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The Comparison of the Design of Fuse Plug Spillways from the Aspect of Erosion and Stability

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ABSTRACT

Currently, there are different methods to provide the capacity of spillway to pass floods with long return period. One of the common choices is the prediction of extra discharge in flood with low-occurrence probability. Auxiliary spillway with erodible embankment is suitable for this choice. When the reservoir water level reaches the design elevation, embankment is breached and is washed out by controlled method and flood passes via auxiliary spillway. Either stone foundation or slop or built slop terminal and lateral walls to keep the sizes of spillway control erosion of spillway channel. After flood passes, spillway embankment is rebuilt. Due to low application, renovation costs are compensated via reduction of initial costs of project construction. In this research the optimized design conditions of these spillways are studied. These conditions are including the study of stability in different conditions of the changes of shell materials parameters- core stability with different materials- stable optimized width- stability in different conditions of reservoir level and earthquake and changes of shell materials and the study of stability in quick discharge condition of reservoir.
KEYWORDS: fuse plug spillway; design criteria; flood control; core clay.

INTRODUCTION

Currently, there are different methods to provide the capacity of spillway to pass floods with long return period. One of the common and cheap choices is creating temporary overburden space to store some flood in reservoir as this border decrease failure until flood is passing from service spillway or main spillway. The other choice is prediction of extra discharge capacity in low -occurrence flood. Auxiliary spillway with erodible embankment is good for this choice. Erodible embankment from constructional aspect is built both by homogeneous material and zoned materials with impervious core. When the lake level reaches design elevation, embankment is reached and is washed by controlled method and flood passes through auxiliary spillway.

The main components of embankment and their performance

1- Pilot channel or guide channel: This channel is short length of embankment crest and it is designed in a way that when the lake level to elevation is increased a little lower than elevation of the main crest, overflows.

2- Impervious core: To avoid embankment failure, by floods smaller than design flood, impervious core is predicted. When pilot channel is overflowing and downstream materials of the core are washed out, the pressure of the lake weight and up-stream materials of the core breach the core.

3- Filters: A clay core can be dried and broken during the years without that lake water reaches the erodible embankment. So, to avoid piping and unpredicted erosion during the sudden rise of lake level, some suitable filters should be installed.

4- Gravel and sand: This material is consisting of the maximum amount of erodible embankment and the main factor is the control and erosion.

5- Slope protection: It is used to predict protection against raining, snow melting, waves striking, beaching, coarse-grained gravel and boulders respectively in upstream and downstream slopes.

Reviewing fuse plug failure phenomenon

a. Destruction and erosion of fuse plug with homogenous materials

By water overflow via pilot channel, its failure is quickly starting with sliding surface of fuse plug. The destruction due to surface sliding in downstream of the structure continues to the considerable reduction of downstream slop during washout. Flatting process of fuse plug is done at the same time with washout of the body opposite to the flow direction and falling of crest level in this section. In this stage the level of spillway crest is constantly decreasing and its water flow is increased. After this stage, wash out speed is decreased considerably. The final stage of wash out of

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these embankments that is the slowest stage is at the same time with its total flatness. Fuse plug materials wash out is as the stage of carrying bed load and by moving the total material, embankment washout is completed.

b. Wash out of fuse plug with heterogeneous materials

Fuse plug with heterogeneous section is including some layers with different grading and its destruction starts from the time the flow is passing from pilot channel and continues to the natural ground bottom or the section built with high stability. Fuse plug break starts from the erosion of pilot channel downstream end and reaches the clay core. After the wash out of clay core downstream materials, the flow will pour from the core as in the shape of waterfall. In this case after clay core downstream materials are emptied and they couldn't resist against water pressure, the core is separated piece by piece and failure occurs. Then, side destruction of embankment is developed and when behind the other part of the clay core is being emptied, it is exposed to water pressure and is broken. This stage is repeated regularly and increases breach in complete wash out of fuse plug.

1- The results of testing Oxbow model

a. The effect of core position

Vertical clay core: In the first stage of the tests, vertical clay core with different thickness were tested to study the effect of core thickness on wash out of embankment. In this figure the time of fuse plug wash out with clay core *T m / H* to the granular embankment erosion without clay core Tg is plotted. Here downstream slop is 2.5:1and upstream slope is 1:4in terms of vertical clay core thickness m/H.

