A Geotechnical Study on Breached Summer Storage Tank

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Abstract. This paper presents some of the observations made as well as geotechnical testing carried out in search of reasons of breached out summer storage tank, which was about to be commissioned for supply of water especially during summer season to the villagers of Nuzendla mandal in Andhra Pradesh. The tank has about 10 acres of storage area and the levels of water in the tank are not the same throughout the area but varying from 3m to 5.5m. The breaching of tank was occurred, at a location where the water level is 5.5m high, and where two mutually perpendicular bunds are joining. The disturbed and undisturbed soil samples collected from the location where breaching of tank took place were tested in the laboratory to understand the basic characteristics of the soil used for bund construction. The grain size analysis, compaction control, free swell index, liquid and plastic limits, permeability and shear characteristics are determined. It is noticed that the locally available soil is used for bund construction and it is of medium to high plastic in nature. The compaction levels at certain places are found to be inappropriate and the slopes of bund throughout are not as per the specifications. The filling up of water into the tank was done at a time, but not in stage by stage filling process. The reasons of breaching of earth bund are noticed as erosion of soil due to windblown water wave action, not providing the revetment on upstream slope and required slope as per the specifications.

Keywords: Summer storage tank, Compaction control, Grain size, Liquid limit, Bund slope, Wave erosion.

1.0 Introduction

Water storage tanks are increasingly built commonly for irrigation and drinking water purposes especially in the dry areas. Several types of tanks such as clay bund, coffer dam, PVC lining, sand-bentonite lining, bitumen lining, lining of concrete or bricks, sand-cement sausages lining is in practice. The choice of a type of earth bund depends largely on the availability of the materials and the costs involved. Water storage tanks made of earth bunds are economical and require a people of minimum skills to construct it. Earth materials are usually three types. These are: 1. Granular: silts, sand, gravels and boulders which are not cemented together 2. Cohesive: clays, or materials which have sufficient clay minerals in them for them to act as clays 3. Lithified: rock. Generally cohesive soils are preferred for earth bund construction. Several types of designs for tank bund sections are available. Since free board varies from one tank to the other depending upon wave height, each tank proposal is required to be designed separately. As the variation in wave height for minor irrigation tanks is within a very small range, it is proposed to have the same free-board for all minor irrigation tanks considering the most severe condition. Increase in cost, if any by adopting such a method, would be marginal and thus it is negligible. Any marginal increase in free-board (by 0.1 or 0.2m.) will have additional factor of safety during cyclones and in the event of any breach of tank on the upstream side. Thickness of revetment as 0.30 m may be considered. However actual thickness of revetment can vary from 0.25m to 0.30m depending upon the size of stone available. For bunds more than 16 m height, the sections are to be finalized based on soil test results. The stability of bund sections must be checked up with slip circle method [1].

In general the earth dams/levees fail by means of hydraulic failure, excessive seepage and structural failure. About 40% of earth dam failures have been attributed to hydraulic failure and these may be due to overtopping, wave erosion, toe erosion and gullying. The earth dam may also fail due to excessive seepage. Uncontrolled seepage can erode fine soil material from the downstream slope or foundation and continue moving towards the upstream slope to form a pipe or cavity often leading to a complete failure of the embankment. About 25% of the dam failures have been attributed to structural failures. Structural failure of an earthen embankment may take in the form of a slide or displacement of material in either the downstream or upstream face. Majority of times the earth dams fail due to hydraulic failures such as wave erosion, toe erosion and gullying. Notching of upstream face by wave action reduces the embankment cross section thickness and weakens embankment material. Hydraulic toe erosion occurs when flow is in the direction of a bank at the bend of the river and the highest velocity is at the outer edge and in the center depth of the water. Gullies are formed due to rainfall erosion of embankment slopes and also caused by traffic from people and vehicles [7, 8, 9].

In the recent past there were many preventive and remedial measures came up into the real practice, which includes modifying the geometry of the slope, controlling the groundwater; constructing tie backs, spreading rock nets, providing proper drainage system and provision of retaining walls, etc. The destructive effects of soil liquefaction, sudden drawdown, ground water flow would cause sometimes sudden or excessive settlements, causing breaching of earth bund. Proper design of foundation system requires the following: (i) purpose of engineering structures, probable service life loadings, types of framing, soil profile, construction methods, construction costs, and client/owner's needs, (ii) design without affecting environment and enough margin of safety with respect to unforeseen events and uncertainty in determination of engineering properties of soil and acceptable tolerable risk level to all the parties, i.e., public at large, the owner, and the engineer [2].

