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Research Article

Assessment the stability of embankment dams during rapid depletion of reservoir

Yousef Parish

Ministry of Energy - The Institute for Energy and Hydro Technology (IEHT) ,
Tehran, Iran & Azerbaijan Higher Education Research Center, Tabriz – Iran
Email: yousefparish@yahoo.com

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ABSTRACT

Sensitive parts of dam might be damaged because of various factors during exploiting an embankment dam, for example some cracks might be seen in crust or some phenomena such as hydraulic fracturing in core, piping phenomenon in the downstream wall and reduction of input to the reservoir as a result of deviation in river path. These factors and similar ones will be inevitably followed rapid depletion of the reservoir. Even after an earthquake in dam area rapid depletion of reservoir might be the only solution for preventing dam's destruction for several hours or some days. Therefore, considering the importance of case, accurate studying about the effects of rapid depletion of the reservoir is necessary to prevent destruction of wall that would lead to dam break through providing appropriate fields about rapid depletion of the reservoir. Environmental problems about assessment the stability of embankment dams during rapid depletion of reservoir and coping strategies with the destruction of the body will be investigated in this article.

Key words: Embankment Dams - Earthquake - sustainability - reservoir - dam break - steep slopes - Landslide**.**

1- INTRODUCTION

Studying the stability of embankment dams' body has its own particular conditions, gables of an embankment dam has relatively different behavior from each other in upstream and downstream in terms of stability. This difference can be considered depending on the impact of water stream and influence in dam's gables and because of this gables' stability is studied in different time sections in terms of the existence of water in gables. Gable stability is relatively equal in upstream during constructing dam and before impounding dam in gable. After finishing construction part and primary impounding, upstream gable will be suddenly exposed to the pore pressure onone hand and on the other hand will be affected by water force inflicted the wall while downstream gable has still its own initial position (construction conditions). After a period of impoundment (steady seepage phase), upstream gable has almost the similar conditions in impoundment while downstream gable has been affected by water movement and finds new situations. During rapid depletion of reservoir, upstream gable will be affected by pore pressure while water pressure has been removed from its wall and downstream gable has almost that condition of steady seepage so using appropriate strategies in each level of construction, impounding, steady seepage, rapid depletion, earthquake and … seem necessary for controlling the stability of upstream and downstream gables.

2- Rapid depletion of reservoir and its effect on dam stability

In a condition that reservoir water is necessary to be depleted in a short time, considering the pressure of pore water existing in Natravayborehole of dam as well as removing resisting force from the water reservoir on the upstream gable, this gable will be in critical situation. As the simultaneousoccurrence of earthquake and rapid depletion of reservoir water is very unlikely so in this mode there is no need to consider the effect of earthquake. Rapid decrease in water surface elevation in reservoir of embankment dams causes the lack of stability in upstream slope, one way of controlling pore water pressure in soil mass in using horizontal drainages. In designing embankment dams, three critical and important levels of increasing pore water pressure should be considered; these three levels are:

-Construction -steady seepage - rapid decline in water

2-1 dam construction phase

In this case, the pressures of pore water because of crush (compression) of backfill material and backfill pressure increase that are usually called executive pressure during constructing backfill, layers with the saturation of 80% to 90% get compressed. Soil compression is with load and height and backfill increase, this case causes increasing the pressures of pore water in fine-grained soils.

2-2 steady seepage phase

This pressure is created when reservoir is left for a long time so that the stream of formed steady seepage and whole soil volume are saturated under free line.

Required time for downstream slope saturation and establishing steady seepage mode depend on the rate of backfill material penetration and the period that the level of reservoir water has been adequately high after a period of seepage.

2-3 the rapid decline in water

This phase which is the subject of this study as well is when the level of reservoir water rapidly decline after one period of steady seepage. Pore water pressures are called pressures derived from water rapid decline.

