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LITERATURE REVIEW FOR THE DEVELOPMENT OF DIKE'S BREACH CHANNEL MECHANISM CAUSED BY EROSION PROCESSES DURING OVERTOPPING FAILURE

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ABSTRACT

The structures of the dam or dike were held long times ago to withstand against the overtopping water preserved in front of the upstream of the dike. It is represented the first hydraulic structures in history and effect on the development of irrigation engineering. Due to their objectives in reserving water, they are exposed to different failures such as overtopping failure, piping failure, sideslope failure and others. During the overtopping failure, an initial breach channel is initiated inside the dike body and extended downstream and upstream slopes of the dike due to several geotechnical parameters. The whole reservoir water is transferred from the upstream to downstream parts of dike as a result of breach failure and thus could affect on lives and properties. The engineering scientist has focused on understanding the mechanism of the breach channel development and tried to conduct a mathematical equation as well as an experimental test to observe overtopping failure. This review paper explains three types of equations; in which empirical equations, parametric equations and numerical software equations also determine the discharge of breach channel of dike. This paper is aimed to review the possible effect of different geotechnics parameters such as soil materials, dike dimensions, and scale factor on the development of erosion pro-cess during the overtopping failure. The literature review shows that the development of breach discharge is dependent mainly on some parameters more than the others. The soil type and soil grain size have played a significant role in decreasing or increasing the erosion process inside the dike.

1. INTRODUCTION

The engineering of embankment dike had tak-en a significant part of the story of civilization. Cultures inclination or declination, which are dependent on dike construction, had a great relationship with dikes. The usage of dike construction had been extended long times ago since the damage of public property and peo-ple lives increases during large flooding, especially when there are no flooding resistance facilities. Several factors such as changing climate condition and lack of maintenance are led to dike's failure all over the world such as the Yangtze flood in China 1998, the Elbe flood in Germany 2002, the New Orleans flood in 2005, the Mississippi Flood in 2008, the Pakistan flood 2010 and the Queensland flood in Australia in 2011. The good engineering maintenance design is affected widely in older and newer dikes to improve and increases the live load of dikes although it could be sometimes a challenging task in e.g. 7,500 km of dikes throughout Germany [1] or 5,500 km simply along the Mississippi River.

The new dike construction has features of well design maintenance method in terms of replacing the older soil while most of older dikes are suffering from the obscurity of engineering design such as dumping additional soil above the existing one to improve the stability of soil. The dike is subjected to different types of failure such as overtopping, piping, sideslope failure and others. The sideslope failure occurs in areas where moderate rainfall inten-sity [2-3] and large intensity is expected such as Malaysia [4], Hong Kong and Brazil [5]. The breach of dike is occurred due to water overtopping above the crest of the dike. It is affected by several geotechnical and hydraulic factors such as dike materials, dike dimensions and dike compaction [6-8]. It is essential to determine the breach discharge of dike construction in order to eliminate the effect of overtopping failure, understanding the nature of breach process, and take necessary actions to determine time needed for overtopping to reach cities.

1.1 Dike's constructions and breach

1.1.1 Dike definition

A dike is an embankment constructed of earth or other suitable material that used to prevent or reduce the effects of water damage on people and property, to control flow in con-junction with floodway, to maintain the aquatic life of fish and other organisms and to provide the suitable environments for the produc-tion of food such as rice. The dike is constructed from loosely placed sediments like gravel, sand, silt and clay. They are simple in construction with no core or surface seal built inside dike body. Despite of virtual similarities between dike and dam, there are some major differences between them in terms of engineering design and objectives. These significant differences had played important roles in determining the main functions of two structures. The dike has a small height in comparison with dam. The head differences between upstream and downstream of earth dams are generally larger than those of dikes [9]. The construction of dikes is normally built on poor foundations because their soil construction is heterogeneous and often taken from vicinity of river bed [10]. The cross section of dike is shown in Fig. 1 [11].

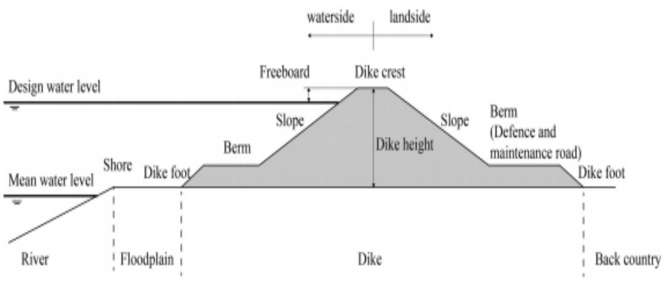

Figure 1: Typical cross section of dike (adapted)

1.1.2 History of dike construction

The construction of dike had been extended since long time ago. It was first built on small hills to prevent damages for people and property from floods. Later, it was initiated from soils adjacent to rivers and the sea and then considered as simple earth wall "dikes". Since that time, dikes were subjected to a series and dangerous failures due to deficiencies in hydrology, hydraulics and geotechnics information. The recent development in the field of river engineering has provided good service in navigation route and protecting settlement and agricultural lands from flooding.

The first preliminary shape of dike was built in Europe since the early middle ages, especially in the9th century on the Rhine River and on the 12th century at the Elbe River [12]. In Netherland, the first dike construction had been extended since the 13th century. Other large dikes were built in Germany and Netherlands at that time. These large dikes were consisted of two walls of simple fences with backfill material of loose soil. Dikes, from the middle ages, have a feature of varied soil's content since soil came from local barrow areas. Knowing the challenging and dangers surrounding the dikes, the required engineering steps to counter failures have developed since the 18th century. The first book described the construction requirements had published by Albert Brahms (1692-1758) and still consid-ered as the reference until now [13].

The applications of the first hydraulic structure and River Engineering in Switzerland could be found in the sentence [14]. The construction work of dike is difficult because of an absence of complicated tools. The linth work in Switzerland is one of important water projects that held in 1784. It serves as a diversion of the River Linth into Lake Walen and its canalization between Lake Walen and Lake Zurich. The diversion is useful to overcome the danger of flooding threatened the nearby towns and protect the agricultural land. The big increase in the proportion of dike construction happened in the 19th century in parallel with the steam engine era revolutionizing due to various vehicles and construction equipment. Different canals constructions are initiated all around the world such as the Suez Canal, opened in 1869, or the Panama Canal, opened in 1914 and etc. These Canals have contributed primarily in water diversion pro-jects into lakes or sea.

