Analysis of Longitudinal Cracks in Crest of Doroodzan Dam

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ABSTRACT

Doroodzan earth dam is located in 85 km north western of Shiraz. Because of the unusual seepage flow in the left abutment, in 1992 an impermeable vane was grouted there. Soon after that, obvious changes in water Table profile occurred and simultaneously some incremental number of cracks in left abutment crest was appeared. In present study seepage through left abutment has been analyzed by considering water Table changes. Different phreatic surface line was carried out from recent 20 years in order to find the most vulnerable one. In addition, Seismic loading used to get proper perception of seismic stability. First, by gathering data from piezometric head through the left abutment, most critical phreatic line in left abutment section of dam was observed. Then by using present phreatic surface in numerical modeling of critical section in the left abutment of dam, long term stability of downstream in different situation were calculated. The conditions were changed by increasing the saturation zone and the time which saturation zone stay through the downstream body.

KEYWORDS: Earth fill dam, Seepage, Longitudinal Crack, Doroodzan dam.

INTRODUCTION

Due to high amount of available soil and rock materials which can be used for constructing earth and rock fill dams most of the constructed dams in Iran are from earth and rock fill materials. One of the pressing issues about earth fill dams is high amount of settlement which leads to both transverse and longitude cracks. However, cracking has developed most commonly in dams of moderate height (less than 33m) and in the upper portions of high dams. Although, the great earth pressures which exist deep within high dams will work against the development of cracks, most of the cracks are not visible and the only way to find their presents is to adopt suitable instruments which can defect water infiltration through the dam body [1]. Moreover, cracks are the inevitable parts of earth dams and they could be due to different reasons such as differential settlements, high relative compressibility of foundations, abutments, or uncontrolled seepage [2]. When the reservoir level is raised, water is percolating through the dam body and it give rise to changing in soil properties specially shear strength parameters and saturation unit weight which have significant effect on dam stability. There are innumerable cases through the history where it can be seen increasing in saturated zone used for dam body did actually lead to decreasing in factor of safety. As a matter of fact, 30% to 40% of dam failures are related to uncontrolled seepage through the dam body, seepage must be controlled by installing sufficient drainage system in dams [3]. Principal factors controlling groundwater levels are fluctuations of the reservoir level, seasonal increases in groundwater flow, migration of seepage paths, tail water levels and reservoir sedimentation [4]. In this study seepage phenomena through the left abutment of Doroodzan dam throughout 37 years operation have been studied in order to find more about reasons of recent longitude cracks in this part.

COMMON REASONS OF CRACK DEVELOPMENT IN EARTH AND ROCK FILL DAMS

Crack develops because portions of the embankment are subjected to tensile strains when the dam is deformed by differential settlement. Depending upon the geometry and relative compressibility of the foundation, abutments, and embankment, earth dam may be twisted in different ways which result in quite different cracking patterns. Cracks maybe open parallel or transverse to the axis of the dam and may form in vertical or horizontal planes or in any intermediate directions. Longitudinal cracks might be either localized or continues for great distances through the impervious core. They may open as much as 15 centimeters. in which, though widths of 2.5 or 5 centimeters have been more common [1]. Furthermore, longitudinal cracks are produced by several types of differential movement. In dams with rolled-earth cutoffs which are much less compressible than the natural foundation soil underlying the slopes, longitudinal cracking may be caused by the tendency of slopes to settle more than the crest. Moreover, whenever longitudinal cracks appear at the crest of a dam, they are probably due in part to the tensile stresses which develop at the tops of earth slopes [2]. Finally and the most importantly, the main danger associated with longitudinal cracks is that they may occur in conjunction with other unseen cracks running transversely through the core. Longitudinal cracks should be carefully observed and, when movement stops, filled by trenching and backfilling with compacted impervious soil [1].