3- The position of embankment dams' body in terms of pore water pressure

3-1 Status of meanwhile building and immediately afterwards

During constructing dam and immediately after that in fine-grained and less penetrating sections of dam and infrastructure, prisoned pore water pressure increase first and then decrease gradually and lower layers will be strengthened and therefor the severity and way of distributing pore water pressure not only depends on strength characteristics and penetration of material and drainage boarder conditions but also depends on the way of performing work in great extant. In these conditions there is no drain still in dam's body and the decrease of water is because of dryness is trivial and only is pressured because of the weight of upper layers of pore water. Some of researchers believe that computational parameters based on effective stress (not whole stress) should be done for investigating the stability of dam body during construction and immediately after that. The value of required quantities is obtained out of three-axis experiments of pressure on undisturbed samples.

In some of dams, penetrable sand layers are built amidst the dam's body to speed up drainage and strengthening. Anyway because the value of pore water pressure isn't accurately clear during construction so through direct measuring, real value of pore pressure can be obtained.

3-2 the position of half full reservoir or steady drainage

After a while that dam river gets full, water practical pressure that is the pressure of drainage will be gradually in state of full reservoir, gable level of upstream will be affected by reservoir water pressure that its stability is more than state that doesn't have such this pressure. The range of this reason in steady drainage of downstream range should be definitely investigated in terms of stability.

Of course, in some conditions, upstream range might be critical in the first reservoir fulfilling and also it may be more critical in state of half full reservoir than full one. For determining pore pressure obtained from drainage in each point of environment, drawing stream channel can be used.

3-3 Rapid depletion of reservoir status

during rapid depletion of reservoir water, upstream range will be into critical states because the pressure of existing water in reservoir which is located on upstream range will be decreased while the surface of free drainage will remain in dam's body because of less penetrable of dam body, this surface's scale is upper than free level in reservoir and water inside dam body takes a while to be drawn gradually to the sides of dam. In such this mode upstream range of dam same as downstream range will be affected and the pressure of existing water in it decreases resisting force.

The status of pore water pressure after rapid deletion of reservoir water depends on the degree of the compressibility of material which form dam. In some parts of dam that are half Trava and relatively compressibility such as those where silt sand material have been formed with appropriate compressibility, the majority of water which has filled the surface of pores water before going dawn remain in holes and the rest will be drawn toward outside without volume change in holes practically. Some parts of these waters will flow toward ranges and if the infrastructure is penetrable will flow that side too. Regardless the effect of dam forming material and that type of material's hugeness, if the speed of water depletion is low, obtained drainage line of a rapid depletion will decrease as well. Therefor in order to determining the status of pore water pressure in a rapid depletion, moreover the characteristics of penetrability and strength of dam constructive material, the rate of depleting reservoir water has also main role in stability. In practice a number of these factors can be determined correctly, in cases that measurements aren't accurate, stability measuring should be done based on the hypothesis of the most inappropriate status (meanwhile compatible with clear facts), it should be considered that depleting dam even in a period near some weeks or some months also might be considered rapid for the conditions of that dam.

4- Coping methods with destruction of embankment dam during reservoir rapid depletion

4-1 stability controller factors during reservoir rapid depletion

In spite of technical development which have been accomplished in the field of constructing embankment dams, still strong and mathematical solutions can barely recommendedfor solving the problems of designing embankment dams so many elements of dams are still designed and performed based on experience and tactfulness of engineers. In another word a sample and unique plan cannot be always recommended. In order to provide an accurate and logic plan in embankment dams, the status of dam's infrastructure and its forming components are necessary to be studied and investigated completely and that would be possible through controlled methods and exactly in accordance with recommended program of designer. The main part of embankment dam which is crushed sand mass (in fact dam structure) is called dam body. The land where dam is located on is infrastructure till that time which is affected by obtained pressure from dam and water penetrability. Except this in main part, other components such as bulkhead, drainages and covers that their importance is trivial in terms of volume but in terms of security and performance of dam have vital role for that.

In terms of technique and structure, embankment dams are two groups that almost all of them are located in roller group and some of them are categorized in hydraulic and semi-hydraulic group. In terms of homogeneity of the dam's body, various types can be recognized from each other which are: Type homogeneous - heterogeneous type - type laminated - type diaphragm.