1.2 Overtopping failure

Overtopping failure is defined as water spilling over the dike crest and lead to erode the channel along the downstream face of the dike [15]. Overtopping failure of an earthen dike starts with head cutting at the downstream toe and develop upstream until the erosion reaches the dam crest and reservoir surface. The sediment material is transported along the foot of the dike because the shear stress of water overtopping is exceeded the critical shear stress of the dike material. The information on sediment transport could be found in [16].

1.2.1 Dike's breach process

Dikes generally consist of compacted cohe-sive soils. The nature and magnitude of material compaction play an important role in the developing dam breach during overtopping due to increase erosion rates in the dike body [17]. Many descriptions have been noticed by researchers to describe the dike breach process that occurred during the water overtopping. Visser [18] studied the behavior of erosion process for non-cohesive embankment dike. He constructed laboratory tests in flume with sand dike height of 0.6 m and field experi-ments of 2.2 to 3.3 m. He discovered five stages described the breach process in sand dikes, which are similar to stage process described by Zhu [9] for noncohesive dike embankments. The clay dikes are defined as earhfill embankment constructed with cohesive materials (clay, silt). Fig.2 shows the stages of erosion process on sand and clay dikes during the overtopping failure:

Stage I ($t0 \leq t<t1$): The steepness of the ini-tial side slope angle is increased to a critical value of β1 as a result of water flow inside the initial breach that eroded materials away from inner slope and crest of dikes. At this stage, the flow velocity in the upper part of inner slope is less than in the lower part and thus, depending on soil properties, lead to increase the steepness of the side-slope angle.

Stage II ($t1 \leq t<t2$): the constant side-slope angle β1is continued through stage II with decreasing in width of the dike's crest. The erosion process in dike body is increased due to combination of breach flow shear erosion, fluidization of the surface of the slope, scour of the dike foundation and headcut undermining, and discrete headcut slope mass failure. The breach outflow is increased at the end of this stage.

Stage III ($t2\leq t<t3$): the top of the dike is lowered more in this stage with the same constant sideslope angle β1. The width of the breach is increased due to rapid increase in breach flow that leads to accelerate the erosion rate. At the end of this stage (t3), the dike body is completely washed out down to the dike foundation or to the toe protection.

Stage IV ($t3 \leq t<t4$): In this stage, the breach outflow is critical in which the breach erosion is increased laterally during this stage. The erodibility of the dike base is an important parameter for increasing the breach growth in vertical direction. Visser [18] distinguished three types of breaches for Stage IV and Stage V for sanddikes and applied later by Zhu [9] for claydikes. The water level in the downstream of dikes starts to increase and therefore effects on breach channel outflow.

Stage V ($t4 \leq t<t5$): the lateral erosion is en-larged in this stage due to subcritical flow in the breach. The erosion process will stop at t5 because of small velocity in the breach and thus no more soil will erode from either the dike body or the dike foundation. The erosion process will usually continue at t6 until the wa-ter level in the upstream part of dike equals that in the downstream face. Based on Visser [18], the submerging of polder may occur, in a small area of polder, in each of stages I, II and III, especially in stage III, where the breach channel outflow is small in I and II stages. According to these observations, the discharge of breach channel outflow, due to erosion pro-cess, are ignored by the authors. Despite of small breach channel outflow in stages I, II and III, the early predictions for these stages on people and property are substantial. Large numbers of people could be saved, through evacuation process, before the huge increasing of the flow amount inside the dike breach. On the other hand, from the physics point of view, the study of breach channel outflow in the first three stages (I, II and III) is important due to their complicated and different characteristics for different dike materials.

2. BREACH AND SEEPAGE MODELLING

The discharge of breach dike's channel during overtopping failure could be estimated by three mathematical methods: empirical equations, parametric equations and numerical software modeling.

2.1 Empirical breach equation

Empirical breach models are considered as the simplest approach to dam and dikebreak modeling. These models are formed from a single or series of regression relationships obtained from either test case studies or observed historical dam failures e.g. Wahl [19]. Different parameters are used as input in empirical equations such as: dam width, height, lake area and volume.

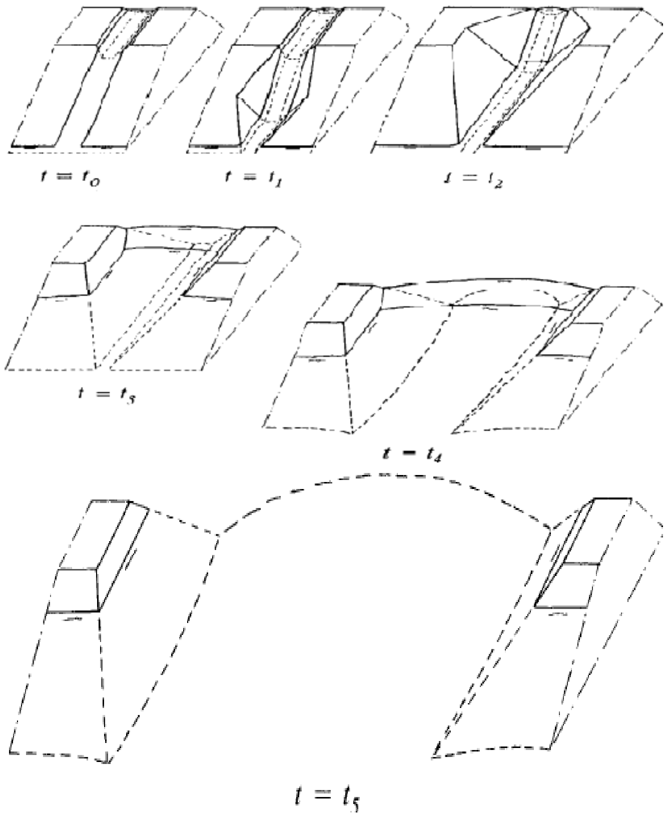

Figure 2: Stages of erosion process during the overtopping failure

If these parameters are unknown, lake volume may also be approximated using a separate empirically-derived equation. Table 1 repre-sents types of empirical equations for different scientists.