The vertical core to $\frac{m}{H} = 0.0250$ increases erosion time and in higher ratios, decreases erosion time.

Inclined clay core: in the next tests, the clay core thickness was considered constant in ratio of core thickness to the embankment height $\frac{m}{H}$=0.05. In this case core angle is changed to study the effect of inclined clay core during wash out. Wash out time of embankment with inclined core$T\emptyset$ to the required time with one granular embankment without clay Tg is shown in the following figure in terms of core inclination angle.

Some studies are carried out to review the location of core; in this study the location of central core inclination position between $0°$, $90°$ to vertical zone is reviewed. The results are shown as the followings:

1- For vertical core it was shown that the core is resisting against water pressure as a strong concrete dam and after more than 1 hour only about 10% of the beginning of the core (upper section) is destroyed and the remaining with more thickness is remained without destruction. Indeed, in this condition downstream shell is quickly washed but core doesn't resist and it doesn't allow that upstream shell destruction.

2- For the core inclination angle $10°$,$20°$, core destruction at the end of the test is about 15% of total. This is almost similar to vertical core.

3- The core with inclination angle of $40°$ is the best position for washing. In this case, the core is neither acting as console nor as vertical concrete dam and is destroyed approximately about 25 to 30 minutes. Core inclination angles between $40°$ to $50°$ shows the best clay core position for fuse plug.

4- For angle $60°$, the core is acting like a console beam and resists for a long time. In this case after a long time only a little part of the core is destructed and the remains are intact.

5- For inclination angle $80°$, we have similar case as the previous one and the core is acting like a console beam.

Thus, using vertical cores or a little inclined (to inclination of $20°$) and very inclined (larger than $50°$) in fuse plug is not correct and the best angle of position of the inclination core is $40°$ to $50°$.

b. The effect of embankment plan compounds

1- According to the core thickness tests it was revealed that the rate of side erosion was depending upon side erosion of no cohesive materials and it is not dependent upon core resistance.

2- **Pilot channel:** Different widths and position of pilot channel is tested. The location of pilot channel doesn't have considerable effect on side erosion rate. Erosion rate in the test pilot channel was in the center of embankment was equal in both sides and it was approximately equal to the rate in which pilot channel was at the beginning or the end of embankment.

3- **Sand filter:** The tests were carried out with or without sand filter surrounding the core. Sand filter has important effect on both failure and side erosion. Without filter, water is not reaching from pilot channel to uncohesive materials of downstream completely and this zone is saturated temporarily and thus, failure stages are getting long. By applying sand filter, the water flows from pilot channel to down face of the core and channel corrosion stages are done rapidly. If downstream sand filter is omitted, side corrosion rate is decreased.

4- **Embankment size:** Relative dimensions are assessed in the tests. The width of fuse plug crest is being double so, corrosion area of the embankment is increased. Corrosion in this test is about 8% more than the test of unit crest width. This increased is approximaly equal to the increase of some part of downstream surface consisting of compact sand and gravel.

2- Stability model results

In this research at first for the computation of seepage lines, SEEP/W software is used and the entry menu of it is completed by filling out the tables and answering the required questions. Graphical outputs including plotting the problem geometry, meshing the problem and drawing semi potential lines and flow lines together or separated.

The results of calculations output with entry data are presented in separate output files. In this program, finite element method is used to solve Laplace underground water equations. Then by XSTABLE software, the stability is evaluated.

First stage:

In this stage by 72 seepage model and 1000 times using, stability model of fuse plug position is reviewed under the following conditions: 1- Different core slopes 2- Different core positions 3- Different core slopes 4- Different width of core. According to the obtained safety coefficients of this stage and fuse plug analysis according to a. conditions without water level- with and without earthquake coefficients b. with total level the following results are found:

1- The best thickness for clay core is between 60cm to 1m.

2- The best position of the core is 1 m higher than the lower edge of spillway crest.

3- The best core slope is one to one. Although two to one slopes provide the stability, it is not economical.

4- The most optimized upstream and downstream slopes of the shell are depending upon the structure height. For example, for 4 m structures, two to one slopes were the best.