4-1-1 Materials used in dam

In different sections of dam, its forming material should have particular features such as penetrability, shear strength, compressibility and resistance against piping. Table 1 shows the order of priorities for using different types of soils in its initial designing and planning.

Table 1 the features of some material used in embankment dam

Relative efficiency of compressibility	Shear relative resistance	Relative resistance against piping	Relative penetrability	priority for dam's heterogeneous borehole	Priority for homogeneous dam	Soil group
Very good	High	Very high	Penetrable		**1**	**GC**
Very good	High	High to average	Half-Penetrable	**4**	**2**	**GM**
Good to average	High to average	High	Non-Penetrable	**2**	**3**	**SC**
Good to average	High	Average	Less-Penetrable	**5**	**4**	**SM**
				3	**5**	**CL**

Used signs are based on unified categorizing.

For the crust of borehole dam, only types of SP, SW, GP, and GW can be used that the preference is with the order which is mentioned. The other types of soils aren't appropriate for dam's heterogeneous borehole at all. Although the other types of soils except what have been mentioned in table 1 for dam borehole or homogenous dam can't be used for sure, but the order of priority merely in order to classifying are: ML, CH, OL, MH and OH

The type of embankment dam first is function of material which exists on that area or near that, the type of embankment dam infrastructure, whatever it is, isn't changeable unless surface layers that might be picked up, is crushed instead of that in case. Therefor the status of land or infrastructure is very important in designing embankment dam. As a comprehensive factor in all aspects, being economic of design will be finally discussed. Generally if penetrable or non-penetrable material should be available as much as needed, borehole dam (heterogeneous) will be preferably used, although volume ratio of non-penetrable material to penetrable one (according to estimation in order to dam non-penetrability and its strength and stability) is also a function of transportation cost and the cost of providing grain is considered. In a homogenous dam, one way of resistance increasing of its wall during rapid depletion of reservoir is increasing the penetrability of dam material. Because of pore pressure increase (that is decreasing water pressure on upstream wall and the existence of pore water pressure) relatively big driving force will be created that moves toward non-stability. If this force can be controlled (decreasing power among holes and increasing the speed of water depletion among material) in fact, something is done for increasing the assurance.

4-1-2 slopes

Slopes are important factors in maintaining the stability of one dam wall that naturally this effect is mentionable at the time of rapid depletion of reservoir. Slopes are usually taken from one to one and a half to three, although slopes of one to six or less either can be sometimes seen. The design of slopes is utterly common so that the slope of higher parts is more selected and less in lower parts or change slopes in several levels. There are different ideas about the amount of stable standard slopes. In first decades of current century although the recommendations have been based on previous experiments but some dams had been also constructed with the slope of one to one. Some people believe that upstream slopes should be less than downstream ones and some had different ideas. Nowadays experts believe that both situation is possible and only depend on conditions. Different researchers such as “Proctor” and “Tarzaqi” and “Scherer” each one has proposed a table for upstream and downstream gable slope. These slopes are based on their components. If we use some material for creating the stability of upstream gable stability, its slope should be considered appropriate with the type of material and always be considered that these two factors have direct relationship with each other. The other effective factor on range slope is dam height, it means whatever dam height is more, and the slope of wall should be less. At the time of rapid depletion of reservoir of a dam, a particular part of its wall will be affected therefor through simple actions such as slight slope and choosing high penetrability material, its descriptive effects of rapid depletion can be decreased and dividing a gable into some slopes is mainly based on this.