The geotechnical or structural failure is an unacceptable difference between expected and observed performance. The failure of a structure may be due to poor design, faulty construction, excessive loads and soil related failure. There are several factors contributing to the failure of foundation, if overlooked or addressed improperly, such as, construction error, improper soil investigation, fluctuation of ground water table, seismic loads, etc [3]. Commonly we find two types of construction errors such as temporary protection measures and actual foundation work [4]. The response of clay to the construction of structures on it is not truly undrained. A significant consolidation develops initially in the over consolidated natural clay, which becomes normally consolidated during construction. An undrained behavior develops only in the normally consolidated clay during the initial stages of the construction. The soil type is important in offering resistance against failure of earth mass and earth slope geometry to avoid slope failure [5, 6].

2.0 Description of Summer Storage Tank

The summer storage tank was built in an area of 10.8 acres in Nuzendla Mandal, Narasaraopet division, Guntur district, Andhra Pradesh state, India. Its storage capacity is 37580 m^3. The highest storage level is 5.65m and this maximum storage level is spotted in the North – East corner of the tank. The plan area of tank is almost rectangular and its line diagram with salient points is shown in Fig.1. Also, the photographs of breached portion are presented in Fig.2.The bed is sloping towards North - East corner. The storage level in the South-West corner is 3m. As the nature of soil in the original bed is pervious and to control the percolation losses, the bed is covered with 0.5m thick clay layer which is of highly compressible in nature and its liquid limit and free swell index are 68% and 110% respectively. The tank is made up of earth bunds in all the four sides with a slope of 2.5(H):1(V) in both the upstream and downstream sides. The soil used for earth bund construction is almost homogeneous and is intermediate to highly compressible clay. The breaching of earth bund took place in the North-East corner of the tank, where the highest water storage level is 5.65m. The breaching of bund is occurred during filling up of water in the tank.

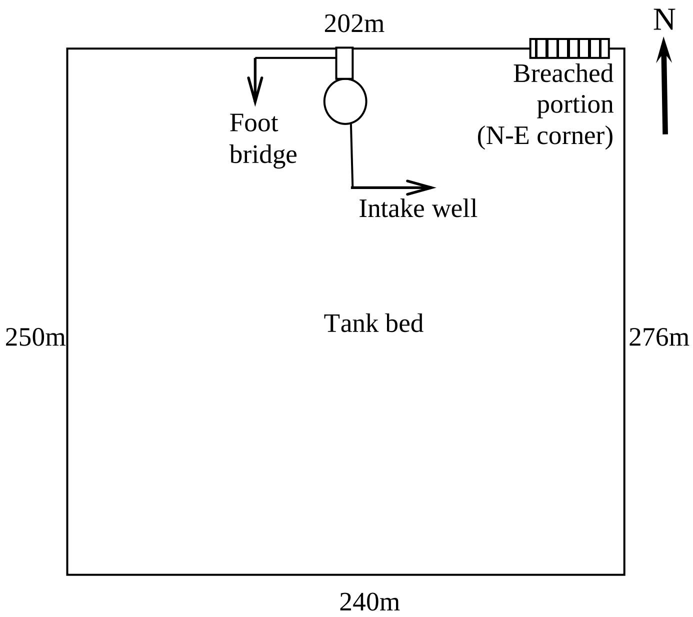

Fig.1. Line diagram of summer storage tank

Fig.2. Photos showing breached sections of summer storage (SS) tank

The summer storage tank consists of homogeneous earth bund made up of CI and CH soils. A 0.6m deep concrete wall is built all around the tank from the bed level to downwards in the upstream side, to avoid seepage beneath the bund section. Rock toe is provided in the downstream side; from North-East corner of the tank, up to about ¼ of the distance either side in the North and East directions of the tank. The width of the breached portion is about 6m to 7m and it took place in the North-East corner. No revetment and gravel cover is provided in the upstream side of the bund in all the four sides.

3.0 Tests Conducted and Discussion of Results

The soil samples were collected from different locations in the vicinity of breached portion of the tank. The location of soil samples collected is presented in Table 1.

