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# Characteristics of Non-Cohesive Embankment Failure

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**Abstract**. Embankments are important infrastructure built to provide flood control. They also present risks to property and life due to their potential to fail and cause catastrophic flooding. To mitigate these risks, authorities and regulators need to carefully analyse and inspect dams to identify potential failure modes and protect against them. This paper presents morphology of an embankment study and its sediment behaviour of different grain sizes after the embankment fails. A few experiments were carried out for the embankment size of 1V:3H with different sediment grain sizes; medium and coarser sand. The embankment material used is non-cohesive soil with the embankment height of 0.1 m. The embankment is tested with inflows rate of $Q$ = 0.8 L/s. Experimental results showed the peak discharge for the same inflow rate is affected by the shape of embankment breached. The peak discharge of medium grain size of the embankment is highest, which gave 3.63 L/s in comparison with a coarser embankment. This concludes that the embankment morphology patterns are dissimilar to each other. The flow and dimension of embankment are shown to influence the characteristics of embankment failure.

## 1. Introduction

Mudflows and flash flood can happen anytime due to embankment failure. Property damage is certain and there is risk of loss of life to population within the area hit by floods. Embankment dam breaching is due to water overtopping the dam, causing the breach. It is one of the major causes of the problems occurring worldwide due to inadequate spillway capacity, foundation defects, and piping and seepage [1][2]. The concentration of sediment after the failure at downstream affects the flow of the river, which causes floods. The population associated near the downstream of the failure dam may have effect on the results, *i.e.* floodplains [14]. Therefore, it is critical to analyse the morphology pattern of sediment transported downstream to minimize the impact of water washout to people and environment.

The failure of embankment dam are influenced by several factors such as overtopping flow, improper design of foundation and construction [4]. There are two main causes of the breach problems, *i.e.* due to overtopping and piping failure [10]. Overtopping is responsible for the majority of dam failures [1][11][13]. In analyzing the embankment failure, the two main primary tasks are involved, which are a) determination of the outlet hydrograph, and b) patterns of the failure modes.

Many studies have been carried out to understand the failure mechanism of an embankment due to overtopping. Understanding the various failure mechanisms that contribute to the breach process is essential in properly assessing the risk of failure. This is because natural processes such as soil erosion, sediment transport morphology are highly complex. There were many numerical models developed since 1950, and although the process is challenging, it is important for hydro scientists and engineers to understand the process [7]. Sediment transport, for example, play important roles in various geological phenomena. Thus, it is important to find out the condition of the sediment transport that occurs during the embankment failure, particularly on a non-cohesive or mixture sediment material.

## 2. Embankment Breaching

Materials or sediments in natural water are classified into two types, which are cohesive such as clay and silt; and non-cohesive type such as sand, gravel, coarse silt and cobble. Both types of particle have its own properties. Cohesive sediment will undergo sediment transport mainly in floc; floc is formed due to large electrostatic forces. However, for non-cohesive sediment, the process of sediment transport will occur in disperse formation [6]. Therefore, in analyzing sediment formulae transport, a few parameters need to be established such as Shields' particle mobility, grain size, bed slope, water depth, flow velocity, and sediment concentration. The first three parameters deal with bed load transport, while the other two deal with total sediment transport.

There are three hydraulic flow regimes and erosion zones for flow overtopping an embankment, as shown in Figure 1 [5]. A highly erodible zone occurs when the subcritical flow happens on the dam crest. At this stage, the energy slopes, velocities, and tractive stresses are relatively low and cause the embankment crest to erode, followed by a transition to supercritical flow on the downstream portion of the crest. As a result, the energy slopes and tractive stresses are higher in this region and erosion is sometimes observed at the knick point at the downstream edge of the crest. When the crest is paved, uplift of the paving materials is also possible if the pavement is underlain by permeable materials. The 3rd zone of erosion is the downstream face of the dam where the flow accelerates at supercritical depths until reaching uniform flow conditions.