Second stage

In this stage the effect of core on stability of fuse plug is investigated and the results are as the followings:

1- Critical sliding surface never exceeds the clay core.

2- Sliding surface including entire core or a part of core is with high reliability coefficient.

3- Sliding surface including entire core a part of core is having reliability coefficient of at least 1 and to be sure of it, the effect of core is negligible.

Third stage:

The selection of optimized width of spillway is depending upon the following factors:

1- material of dam

2- The distance of drainage to dam crest

3- Final height of the dam

4- The importance of dam crest from going and coming

To calculate the optimized width by experimental equations and stability control of spillway the following results are obtained:

Fourth stage

In this stage, the stability of fuse plug at quick discharge is done by Morgenstern method. As the dam reservoir is discharged at very short time, due to the existing drainage force in the core going into the reservoir and destroys it, the reliability coefficient of upstream range is decreased. The results of Morgenstern method is shown in the following. Totally, for the height of 15 m due to the low height of dam, stability is good at all the conditions.

Figure 1: Wash out of fuse plug with downstream homogeneous materials

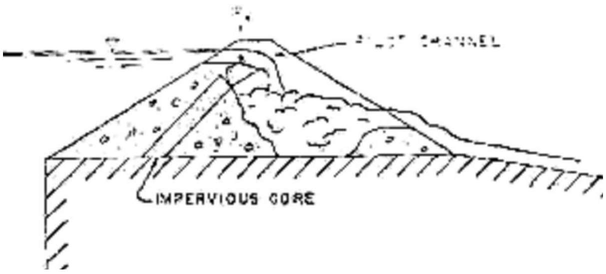

Figure 2: Fuse plug wash out with heterogeneous materials

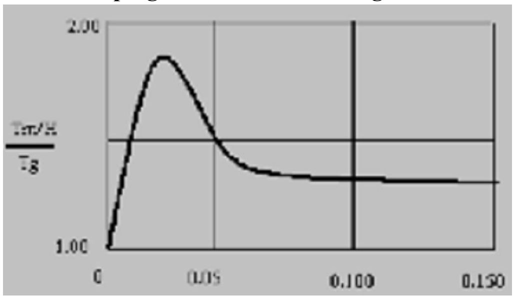

Figure 3: The effect of vertical core position on washing

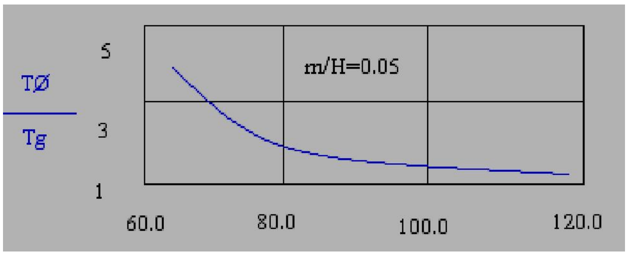

Figure 4: The effect of inclined core position on washing

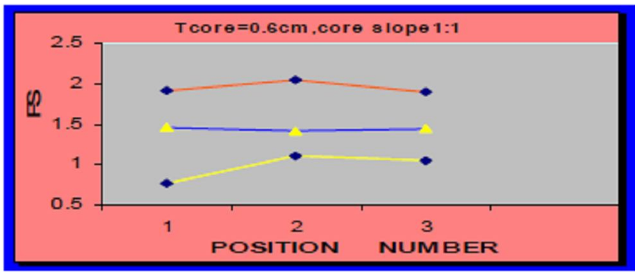

Figure 5: Core slope 1:1- Core thickness 60 cm

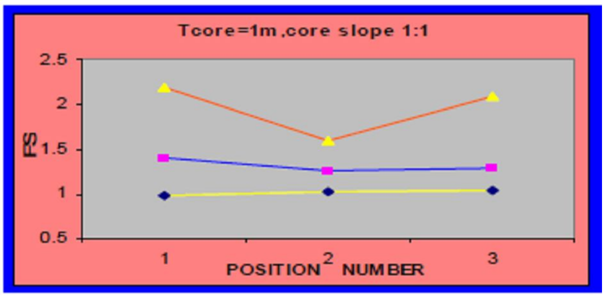

Figure 6: Core slope 1:1- Core thickness 1 m

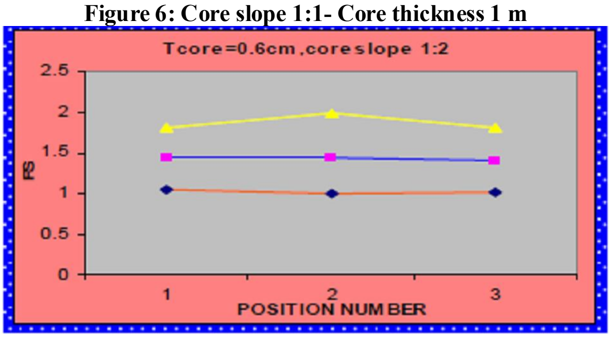

Figure 7: Core slope 1:2- Core thickness 60 cm

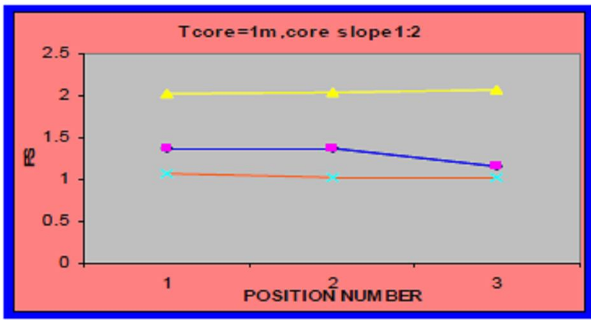

Figure 8: Core slope 1:2- Core thickness 1 m

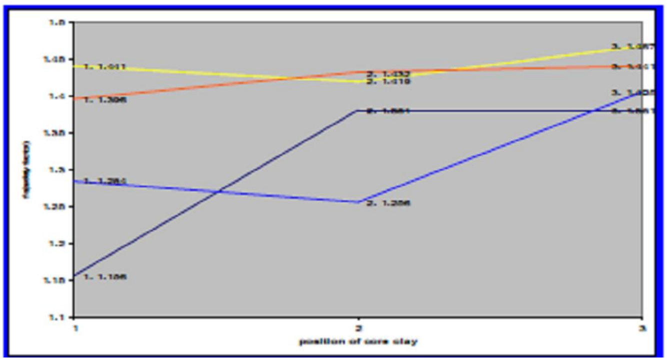

Figure 9: The comparison of the core position

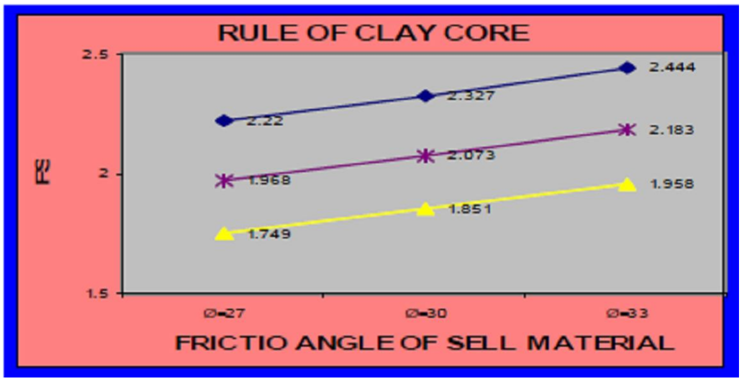

Figure 10: The stability position of fuse plug core for different states of clay core