In practice, in reservoir dam of Sonqor Suleiman king where various parts of dam have been studied as evidence, above subjects works. It means in downstream part that is a combination of three different parts with different slopes, if we consider an average slope for three above parts, confidence coefficient will be 1.20 in that condition which is less than 1.746 in natural conditions. In upstream part also existing gable consists of two parts that each part’s slope at the time of rapid depletion of reservoir respectively from torn to footing is 1.71 and 1.83 that in status of combining two gables and calculating confident coefficient on that very situation we will reach to 1.98, in fact second part of gable has drawn researchers’ attention recently in ST.Hill and ST.BEDE and has been investigating namely berm. Therefor as it was mentioned, through dividing a gable to some sections and considering the stability need and also wall slope in various parts of gable, changes can be created for increasing the stability in particular situations for example about rapid depletion of reservoir, that part of wall which is affected by pore water pressure should be separated and give it required slope and in other parts create slope and slope length, it is natural that this action can be effective both in terms of executive or economic and because of possibility of existing rapid depletion we don’t have to increase operation volume and in fact don’t have to spend extra money.

4-1-3 drains

The type of drain and its location is very important. It means that selecting type of drain material should be in a way that in appropriate time decrease pore water pressure and its location shouldn’t have a point from pore water pressure gable as much as possible. Since drains have higher penetrability than upstream wall, their relationship with wall is necessary to be gradual that is it should have appropriate filter because the existence of big amount of water in upstream and downstream gable of reservoir water and moving water toward outside wall, piping phenomenon might be created and sections that are weak because of executive problems (compression, grange and …) are exposed to the risk of being hollow.

We know that a combination of horizontal draining is more effective than separated mode and can decrease the pressure of pore water pressure in appropriate volume and speed and as result increase gable stability during rapid depletion of reservoir. Of course it has to be noticed that if we put above drainage in the middle of gable exposing to depletion, the efficiency will be more. If the volume of middle drain of dam is significant toward total volume of body that should be named borehole draining. This case is also tried in dam construction and Vratc dam in Yugoslavia can be named that is 18 meter height having a drain borehole 12 meter high and 18 meter width.

4-1-4 the shape and type of borehole

Embankment dams are usually constructed in two ways of homogeneous and heterogeneous. Homogenous dams are made from one type of material but according to what has been mentioned before, in this case the penetrability of different sections should be considered in a way that two criteria of non-penetrability and stability are met there. Heterogeneous dams generally have a part with low penetrability that has the role of bulkhead. The location of non-penetrable core and its performing method is also different. For beginning we investigate right in the middle of the dam core mass. The most important possible damage in this case is hydraulic break which briefly explained as below. If water pressure in a soil mass causes breaking and crack in environment,that destruction will be called hydraulic break. Water pressure in this process causes stress and shear mechanism in one point move toward the destruction and as result some cracks are created in soil mass, these cracks are called hydraulic ones. Embankment dams’ core is such an environment where soil masses are affected by water pressure and some cracks might be created because of this pressure. Based on this hydraulic break is considered as one of the most dangerous destructions in dam with clay core. This phenomenon happens following damps during impounding from reservoir. Hydraulic break and its result that is hydraulic crack are generally called destructive phenomenon. A significant number of researchers have done lab, analysis and numerical studies about hydraulic break in soil masses. Scherer (1986) has discussed hydraulic break in embankment dams out of analytical attitude and has mentioned the factors and mechanisms of this destruction. Using existing theories for material behavior and through selecting an appropriate criterion for soil yeild, a theoretical solution for hydraulic break can be obtained and then the effect of rapid depletion in it which is ultimately led to stability of whole wall can be studied. For idealizing the soil behavior, linear or non-linear models of material behavior are efficient. Numerous yield criteria also can be used for material rupture that among them Mohr-Coulomb yield criterion is superior according to two reasons. First, the parameters of this criterion are easily available and are known for users as well and second, numerical solving of equated environments is easier with that.