CASE STUDY, DOROODZAN DAM

The multipurpose earthfill Doroodzan dam is located 85 km North West of Shiraz and built on Kor River in the Bakhtegan lake catchment area. Doroodzan dam studies and investigations were carried out between 1963 to 1966 .The dam constructions started in 1970 and completed in 1974. As illustrated in Table 1 Doroodzan dam is kind of homogenous earthfill dam with 57 meter height and 993 million cube meter reservoir volume. Regarding controlling seepage through the dam chimney drain were used as well as horizontal drains and reduction pressure wells in downstream. It should be mentioned that there were 15 old piezometers since operation of dam was started. On the one hand, due to some instrument renovation 12 new piezometers were installed. These piezometers will be used in order to find phreatic surface in different condition through the dam. So, data from 11 years operating of Doroodzan dam were collected in regard. Table 1 provides information about Doroodzan dam properties [6].

Table 1: general information about Doroodzan dam

Type	Homogeneous embankment with riprap protection	units
Height	57	m
Volume	993	m.c.m.
Surface at normal water level	55	km^2
Dead storage	133	m.c.m.
Catchment's area	4372	km^2
Mean annual inflow to the reservoir	1192	m.c.m.
Mean annual evaporation from the reservoir	64	m.c.m.
Mean Annual Precipitation	485	mm

Instrumentation system in Doroodzan dam

As mentioned before, Doroodzan dam is kind of homogenous dam with 57 meter height and 993 cube meter reservoir volume. Chimney drains were used as well as horizontal drains in order to controlling seepage through the dam. As can it be seen from the Figure 1, 12 new piezometers, NP_1 to NP_{12} be used in order to monitor the position of phreatic surface and seepage behavior through the dam. By monitoring some of the old piezometers, it is observed after 1997 which one impermeable vane was grouted, some longitudinal cracks were carried out in left abutment. As a matter of fact, phreatic line which caused by seepage situation through the body, piezometer C_5 which is one of the initial piezometers in left abutment showed a significant increase [7].