Table.1 Location of soil samples collected for investigation

No.	Sample Location
1	71.00m from intake well foot bridge at RL.101.625 towards breached location
2	71.00m from intake well foot bridge at RL.101.255 towards breached location
3	71.00m from intake well foot bridge at RL.101.165 towards breached location
4	60.00m from intake well foot bridge at RL.99.760 towards breached location
5	60.00m from intake well foot bridge at RL.100.695 towards breached location
6	60.00m from intake well foot bridge at RL.101.770 towards breached location
7	51.00m from intake well foot bridge at RL.102.225 towards breached location
8	74.00m from intake well foot bridge at RL.102.300 towards breached location
9	74.00m from intake well foot bridge at RL.102.585 towards breached location
10	Bed portion of SS Tank

The location of soil samples is measured with reference to the foot bridge of intake well in the tank area. The undisturbed soil samples are collected in the form of cores from sample locations 6, 7, 8 and 9 to ascertain their field dry density and field moisture contents. Also the direct shear test is conducted on the undisturbed soil samples. The disturbed soil samples collected from the locations 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 are utilized for determining the index properties of soils such as liquid limit, plastic limit, free swell index, grain size distribution and compaction characteristics. The respective test results are presented and discussed in the following sub-sections. The tests were conducted as per the Bureau of Indian Standard (BIS) test procedures [10, 11, 12, 13, 14, 15].

3.1 Atterberg limits and Free swell index

The liquid limit, plastic limit and free swell index tests are conducted on all the ten samples which were collected from the site. The standard test procedure is followed while testing the soil samples in the laboratory [10, 11]. From the results presented in Table 2, it is observed that the liquid limit of soil samples 1 to 9, is varying from minimum 46% to maximum 66%. The bed clay, i.e., soil sample 10 has a liquid limit of 68%. The free swell index is varying from 65% to 85% and for bed clay, it is 110%. The compressibility of soils is varying from intermediate to highly compressible nature.

3.2 Sieve analysis

The soil samples were tested for grain size distribution by conducting the wet sieve analysis as per the standard test procedure of testing of soils in the laboratory [12]. The results obtained are presented in Table. 3. Also grain size distribution curves for the samples 1 to 5 and 6 to 10 are presented in Figs. 3 and 4 respectively.

Table 2. LL, PL, PI and FSI for soil samples 1 to 10

Sample No	Liquid Limit (LL) in %	Plastic Limit (PL) in %	Plasticity Index (PI)	Free Swell Index (FSI) in %
S1	62	28	34	76
S2	66	29	37	80
S3	48.5	19	29.5	70
S4	64	27	37	75
S5	48	18	30	70
S6	47	19	28	65
S7	46	18	28	65
S8	61	26	35	70
S9	56	22	34	75
S10	68	28	40	110

From the results (Table 3), it is noticed that all the soil samples have percentage silt & clay fraction more than 50%. Fine sand fraction is varying from 8% to 22.5% and remaining soil fractions such as gravel, coarse sand and medium sand are negligible. With the help of test results presented in Tables 2 and 3, the soil samples are classified. The percentage of soil fraction available in each soil sample is further presented in Fig.5 in the form of bar chart. From the classification of soil samples presented in

Table 4, it is noticed that some of the soil samples are in the intermediate compressible clay (CI) category and some of them are in the category of highly compressible clay (CH) soil.

