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Internal erosion under spillway: a case study

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In this paper we investigate the mechanism of the internal erosion caused in the right abutment of the Shahghasem dam's spillway. Shahghasem dam is an earthen dam located in Yasouj city, southwest of Iran. A significant hole and pipe was observed in the corner of the right abutment from upnstream view. The soil foundation is granular which is cohesionless and susceptible for internal erosion and piping in some conditions. Going through details of the design maps has shown that Lane's criteria for selecting safe dimensions of the seepage control measures have not considered. To safely control of the destructive phenomena a supportive wall is designed to attach to the left section of the spillway in order to increase seepage length and also the pipe route of the erosion should be grouted with high quality concrete.

Key words
Seepage, internal erosion, Shahghasem dam, piping, spillway

I INTRODUCTION

Seepage under hydraulic structures is very important in designing of such structures and if it is not considered, the whole structure may fail due to both effects of uplift pressure and piping phenomenon. (Sedghi-Asl *et al.* 2010, 2012).

Terzaghi (1939), Lane (1934), and Sherard et al. (1963) present a model of piping in which particles are progressively dislodged from the soil matrix through tractive forces produced by intergranular seeping water. The mobilizing tractive forces are balanced by the shear resistance of grains, weight of the soil particles and filtration. The erosive forces are greatest where flow concentrates at an exit point and once soil particles are removed by erosion the magnitude of the erosive forces increases due to the increased concentration of flow. This view of piping is the classic backwards-erosion style of piping. ''Backwards erosion'' is generally produced where a roof of competent soil or some other structure allows the formation of a bridged opening. The tractive force causing this type of erosion is directly proportional to the velocity of intergranular flow (Richards and Reddy 2007). In a different defination, internal erosion gathers four types of erosion: concentrated leak erosion, backward erosion, contact erosion and suffusion (Fell and Fry 2007).

''Internal erosion'' is similar to backwards erosion piping in that tractive forces remove soil particles. However, internal erosion is due to flow along pre-existing openings such as cracks in cohesive material or voids along a soil-structure contact. By this definition, internal erosion is not due to the dynamics of intergranular flow and the hydraulics of the problem are quite different than for backwards erosion (Lane

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1934). Rather than being initiated by Darcian flow at an exit point, internal erosion is initiated by erosive forces of water along a pre-existing planar opening (Richards and Reddy 2007).

Formulating his creeping theory, Bligh (1912) assumed the creeping length to be the sum of horizontal and vertical distances traversed by a fluid particle from the upstream bed level. Based on Bligh's theory, the hydraulic gradient is assumed to be constant in any location through the structure and equal to $\Delta h/L$ where Δh is the difference between upstream and downstream water levels and L is the flow creeping length. Also, it was recommended that the creeping factor $C=L/\Delta h$ be equal or more than an optimum value so that the structure could resist against any internal erosion (Lane 1932). This method provides a highly conservative value for the safety factor. Boiling and piping phenomena occur in cohesionless materials cohesive soils especially clean-fine sand. Due to lack of cohesion and low effective stress between the particles, sand grains are easily floated and migrate along with seepage flow. Lane (1932), after studying more than 200 dams worldwide, proposed his weighting-creep theory which postulates a higher head drop in the vertical direction than horizontal (see Leliavsky 1965). To meet this, weighting factors of 0.33 and unity were assigned to the horizontal and vertical directions, respectively. Also, the creeping line is considered horizontal if it makes an angle less than 45 degrees with horizontal; otherwise, it is considered vertical. The Lane method yields lower values for uplift pressure than Bligh's. Table 1 shows the creeping factor for various foundation materials. This paper aims to investigate the reasons for piping the right abutment of Shahghasem spillway and finally provides remedial actions to control this phenomenon safely.

Material of foundation	Safe weighted creep ratio (Lane's value)	Bligh's value for comparison
Very fine sand or silt	8.5	18
Fine sand	7.0	15
Medium sand	6.0	-
Coarse sand	5.0	12
Fine gravel	4.0	-
Medium gravel	3.5	-
Gravel and sand	-	9
Coarse gravel, including cobbles	3	-
Boulders with some cobbles and gravel	2.5	-
Boulders, gravel and sand	-	4 to 6
Soft clay	3.0	-
Medium clay	1.8	-
Hard clay	1.8	-
Very hard clay or hardpan	1.8	-

Table 1: Proposed creeping factor by Lane (1935) for various foundation materials (Leliavsky 1965)

II OBSERVATIONS

Shahghasem dam is an embankment dam which is located at Yasouj city, Kohgiloye and Boyerahmad province southwest of Iran. Axes length of dam at is 250m and the height of dam is 47.2m. the date of end of construction of the Shahghasem dam was 1995, and the dam was not filled due to drought period for 5 years. Recently field observation of the Shahghasem spillway has demonstrated local erosion occurred in the right abutment. Based on the geology of the dam site, in this part the predominant foundation material is marl which contains limestone with fine and homogenous grain size. The main thing is that the cohesion of this material is low, therefore is erodible. Looking at design reports showed that There was no watertight barrier between the concrete structure and the abutment or the embankment and also downstream filter to plug eroded particles. Figures 1 and 2 show the observed hole in downstream part of the spillway. With respect to time, expanding of the hole was significant. The main thing is that the seeping flow was clear water. Before the repair work, there was no remedial or safety measure to control this phenomena. Up to now, remedial measures have not performed yet. Figure 3 shows the location of seeping hole in the right abutment of the weir.