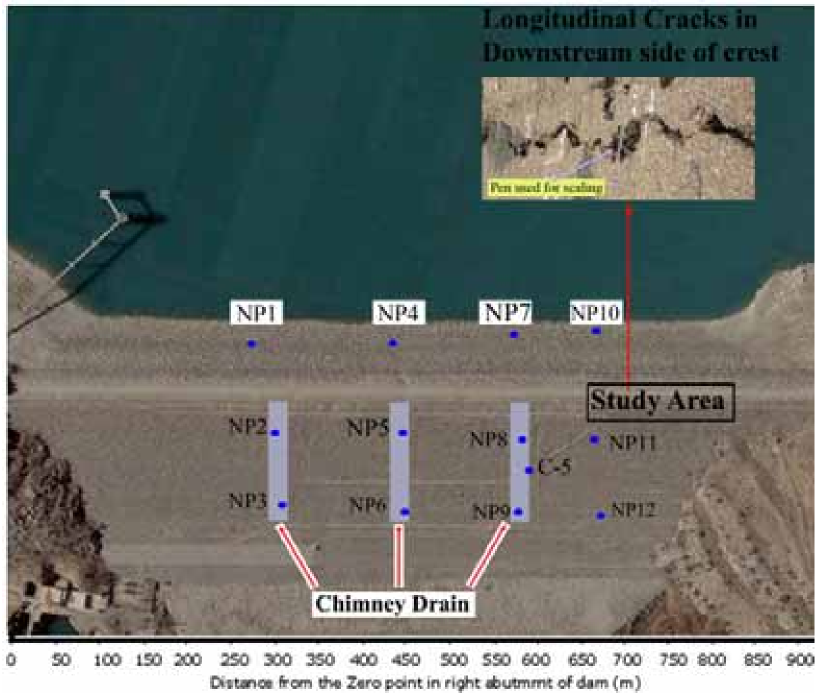


Figure 1: Location of study area and dam equipments

Field observation and literature review of cracks in Doroodzan dam

To start with, during first operation in 1972 of Doroodzan dam, small and large crack were observed in the left abutment of crest. It is always advisable to put down test pits to be sure that a crack is actually vertical and longitudinal and not a surface manifestation of inclined crack cutting through the dam core. If a crack is of appreciable depth and length, the engineer should try to prevent it from filling with surface water during observation and before it is sealed. Due to the test pit on crest location, it has defined that those cracks were not extend deep [5]. According to the results of test pit, the chief engineer did not order any injection or stabilizing method for available cracks in that time. However, in 1992 an impermeable vane was grouted there in order to reduce the water leakage from the left abutment. A recent research by Torabi, 2002 has illustrated, not only it was not useful to reduce the amount of leakage discharge but also it was one of the most important reasons of further cracks whereas during 1998 up to 2001, more than 72 new longitudinal cracks were appeared between $0+600$ and $0+800$ meter from right abutment in the left abutment [6]. Figure 2 shows some of the cracks in downstream side of crest in left abutment of Doroodzan dam.

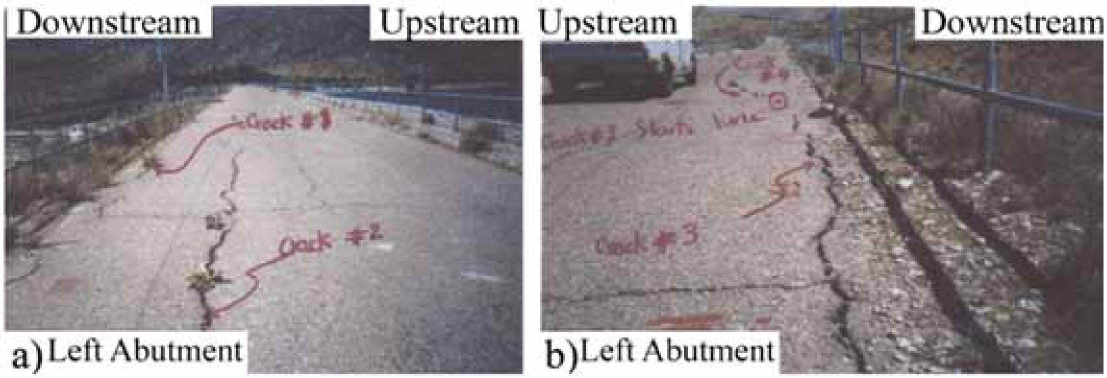


Figure 2: Longitudinal cracks in study area

New cracks not only located in surface layers but also this time cracks penetrated through the cores. So new test pits have done to find cracks direction and depth [5]. Moreover, test pits were conducted in Doroodzan dams to find more about crack direction. There is some evidence where it can be seen changing water level in reservoir did actually lead to changing in cracks width. For instance, by filling or drawdown of reservoir crack width changed and become more serious problem throughout operation years. Furthermore, in dry seasons which the level of reservoir did not have any significant increases, only small change in crack size were observed. As it can be seen from the Figure 3, initial countermeasure liquid asphalt was grouted to filling between cracks.

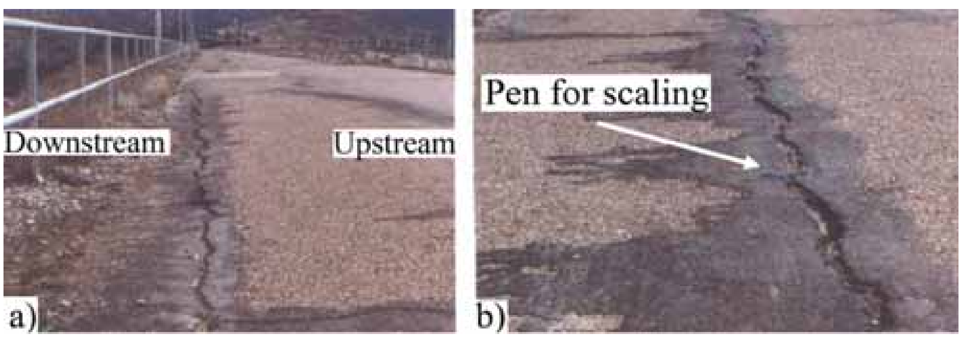


Figure 3: Stabilizing of cracks with grouting liquid asphalt

Recent study has illustrated that there is only one possible reason for these cracks is grouting performance of impermeable vane in left abutment of dam. [6]