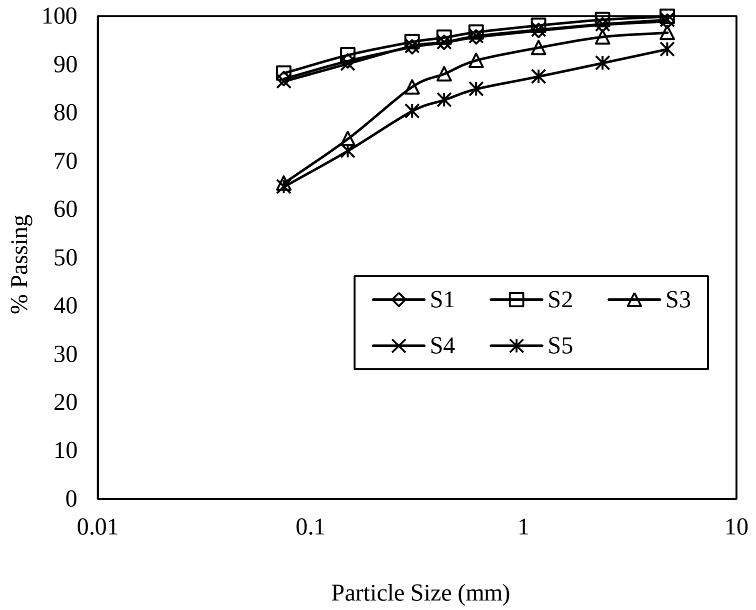

Fig.3. Grain size distribution curves for soil samples 1 to 5

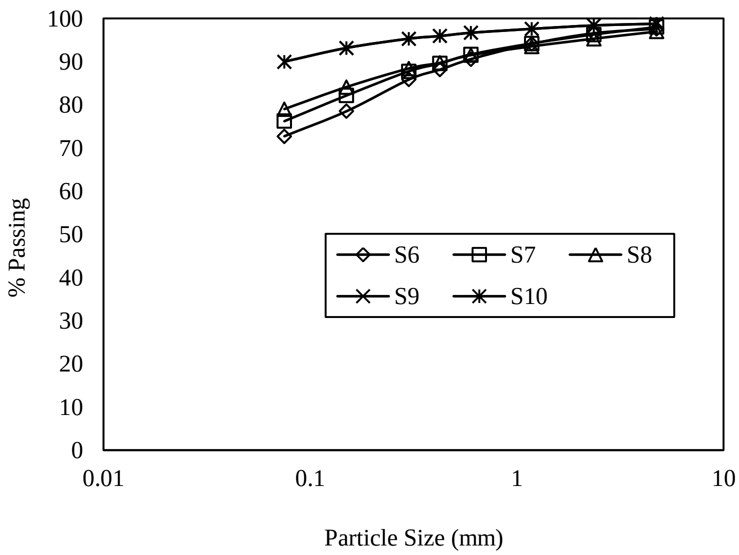

Fig.4. Grain size distribution curves for soil samples 6 to 10

Table. 3 Soil fractions in per cent present in samples 1 to 10

Sample No.	% Soil Fraction				
	Gravel	Coarse Sand	Medium Sand	Fine Sand	Silt & Clay
S1	1	1	3	8	87
S2	0	1	3	8	88
S3	3.5	1.5	7.5	22.5	65
S4	1	1	3	8.5	86.5
S5	7	3	7	18.5	64.5
S6	2.5	1.5	8	15	73
S7	2	2	6	14	76
S8	3	2	5	11	79
S9	1.5	2	4.5	15	77
S10	1	1	2.5	5.5	90

