Design of Recharge Structure – Percolation Tank

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Percolation Tank

Percolation tanks are water storage structures constructed by excavating a depression forming a small reservoir, or, by constructing an embankment in a natural ravine or gully to collect and impound the surface runoff from the catchment during monsoon rain and store it for longer time to facilitate infiltration and percolation of water into the substrata to raise the groundwater level in the zone of influence of pond. Thus, percolation tanks are artificially created surface water bodies, submerging a land area with adequate permeability to facilitate sufficient percolation of impounded surface runoff to recharge the ground water.

General Guidelines

- Percolation tanks should normally be constructed in a terrain with highly fractured and weathered rock for speedy recharge. In case of alluvium, the boulder formations are ideal. However, the permeability should not be too high that may result in the percolated water escaping in the downstream as regenerated surface flow.
- The aquifer to be recharged should have sufficient thickness of permeable vadose zone to accommodate recharge. The vadose zone should normally be about 3 m below the ground level to minimize the possibility of water logging.
- The benefited area should have sufficient number of wells, hand pumps etc. A minimum well density of 3 to 5 per square kilometres is desirable. The aquifer zone should extend up to the benefited area.
- Submergence area should be uncultivated as far as possible.
- Rainfall pattern based on long-term evaluation is to be studied so that the percolation tank gets filled up fully during monsoon (preferably more than once).
- Soils in the catchment area should preferably be of light sandy type to avoid silting up of the tank bed.
- The location of the tank should preferably be downstream of runoff zone or in the upper part of the transition zone, with a land slope gradient of 3 to 5%.
- The yield of a catchment area is generally from 0.44 to 0.55 MCM/km^2 in a low catchment area. Accordingly, the catchment area for small tanks varies from 2.5 to 4 km^2 and for larger tanks from 5 to 8 km^2.
- The size of percolation tank is governed more by the percolating capacity of the formation under submergence rather than the yield of the catchment. Therefore, depending on the percolation capacity, the tank is to be designed. Generally, a percolation tank is designed for a storage capacity of 2.25 to 5.65 MCM. As a

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general guide the design capacity should normally not be more than 50 percent of the total quantum of utilizable runoff from the catchment.

- While designing, due care should be taken to keep the height of the ponded water column about 3 to 4.5 m above the bed level. It is desirable to exhaust the storage by February since evaporation losses become substantial from February onwards. It is preferable that in the downstream area, the water table is at a depth of 3 to 5 m below ground level during the post monsoon period, implying that the benefited area possesses a potential shallow aquifer.

Design Aspects

The design of percolation tanks involves detailed consideration of the following aspects:

- Percolation tanks are normally earthen dams with masonry structures only for the spillway. Construction materials consist of a mixture of soil, silt, loam, clay, sand, gravel, suitably mixed and laid in layers and properly compacted to achieve stability and water tightness. The dam is not to be overtopped, by providing adequate length of waste weir and adequate free board.
- The design of the dam is to be done on the basis of (a) the topographical setting of the impounded area, to calculate the height and length of the dam wall, its gradient, width and the depth of the foundation, taking into account the nature of the underlying formation; (b) details of the cut-off trench, to reduce seepage losses; (c) height of stone pitching on the upstream slope to avoid erosion due to ripple action and on the down stream slope from rain by suitable turfing; (d) upstream and downstream slopes to be moderate so that shear stress is not induced in the foundation beyond a permissible limit; and (e) stability of the dam.
- A waste weir is provided to discharge surplus water when the full pond level is reached. Maximum permissible discharge from the catchment is to be calculated using the formula approved by the competent authority based on local conditions. In the absence of such a formula, empirical formulas such as Dicken's or Ryve's formula may be used based on the observed or design discharge and catchment areas for local culverts under road or railway bridges. Once the discharge is known the length of the waste weir is decided depending on the maximum flood discharge and permissible flood depth of the crest of waste weir.
- Measures for the protection of catchment areas of rock dams hold good in the case of percolation tanks also.
- The percolation tanks in a watershed may not have enough catchment discharge though a high capacity tank is possible as per site conditions. In such situations stream from nearby watershed can be diverted with some additional cost and the tank can be made more efficient.

Storage Capacity of Tank

The tank or pond capacity can be determined with the help of contour maps of the watershed area where the pond is to be located. The volume of water that can be stored by the pond or reservoir at a certain water surface elevation can be computed after determining the increment of storage (Δs) between two elevations. The value of Δs is computed by multiplying the average of the areas at the two elevations by the elevation difference (Δh), e.g., if A1 and A2 represent the areas enclosed between two successive contours, then the increment of storage between these contours is taken as $\Delta s = [(A1+A2)/2]\ \Delta h$. The summation of these increments below any elevation is the storage volume below that level.

