American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-7, Issue-10, pp-57-64
www.ajer.org
Research Paper Open Access

Modeling of Internal Erosion and Initiation of Piping Phenomenon in a Dam

Drame Aboubacar Sidiki [a,b,*], Wang Li [a,b] , Camara Tamba[c]
[a] *University of Science and Technology Beijing, Beijing 100083, China,*
[b] *School of Energy and Environmental Engineering,*
[c] *Faculty of Science and Technology of Bamako,*
Corresponding Author:Drame Aboubacar Sidiki

ABSTRACT:*The initiation of a piping phenomenon which may occur under the dam is modeled. The model constructed to represent this problem is bi-dimensional. It combines the Darcy equation, the mass conservation equation for the fluid phase, the plane strain elasticity equation and a classical law of internal erosion. The conditions favoring the piping initiation are analyzed as function as the various parameters involved in the problem.The erosion equation is solved. The results obtained make it possible to plot under Comsol the isovalues of the porosity. Previous studies' model assume that the fluid flow and erosion occur in a matrix that remains rigid at time t so that the deformation of the skeleton does not directly have any effect on them. The initiation of piping phenomenon is characterized by a sudden local variation in the porosity. Its development cannot be grasped through this simple system which assumes that the soil is homogeneous.*

KEYSWORDS:*internal erosion; piping phenomenon; porous medium; Darcy's law and plane deformations*

Date of Submission:02-10-2018 Date of acceptance: 13-10-2018

I. INTRODUCTION

The internal erosion of granular soil is the major mechanism responsible for the breakdown of hydraulic structures in earth. It is one of the main causes of structural failure hydraulic backfill. Two conditions govern this type of erosion: The extraction and the transport of particles.

Internal erosion is a gradual destruction which happens in disconnected soils under the influence of fluid flowing (Bonelli & Nicot 2013). This phenomenon presents a real risk for hydraulic structures (dikes, dams).In 20 years, 136 earth dams in the world have suffered disorders including 6% by sliding, 46% by internal erosion and 48% by overflow which itself may be due to internal erosion(Foster et al. 2000). It can cause the rupture of these structures, whose function is to retain or store water, and thencause flooding(Fjar E., Holt R.M., Horsrud P., Raaen A.M. 2004; Fry 1997; Mattsson 2008; Charles 2002; Zhang, L. M., & Chen 2006). A statistical study (He et al. 2009) shows that the consequences can be dramatic in terms of human lives, property damage and economic losses.Internal erosion is produced by the gradual filtration of the fine particles which are torn off and transported by the fluid through the porous medium, what leads to a development of soil porousness and damage of its mechanic characteristics(Mattsson 2008).Internal erosion processes are complicated and rely on numerous settings which are connected with one another.

Generally, internal erosion is connected to two principal phenomena (Stavropoulou et al. 1998):The suffusion which results from an internal redistribution of the fine particles originally contained in the soil. Particle size distribution of soil does not change, but the homogeneity of the soils is no longer the same and the permeability decreases in some regions. This redistribution of the particles causes high pressures, located downstream of the flow, which can lead to the departure of particles of larger diameter. In general, the evolution of this phenomenon of suffusion is very slow, which allows its detection. The other phenomenon is the piping phenomenon which intervenes an advanced stage of the internal erosion. It is associated with a regressive departure flow of the particles which begins downstream and propagates to the upstream causing the formation of a cavity in the soil. In this work, the focus is on the initiation of piping which is a phenomenon difficult to detect because it is very short, allowing only a very short time to act against it.