In hydraulic break, most of researchers have done their experiments on hollow cylindrical samples. Empirical studies which are done simultaneously with this one also have been performed using mentioned geometry. For geometrical simulation of adequate experimental samples, the screen image of the hollow cylindrical is used. the features of embankment dams body change in various levels of construction and exploitation. This is because several years after reservoir impoundment, the core will be saturated and during this period and construction, core has non-saturation status. Some of loadings also such as earthquake loading place the core in drained status under load. Therefor the parameters of obtained formula which are achieved for soil mass will change in case of using for embankment dam core during dam’s life. Main five levels for analyzing embankment dams are:

- The end of the construction phase
- Initial impoundment
- Steady seepage
- Reservoir rapid depletion
- Earthquake occurrence

Here we talk about reservoir rapid depletion. As we know in rapid depletion if depletion is faster than water drainer inside core which usually is, water pressure will be taken from downstream while pore water pressure remains inside core, it is obvious that this mode isn’t because of eliminating critical reservoir water pressure for the occurrence of hydraulic break. Considering above information, the other appropriate solution can be achieved for decreasing pore water pressure and as result higher confidence coefficient during rapid depletion through closing non-penetrable core to upstream wall more because through this, pore water pressure creation will be prevented and stability will be added while rapid depletion of reservoir doesn't affect core and creating hydraulic break.

If confidence coefficient still is low in spite of using this method and placing an appropriate drainer in downstream, the core can be performed obliquely with that very slope of upstream (with appropriate drainer) in this case considering more decrease of pore pressure, the stability will be definitely increased. During using oblique borehole, since borehole is almost non-penetrable and wall (body) upstream has a little width and one hand drawn rupture circle will include the majority of borehole, the pressure of pore water doesn't affect much therefor hydraulic crack won't be also created.

4-1-5 embankment dam infrastructure

Embankment dam infrastructure is used for that part of land under dam that is somehow affected by loads of dam as well as drainage. So it is necessary to have below characteristics:

- It should be a strong infrastructure in all loading conditions and its deposit shouldn't be in an extent that causes dam destruction.
- It should be strong against drain power not to cause piping.
- Its penetrability shouldn't be too much to include water waste through the drain of significant section. Water waste can be usually prevented in this case, in case that exceptional condition of infrastructure impounding isn't possible, that land won't be appropriate infrastructure for creating dam. Infrastructure can be stone, rock or soil half that in this case, it can be made penetrable or impenetrable.

In order to investigate the stability of infrastructures, it has been recommended that calculations will be done based on infrastructure stability and the resistance of dam body will be eliminated in calculating stability. Of course this suggestion seems rational because under the effect of very deposit in infrastructure, dam body will be affected by significant strain stress in a way that the possibility of non-simultaneous rupture of body and infrastructure will increase and even dam body might be stable before that infrastructure reaches rupture limit and only because of infrastructure resistance. In loose infrastructures, there is the risk of soil drift under the dam which is likely because of horizontal shear stress.

The other methods of increasing infrastructure stability which are led to increasing wall stability are:

Phase dam construction, creating sand pit, low slope of the hillsides as well as creating terraces layers on the sides of hillsides can be named. The penetrability of infrastructure material toward wall can somehow increase gable stability on infrastructure. The penetrability of infrastructure causes creating water flow from wall toward infrastructure that this subject during reservoir rapid depletion can somehow decrease the pressure of pore water existing in gable on infrastructure and increase confidence coefficient. Of course this subject causes a little water to be extracted through infrastructure that if it isn't controller even can cause piping phenomenon as well therefore some solutions should be taken for prevention method of these phenomena depending on conditions in location such as the thickness of penetrable layer. In a way that till 15 meter thickness can be impounded through trenching seal or metal shield curtain and other techniques and other measures should be used for more thicknesses.

4-1-6 Effect of Landslide

Semi-saturated soil shear strength especially fine-grained decrease affected by complete saturation, the reason is that part of the strength of semi-saturated soil is as a result of water surface tension between grains and this strength will be removed during complete saturation even in loose dams which are somehow cemented because of water flow and their cement dissolving, their strength is decreased. Filling water reservoir leads to landslide for example, inside Maranha landslide and glacier sediments of Austria or landslides related to filling Roosevelt River in Washington can be named. Water rapid decline in dam river can also cause landslide therefor dam behavior against can be considered and studied earthquake during rapid depletion of reservoir for dam.