In the absence of topographic maps, the cross-sections of the reservoir can be surveyed and the capacity computed from these vertical cross-sections by using Trapezoidal or Prismoidal formula.

Trapezoidal formula

$$V = h\ [(A_1+A_n)/2 + A_2 + A_3 + \ldots + A_{n-1}] \qquad (1)$$

Prismoidal formula

$$V = (h/3)[(A_1 + A_n) + 4(A_2 + A_4 + \ldots) + 2(A_3 + A_5 + \ldots)] \qquad (2)$$

where V is the volume of water stored in pond; and A_1, A_2, A_3, A_4, ... are the areas enclosed within successive contours spaced with contour interval of h.

Design of Embankment

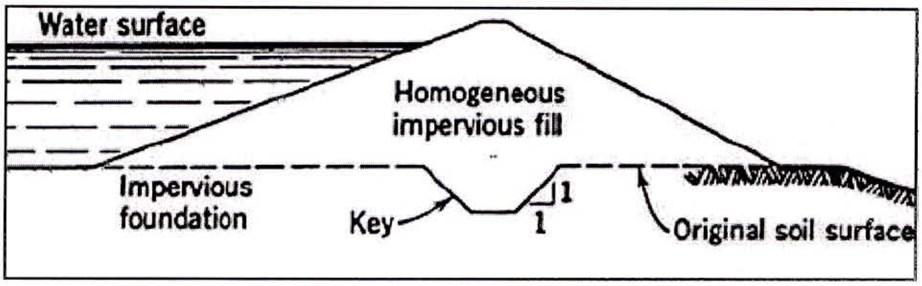
The tank bund is a small-sized earth dam; its design and construction are carried out in accordance with the principles applicable to earth dams.

Types of tank bunds: Tank bunds may be of three types: (A) Homogeneous embankment (B) Zoned embankment (C) Diaphragm type.

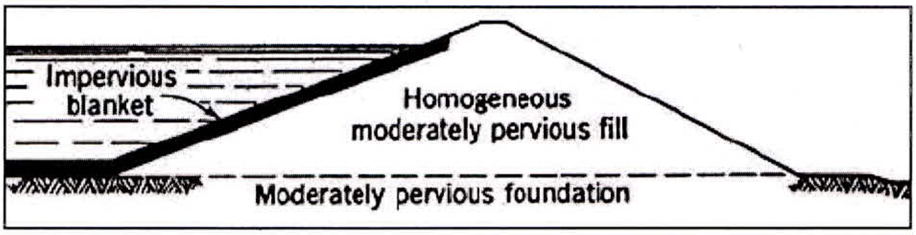
Homogeneous embankment: It is constructed with relatively homogeneous soil material and is either keyed into an impervious foundation stratum (Fig. 1a) or is constructed with an upstream blanket of an impervious material (Fig. 1b). The homogeneous embankment type is adopted for constructing low dams where sufficient volumes of satisfactory fill materials are available. A purely homogeneous section poses the problem of seepage and huge sections are required to make it safe against piping, stability etc. due to this, a homogeneous section is generally added with an internal drainage system, such as a horizontal drainage filter, rock toe etc. The internal drainage system keeps the phreatic line well within the body of the dam, and so steeper slopes can be used.

Zoned embankment: In zoned embankment, a central highly impervious core is flanked by a comparatively pervious transition zone which is finally surrounded by a much more pervious outer zone. The central core checks the seepage. The transition zone prevents piping through cracks which may develop in the core. The outer zone gives stability to the central impervious fill and also distributes the load over a larger area of foundation. Clay is mixed with fine sand or fine gravel for the central impervious core. Freely draining material such as coarse sand and gravel are used in the outer zone.

Diaphragm type: In this type, the bulk of the embankment is constructed with pervious material (sand, gravel or rock) and a thin impervious core (diaphragm) of impermeable material like plastic, concrete, steel or wood to act as a barrier against seepage through the fill is provided. The diaphragm must be tied to the bed rock or to impervious foundation material, if excessive under-seepage through existing pervious foundation is to be avoided.



(a)



(b)

Fig. 1 Different types of homogeneous embankments.

Expected yield of runoff: The total expected yield of runoff can be estimated using Strange's table using average monsoon rainfall and catchment area. The runoff yield can be estimated by dividing the area under good, average and bad catchment

Height of the embankment: The height of dam should be selected in such a way that the cost of dam per unit of storage is minimum. The depth-capacity curve and the area-capacity curve for the tank are used to determine the most suitable height for a given storage volume. The height of small earthen dams should not normally exceed 16 m. Dam height is determined based on the necessary storage volume plus flood storage and freeboard.