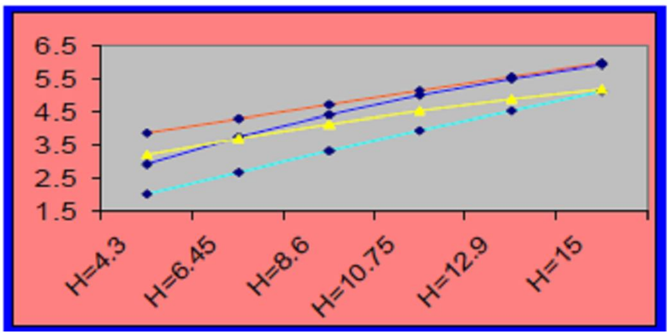

Figure 11: The calculated widths for fuse plug

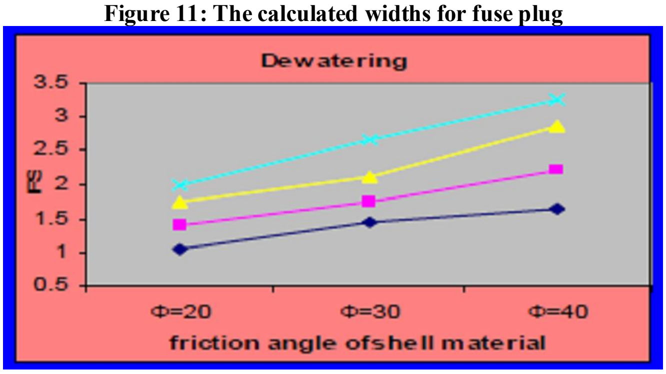

Table 1-Stability changes of 4 m fuse plug

Core slope	Core thickness	Downstream slope	The core under the upper edge of the spillway (1)	The core 0.5 m above the edge (2)	The core 1 m above the edge (3)
Slope 1:1	60cm	1:1,5	1.055	1.103	0.763
Slope 1:1	60cm	1:2	1.441	1.419	1.467
Slope 1:1	60cm	1:3	1.909	2.05	1.92
Slope 1:1	100cm	1:1	1.044	1.03	0.975
Slope 1:1	100cm	1:2	1.284	1.256	1.405
Slope 1:1	100cm	1:3	2.09	1.59	2.192
Slope 1:2	60cm	1:1	1.016	0. 996	1.041
Slope 1:2	60cm	1:2	1.396	1.432	1.441
Slope 1:2	60cm	1:3	1.809	1.988	1.802
Slope 1:2	100cm	1:1	1.022	1.015	1.068
Slope 1:2	100cm	1:2	1.156	1.381	1.381
Slope 1:2	100cm	1:3	2.07	2.035	2.026

Table 2- Stability changes of fuse plug for different values of core materials

	Internal friction angle of shell materials	FS	FS	FS
Internal friction angle of core materials		Ø = 27	Ø=30	Ø =30
Without water level	Ø =30	1.749	1.851	1.958
Without water level	Ø =36	1.968	2.073	2.183
Without water level	Ø =42	2.22	2.327	2.444
Without water level with earthquake	Ø =30	1.259	1.328	1.4
Without water level with earthquake	Ø =36	1.426	1.497	1.571
Without water level with earthquake	Ø =42	1.615	1.689	1.756
With total water level	Ø =30	1.852	1.961	2.069
With total water level	Ø =36	2.084	2.189	2.99
With total water level	Ø =42	2.343	2.45	2.562

Table 3- The calculation of optimized width

The height of fuse plug	H=4.3	H=6,45	H=8.6	H=10,75	H=12,9	H=15
USBR B=1.104H^0.5+0.915	3,2	3,72	4,15	4,53	4,88	5,19
Technical office of dam construction in America B=H/5+3	3,86	4,29	4,72	5,15	5,58	6
The dams under 30 m B=0.55√H+0.2H	2,00	2,68	3,33	3,95	4,55	5,13
Japan dam construction code B=3.63(H)^0. 33-3	2,9	3,75	4,43	5	5,5	5,94
Optimized chart	2,0	2,7	3,3	4	4,45	5

Table 4- The calculation of spillway stability at quick discharge condition

H=15m	Slope 2:1	Slope 3:1	Slope 4:1	Slope 5:1
Internal friction angle 20°	1.05	1.4	1.75	2
Internal friction angle 30°	1.45	1.75	2.1	2.65
Internal friction angle 40°	1.65	2.2	2.85	3.25

Conclusion

According to the results of the current research and oxbow spillway test we have:

1- The best core slope is between $40° \ to \ 50°$ from stability, economic and erosion.

2- The best optimized stable and economical width is calculated from the equations of dams under 30m. Also, the spillway width doesn't influence washing process.

3- For all the fuse plug spillways at quick discharge condition there is no problem.

4- The role of clay core is avoiding seepage that is influensive in stability process and is not influencing the washing trend. Because after the corrosion is starting from the shell, the core is being emptied and core is washed.

5- The position of core inclined to the upstream shell to control seepage, stability and washing is the best selection.

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