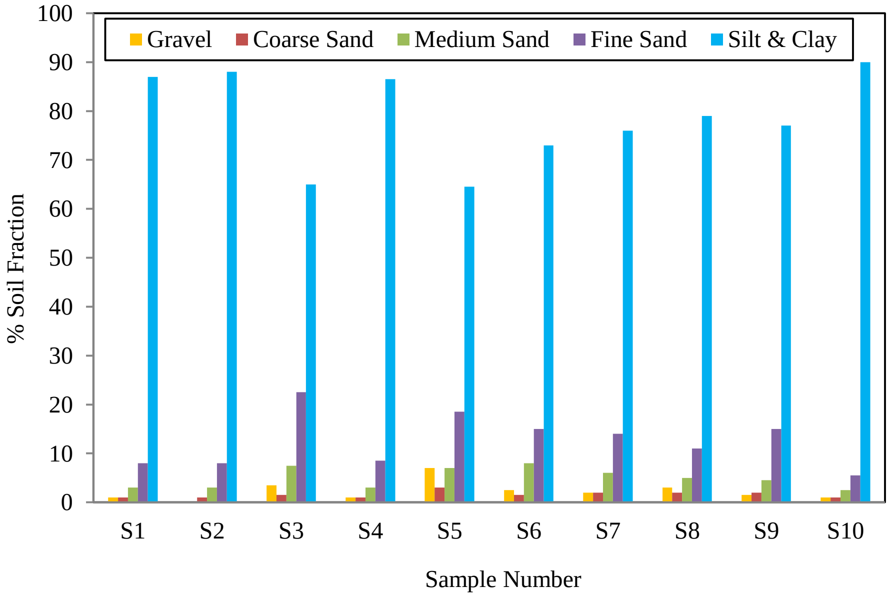

Fig.5. Soil fraction in per cent present in soil samples 1 to 10

Samples 1, 2, 4 and 10 have fine fraction (which is passing through 75 micron sieve) more than 85%. Soil samples 6, 7, 8 and 9 have the % fine fraction above 70 and below 80. Soil samples 3 and 5 have the fine fraction about 65%. Overall all the samples 1 to 10 have the fine fraction above 50%. The sample 10 is the bed sample and it has fine fraction 90%.

Table 4. Classification of soil samples 1 to 10

Sample No.	Soil Classification	
1	CH	Highly Compressible Clay
2	CH	Highly Compressible Clay
3	CI	Intermediate Compressible Clay
4	CH	Highly Compressible Clay
5	CI	Intermediate Compressible Clay
6	CI	Intermediate Compressible Clay
7	CI	Intermediate Compressible Clay
8	CH	Highly Compressible Clay
9	CH	Highly Compressible Clay
10	CH	Highly Compressible Clay

3.3 Compaction Test

The standard Proctor's compaction test was conducted on all the samples in the laboratory as per the standard test procedure of testing of soils [13]. The compaction curves showing water content-dry density relationship are presented in Figs. 6 to 7. The optimum moisture content (OMC) and the maximum dry density (MDD) results obtained from the compaction curves are presented in Table 5. From the OMC, MDD results, it is noticed that the soil samples possess typical clayey soil behaviour. The MDD of earth bund soil samples (1 to 9), is varying from 16.3 kN/m^3 to 17.25 kN/m^3 and OMC is varying from 17% to 22.5%. The tank bed sample has OMC 25% and MDD 15.10 kN/m^3. The bed clay is highly compressible and impervious in nature.