On the other hand, these equations are often including useless in achieving its goal because they failed to include basic hydraulic principles that related to breach initiation and also their input information are extracted from failed dike types and settings, including artificial constructs [20]. Although the usage of theoretical equations is stronger than standard empirical equation from the scientific issue, they cannot apply correctly because it is assumed that users can determine the erosion rate. Another disadvantage, is the limited representation the inundation maps and both hydrography and flood attenuation data.

2.2 Parametric equations of breach models

The breach discharge of dike initiated through overtopping failure could be calculat-ed through different complex and simple equa-tions. Some equations are difficult to obtain by hand calculation and need specific program software such as Shallow Water Equations (SWE) [24] and Saint-Venant Equations (SVE) [25]. The broad weir equation is con-sidered the simplest due to its easiest applica-tion in determining the breach discharge of dike.

2.2.1 Broad weir equation

The application of weir discharge could be considered as type of small over-flow dike that used to provide a higher water level, in the up-stream of the dam, for irrigation and naviga-tion purposes. It is hydraulically allowed for flow discharge measurement via flow depth where flow behaves as critical flow depth above the dam crest.

Table 1: Empirical equations for discharge of breach's channel.

Type	R^2 (If known)	No. of case: Real	No. of case: Simulat-	Empirical equation
Best fit [21]	0.790	13	6	$Q_p = 1.268(H_w + 0.3)^{2.5}$
Enve-lope[22]	-	13		$Q_p = 16.6(H_w)^{1.85}$
Enve-lope[23]	0.724	21		$Q_p = 19.1(H_w)^{1.85}$

*H_w is depth of water above breach channel;
Q_p is the peak discharge of breach channel; R is the ratio between basal breach width to breach depth.

The broad crested weir equation is a part of parametric models that required intervention from the user by using input values for of final breach dimensions (width, depth and sidewall angle) and breach development time. The dikes are acting as a broad crested weir by assuming the water flow depth is critical in the breach inlet channel throughout the dike overtopping. The transition of water from super-critical flow into critical flow is occurred when the tailwater effect, in the downstream of the dam, is small or negligible. The usage of broad equations is suitable in free flow condition where the critical flow depth is controlled and the reservoir level upstream equals the corresponding energy grade line through dam overtopping. It is also assumed the dike breach channel starts and develops as a uniform shape such as triangular, trapezoidal and parabolic cross section.

The shape of final dam breach in most dams and dikes are trapezoidal, and it could possibly be shaped during much of their development [15]. The Weir flow equation is used to calculate discharge in breach dam regarding the influence of energy losses, nonuniform velocity distribution and streamline curvature parameters. Therefore, the discharge coefficients are introduced to account all these parameters. The sketch of flow over a trapezoidal weir and is shown in Figure 3[26]

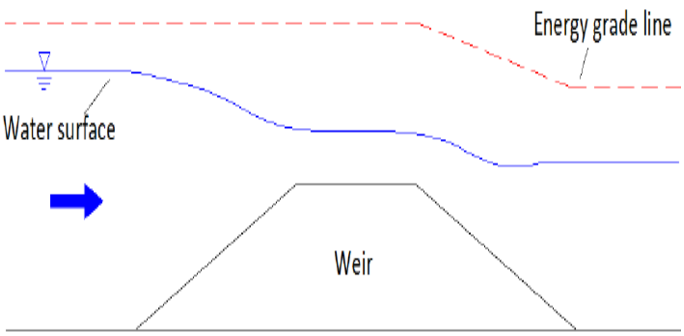

Figure 3: Water flow above the dike of trapezoidal shape

Henderson [27] presented a broad crested equation to describe the trapezoidal shape of dike during the overtopping failure:

$$Q_b = g^{0.5} H^{2.5} f \quad (1)$$

Where g is the acceleration of gravity, (H) is head over the breach and (f) is the breach shape factor. Another equation for calculating the discharge of the breach channel during the overtopping failure is introduced [28-29]:

$$Q = C_d b \left(2gH_\circ^3\right)^{1/2} \quad (2)$$

C_d = discharge coefficient, b = overflow width,

$H_\circ = h_\circ + Q^2 / \left[2gb^2 (h_\circ + w)^2\right]$ =approach flow energy head, h_o = approach flow overflow depth, and w = dike height. The discharge coefficient for broadcrested weirs is:

$$C_d = 0.43 + 0.06 \sin[\pi(\xi - 0.55)] \quad (3)$$

With $\xi = H_\circ (H_\circ + L_k)$ = relative crest length and L_k = crest length. The discharge of breach channel is changed, during the erosion process, due to variation of breach shape. The breach shape is often as circular-crested weir in case of for 2D dike breaching [30]. Therefore, the discharge coefficient for the circular crested weir will be [31]:

$$C_d = \frac{2}{3\sqrt{3}} \left(1 + \frac{3\rho_k}{11 + \Omega\rho_k}\right) \quad (4)$$

With $\rho_k = H_\circ / R'$ = relative crest curvature, R' = crest radius and Ω = 4.5. The discharge coefficient for the weir slopes of circular crested weir is discovered by Schmocker [15] as:

$$C_d = \frac{2}{3\sqrt{3}} \left(1 + \frac{3\rho'_k}{11 + \Omega\rho'_k}\right) \quad (5)$$

$$\rho'_k = \frac{H_\circ}{R} \left(\frac{\alpha_\circ + 2\alpha_d}{270}\right)^{\frac{1}{3}} \quad (6)$$

Here $[(\alpha_o+2\alpha_d)/270]^{1/3}$ is the weir angle ratio, α_o and α_d are the upstream and downstream weir angle respectively. For the standard circular crested weir ($\alpha_o = \alpha_d = 90^o$), this ratio equals 1, and $\rho'_k = \rho_k = H_o / R$. It is important to say that the duration of the dike's breach enlargement and peak discharge is dependent on several factors such as soil properties, dike's dimension and volume of water in the reservoir.

