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RESEARCH ARTICLE

ANALYSIS OF EARTH FILL HYDRAULIC DAM WITH VARYING CREST LENGTH AND PERMEABILITY TO DEVELOP CORRELATIONS

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ABSTRACT

In this paper, an earthen dam is analysed using different soil layers having different soil properties and dimensions. Normally a slope fail when the shear strength reduces from the minimum required value which keeps it stable. Internal erosion is the main cause which causes a dam to fail and it is mainly due seepage with time. A detail analysis of a predefined dam slope is performed in different layers to check the seepage variation as well as the factor of safety. Different soil layers and properties were used such that it is investigated from a fail condition to a complete stable condition. Limit equilibrium and finite element approaches are used. Correlations for factor of safety between these two approaches are also developed. These correlations and results could be used as guidelines in any dam or slope safety calculation.

KEYWORDS

Slope stability analysis, Crest length, Correlations, Factor of safety, Seepage

1. INTRODUCTION

Dam studies is one of the most essential field of studies and with time, many lessons were learned from the dam failure cases. The past experience and research helped a lot to improve the safety, design and construction procedure and still needs more work to get more useful results. In past few decades, dam safety got much attention of people and researchers because of the floods and earthquakes which causes huge loss to human lives as well as damage public property. Dam and slope structures on major highways are one of the most important structures which require huge economy to construct and its failure huge loss to economy and sometimes huge loss to human lives. Therefore, slope structures needs to be stable enough and not to fail throughout its estimated life. Loss to life and economy during any dam or slope failure is inversely proportional to the warning time which a dam or slope can give based on its stability. More the warning time, less will be the damage to lives, property and economy and vice versa. It means that if the dam or slope is stable enough and have more factor of safety, it will have long life as well as in case of failure, it will give more warning time and hence will minimize the loss. Dam is always associated with seepage and the seepage always occurs in slope areas of least resistance to the water flow (Abhilasha et al., 2014).

Keeping the above discussion in considerations, it is well understood that dam and slope must be designed such that its slope is stable for long time. Stability of any dam or slope depends on:

1. Shear strength of soil
2. Slope ratio
3. Environmental condition

Regarding slope ratio and environmental condition, they could be considered as constant as slope ratio could be kept any reasonable value while environmental condition like raining, temperature are normally out of the designer scope as they could be changed naturally.
Important point for designers is shear strength of soil which mainly depends on:

1. Soil type (cohesive or cohesion less)
2. Moisture content
3. Compaction
4. Consolidation
5. Soil layering
6. Soil-water interaction

To understand the causes of dam failure, the previous case histories could be considered which can give reasonable explanation to all such failures and its causes. Study of all such cases shows that one of the main cause of dam failure is piping and internal erosion of soil. This internal erosion again depends on the shear strength. Internal erosion and piping has historically resulted in about 0.5% (1 in 200) earthen dams failing, and 1.5% (1 in 60) experiencing a piping incident. Of these failures and accidents, about half are in the embankment, 40% in the foundations, and 10% from the embankment to foundation (Foster et al., 1998). Singh discussed that the erosion rate may also be different in case of cohesive and granular soil (Singh, 1996). In case of granular material, the warning time and factor of safety may be less as they gets removed rapidly. While because of the low permeability in case of cohesive material, it takes

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longer time to fail.

ASTM defined erosion as the removal of soil particles by water which leads channels inside the soil mass (ASTM, 2002). Generally, the erosion inside soil is started once the resistant forces are smaller than the driving forces and hence it causes an inside piping which get increased with time. Once it reached the maximum limit, the slope collapsed same like in case of overtopping or so (Xu and Zhang, 2009). Moreover, in case of piping failure, the failure may be due to piping from embankment to foundation or vice versa. It is twenty times higher than piping from foundation to embankment (Foster et al., 2000).

Teton dam is one of the example which failed due to internal erosion and seepage in 1976 that was located in United States on Teton River. It failed on its first filling and made a huge loss to the economy as well as some human lives. Panel of experts provided many reasons for its failure and one of it was internal erosion and the mixing of soil in different proportion that was not suitable to have high factor of safety (Sharma and Kumar, 2013).