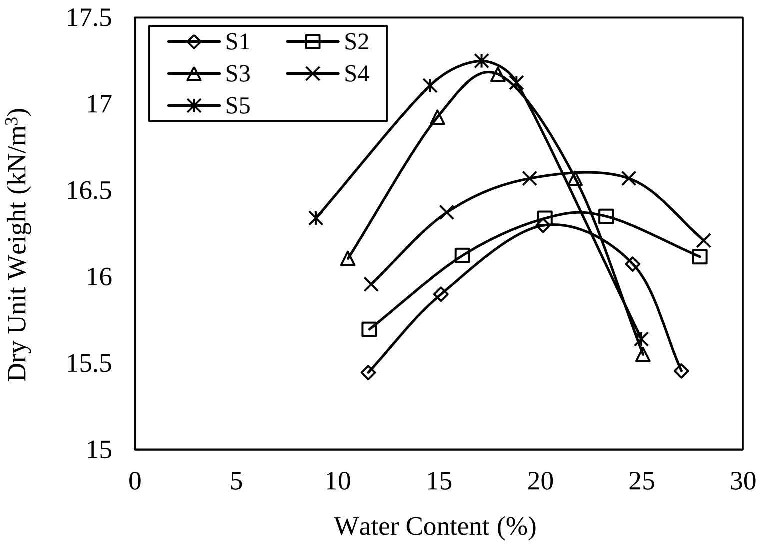

Fig.6. Compaction curves for soil samples 1 to 5

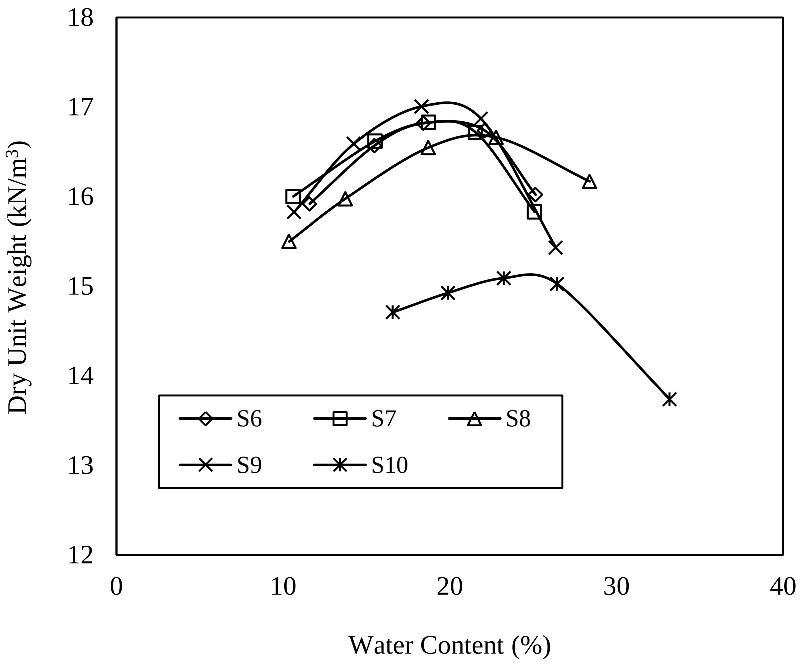

Fig.7. Compaction curves for soil samples 6 to 10

For soil samples 6, 7, 8 and 9, the degree of compaction is estimated and the result is presented in Table.6. For the above four samples the degree of compaction is above 95%.

Table. 5 OMC and MDD of soil samples 1 to 10

Sample No	Compaction Characteristics	
	Optimum Moisture Content, OMC in %	Maximum Dry Density, MDD in kN/m^3
S1	21.00	16.30
S2	22	16.37
S3	17.5	17.2
S4	22.50	16.60
S5	17.00	17.25
S6	20.5	16.85
S7	20.00	16.86
S8	21.50	16.70
S9	20.00	17.05
S10	25.00	15.10

Table 6. Field dry density and Field moisture content of core samples

Sample No.	S6	S7	S8	S9
Field Moisture Content (FMC) in %	18.37	16.81	14.34	20.66
Field dry Density (FDD) in kN/m^3	16.21	16.80	16.01	16.87
Maximum Dry Density (MDD) in kN/m^3	16.85	16.86	16.70	17.05
Relative Compaction (%)	96.20	99.64	95.86	98.94

3.4 Direct Shear Test

A simple direct shear test (quick test) was conducted on the undisturbed soils collected from the locations 6, 7, 8 and 9 of an earth bund near the breached portion. The test was conducted as per the standard test procedure [14]. The strength envelopes obtained from the tests are presented in Fig.8. The shear parameters such as cohesion and angle of shearing resistance obtained from the tests are presented in Table 6. The cohesive strength is varying from 30 kPa to 50 kPa and the angle of shearing resistance is varying from 7.75 degrees to 19.87 degrees.

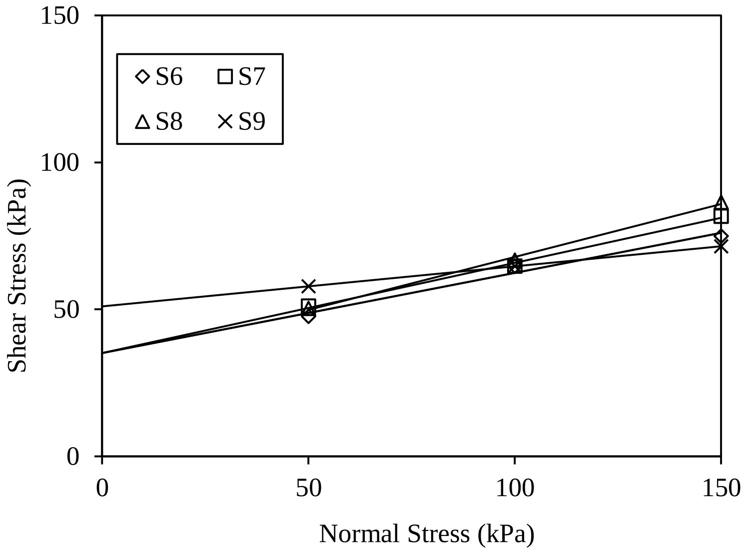

Fig.8. Shear stress verus normal stress curves for samples 6 to 9

Table 7. Direct shear test results of core samples

Sample No.	S6	S7	S8	S9
Undrained cohesion, c in kPa	35	36	30	50
Angle of shearing resistance, ϕ (^{o})	15.22	17	19.83	7.75

3.5 Permeability Test

The sample collected from the locations 6, 7, 8 and 9 are prepared at their respective OMC and kept for saturation in the permeameter mould as per the standard test procedure of testing of soils for permeability [15]. As the per cent fine fraction present in soil samples is more, a falling head permeability test was conducted. The coefficient of permeability of four soil samples 6, 7, 8 and 9 is in the order of 10^{-6} cm/s to 10^{-8} cm/s and on an average 10^{-7}cm/s. From the permeability results, it is observed that the soil samples used for earth bund are impervious to highly impervious in nature.