2.3 Numerical models

The development of construction dikes and dams has forces engineering scientific community to develop different methods for analyzing dikes failure due to overtopping. The major hydraulic laboratories all over the world have presented physical model studies to simu-late dam and dike break failure. The physical numerical models have been introduced to determine breach widening during dam failure. These models are dependent on several physical processes that occurred during dike failure, such as breach flow hydraulics and sediment transport, as well as soil erodibility relation-ships and structural models [32].

Factors like high computational cost have a relation directly with numerical model and sometimes contributed to reduce their widespread in breach dike applications. The widely usage of The Dynamic Wave Operational Model (DWOPER), has been appeared in the early 1980's and has several advantages for rivers applications such as irregular geometry, variable roughness parameters, lateral inflows, flow diversions, offchannel storage, local head losses such as bridge contraction expansions, lock and dam operations, and wind effects.

The scientific community also has developed programs software for determining the discharge of breach channel in dikes. These programs are specified and rarely compared to other dam's programs. A BRES model software developed by famous scientist Visser [18] has been used to calculate the breach outflow hydrograph of homogeneous dikes that constructed from non-cohesive soil materials (sand-dike). Information inserted from the Zwin channel field tests in 1898, and 1994, and the Delft university of Technology (TU) Delft laboratory experiments in 1988 and 1996 have been used by the author as sources for BRES model. The erosion process for sand dikes in this program is developed through five stages [18]. The usage of numerical programs is usually hard due to its financial cost compared with other methods [33].

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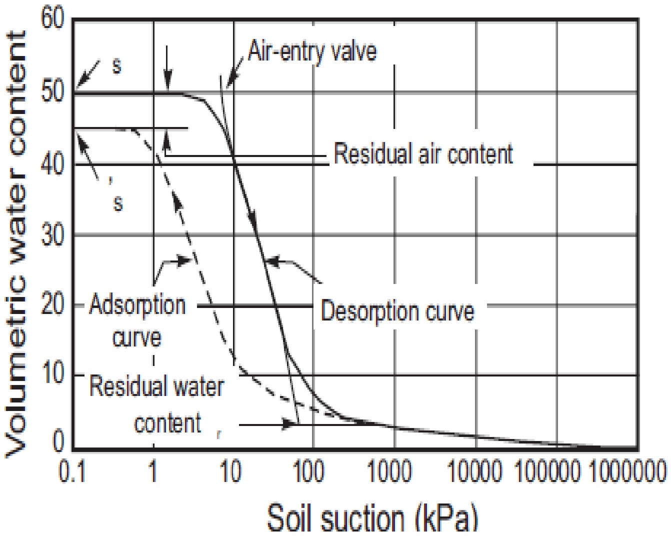

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&ÉÇÕÒÅ τ ÒÅÐÒÅÓÅÎÔÓ ÔÈÅ ÂÁÓÉÃ ÓÙÍ ÂÏÌÉÚÁÓ ÔÈÁÔ ÆÏÒ Í Ó ÔÈÅ ÔÙÏ ÃÕÒÖÅÓ ÏÆ ×ÁÔÅÒ ÃÏÎÔÅÎÔ ÓÕÃÔÉÏÎ ÒÅÌÁÔÉÏÎ ÓÕÃÈ ÁÓ ÁÉÒ ÅÎÔÒÙ ÖÁÌÕÅ ʝ!%6ʞ ÒÅÓÉÄÕÁÌ ×ÁÔÅÒ ÃÏÎÔÅÎÔ ÁÎÄ ÔÈÅ ÄÅÓÁÔÕÒÁÔÉÏÎ ÚÏÎÅ8 4ÈÅ ÁÉÒ ÅÎÔÒÙ ÉÓ ÄÅÆÉÎÅÄ ÁÓ ÔÈÅ ÐÏÉÎÔ ÁÔ ×ÈÉÃÈ Á ÌÁÒÇÅ ÐÏÒÅ ×ÉÔÈ ÁÉÒ ÅÎÔÅÒÓ ÉÎÔÏ ÔÈÅ ÓÏÉÌ8)Ô ÒÅÐÒÅÓÅÎÔÓ ÔÈÅ ÓÔÁÇÅ ÏÆ ÒÅÐÌÁÃÉÎÇ ×ÁÔÅÒ ÂÙ ÁÉÒ ÉÎ ÔÈÅ ÓÏÉÌ ÕÎÄÅÒ ÁÐÐÌÉÅÄ ÐÒÅÓÓÕÒÅ8 4ÈÅ ÄÅÓÁÔÕÒÁÔÉÏÎ ÐÒÏÃÅÓÓ ÓÔÁÒÔÓ ×ÈÅÎ ÔÈÅ ÁÉÒ ÅÎÔÒÙ ÖÁÌÕÅ ÉÓ Ó ÍÁÌÌÅÒ ÔÈÁÎ ÔÈÅ ÓÏÉÌ ÓÕÃÔÉÏÎ8 4ÈÅ ÁÉÒ ÅÎÔÒÙ ÖÁÌÕÅ ÉÓ ÔÈÅ ÏÎÓÅÔ ÏÆ ÔÈÅ ÉÎÆÉÌÔÒÁÔÉÏÎ ÐÒÏÃÅÓÓ ʝ×ÁÚÏÒÚÁÎÔÏÒʞ ÁÓ ÔÈÅ ×ÅÔÔÉÎÇ ÆÒÏÎÔ ÁÎÄ ÔÈÅ ÄÒÁÉÎÁÇÅ ÐÒÏÃÅÓÓ ÁÓ ÔÈÅ ÓÏÉÌ ÓÕÒÆÁÃÅ ʡσρΥ8 4ÈÅ ÒÅÓÉÄÕÁÌ ×ÁÔÅÒ ÃÏÎÔÅÎÔ ÉÓ ÄÅÆÉÎÅÄ ÁÓ Á ÃÏÎÓÔÁÎÔ ×ÁÔÅÒ ÃÏÎÔÅÎÔͬ ÁÆÔÅÒ Á ×ÈÉÌÅÌ ÏÆ ÁÎÙ ÆÕÒÔÈÅÒ ÉÎÃÒÅÁÓÅ ÏÆ ÐÒÅÓÓÕÒÅ8 4ÈÅ ÓÁÔÕÒÁÔÉÏÎ ÓÔÁÔÅ ÏÆ ÉÎÆÉÌÔÒÁÔÅ ÔÈÅ ÐÏÓÓÉÂÌÅ ÆÁÉÌÕÒÅ ÂÁÓÅ ÏÆ ÇÅÏÔÅÃÈÎÉÃÁÌ ÐÒÏÂÌÅÍ Ó ÏÆ ÆÉÌÌ ÏÆ ÂÁÔÃÈ ÓÕÂÓÏÉÌ ÔÈÒÏÕÇÈ ÓÕÃÔÉÏÎ ÒÅÄÕÃÔÉÏÎÓ ÓÕÃÈ ÁÓ 4ÁÎÇÅÒ Í ÁÒÔÓ ÓÁÎÉÔÙ8 4ÁÎÇÅÒ Í ÁÒÔ ÉÓ ÕÓÅÄ ÔÏ ÄÅÔÅÒÍÉÎÅ ÔÈÅ ÉÎÆÌÕÅÎÃÅ ÁÎÄ ÐÏÒÅ ×ÁÔÅÒ ÐÒÅÓÓÕÒÅ ÉÎÓÉÄÅ ÔÈÅ ÓÏÉÌ ʡσςζττΥ8 4ÈÅ ÈÁÎÇÉÎÇ ×ÁÔÅÒ ÃÏÌÕÍ Í ÁÔÈÏÄ ÉÓ ÒÅÃÏÍÍÅÎÄÅÄ ÆÏÒ ÔÈÅ ×ÁÔÅÒ ÓÕÃÔÉÏÎ ÂÅÔ×ÅÅÎ ÒÁÎÇÅ ÏÆ πζψπÈÐÁ ʡσυΥ8 $ÉÆÆÅÒÅÎÔ ÌÁÂÏÒÁÔÏÒÙ ÅÑÕÉÐÍ ÅÎÔ ÉÓ ÕÓÅÄ ÔÏ ÐÒÅÄÉÃÔ ÔÈÅ 3 7 ## ÓÕÃÈ ÁÓ ÆÉÌÔÅÒ ÐÁÐÅÒ Í ÅÔÈÏÄ ʡσφΥ ÁÎÄ ÔÈÅÒÍ ÁÌ ÃÏÎÄÕÃÔÉÖÉÔÙ ÓÅÎÓÏÒÓ ʡσχΥ8