Problem definition

The amount of cracking which will develop at a given dam depends on the magnitude of the strain imposed and on the deformability of the embankment. Due to the fact that, the amount of cracking significantly depend upon to embankment properties, it has turned to a vital part of dam stability to find proper perception of changing in material behavior which might be changed in time of wetting. Consequently, uncontrolled seepage is one of the most possible reasons of instability of earth fill dams because in quick view material wetting leads changing in material properties. Such seepage could be raised from different matters such as pipeline breakage or unsuitable draining system and also transmitting water through the both longitudinal and transverse cracks. The bigger saturation zone become, the less factor of safety evaluated. Consequently, by expanding saturation zone downstream will be more vulnerable to sliding. Furthermore, water always percolating through the pervious gravel/rock fill shell enters into the core and travels along the path of least resistance created by the presence of gravel clusters containing relatively small amounts of plastic fines [8].

RESULTS AND DISCUSSION

The most reliable piezometers which can be mentioned here are NP_1 to NP_{14}. As could be seen from the Figure 1, they were located in 4 transverse and 3 longitudinal directions. Due to the fact that NP_3, NP_6, NP_9 and NP_{12} placed after the chimney drain, consequently, changing in water level in reservoir should not have any influence on water head in these piezometers. However as it is monitored after grouting impermeable vane from the Figure 4, NP_{12} showed a different behavior. In fact increasing in water level in reservoir did actually lead to increasing in NP_{12} piezometric head. It could be due to expanding saturated area which made by water infiltration from left abutment.

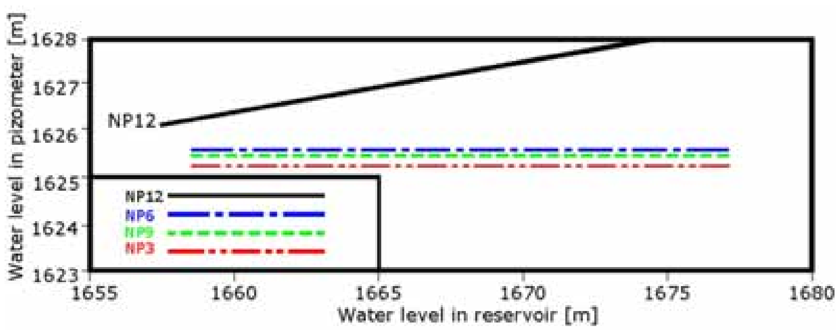


Figure 4: water head change in piezometers NP_3, NP_6, NP_9 and NP_{12}.

Effect of grouting impermeable vane on amount of run off

After exploration of abutment leakage condition which was from loan rock, in 1992 both right and left abutments, an impermeable vane was grouted [7]. Since after grouting in left abutment, a small stream in downstream defined which flow to the toe drain of dam. The amount of leakage discharge is directly related to the water level in reservoir. This can be seen in Figure 5.

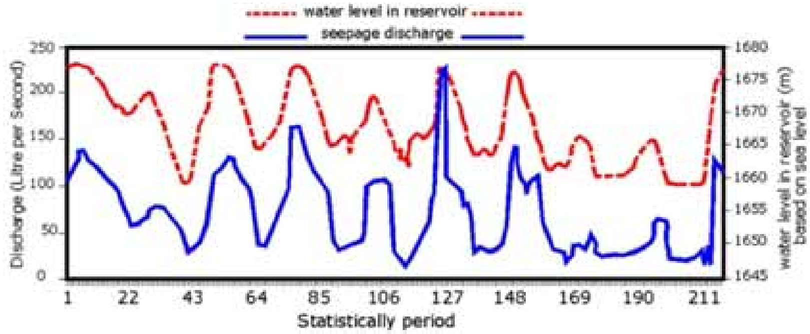


Figure 5: Directly relation between both water levels in reservoir and leakage discharge in left abutment

In glimpse, grouting impermeable vane leads to more vulnerable slopes in downstream, caused by expanding the saturated zone which has depicted in Figure 6. In fact between $0+600$ and $0+800$, leakage caused a significant change in material properties and actually it gives rise to increasing in the number of longitudinal cracks in the left abutment of Doroodzan dam.

