STRENGTHENING OF RESERVOIR EMBANKMENTS

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Power plants, chemical and industrial plants have very large requirements of raw water for their process needs. Water which is very scarce these days is got from a source nearest to the plant; which can be a river, lake or a dam reservoir and this water is then pumped and stored within plant limits in a raw water reservoir built by enclosing a low lying area within the plant boundary with the help of earthen bunds. As water is precious; some amount of water to help run the plant for a few days/ weeks in case of an emergency or to tide over dry season; is generally stored within the plant limits. In addition to storing raw water, industrial plants also need to store wastes like ash, sludge, slime etc. in reservoirs outside plant limits constructed with the help of high earthen embankments.

TCE have executed projects in which small to large capacities of raw water reservoirs, ash ponds etc. had to be designed and constructed. In addition TCE were also called in after reservoirs/ pond embankments had breached; to carry out root cause analysis of the failure and thereafter to suggest strengthening measures for the breached embankments.

During the engineering of reservoirs/ ponds; engineering studies are carried out by TCE which include stability analysis, seepage analysis, freeboard analysis; using various softwares. Experience is crucial to effectively model the problem and also to interpret and validate the results of the studies and thereafter design / strengthen the embankments.

An embankment can be composed of single type of material which is soil or can have an inside impermeable core surrounded with soil. In industrial and power plants very often the height of the embankments can even go upto 20m. Many times the reservoir/ pond bed and the upstream side of the bund is lined with impermeable membranes – LDPE/ HPDE/ Geotextiles with concrete tiles or sand over them and above which the material to be stored is placed.

The basic requirements for design of embankment dam are to ensure:

- **Safety against overtopping:** During design of embankment it shall be ensured that the full tank level and top of bund level is such that water stored in the reservoir does not overtop the embankment during filling and due to waves generated in the reservoir. For this the freeboard should be sufficient to prevent overtopping by waves. The free board design should also take into account the settlement of the embankment and foundation so that with time after settlement has occurred adequate free board is still available.
- **Stability:** The slopes of the embankment should be flat enough so as not to impose excessive stresses on foundation and should be designed to be stable under all loading conditions. Extensive investigations of the foundation soil and borrow area soil is required to be carried out before taking up the stability design of the embankment dam. Stability analysis of embankments can be carried out using software like SLOPE/W of Geoslope package. Various possible phases of construction and operation are to be understood and the earth embankments have to be analysed for all these phases to ensure their safety and stability.

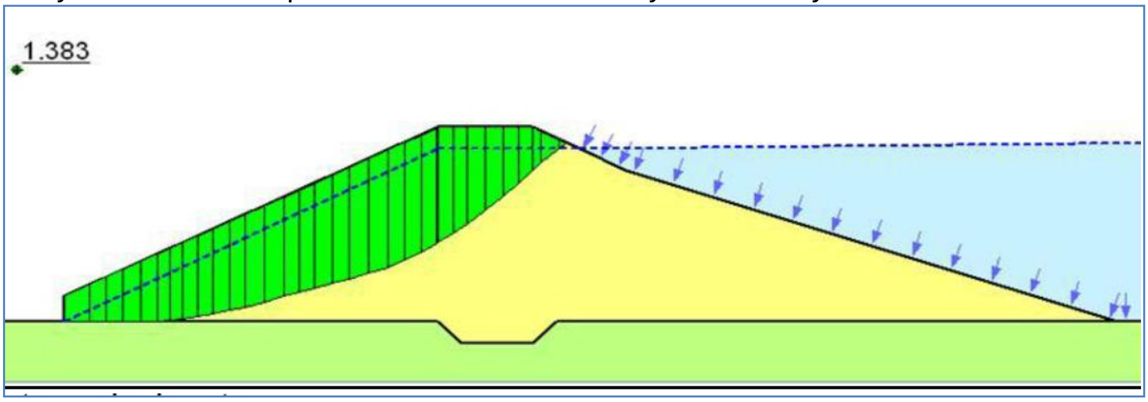

Figure 1- Typical slope stability analysis conducted using SLOPE/W software

In case of breached embankments to understand the reason for the failure; experience is required. The team that visits site after a breach to conduct a root cause analysis of the failure; tries to collect as much site data as possible and looks for tell-tale signs that could point out the probable reason for failure to have occurred; like-

- Presence of localized concentrations of seepage, rain cuts, gullys and holes in the downstream slope and general condition of the downstream slope.
- Presence of downstream slope protection like turfing/ pitching and its condition.
- Presence of toe drain and its condition.
- Condition of the toe of the embankment.
- Condition of the top of bund and presence of cuts/ cracks.
- Condition of upstream lining if any.

The team also talks to the site personnel, collects existing drawings of the embankment, collects the existing geotechnical reports of the reservoir/ embankment area. The history of embankment construction is collected from site. Many a times the embankment is built in stages/ phases. With all this data and with additional tests which may be required like soil tests; the reason for the failure and the strengthening measures for the embankment can be arrived at.