2.4.2 Estimation of SWCC

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$$\theta_n = \frac{\theta_w - \theta_r}{\theta_s - \theta_r} = \left(\frac{\psi_b}{\psi}\right)^{\lambda_\psi} \quad \text{for}\ \psi \succ \psi_b \qquad (7)$$

Where θ_n = normalized (or dimensional) water content, θ_s , θ_r and θ_w are the saturated and residual volumetric water content and volumetric water content, respectively, ψ = suction, ψ_b = air entry value, and λ = pore size distribution index. The normalized water content is also expressed as degree of saturation as [49]:

$$S_e = \frac{\theta_w - \theta_r}{\theta_s - \theta_r} = \frac{S - S_r}{1 - S_r} \qquad (8)$$

Where, S_e is the dimensionless degree of saturation, and S_r is the residual degree of saturation. The SWCC value has been estimated by van Genuchten [50] and William [51] in term of curve fitting parameters. Van Genuchten [50] has produced the following equation as a function of the AEV, slope of the straight line segment in SWCC and the residual water content:

$$S = \frac{1}{\left[1 + (\frac{\psi}{\alpha})^n\right]^m} \qquad (9)$$

Where α, n, m and S are a function of the AEV, slope of the straight line segment in SWCC, the residual water content and degree of saturation, respectively. William [51] has described the SWCC as a relationship between the logarithm of volumetric water content and the logarithm of soil suction for many soils in Australia.

$$\ln\psi = \alpha_1 + b_1 \ln\theta \qquad (10)$$

Where α_1 , b_1 are curve fitting parameters. A new exponential equation of "Boltzmann dis-tribution" has been estimated by McKee and Bumb [52] to determine SWCC in term of normalized water content and suction.

$$\theta = e^{-(\psi - a2)/b2} \quad (11)$$

Where θ is normalized water content. a_2 and b_2 are curve fitting parameter. The pore size distribution has been entered as an important factor to predict the SWCC by Fredlund and Xing [40]. They used a fourth parameter, named as correction factor, C, at which the SWCC retained in dry state under low suction.

$$\theta_W = C(\psi) \frac{\theta_S}{\left\{\ln\left[e + \left(\frac{\psi}{a_\psi}\right)^{n_\psi}\right]\right\}^{m_\psi}} \qquad (12)$$

Where e the natural number. The curve pa-rameters of α, n and m represent the Air Entry Value (AEV) of the soil, control parameter for the slope of SWCC function and parameter related to the residual water content, respectively. The correction factor could be expressed as:

$$C(\psi) = 1 - \frac{\ln(1 + \frac{\psi}{\psi_r})}{\ln(1 + \frac{10^6}{\psi_r})} \qquad (13)$$

Where ψ_r is suction corresponding to the residual water content. The equation estimated by Fredlund and Xing [40] is more suitable than other equations model to predict the SWCC because it contains three- curve fitting parameters in comparison with one or two parameters for other equations and it could be applied to a wide range of soil suction from zero to 10^6 kpa.

3. RESULTS AND DISCUSSION

Different laboratory tests have been con-ducted all over the world to determine the effect of different soil parameters on the development of erosion process in the embankment dike. The tests included construction like canal overtopping [53], river embankment [54] and full scale levee [55]. The details of literature of embankment breach for different scientist could be reviewed in EWRI [56].