Figure 1 : Ogee spillway of Shahghasem dam

Figure 2 : piping hole and seeping flow between abutment and concrete body

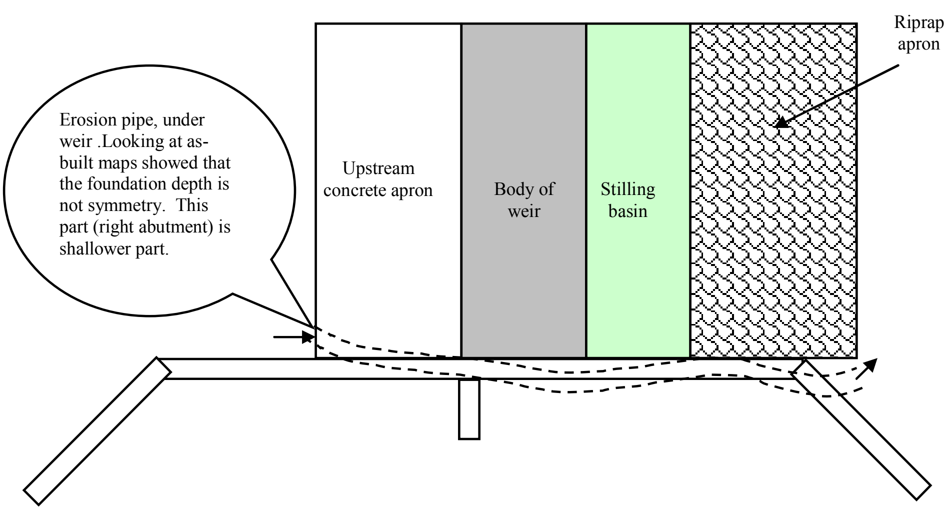

Figure 3 : The location of seeping pipe under right abutment and concrete body on the plan veiw.

III RESULTS AND DISSCUSIONS

The quantity of the seeped water was about 7 lit/sec which increases gradually with time. Since the soil foundation is erodible and susceptible therefore, there is a necessity to do remedial measures. As it mentioned before, the Lane's empirical method is used to evaluate piping phenomenon. Based on the dimensions of the wire and creeping length, Δh and L were determined by using as-built maps as 6 and 15m respectively. Using lane's criteria the C was computed 2.5 which are quite less than recommended values by Lane (1934). The recommended value for this type of soil is 4, so by this soil the creeping length should increased to 24. Form hydraulic and structural view point, concrete wall attached to main wall of spillway should be considered. The best case is an integrated approach to control erosion as well as piping. The first part is to attach a concrete wall to the main wall provided that the Lane's criterion is satisfied. The second remedial action is to fill the hole pipe with concrete and cement. Figures 4 shows final design and remedial action of piping under Shahghasem dam.

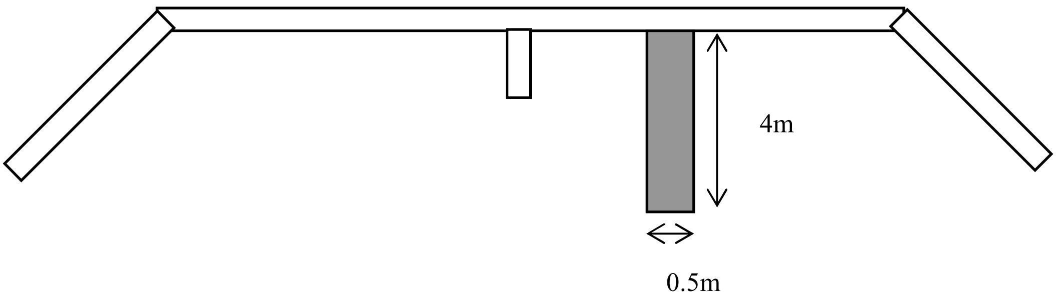

Figure 4: remedial measure for controlling piping at left side of spillway (attached wall is colored section)

IV CONCLUSIONS

Simple laboratory procedures are available to assess piping potential in cohesive materials, but no such methods exist for noncohesive soils. In this research, piping type is categorized as internal erosion. According to Lane's creeping factor, practical remedial measures which can be prescribed for this special case is to first: attaching a secondary wall to the left wall of spillway as figure 3 and second: filling the piping hole with high quality cement.

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