed level. The road sub-base is an earth fill embankment with 2:1 side slopes, protected against water leakage and environmental effects by the same Reservoir upstream lining.

■ Belt Reservoir Road

A 2 lane, 7.00 meter wide belt road surrounding Reservoir site is provided for functional access to Reservoir vicinity. Its linked to Belt Crest Road, and connected to local roads network. The road center line is 43.50 meter apart from down stream toe. It comprises 0.10 meter crushed lime stone surface based on the well compacted local site material.

■ Control / Mechanical / Electrical Rooms

Rooms are located close by the Reservoir to monitor the necessary operations. Control room is elevated on R.C. frames to supervise the site functions. Mechanical /Electrical room(s) are in the vicinity of their functional components.

■ Cleaning

Ramp road discussed here above shall allow cleaning trucks to have access to Reservoir's bottom, so as to sedimentation could be carried away.

■ Evaporation Control

Glazed white rubber foam plates are recommended. Dimensions, and orientation of the plates are to be selected , as such evaporation is minimized. Fetsh and wind velocity control the horizontal dimension of each rubber plate. Whereas, plate weight, and wave velocity dominate the choice of the plate's thickness. Our experience, supported by mathematical model developed for this purpose, indicates a 75% reduction in the evaporation value, is visible via the above proposed method. Yet, the foam plates have no influence on environmental conditions, which are certainly affected by the use of oil sheet. Cost is also a parameter that promotes foam plates over oil sheet.

■ Water Treatment

In principle, suspended solids, such as; clays, minerals, siliceous mater, and vegetable debris, and organic matters, such as; organic acids, humus, peat, algae, faecal matter, are basic foreign elements may exist in the storing water.

Chemical treatment is recommended. Aluminum Sulphate (alum), Ferrous Sulphate (copperas), Ferric Chloride, and Sodium aluminate are coagulant examples to be used to neutralize suspended solids. The growth of sever blooms of algae would be inhibited by the use of an algicide, such as Copper Sulphate (blue stone).

■ SURVEILLANCE

- Design of Surveillance System [References 5,6]

Five critical phases in the life cycle of the Reservoir are identified, and considered in the design, which are; the pre-construction phase, the construction period, the period of first reservoir filling, the early operational period of the Reservoir, and the subsequent aging of the operating Reservoir, and infrequent exposure to extremes of hydraulic and seismic external loading.

Slope stability analyses have been conducted on the Reservoir upstream and downstream faces. The five critical phases identified above, are transformed to the following six condition cases as listed in Table (1).

Table 1. Critical Phases and Corresponding Safety Factors.

Case No.	Case condition	Up stream safety factor	Down stream safety factor
1	Complete dry condition, right after construction	2.65	1.82
2	Reservoir full storage capacity, No seepage	5.73	1.74
3	Reservoir full storage capacity, seepage allowed through Embankment Seepage ratio =0.15	4.83	1.42
4	Reservoir full storage capacity, seepage allowed through embankment Seepage ratio =0.15, in addition to Earthquake force = 0.10 g	3.54	1.30
5	Complete dry state, right after construction, in addition to Earthquake force = 0.10 g	2.07	1.45
6	Reservoir full storage capacity, in addition to Earthquake force = 0.10 g	4.20	1.39

The above values are compared to United States (Federal Register, 1977) , who suggested the following values for the safety factors corresponding to the cross listed case conditions listed in Table 2,

Table 2. Recommended Safety Factors for Cross Listed Case Conditions, Ref. [13].

Case condition	Safety factor
I End of construction	1.3
II Partial pool with steady seepage saturation	1.5
III Steady seepage from spillway or decant crest	1.5
IV Earthquake (case II and III and with seismic loading)	1.0

The design does not allow, under normal conditions, for any seepage through Reservoir embankment, due to the presence of the Geomembrane layer. Consequently, such case is considered an extreme condition, and treated with a rather relaxed safety factor.

- Measurements

Inspection should always be supplemented by measurements. Education of seepage, and settlement trends, and the internal of the Reservoir, and its foundation conditions could only be assessable through instrumentation.

□ **Vertical Movement Measurement**

Monitoring vertical movement beneath, within, and on the surface of the Reservoir is acquired via installing a permanent Bench Mark.

□ **Slope Deformation**

The pre -installed Bench Mark is used, with the monuments located at the required points deformation. Theodolites are employed here for precise measurements.

□ **Seepage Flow Measurements /Reservoir Water Level Detection**

Piezometers are installed between the Reservoir upstream and downstream faces to detect the effectiveness of the seepage control method. Piezometer type and components are to be selected to comply with the earth fill permeability properties.

- Inspection

Inspection aims to recognize indications of possible distress such as joint movement, piezometer fluctuations, seepage variation, settlement and horizontal misalignments, slope movement, cracking, erosion, and corrosion of equipment, and conduits. Examination should be made periodically when the reservoir is full. Comprehensive inspection is commonly accomplished at intervals of 6 months to 2 years.

- Emergency Access

Outlet works, and spillways should be maintained to be always accessible. Auxiliary power should be provided. Equipment and supplies for handling adverse conditions are essential. Roads to the site must enable the transport of equipment necessary for servicing the Reservoir during any adverse conditions.

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