3.1 Tests in University of Auckland

A series of tests on the developing of breach discharge of noncohesive materials during the overtopping failure has been conducted by Coleman [57] at the University of Auckland, New Zealand. The test setup is shown in Fig. 5. Two tests with different soil materials are constructed inside the flume channel. The first test comprised of volcanic gravel where the other contains ranges of medium sand to fine sand. For simplifying the test procedure, the tailwater effect was eliminated through constructing the dike at the end of the flume. The friction angle of all soil particles is 32°. Three probes are installed in the upstream reservoir, V-notch basin and between the flap gate and dike crest for measuring the surface water level. For the initiation of breach channel inside the dike, they cut a triangular charge Q_b of channel was calculated by using water surface levels in the V-notch weir basin and by capacitance in the reservoir as shown in Figure 6.

Coleman [57] observed the shape of erosion process during the overtopping failure. They stated that the shape of the final dimension of breach channel is similar to parabolic cross section as shown in Figure 7. They empha-sized that the assumption of trapezoidal shape of dike breach, based on final dimensions, is affected by the falling head in the reservoir.

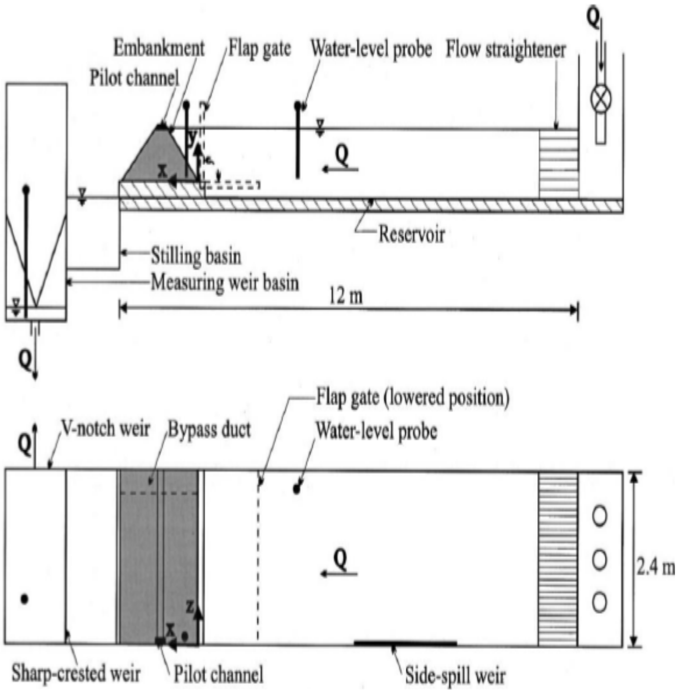


Figure 5: Experimental setup of labaratory test

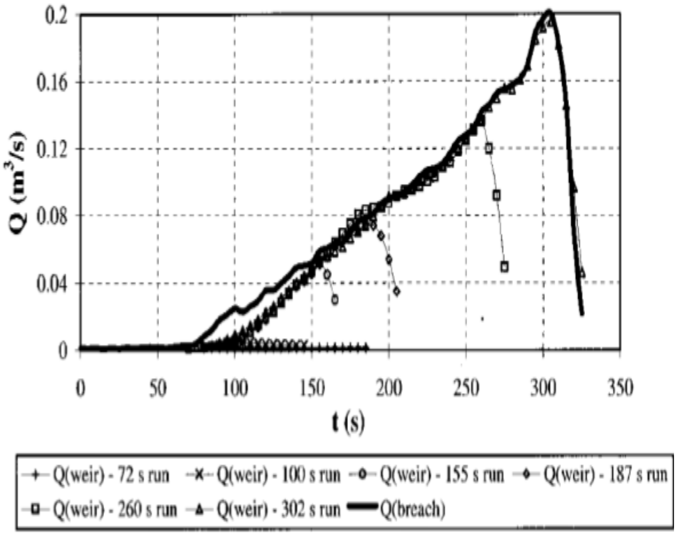


Figure 6: Development of breach discharge for medium sand

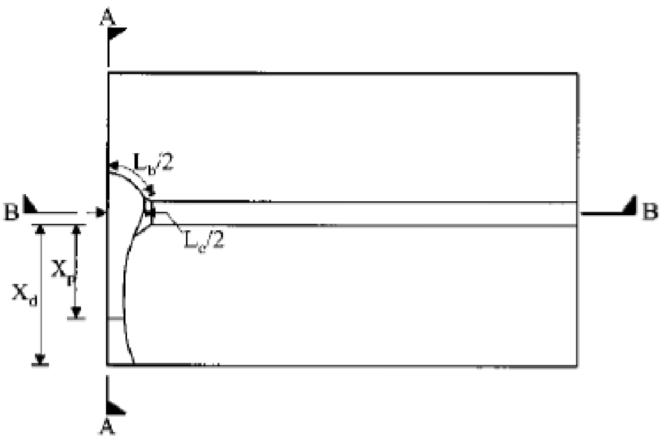


Figure 7: Plan view of final breach channel

3.2 Tests in Zurich, Switzerland

Both of Schmocker and Hager [58] are stud-ied the breach channel of (2D) plane overtopping failure in dikes at the laboratory of Hydrology and Glaciology of the Swiss Federal Institute of Technology in Zurich, in Switzerland. Their study is focusing on the effect of erosion process on the failure of noncohesive homogeneous river dikes. Different parameters are tested during the experiments such as scale effect and grain size diameters. The geometric scale factor could be defined as the ratio be-tween prototype variable to model variable [59]. The flume tests are shown in Figure 8. The test program was comprised of nine exact scale series, fifteen repeatability and fifteen sidewall effects tests. The authors are interested to show the similarity model between hydraulic model and prototype through Froude simulated laws. The Froude criterion is applied on discharge outflow, velocity, storage volume and time.

The sediment material is scaled based on Shields number. Three scale factors Lrr of 1, 0.5 and 0.25, with a reference scale dike of 1, are chosen in this experiment with their rela-tive dike's toe distance of 2.66m, 1m and 0.17, respectively as shown in Figure 9. The applicability of dike to withstand against the overtopping failure were also tested through different three dike's widths of 0.1, 0.2 and 0.4m, respectively. In order to reduce the effect of seepage on dike's downstream, the authors had used a drainage element of PVC false floor material on the upstream side of the dike.