4-1-7 loading on claw

About less deep landslides, this method can be used. in order to this, piling into claws, guardian outer wall and diaphragm walls along the claw or heavy load on the claw can be used. These materials may be made of different materials or even the stuff of gable.

Finding the necessary weight and dimensions of the claw (berm) is very simple through stability calculation methods that the force of this loading can be considered as resisting force to able to achieve necessary confidence coefficient, on the other hand the value of power derived from extra pore pressure can be modified through this loading. Of course in dams where their gable slope consists of several parts, the part which is placed on the ground in fact plays that very role of loading on claw. The location of this berm is easily calculable, it means that berm should be placed in way that the place of berm weight is due to the place of destructive power effect and makes each other neutral, and on the other hand rupture collision with the ground surface is better to be in the middle of berm.

4-1-8 maintaining by soil anchoring

As it can be seen in below picture schematically, these anchors are under stress and pressure and we can see that obtain power of slope stability should be estimated as axis power and considered along that.

4-1-9 maintaining by sheet piling

This method is also used in status of wall stability increase against slide. A scientific sample used in this method is in the north of England (nally team). This method might be performed by metal, concrete sheets with long piles or without piling. Considering that during instability that might happen during rapid deletion of reservoir, sheets and piling are given some powers that if sheets and piling have appropriate resistance, they will make the majority of these powers neutral (The rotation and torque) and structure can resist easily against gable instability. The effect of sheets and piling should be well impounded even they can act as an impoundment curtain, control the value of passing drain from dam body or even infrastructure and provide two targets of constructing dam (stability and impenetrability). Calculating aspects, the location of sheets and piling also are those common methods in designing retaining wall and piling and driving and strong powers are also completely clear.

4-1-10 retaining structures

Using these structures which were used in past will expand in future as well. These structures are a combination of previous methods and their designing and constructing resist against gable instability based on what either work as weight or frictional forces that create ground level. These structures can prevent changing walls well in a long time.

Some mentioned methods might look difficult first but through investigations that were done by two universities which were mentioned above, performing these structures is recommended for increasing the capability of stability against sliding for gables. On the other hand considering the decrease of soil operation amount to increase slope during using these structures, their cost will significantly decrease.

4-1-11 Electro-osmosis method

Under the effect of passing electricity from saturated soil, pore waters will decrease inside soil, for example based on reports of researchers such as Casagrandeh through this method, a soil gable was fixed on the Beach of Litany River in

Canada. The soil of this gable consists of saturated silt. Electrodes are placed within 3 meter distances and a potential equal to 100 Volt is connected to them, the depth of effect had been at least 12 meter, the level of underground water till 10 meter in upstream sections and 15 meter in low gable claw. After draining, they could dig till 16 meter depth with 1.1 slopes, while before performing this operation; obtained gable didn't have confident stability even with slope of 1 to 5.2.

The other successful samples can be found in this field. Therefor through this method, appropriate stability of upstream gable mode during rapid depletion of reservoir will be provided so that first the area which will have water pore pressure during rapid depletion reservoir should be identified and in those areas required installations should be embodied in order to use electro-osmosis and use it easily in case.

4-1-12 thermal methods

A sample of method function was done in this way that some holes with diameter of 20 to 30 centimeter distancing 0.8 to 1.2 meter were dig in purpose soil, hot air was passed through them with the temperature of 800 degree, after 6 to 8 days, the diameter of brick columns reached 1.5 meter, this case increases its mechanical power as well as drying soil.

This method can be done by horizontal galleries.

4-1-13 soil reinforcing

One method of reinforcing soil which drew attentions recently is using a kind of fiber from resistant woven which is called Geotextiles, these kinds of fibers moreover increase frictional resistance of soil structure, has had pleasant penetrability and there is no prohibition for moving of water inside soil.

Based on the type of soil and calculating the rate of its stability, an embankment dam or in embankment gable, these fibers can be adequately used to either provide required slope or assure of that gable strength.