Similarly another dam namely Baldwin hills dam was failed after 12 years of operation in 1963 due to erosion inside the embankment and the lesson which designers learned from all such failures is to design a dam or slope which could be non-erodible and there must be no chances of piping inside the slope. To achieve this goal, the main important factor is the soil itself and its compaction in different layers having different properties. With varying properties, it always gives different value for the seepage. This paper is one of the attempt to investigate a pre-defined slope in case of different soil layers having properties and to check the seepage as well.

2. METHODOLOGY

Limit equilibrium approach was used in this analysis as it is one of the easiest method to analyse slopes. The difference between limit equilibrium and continuum methods comes out to be 10% (Kevin and Krishna, 2005). In some cases, the limit equilibrium gives conservative values while in other cases, continuum or finite element methods gives conservative values for factor of safety. Therefore, normally in complex cases, designers prefer to use finite element approach while in non-complex cases, they use limit equilibrium approach for ease. Moreover, many other research was also conducted using stochastic approach (Fenton and Griffiths, 1996; Ahmed, 2009; Cho, 2012; Calamak et al., 2012; Le et al., 2012; Calamak et al., 2013). This research is conducted in two stages:

1. Homogenous throughout. This phase is further divided into four parts for the minimum and maximum values of clay and clayey sand. Material 1 and 10 is the minimum and maximum range for clay type while material 11 and material 20 are the minimum and maximum range of clayey sand.
2. Developed correlations for seepage and factor of safeties in different conditions

3. MATERIAL PROPERTIES AND ANALYSIS

Two general types of material are used in this analysis. The soil properties are shown in table 1.

Table 1: Material Properties

Material Number	Cohesion c	Friction ϕ	Unit Weight (γ)	Material Type
1	10.5	27.5	13	Clay
2	11.5	28.5	13.5	Clay
3	12.5	29.5	14.25	Clay
4	13.5	30.5	14.85	Clay
5	14.5	31.5	15.45	Clay
6	15.5	32.5	16.5	Clay
7	16.5	33.5	16.65	Clay
8	17.5	34.5	17.25	Clay
9	18.5	35.5	17.85	Clay
10	19.5	36.5	18.45	Clay
11	1.5	25.5	16.40	Clayey Sand
12	2.5	26.5	16.45	Clayey Sand
13	3.5	27.5	16.50	Clayey Sand
14	4.5	28.5	16.75	Clayey Sand
15	5.5	29.5	16.86	Clayey Sand
16	6.5	30.5	16.96	Clayey Sand
17	7.5	31.5	17.5	Clayey Sand
18	8.5	32.5	17.65	Clayey Sand
19	9.5	33.5	17.70	Clayey Sand
20	10.5	34.5	17.75	Clayey Sand

4. RESULTS AND DISCUSSION

Phase 1 Analysis - Crest length is 975m

Table 2 shows the factor of safety and seepage values in case of material 1, 10, 11 and 20 in which the minimum and maximum property values of clay and clayey sand are considered.

Table 2: Factor of safety and seepage in case of Material 1, 10, 11 and 20

Material Number	Factor of safety	Seepage m^3 / day k = 1e-7		Seepage m^3 / day k = 1e-6		Seepage m^3 / day k= 1e-5	
		Downstream Slope Face	Downstream Bottom Face	Downstream Slope Face	Downstream Bottom Face	Downstream Slope Face	Downstream Bottom Face
1	3.799	0.028	0.013	0.28	0.12	2.8	1.26
10	5.375	0.028	0.013	0.28	0.12	2.8	1.26
11	3.223	0.028	0.013	0.28	0.12	2.8	1.26
20	4.868	0.028	0.013	0.28	0.12	2.8	1.26

Table 2 shows that the average change in seepage with changing the permeability of slope in case of downstream slope face is

Figure 1 shows the factor of safety and slope model that is used in this analysis. The dam dimensions are assumed almost same as Teton dam which was failed back in 1976 due to erosion and piping.

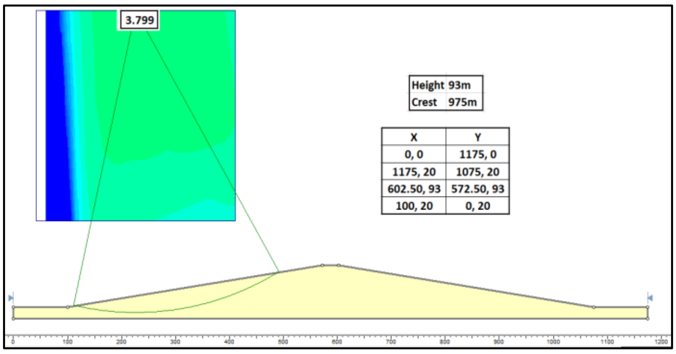


Figure 1: Dam model

Figure 2 shows the seepage values in case of material 1.