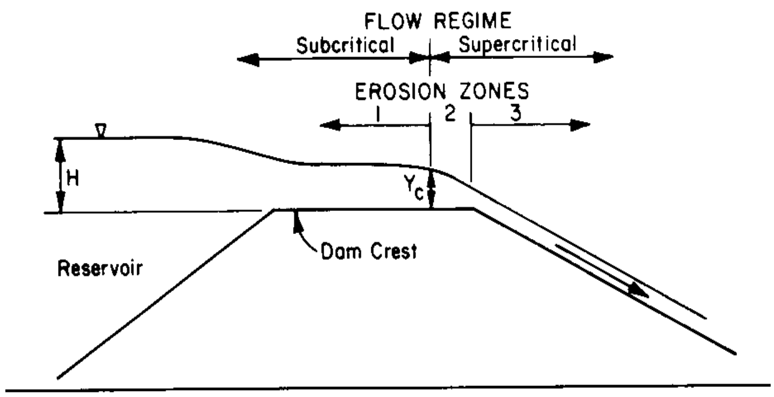


**Figure 1.** Classification of flow regimes and erosion zones in an embankment overtopping [5]

The process of embankment failure accelerates the sediment entrainment into the flow and causes significant embankment erosion. In many cases of dam failure, the bottom of the breach will continually be eroded downwards until it reaches the bottom of the dam. Thus, suspended load is gradually transported downstream with respect to time and caused sand deposition until the embankment reaches a maximum failure. The formation of sediment typically changes along the length of the channel due to continuous flowing water [12]. There are variety of shapes which can be used to represent breach morphology, including rectangular, triangular, trapezoidal, parabolic, and semicircular, among others. At the moment, there does not appear to be a method by which an exact breach shape can be computed.

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## 3. Experimental apparatus and procedures

The breaching test for the embankment sand took place at the Hydraulics and Hydrology Laboratory, Department of Hydraulics and Hydrology, Faculty of Civil Engineering, UTM. The test was conducted in a 11 m long × 0.6 m deep × 0.5 m wide flume (Figure 2). Non-cohesive soil is used to construct the 0.1 m high embankment. The width of the embankment crest is 0.1 m as well. The face slope of the embankment is fixed at 1V:3H, as shown in Figure 3. The breaching test uses a constant inflow rate of $0.8 \times 10^{-3}$ $m^3/s$. The inflow is kept constant until the overtopping process started and the water then flows through the notch above the dam crest, as shown in Figure 4. The flow rate from upstream to downstream area passes through the embankment dam, which is located at the middle of the channel.

**Figure 2**. A 11 m long × 0.6 m deep × 0.5 m wide flume

The initial step in the testing procedure was sieving the material of non-cohesive soil, which is in range between 600μ and 250μ. Material sieved was compacted layer by layer in the middle of flume, as shown in Figure 3.

(a) (b)

**Figure 3**. Compacting the embankment; (a) compaction method, (b) final shape of the embankment

(a) (b)

**Figure 4**. Model setup; (a) a handmade notch (b) a V-notch to measure discharge

Once the initial breach is formed, the hydrodynamic force continues to enlarge it by eroding the soil material. The eroded sediment was transported by water downstream. It must be emphasized that little is known about mechanic of non-homogeneous sediment transport especially under highly dynamic conditions, such as existing for dam breach. Thus, one has to resort to employ sediment transport method based on experience from alluvial streams.

During the experiment, video cameras were used to record the temporal progression of breaching patterns. The discharge is then measured using a V-notch with a $90^0$ angle, located at the outlet of the flume. The discharge is calculated using the formulae,

$$Q = \frac{8}{15} \times C_d \times \sqrt{2g} \times \tan\left(\frac{\theta}{2}\right) H^{\frac{5}{2}} \tag{1}$$

where $Q$ is the rate of discharge ($m^3/s$), $C_d$ is the coefficient of discharge, $g$ is the acceleration due to gravity, $\theta$ is the angle of the V-notch and $H$ is the height of water flowing through the notch. Equation (1) is then used to obtain the hydrograph by plotting the discharge value against time taken during the test. The value of peak outflow and time to peak are also determined from the hydrograph obtained. Meanwhile, the water depth at the V-notch is measured using a point gauge to calculate the outflow discharge.