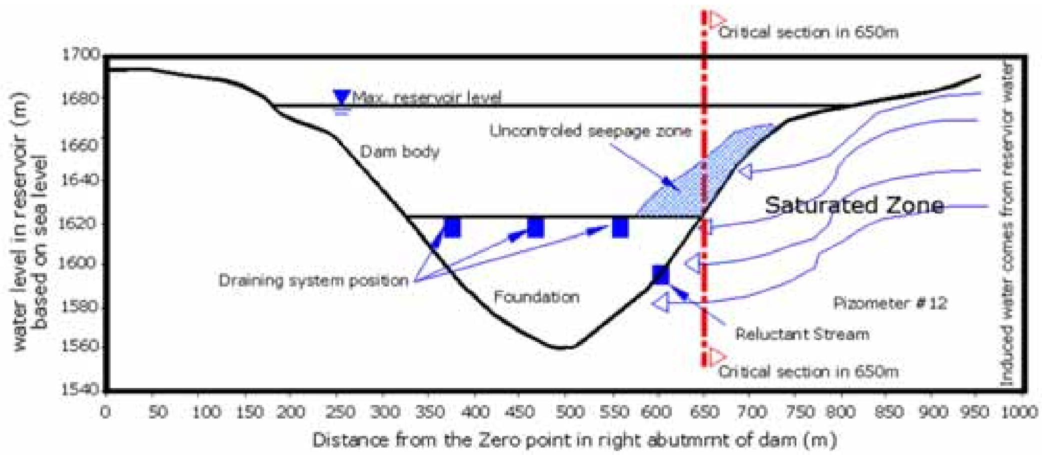


Figure 6: critical section in Doroodzan dam

Undoubtedly the amount of leakage is related to water level in reservoir. When filling reservoir has done, consequently, water stays in the study area (650 meter from the zero point in the right abutment) until next draw down, so it could be very dangerous for downstream stability. Perhaps it reflects decreasing in shear strength parameters of downstream material in study area. Besides, it is worth being noting that by increasing in area of saturated zone, problem become more serious. Figure 7 shows the change in C_5, one of the old piezometers in study area. As can be observed from this graph after the impermeable vane was grouted in 1992, water head in this piezometer sharply soar from 1645 to 1654 and it remains constant in 1654. It is worth being mentioning that this piezometer might be damaged and it has not been working throughout these years.