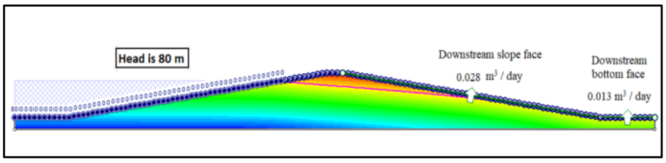


Figure 2: Seepage values in case of material 1

Figure 3 shows the slope which is divided into seven layers having different properties that are mentioned in table 1.

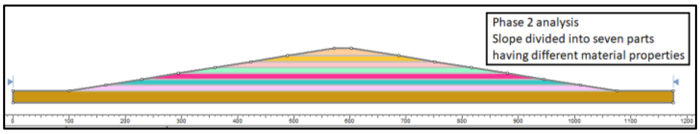


Figure 3: Phase 2 analysis – Clay material

The factor of slope safety in case of phase 2 comes out to be 4.934. The discharge on the downstream side was noted to be 4.9 x 10^{-15} m^3 / day on slope face while it was recorded to be 2.6 x 10^{-16} m^3 / day on the bottom face. It shows that the discharge in case of the layers has less compare to the homogenous slope and it is a positive sign to have less discharge.

In case of clayey sand, the slope factor of safety without the ponded water was noted 4.034 and with ponded water it was 3.511.

Phase 2 analysis – Crest length 675m

In phase two the dam crest length was minimized and kept it as 675m and rest all properties were kept same as in case of phase 1. The factor of safety and seepage values in case of phase 2 are shown in table 3.

Table 3: Phase 2 analysis

Material Number	Factor of safety	Seepage m^3 / day k = 1e-7		Seepage m^3 / day k= 1e-6		Seepage m^3 / day k= 1e-5	
		Downstream Slope Face	Downstream Bottom Face	Downstream Slope Face	Downstream Bottom Face	Downstream Slope Face	Downstream Bottom Face
1	2.654	0.043	0.018	0.43	0.18	4.27	1.84
10	3.746	0.043	0.018	0.43	0.18	4.27	1.84
11	2.203	0.043	0.018	0.43	0.18	4.27	1.84
20	3.350	0.043	0.018	0.43	0.18	4.27	1.84

Phase 3 analysis – Crest length 375m

In phase two the dam crest length was minimized and kept it as 375m and rest all properties were kept same as in case of phase 1 and 2. The factor of safety and seepage values in case of phase 3 are shown in table 4.

Table 4: Phase 3 analysis

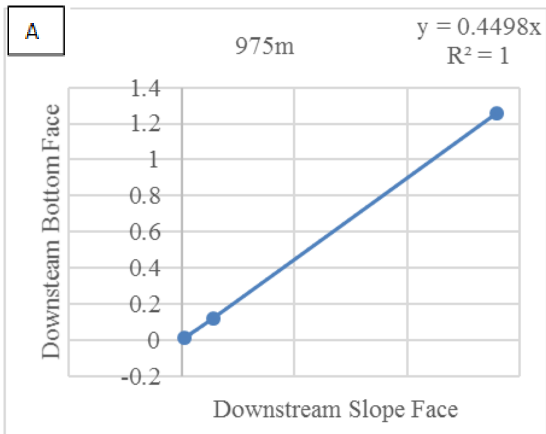
Material Number	Factor of safety	Seepage m^3 / day k = 1e-7		Seepage m^3 / day k = 1e-6		Seepage m^3 / day k = 1e-5	
		Downstream Slope Face	Downstream Bottom Face	Downstream Slope Face	Downstream Bottom Face	Downstream Slope Face	Downstream Bottom Face
1	1.496	0.12	0.004	1.08	0.042	10.79	0.42
10	2.103	0.12	0.004	1.08	0.042	10.79	0.42
11	1.191	0.12	0.004	1.08	0.042	10.79	0.42
20	1.857	0.12	0.004	1.08	0.042	10.79	0.42

4. Correlations

Correlation between seepage values and factor of safety between these three phases have been developed.