4-2- Morgenstern method in the condition of rapid depletion of reservoir

If reservoir is depleted hugely in short time (for example some days or even some weeks) or in another word the level of reservoir water is being less because of existing drain power in borehole section (or in whole homogeneous dam bodies) which work toward destructing reservoir upstream confident coefficient will be decreased. There are various methods for analyzing upstream range stability such as using provided diagrams by Morgenstern. Of course in a method that is used be mentioned person, stone infrastructure is imagined as a strong stone or layer so stability or rupture analysis has only been done based on resistance or non-resistance of dam body. The hypotheses which are used in calculations and conclusion of this method are:

- Soil parameters are equal and stable in all dam body
- The pressure of pore water in each point is (the weight of water unit- its height till soil range level above that)
- The coefficient of pore water pressure in dam body is equal to unit in conditions of rapid decline in water level
- The circle of imaginary landslide for investigating stability is circles which are tangent on the base of norm.

Different offices and institutions have recently performed some programs which are obtained from software which is designed based on those initial principles and can calculate the stability of walls after fast depletion.

4-3 controlling the pressures of pore water as result of water rapid decline

In heterogeneous dams, if the material of outside layer is penetrable, pore pressures are only created in impenetrable layer or core. If the thickness of core is average pore pressures of rapid water decline will be low inside slide level. Pore pressures of stable mode as well as pore pressures of water rapid decline can be decreased in a great extent using a thin and oblique core.

The direction of flow during water level decline in thine and oblique core is almost vertical downward and pore pressures are less in this mode.

In mode of steady seepage, slide circle only cut a small part of core above that. but in critical mode of core weaker material, it will go more to upstream and the level of critical slide will pass core material, this position causes that upstream slide is selected more slight even if pore pressures are small.

Anyway, main problem of controlling pore pressures because of water rapid decline will be created when dam external layer isn't completely penetrable. These conditions will be created in a place that the available material is fine-grained one or used materials in external layer don't have free drain.

In these cases, if pore pressures aren't controlled, we have to consider upstream slope very slightly. However considering appropriate draining system, pore pressures because of water rapid decline can be controlled or removed.

4-4 studying drainage systems

4-4-1 upstream stone claw

The comparison study performed by researchers (such as Fend) on upstream slope of a homogenous embankment and an embankment which has drainage with the height of 0.3H in claw of upstream in rapid decline of water showed that this drainage doesn't make significant reduction in pore pressures because the lines with same potential remain completely stable and pore pressures still exist in upstream slope. On the other hand stone claw bigger than 0.3H in constructions where there aren't washed gravels will be very expensive.

4-4-2 chimney draining

It has been seen that chimney draining with low height decrease pore pressures in a great extant.in spite of that flow channel shows that chimney drain has not decrease pore pressures a lot, it has been seen in practice that chimney draining is more trustable because they pass different horizontal layers that might be more penetrable than other layer. In mode that upstream of embankment might be drained using oblique drainages , theoretical pore pressures beside draining and above water decline level because lack of relationship of chimney draining with free air, might get a negative value (below atmosphere).

5- CONCLUSION

Below results are obtained in case study "the effect of rapid depletion of reservoir on the stability of embankment dams":

1. Through horizontal or chimney draining, the stability of dam upstream gables will increase during rapid depletion of reservoir.
2. In performed case study, using horizontal draining with thickness of 0.5 meter increases the stability of upstream gable during rapid depletion of reservoir about 7 percent.
3. For each 50 centimeter increase in drain thickness, about 2 percent will be added to confident coefficient.
4. In special cases that horizontal draining cannot create required confident level, using chimney draining is the most appropriate replacement for increasing stability.
5. Using draining in upstream will bring the decrease of slope and as result decrease of soil operation volume and costs.
6. Using berm increases gables' stability during rapid depletion of reservoir.

It is suggested:

1. Controlling the cost of establishing chimney and horizontal drainage in stability of upstream gable
2. Controlling the stability of dam upstream slopes using required facilities
3. Finding the optimal place for locating berm in dam upstream gables

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