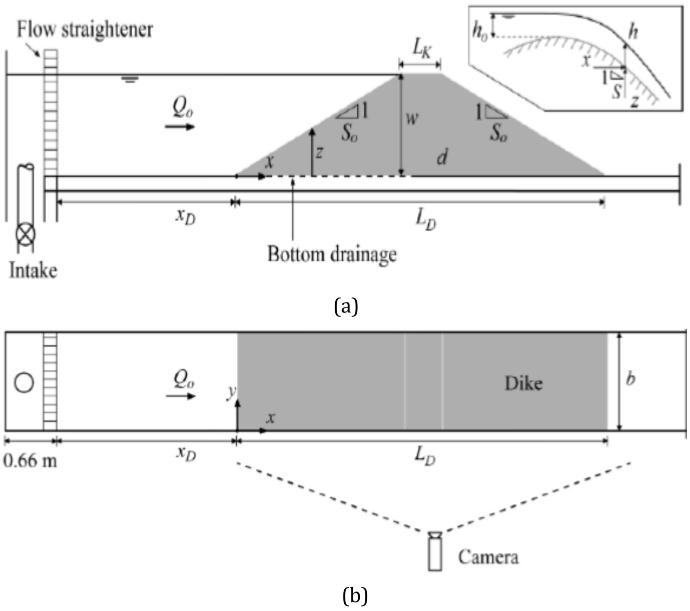


Figure 8: Flume components for overtopping tests

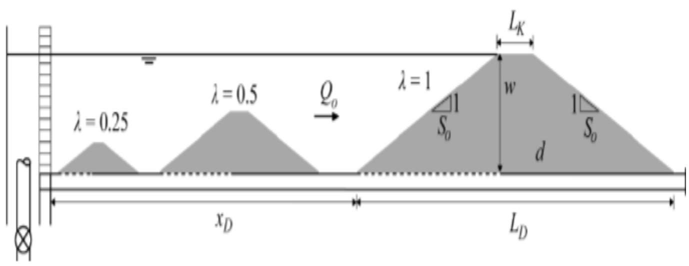


Figure 9: View side of embankment's scale families

They conducted the tests with steady inflow discharges to simplify the boundary condition and reduce the laboratory effort. They fill the reservoir within 30 second. They stated that the seepage inside dike are controlled the side-slope stability. They had used sediment size of d > 5.5 mm in order to control the seepage process well. The test repeatability for dike height, width and sediment size are represented with different values. In general, they had suggested an embankment dike with 0.20 m height, 0.20 m width and sediment diameter between 1mm to 4mm to perform the experimental tests smoothly. They tried to prevent using the diameter of soil particles › 8mm in side wall effects and repeatability tests to represent the seepage process clearly and avoid side slope failure. They have concluded that the breach discharge of dike is more obvious with soil particles ˂ 4mm and sidewall of small depth (0.1m).

The scale effect of 0.25 is also negligible in widening the breach failure due to shallower overtopping depth. Based on laboratory tests, the sliding failure of small soil diameters of 1,2,4 mm is less affected compared with other large diameters of 2,4,8mm in which the slid-ing failure in the latter played a dominant role in breach widening in term due to the immediate saturation as shown in Figure 10 and 11, respectively. Schmocker [60] calculated the breach discharge of non-cohesive dike through (4.2.2) equation for particle diameter, dike width, side-slope and inflow discharges of 2m. 0.2m 1:2 and 8 m/s, respectively. At the beginning of the erosion process, the shape of dike is similar to sharp crested and then turned to round weir for the rest of experi-mental tests. The laboratory tests for breach discharge has stopped when most of dike is removed. The breach discharge (Q) is bigger than the inflow discharge (Q_o) at the beginning of overtopping and then decreases at the end of the test ($Q = Q_o$) as shown in Figure 12.

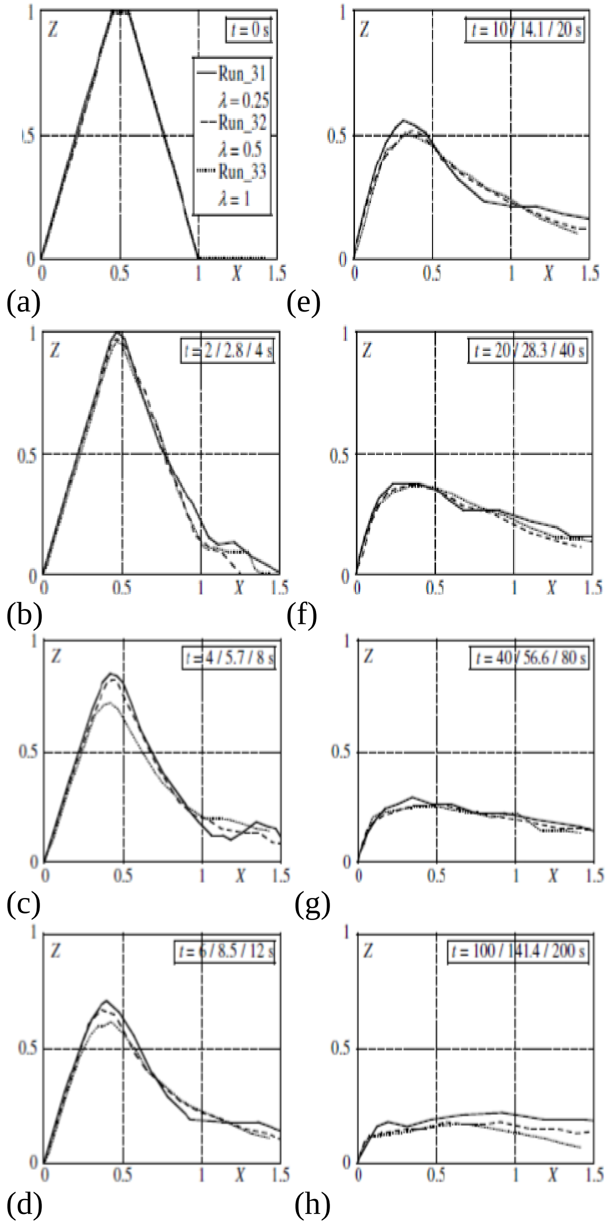
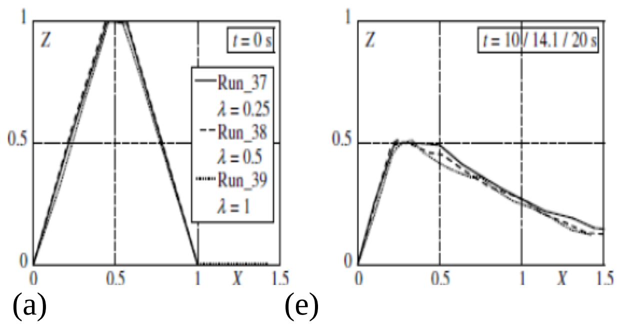