## 4. Result and Discussion

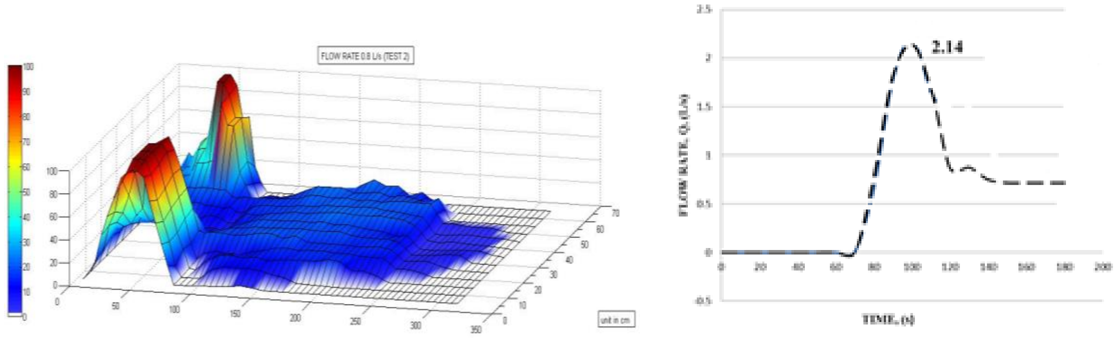
The breaching process starts when the flow enters into notch as the result of overtopping flow. This is due to the fact that the water forces the embankment material to become eroded. Also, the effect of hydrostatic force behind the embankment triggers the embankment material to be transported away due to instability, causing further failure to embankment. After breaching process is complete, sediment transported by the stream will form bed lock as shown in Figure 5. The formation of sediment transports were varied from each test because of uncertainties in the experiment.

**Figure 5**: A plan view of a breached embankment

When the embankment starts to breach, it continues to erode parts of the embankment. The process was initiated by the weakness of the sediment. In this study, the final shape of the breached embankment was almost symmetrical between both sides, which is similar to a result found in [9]. Additionally, the study has found that only half of the embankment width eroded when using lower inflow rate, which has similar outcome as [8]. Figure 6 shows the sediment deposited pattern at downstream after the embankment has completely breached.

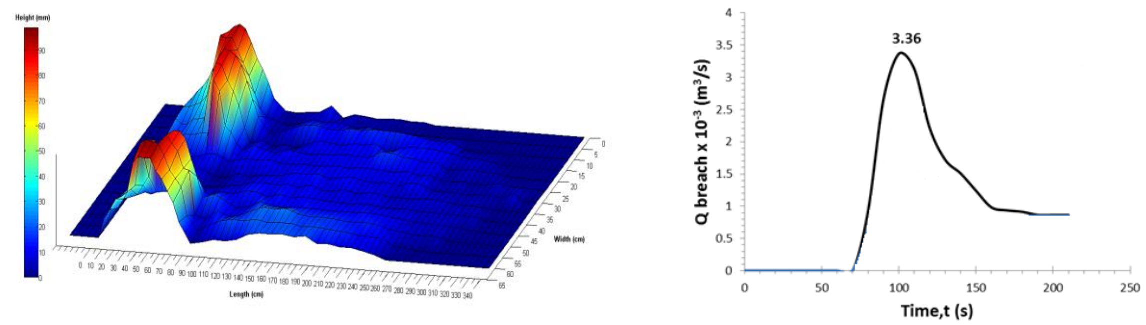
**Figure 6**. Failure and sediment pattern at downstream after completely breached

Figures 7 and 8 show a plot of breached morphology and breached hydrographs after the embankment has completely breached for medium and coarser embankments. The heights of sediment were recorded and plotted in MATLAB. The length and height of sediment transported downstream are measured at 5 second interval. The result of peak flow rate obtained was approximately at 2.14 $m^3/s$ at 95 s for the medium embankment, while for the coarser embankment, the peak flow was recorded at 3.36 $m^3/s$. The morphology of breached sediment occurred at the middle and is shaped like a trapezoidal from front view. This might be due to the initial shape of v-notch built at the crest of the embankment to trigger the erosion. The water started to flow through the initial v-notch to erode at the middle of the notch until the embankment fails.




(a) Sediment morphology (b) breached hydrograph

**Figure 7**. A breached morphology and a hydrograph of a medium embankment after the failure




(a) Sediment morphology (b) breached hydrograph

**Figure 8**. A breached morphology and a hydrograph of a coarser embankment after the failure

Findings from both experiments showed that sediment morphology patterns were various and inconsistent because of the implementation of different inflow rates and embankment sizes. From the morphology plotted, it could be concluded that the higher the flow through the embankment, the more sediment will be transported to downstream. This occurs due to higher flow rates that affect the time taken for the embankment to fail.

## 5. Conclusion

Sediment deposited at the middle failure showed that the surface of the sediment transport was more even as compared to the surface of the deposition at the upper downstream of the channel. The width of the sediment deposition also became narrower as compared to the upstream that transported too wide towards the wall of the channel. As a result, sediment deposition towards the downstream tends to form tapered shape. The results showed a similar trend of hydrographs but the profile of sediment morphology was different. It can be concluded that the pattern of sediment transport is depending on factors such as material, degree of compaction, flow rates, embankment size and slope. Even though the results have shown the similar pattern of hydrographs, the morphology profiles could not give the similar results.

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