Causes of Failure

Reservoir embankment failures may be classified under:

a. **Hydraulic failure**: More than 40% of earth dam failures are Hydraulic failures and may be due to the following reasons:

i. Overtopping: Sufficient freeboard above the maximum water level needs to be maintained to avoid this failure.

ii. Erosion of downstream toe: A toe drain can provided so as to divert water from rains or due to seepage away from the embankment toe thus protecting it.

iii. Erosion of upstream surface: Erosion of the upstream surface can be prevented by linings.

iv. Erosion of downstream face by gully formation: Rain water flowing over the downstream face can erode the surface and can create gullies leading to failures. This can be prevented by providing turfing or pitching on the downstream slope and by properly inspecting and maintaining them.

b. **Seepage failure**: Seepage is one of the main reasons for reservoir embankment failure. If the magnitude is within design limits, stability of embankments will not be affected. Saturation of the downstream toe of embankments leads to the erosion of toe; which may lead to the process of failure due to sloughing. This needs sufficient time to develop. Seepage analysis of the embankments can be carried out using SEEP/W software of Geoslope package, based on Finite Element Method. The amount of water seeping through and under the embankments can be estimated and the evaluation of seepage is crucial as uncontrolled seepage that can develop during filling of reservoir to its FRL can destabilize the structure leading to total structural failure. The quantity of seepage, its exit gradient and maximum velocity can be evaluated for checking the stability of embankments against seepage. The visually confirmed seepage conditions to be avoided are:

- The exit of the phreatic surface on the downstream slope
- Development of hydrostatic heads sufficient to create downstream erosion by “piping”
- Localized concentrations of seepage along conduits or pervious zones.

These can be analysed and checked through the SEEP/W software of Geoslope package.

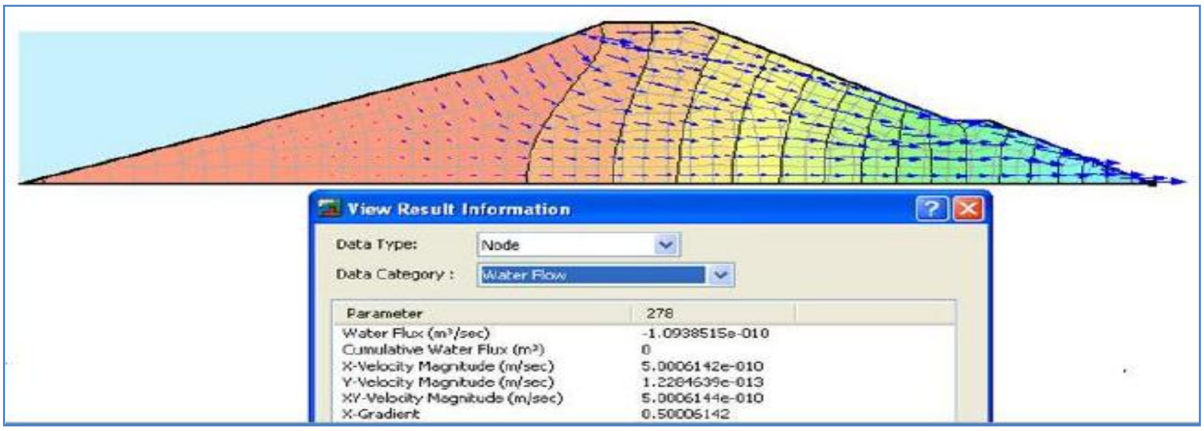

Figure 2- Typical seepage analysis conducted using SEEP/W software

c. **Structural failure**: This failure is mainly due to shear failure which causes slide along the slopes and may be due to:

   i. Slide in embankment: When there is a sudden drawdown there could be development of very high pore pressures which decreases the shearing strength of the soil leading to the failure of the embankment.
   ii. Foundation slide: This kind of failure can occur when sufficient bearing capacity is not available for the foundation of the embankment.
   iii. Faulty construction and poor maintenance: Soils compacted with water less than optimum water content of soil have a certain skeleton strength due to the suction effect between soil particles. This skeleton strength easily disappears by wetting or saturation of embankment soil that occurs during the filling of the reservoir resulting in large settlements; leading to formation of cracks in embankment leading to its failure.

Based on the result of root cause analysis of the failure; strengthening measures are adopted. This needs experience. Some of the most common strengthening measures are listed below:

a) **Cut-off** in the form of trench, sheet piling or a diaphragm of impervious materials like bentonite, concrete, etc. can be provided to reduce loss of stored water through foundation and to prevent subsurface erosion by piping.
b) **Core**- By providing impermeable core within the body of the embankment seepage can be controlled. To control cracking of the embankments plastic clay cores rolled at slightly more than optimum moisture content is provided. Many times, 2 to 5 percent bentonite of 200 to 300 liquid limit is mixed to increase the plasticity of the core material. Use of wider cores also helps to reduce the possibility of extension of horizontal cracks.
c) Casing- This is provided to protect the core from cracking and to make the embankment stable.
d) **Internal drainage system –**Many times internal drainage system within the earthen bund comprising of inclined, horizontal or vertical drains filled with filter material is provided to channelize the seepage water safely to a toe drain and thereby reduce destabilizing forces on the bund. For this suitable toe protection is also needed.
e) **Slope protection-** Upstream slope protection by riprap / concrete/ liners and downstream slope protection by grass turfing /riprap also help prevent bund collapse.
f) **Impervious blanket**- This arrangement is resorted to increase the path of seepage when full cut-off is not practicable on pervious foundations.
g) **Relief wells**- These are very often provided to release uplift pressure and make the embankment stable.

Careful selection of fill materials to reduce the differential movement is very important. Transition zones of properly graded filters of adequate width are also provided for handling drainage when cracks develop. Special treatments to the foundation; like preloading, pre-saturation, removal of weak material, etc., may sometimes be required. Delaying placement of core material in the cracked region till most of the settlement takes place is also suggested many times.

TCE have engineered a number of reservoirs / ponds with earth embankments. TCE have also carried out root cause analysis of embankment failures and suggested strengthening measures for the breached embankments with the help of trained engineers and have the required software’s and experience for this. Experience is the key factor to identify the reason for failures and also to suggest the right remedial measures.