Figure 10: Development of dike's breach pro-file during overtopping tests for soil diameter of 1, 2and 4mm with scale families of L_{yy} of 0.25, 0.5 and 1.0, respectively



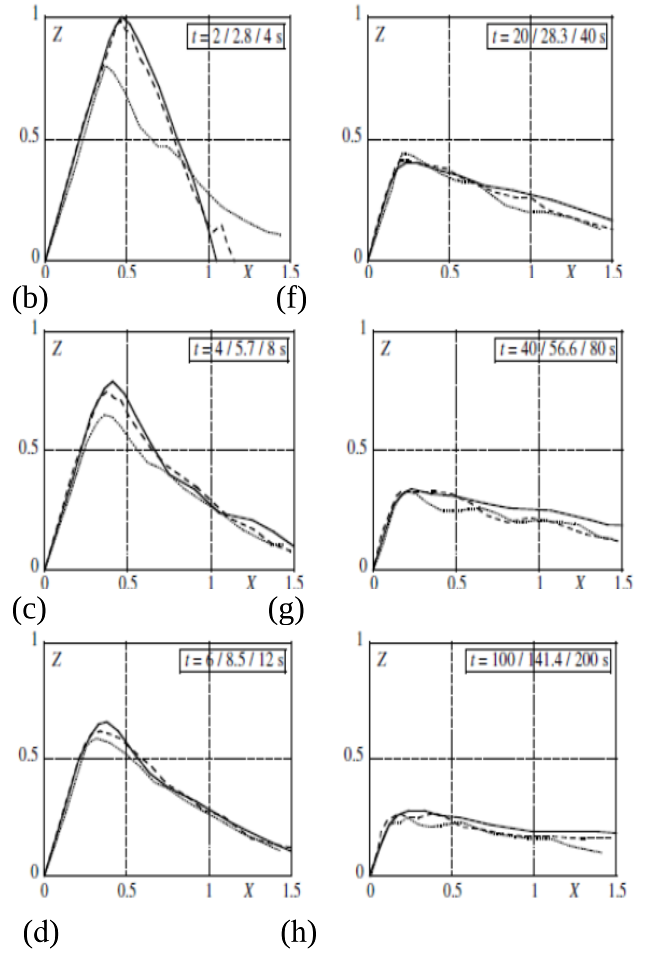


Figure 11: Development of dike's breach pro-file during overtopping tests for soil diameter of 2, 4 and 8mm with scale families of L_{yy} of 0.25, 0.5 and 1.0, respectively

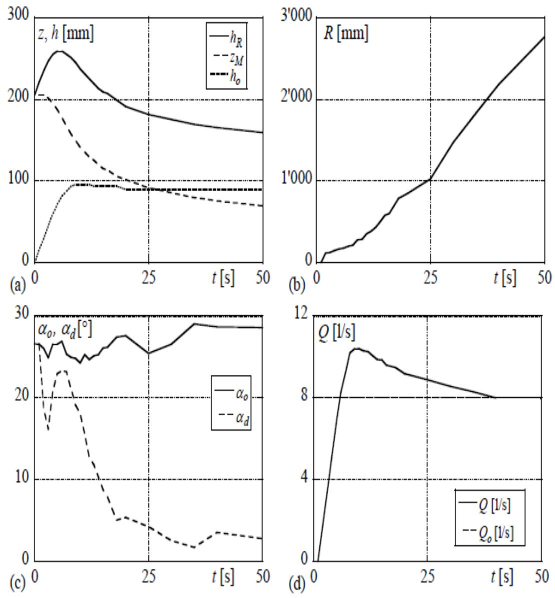


Figure 12: Development of breach channel of (a) overflow depth $ho(t)$, reservoir water level hR (t) and maximum dike height $z_m(t)$, (b) crest radius R (t), (c) up- and downstream dike face angles $\alpha 0$ (t), αd (t), and (d) breach dis-charge Q (t)

4. CONCLUSION

The overtopping water considered one of most dangerous failure effect on dikes as well as dam construction. It is led to initiate breach channel inside dike crest and thus a huge amount of water transferring from upstream into downstream slope. The mechanism of overtopping failure is related to vertical and horizontal erosion process; thus, many reearchers are interested to understand the dike behavior during erosion. The determination of erosion rate and sediment transported are calculated through theoretical and practical analysis. The theoretical analysis includes the empirical, parametric and numerical software equations, while the practical analysis is conducted in laboratory and field tests. Both of two analyses are highlighted in this review paper. The empirical and parametric equations are considered simple compared with numerical modelling, while the latter is rare and high cost. The dike embankment is constructed in large and small flumes in laboratory tests to observe the development of breach channel using different geotechnical parameters such as bottom drainage, grain size diameter, scale families and soil types. The bottom drainage in the dike toe reduces the effect of seepage in downstream slope prior to overtopping failure, consequently it prevents the slide slope instability. The PVC drainage is preferred due to its easiest installation. The bigger grain size accelerates the distribution of water content inside soil particles and thus reduce the shear strength parameters. On the other hand, the usage of small grain size will delay the progression of the erosion process. The similarities between prototype and embankment model are essential to understand the real effect of geotechnical and hydraulic parameters. Neglect these scales may overestimate the erosion rate during overtopping failure. The stages of erosion process for cohesive dike are differ in noncohesive dikes due to the presence of fine particles and thus the development of breach channel is faster in pervious than that in the latter. Additional researches should be done to understand the mechanism of erosion inside clay embankment.

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