Free board and wave protection: Free board is the additional height of the dam provided as a safety factor to prevent waves and runoff from storms greater than the design frequency from overtopping the embankment. It is the vertical distance between the elevation of the highest flood level and top level of the dam after all settlement has taken place. Normally, 10-15 percent is added as free board to the highest flood level of the dam. Wave heights for determining free board can also be computed using Hawksley's formula:

$$F = 1.5\ h_w \tag{3}$$

where F = free board in m, $h_w = 0.014\ (D_m)^{0.5}$ = wave height in m, D_m = fetch length (the longest exposed water surface on the reservoir) in m

Allowance for settlement: Settlement includes consolidation of the fill materials and the foundation materials due to the weight of the dam and the increased moisture caused by the storage of water (Fig. 2). It depends upon the type of fill material and the method and speed of construction. It varies from 10% of design height for hand compacted (normally constructed) fill to 5% for machine compacted (rolled at optimum moisture) fill.

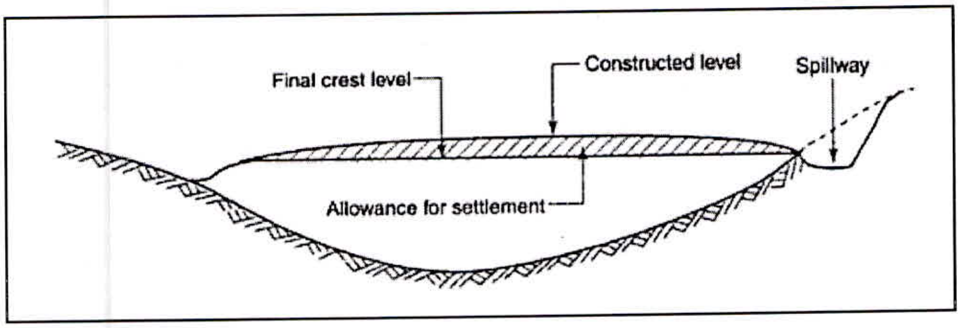


Fig. 2 Allowance for settlement

Top width of embankment: Adequate top width especially when the crest is to be used as roadway for connecting adjoining villages or watersheds. Simple formula relating top width with height of dam may be used:

$$W = H/5 + 1.5 \tag{4}$$

where W = top width of embankment, m; H = total height of embankment, m.

Bottom width (B) of embankment is computed as

$$B = \text{top width} + \text{upstream slope} \times \text{height} + \text{downstream slope} \times \text{height} \tag{5}$$

Side slopes of embankment: Embankment slopes are required for stability of the embankment on stable foundations. The side slopes are dependent upon the height of dam, nature of foundation material and nature of fill material. To protect the embankment from wave action of water and avoid overtopping, the upstream slope of embankment should be flatter than the downward slope. The recommended side slopes for earthen embankments are given in Table 1. For protection purposes, stone pitching is provided on the upstream face of the dam extending from the ground surface to the top of the dam excluding top width.

Table 1. Recommended side slopes for earth dams

Type of material	Upstream slope	Downstream slope
Homogeneous well graded	2.5:1	2:1
Homogeneous coarse silt	3:1	2.5:1
Homogeneous silty clay (i) Height less than 15 m (ii) Height more than 15 m	 2.5:1 3:1	 2:1 2.5:1
Sand or sand and gravel with central clay core	3:1	2.5:1

Filters and toe drains: On impounding water behind a dam, water seeps through the dam body. The head of water decreases downstream till it meets the base at some point. The saturation line is the line between saturated and unsaturated zones in the earth dams (Fig. 3(a)). The phreatic line (i.e. the upper zone of saturation) must remain within the base width of the embankment. In case the saturation line merges out on the downstream face of the dam, there is danger of piping leading to failure of the dam. By providing a horizontal filter of gravel or coarse sand of sufficient thickness placed on the downstream base of the dam (Fig. 3(b)), the phreatic surface is lowered. In case of bigger dams, specially designed toe filters and drains need to be provided.

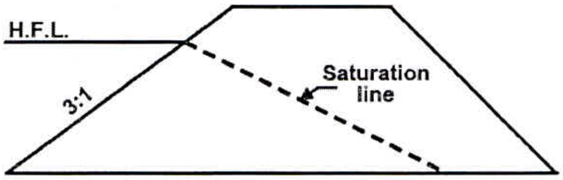


Fig. 3(a): Saturation line in an embankment

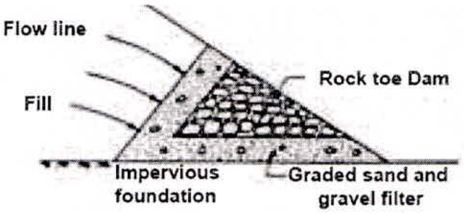


Fig. 3(b): Filter at the toe of the dam

Foundation key/Cut off: There is flow of water in the foundation under pressure. A foundation key joins the impervious stratum in the foundation with the base of the dam. The most common type of key is constructed of compacted or puddled clay material. A trench, also called key trench, is cut parallel to the central line of the dam to a depth that extends well into the impervious layer. The trench should have a bottom width of not less than 1.5 metres but adequate to allow the use of mechanical equipment if necessary to obtain proper compaction. For effective control of seepage, the cut-off trenches in between upstream and downstream toe lines of the embankment, especially on the stream bed portion should be filled with puddled clay and placed along with the central key trench.