4.1 Correlation between seepage with changing crest size

In case of downstream seepage at slope, the correlation between phase 1, 2 and 3 is developed by taking the mean value. Figure 4 shows the bar graph between these three phases.



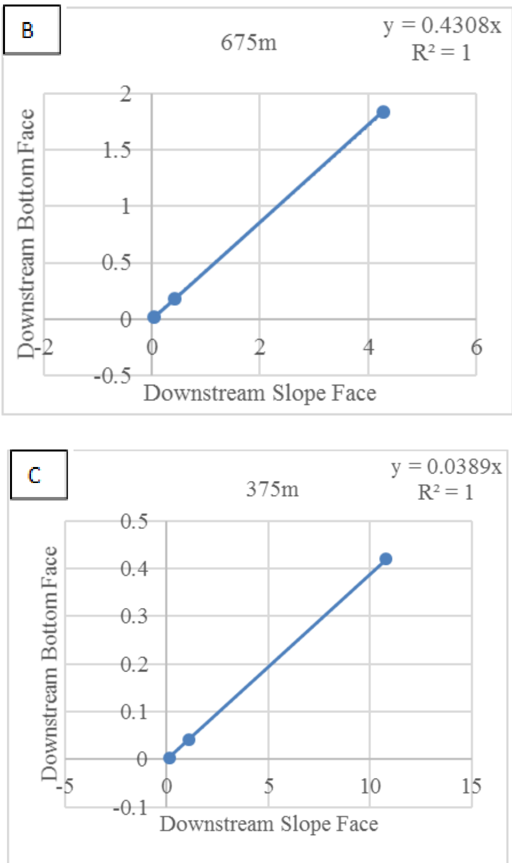


Figure 4: (A, B and C) Graphs showing the seepage values in case phase 1, 2 and 3

The total seepage will always be seepage on slope plus seepage on bottom face that is y + x. The final correlation which is calculated by taking mean of all the three comes out to be:

$$y = 0.306x \tag{1}$$

Where y is seepage on slope and x is seepage on bottom.

4.2 Correlation between factor of safety in empty and filled reservoir

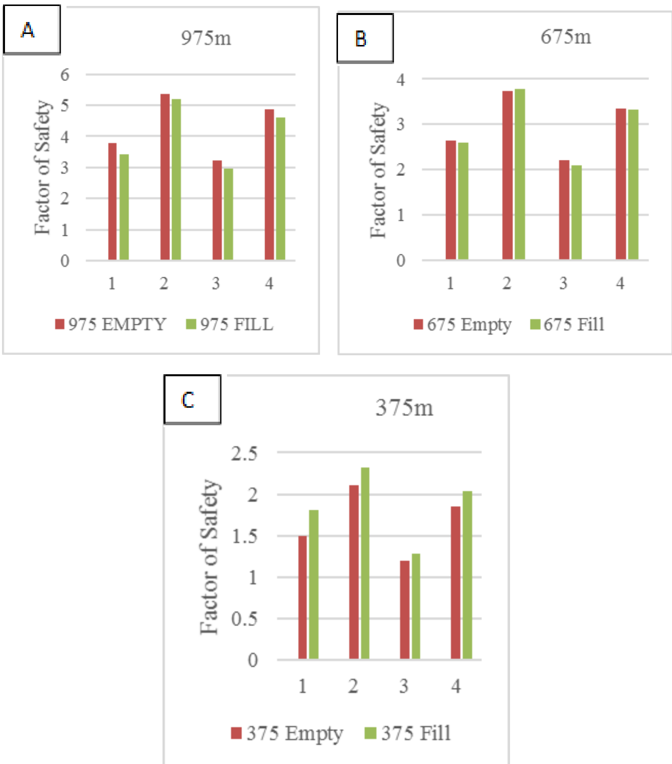


Figure 5: (A, B and C) Seepage difference between slope face and bottom

Figure 5 shows the difference between seepage on slope face and bottom of the dam.

The final correlation comes out to be:

$$FS_{empty} = 0.03 \text{ x } FS_{fill} \tag{2}$$

Where FS is Factor of Safety.

4.3 Variation of seepage with changing permeability

Figure 6 shows the variation of seepage with change of 10% decrease in permeability of soil.