4.0 Reasons of Breaching of Bund and Recommendations

From the field observations and laboratory test results of soil samples of breached portion, the following points are identified as reasons for earth bund breaching.

- The sloping of bed towards breached portion caused more concentration of water pressure as compared to the other portions of bund.
- Instead filling the tank with water in stages, the tank was filled up at a time to the full storage level.
- As per the specifications the revetment of thickness 0.25m to 0.3m is required to be provided on the upstream slope, but it was not provided.
- The windblown water wave action was prevailed predominantly in the tank area.
- The compaction of soil was inappropriate.

5.0 Conclusions

From the field observations and test results, the following measures for closing the breached portion are suggested.

- No gullies and slope failures in the bund are noticed around the tank. The failure is due to hydraulic action on the upstream slope of bund where water concentration is high.
- The breached portion of the earth bund can be closed by selecting a suitable soil such as GC, GW, SC, SM and required to compact in layers as per the specifications and ensured the required degree of compaction.
- If it is expensive to get the suitable soil to close the breached portion of the earth bund, the same clay soil (CI or CH) which was used previously for earth bund formation can be used towards closing of the breached portion provided; the upstream and downstream slopes respectively are required to be changed from 2.5:1 and 2.5:1 to 3.5:1 and 2.5:1.
- A gravel cover and revetment layer each of minimum 300mm thick as per the specifications is required to be provided so as to avoid the direct attack of wind generated water waves and to keep the upstream slope safe.
- It is required to ensure such that no gaps and uncompacted soil is left while closing the breached portion of the bund and it is also required to ensure the appropriateness of connectivity of bund formations.
- It is important to ensure that the filling up of water in the tank should be done in stages not at a time to the full capacity.

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References

1. Andhra Pradesh Community Based Tank Management Project Operational Manual: Volume – V(b) of VI, Technical Manual, Irrigation & CAD Department, Government of Andhra Pradesh (2007).
2. Bowles, JE: Foundation Analysis and Design. McGraw – Hill Publications, (1996).
3. Leonards, GA: Investigation of failures. Journal of Geotechnical Engineering, ASCE, 108, No. GT-2, pp.187-246(1982).
4. Campbell, P: Learning from construction failures. Applied Forensic Engineering, John Wiley and Sons (2001).
5. Popescu, ME: A Suggested Method for Reporting Landslide Remedial Measures. IAEG Bulletin, 60, No. 1, pp.69-74 (2001).
6. Glade, T, Anderson MG and Crozier MJ: Landslide Hazard and Risk. John Wiley (2006).
7. BIS: 14954, Distress and Remedial Measures in Earth and Rock fill Dams-Guidelines, Bureau of Indian Standards, New Delhi (2001).
8. Garg, S.K, Irrigation Engineering and Hydraulic Structures, Khanna Publishers, New Delhi (2012).
9. Stephens, T, Manual of Small Earth Dams, Food and Agriculture Organization of the United Nations, Rome (2010).
10. BIS: 2720-Part 5, Bureau of Indian Standard methods of test for soils, Part5: Laboratory determination of Atterberg limits of soil (1985).
11. BIS: 2720-Part 40, Bureau of Indian Standard methods of test for soils, Part 40: Laboratory determination of free swell index of soil (1977).
12. BIS: 2720-Part4, Bureau of Indian Standard methods of test for soils, Part 4: Laboratory determination of grain size through sieve analysis (1985).
13. BIS: 2720-Part 7, Bureau of Indian Standard methods of test for soil, Part 7: Laboratory determination of compaction characteristics of soil (1980).
14. BIS: 2720-Part 13, Bureau of Indian Standard methods of test for soil, Part 13: Laboratory determination of shear characteristics of soil through direct shear test (1986).
15. BIS: 2720-Part 17, Bureau of Indian Standard methods of test for soil, Part 17: Laboratory determination of permeability of soil (1986).