It may be noted that storage capacity for large embankments is estimated from the submergence area. For small embankments, storage capacity may be roughly calculated as:

Storage capacity (ha-m) = 0.4 DA (6)

where D = maximum depth of water (m), and A = area of water spread at waste weir (ha).

Tank Weirs or Surplus Escape Weirs

To check the rise of water in the tank above MWL (maximum water level), excess surplus water is spilled from the tank into a downstream channel. The water starts spilling over the crest of this escape weir when it rises above FTL (full tank level). The discharging capacity of this weir is designed such as to pass the maximum flood discharge (likely to enter the tank) with a depth over the weir equal to the difference between FTL and MWL.

***Length of the tank weir*:** The capacity of the weir should be sufficient to discharge the peak rate of runoff. To determine the length of the weir, therefore, it is first necessary to determine the maximum flood discharge that may enter into a tank after it is filled up to the full tank level. This *peak discharge* that may come from the catchment of tank can be estimated using empirical formulas. For example, for catchments with area up to 1300 ha, peak rate of runoff may be calculated by the rational method; for catchment area over 1300 ha, Dicken's formula may be used.

Rational method: $Q = CIA/36$ (7)

where Q = peak discharge, m^3/s; C = runoff coefficient; I = Intensity of rainfall for duration equal to the time of concentration of the watershed, cm/hr; A = catchment area of the watershed, ha.

Dicken's formula: $Q = CA^{3/4}$ (8)

where Q = peak discharge, m^3/s; A = catchment area in km^2; C = constant (for North India, C = 11.5; Central India, C = 14 to 19.5; Western India, C = 22 to 25). The formula is generally useful for catchments of North India. An average value of C equal to 11.5 is generally used and it is increased for hilly catchments and vice versa.

Ryve's formula: $Q = CA^{2/3}$ (9)

where Q = peak discharge, m^3/s; A = catchment area in km^2; C = constant (for areas within 80 km from coast, C = 6.8; areas within 80-2400 km from coast, C = 8.8; areas near hills, C = 10.1; actual observed values, C up to 40). The formula is applicable to catchments in South India. The average value of C to be used is 6.8 with less value for flat catchments and more for hilly catchments.

The length of the weir is computed using appropriate discharge formula applicable to the weir type adopted in the project. In general, the discharge over a broad crested free weir is given as:

$$Q = CLh^{3/2} \quad (10)$$

where C = constant; L = length of weir in m; h = head of water over the weir in m (i.e. the difference between MWL and FTL).

Width of horizontal floor: The width of horizontal floor of masonry weirs with vertical drop, from the foot of the drop wall to the downstream edge of the floor should not be less than 2(D+H) where D is the height of the drop wall and H is the maximum head of water over the wall. The rough stone apron forming a talus below the last wall may be of varying widths depending upon the nature of the soil and the velocity and annual probable quantity of runoff. It generally varies from 2.5(D+H) to 5(D+H) depending upon the varying conditions.

Problem 1. The area enclosed by different contours at a tank site are as follows:

S.No.	Contour (m)	Area enclosed (m^2)
1	300	260
2	302	10430
3	304	75590
4	306	143000
5	308	260000
6	310	414400
7	312	460700
8	314	586700
9	316	640000

Assuming 300 as the bottom level of reservoir and 316 as the highest water level, find the volume of water in the reservoir in cubic meters.

Problem 2. Design an earthen embankment using the following data:

Catchment area = 21 ha
Intensity of rainfall = 17 cm/hr
RL of ground surface = 100 m
RL of HFL = 103.00 m
Runoff coefficient C = 0.3
Soil type is sandy loam
Slope of saturation line = 4:1
Assume a fetch of 500 m.

Problem 3. Design a vertical drop horizontal floor tank surplus weir using the following data:

Catchment area = 19 km^2
RL of ground surface = 105.8 m
RL of MWL = 107.5 m
RL of FTL = 106.7 m
Bund top width = 1.8 m
Slope on either side of bund = 2:1
Ryve's coefficient = 9.0

Further Reading

Singh, P.K. (2000) Watershed Management (Design and Practices). E-media Publications, Udaipur.

Singh, R.P. Sharma, S., Padmanabhan, M.V., Das, S.K. and Mishra, P.K. (1990) Field Manual on Watershed Management, CRIDA, Hyderabad.

Tideman, E.M. (1999) Watershed Management – Guidelines for Indian Conditions. Omega Scientific Publishers, New Delhi.