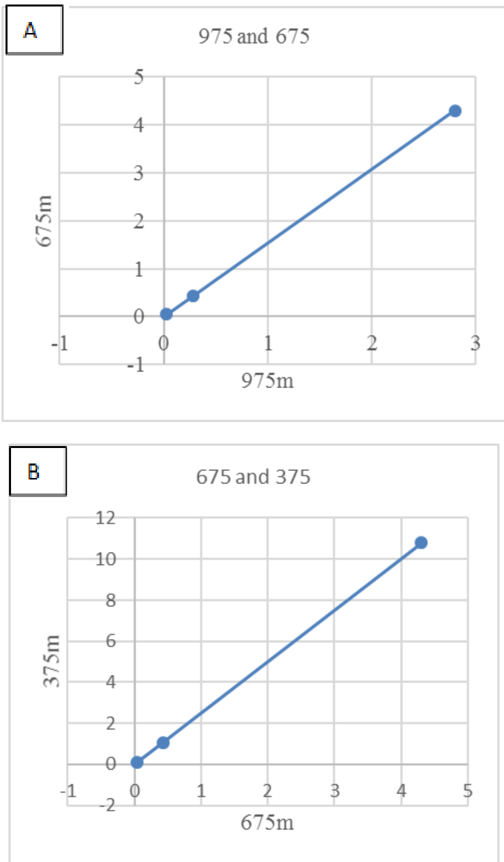


Figure 6: (A and B) Seepage variation with change in permeability

The average change in seepage comes out to be 3% with variation of permeability as 10%.

5. Conclusions

The final conclusion from this research comes out to be:

1. Equation 1 and 2 could be used to know the seepage difference and factor of safety in any dam design and project.
2. With different soil layers and properties, the seepage and factor of safety is changed depends on soil layering and permeability.
3. The average change in seepage comes out to be 3% with variation of permeability as 10%.

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References

Abhilasha, P.S., and T.G. Antony Balan. 2014. "Numerical Analysis of Seepage in Embankment Dams," IOSR Journal of Mechanical and Civil Engineering, 13-23.

Ahmed, A.A. 2009. "Stochastic analysis of free surface flow through earth dams," Computers and Geotechnics, 36(7), 1186-1190.

ASTM. 2002. "Standard terminology relating to soil, rock, and contained fluids," no. ASTM D 653-02a, ASTM, West Conshohoken, Pa.

Calamak, M., E. Kentel, and A.M. Yanmaz. 2012. "Seepage analysis through earth-fill dams having random fields," 10th International Congress on Advances in Civil Engineering, Ankara, Turkey, 97.

Calamak, M., E. Kentel, and A.M. Yanmaz. 2013. "Spatial variability in seepage flow through earth-fill dams," Canadian Dam Association 2013 Annual Conference, Montreal, Quebec, Canada, 37.

Cho, S.E. 2012. "Probabilistic analysis of seepage that considers the spatial variability of permeability for an embankment on soil foundation," Engineering Geology, 133-134, 30-39.

Fenton, G.A., and D.V. Griffiths. 1996. "Statistics of free surface flow through stochastic earth dam," Journal of Geotechnical Engineering, 122(6), 427-436.

Foster, M.A., R. Fell, and M. Spannagle. 1998. "Analysis of embankment dam incidents, UNCIV Rep. No. R-374," no. Univ. of New South Wales, Sydney, Australia.

Foster, M.A., R. Fell, and M. Spannagle. 2000. "A method for estimating the relative likelihood of failure of embankment," Canadian Geotechnical Journal, 37(5), 1025-1061.

Kevin, S.R., and R.R. Krishna. 2005. "Slope Failure of Embankment Dam under Extreme Flooding Conditions: Comparison of Limit Equilibrium and Continuum Models," Proceedings of the Geo-Frontiers 2005 Conference, ASCE, Austin, Texas.

Le, T.M.H., D. Gallipoli, M. Sanchez, and S.J. Wheeler. 2012. "Stochastic analysis of unsaturated seepage through randomly heterogeneous earth embankments," International Journal for Numerical and Analytical Methods in Geomechanics, 36(8), 1056-1076.

Sharma, R.P., and A. Kumar. 2013. "Case histories of earthen dam failures," Seventh International Conference on Case Histories in Geotechnical Engineering, Missouri University of Science and Technology.

Singh, V.P. 1996. "Dam breach modeling technology", Kluwer Academic, Boston.

Xu, Y., and M. Zhang. 2009. "Breaching parameters for earth and rockfill dams," J. Geotech. Geoinvironmen. Eng. ASCE, 135(12), 1957-1970.