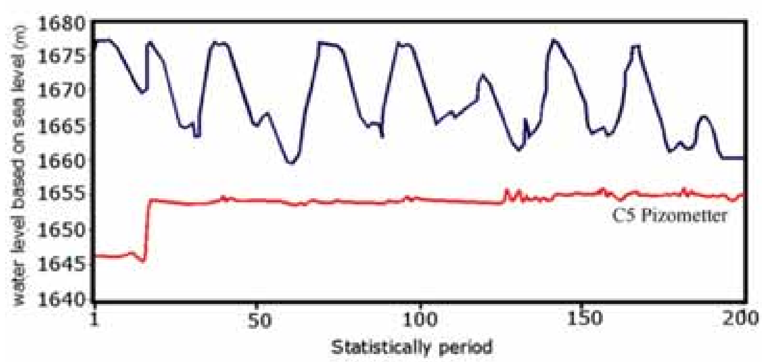


Figure 7: Changing water head in C_5, before and after grouting impermeable vane

Numerical modeling

Limit equilibrium slope stability analyses were used to model the failures using the soil properties from the field and laboratory testing programs. The modeling was done using Slide5.0 (proprietary software products of Rockscience International, Ltd.,). Slide is a 2D slope stability program for evaluating the safety factor or probability of failure, of circular or non-circular failure surfaces in soil or rock slopes. Slides were used for all complex geotechnical problems because external loading, groundwater and support can all be modeled in a variety of ways. In present study, sensitivity analyzing was used to explain about the effect of material parameters changing on factor of safety of downstream. Based on maximum level of water in reservoir during three of the piezometers which were in conjunction with critical section of study are in 650 m distance from zero point in right abutment. On the one hand, water levels shown in Table 2 give rise from maximum head of piezometer during our statistical periods.

Table 2: Relation between Reservoir level and piezometer head placed in left abutment

Reservoir level	NF.10	NF.11	NF.12	
1676.89	1671.85	1629.57	1627.58	Max.
1658.77	1652.02	1627.72	1625.8	Min.

Effect of Downstream Material properties on Stability

By using sensitive analyzing and based on changing in material parameters such as saturation unit weight, internal friction angle and cohesion, factor of safety for downstream was calculated. It is worth being mentioning that effect of horizontal seismic coefficient was considered in order to find more about seismic stability in present situation. Table 3 provides data about different parameters and differential increasing or decreasing amount for download material.

Table 3: Sensitivity analyzing parameters

	Material used in downstream side			
#	property name	Base value	Decrease. Min	Increase. Max
1	cohesion	25	10	5

2	Phi	25	10	5
3	Unit weight	18	0	4
	Applying Seismic Loading			
1	Horizontal seismic coefficient	0.3	0.3	0

Figures 8 to 11 illustrate different parameter changing effect during becoming saturate on downstream side of crest in Doroodzan dam. As a result, the most influential parameter is internal friction angle [ϕ] which by a slight decrease factor of safety sharply decreases. It could be done during saturation process. It means that by expanding the saturation zone, both cohesion and internal friction angle will decrease to their lowest level, because of leakage through the dam body and also capillarity forces.

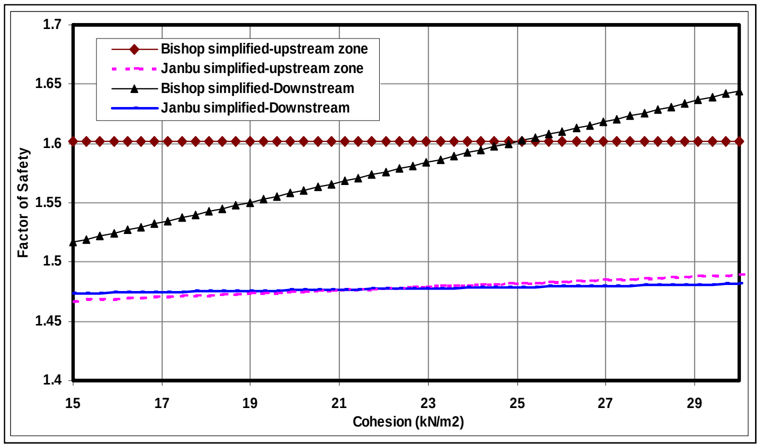


Figure 8: Effect of cohesion in downstream and upstream factor of safety based on Bishop and Janbu methods

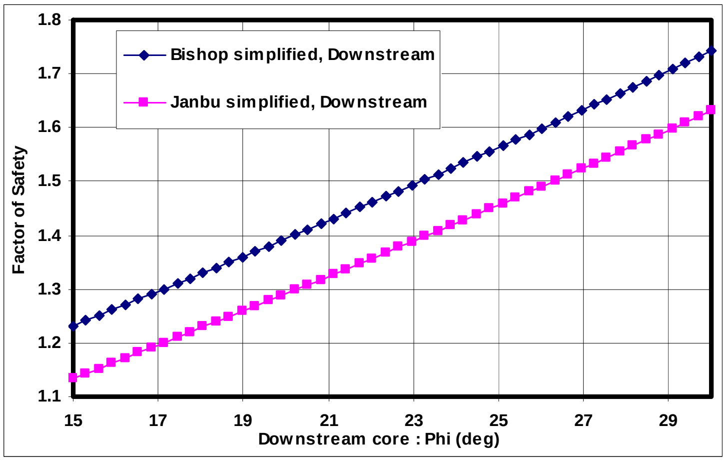


Figure 9: Effect of internal friction angle in downstream factor of safety based on Bishop and Janbu methods

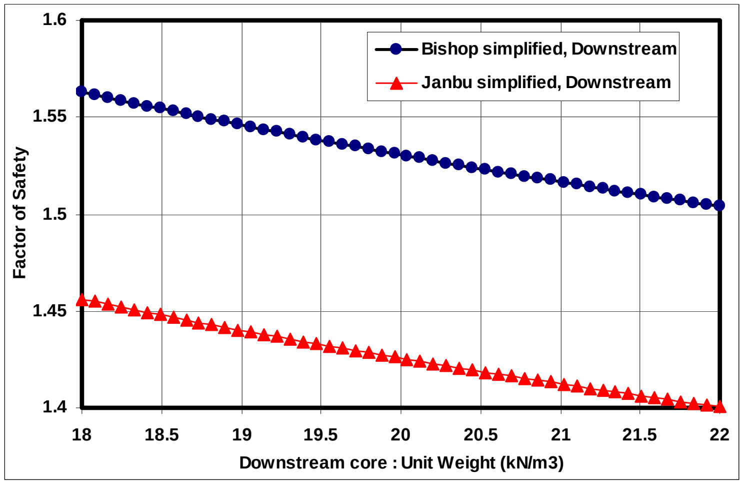
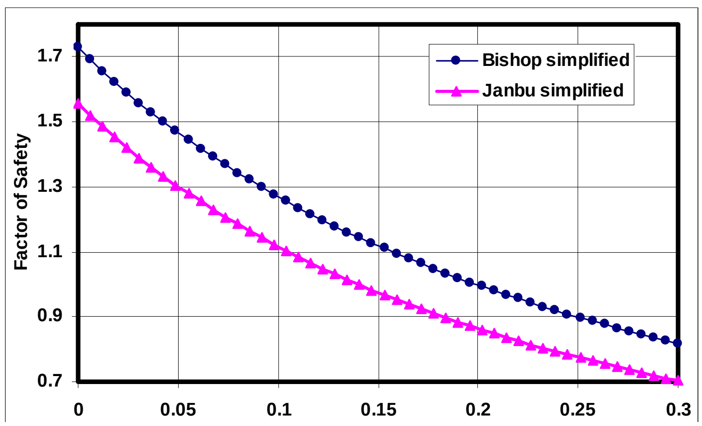


Figure 10: Effect of unit weight in downstream factor of safety based on Bishop and Janbu methods



Horizontal seismic coefficient

Figure 11: Effect of Horizontal Seismic Coefficient in downstream factor of safety based on Bishop and Janbu methods

CONCLUSION

Continuous seepage from the left abutment of Droodzan dam can cause progressive erosion and piping in future. It is more susceptible in saturated zone through the dam body. In 1992, impermeable vane was grouted in order to reduce the seepage rate but it was not succeed.. So, the impermeable vane did not work out and it turn out to a problem which caused a huge number of small and large longitudinal cracks in the left abutment of Doroodzan dam. In addition, this phenomenon reduces the cohesion between core materials or separating soil particles from each others and reduction in internal friction angles in downstream as well. Comparing parameters shows reduction in internal friction angle has the most influence on factor of safety. In fact, by decreasing the shear strength parameters in downstream, sliding susceptibility will increase, consequently, longitudinal cracks in downstream side of crest in left abutment related to some sliding is possibility in future. With expanding the saturation zone for example when the water level in reservoir stays in its highest level for a long period, so, it is inevitable to increase the number and size of these cracks. This situation could leads to a huge slide in downstream of left abutment side especially by considering seismic loading.

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