Several advances have been made on the modeling of internal erosion and the initiation of Piping, particularly in the framework of issues related to cold production of heavy oils (Vardoulakis et al. 1996) and

(Vardoulakis 2004). Hydraulic piping phenomenon ismodeled byStephane et al (Stephane et al. 2007). They, from the two-phase flow equations with diffusion and the jump equations with erosion, proposed a two-parameter model describing the expansion of a pipe by hydraulic erosion, and for a hydraulic structure (dam, dike), a possible evaluation of the remaining time until the breach can then be deduced.For this, it is imperative to have visually detected the piping and have conducted preliminary tests of erosion on the soil in question(Stéphane et al. 2007). Concerning the internal erosion of the structure, eight phenomena of detachment (the quicksand, suffusion, regressive erosion, cleaning, dissolution, dispersion, entrainment and exsolution) and two sort of transportation (the transportation in a duct, and the transportation in the permeable inter-particulate area) were established by Fry et al(Fry 1997). For simplifying the description, Foster et al. proposed four mechanisms of initiation and progression(Foster & Fell 2001): the initiation, the filtration, the progression and the rupture. The initiation represents the fact that the hydraulic stress is greater than an erosion threshold. Filtration is a phase which depends on the presence of a filter, and effectiveness: this phase reflects the boundary conditions. Progression is the erosion development phase within the structure. The rupture is the ultimate phase. Many studies have been made recently in the world. Amongst them (Bendahmane et al. 2008) make known an investigational research so as to explore the impact of three crucial parameters on the erosion processes of a sand-clay mixing. The authors show that at low hydraulic gradient, the erosion of the clay structure is due to suffusion. When the hydraulic gradient becomes larger, the erosion of the sand fraction is of regressive type. They also show that the extent of erosion depends on the clay content and that the containment constraint plays a complex role in this phenomenon of erosion. Bonelli and Marot (Bonelli & Marot 2008) presented a model where the erosion by suffusion of a clay sand mixture is considered as surface erosion on a microscopic scale. The authors show that the surface erosion coefficient of the argillaceous matrix can be used to quantify the rate of erosion. The law of erosion which they have thus constructed depends on the volume fraction of the clay phase and accounts for the effect of the hydraulic gradient. The comparisons with results from experimental tests validated the proposed modeling. S. Bonelli et al. (Stéphane et al. 2007)introduced a simulation of an erosion testing at the orifice in use to determine the kinetics of piping erosion. Starting from the diphasic flow equations with diffusion, and equations of leaping with erosion, they developed a model for piping erosion. The authors proposed a formula which makes, it possible, to evaluate the characteristic time of this erosion mechanism and validate their approach by comparison with experimental results. S Bonelli and N Behamed (Bonelli et al. 2011) show that for water retaining structure, the coefficient of erosion is the first important parameter, it can serve as an indicator of the remaining time to breaching but they think that visual detection of the piping event and reporting is required. This coefficient can be obtained with the hole erosion test. However, the issue of the way the change of scale (from the laboratory to the structure)could affect the coefficient of erosion remains to be addressed.

The theory of poroelasticity presented initially in 1955 by Biot (Biot 1955) makes it possible to describe the interaction between the fluid flow and the deformation of the porous medium.
The characteristic erosion time has been written by S. Bonelli et al (Stéphane et al. 2007). This time is a function of parameters having a precise physical meaning: the erosion coefficient k_{er}, the soil density γ_s, the density of water γ_w, the gap of hydraulic level betweenthe up-front and the lower down ΔH_w, the length of the duct L and the gravitational constant g. They proposed an expression to estimate the time remaining before the breach and made a schematic diagram of the evolution of the process

II. METHODOLOGY

We hypothesize that, for the foundation mass, the three phases (skeleton, interstitial fluid, eroded particles) are homogeneous and isotropic and that they are regulated by the mass conservation theory.

The mechanism of internal erosion is in general divided into four steps: 1) initiation of erosion; 2) continuation of erosion; 3) progression of erosion; and 4) initiation of breaking.The first three steps are explained in Figures I and II for internal erosion in the earthwork. Analogous mechanisms apply for internal erosion in the foundation (Figure I) and internal erosion into or at the foundation of the earthworks (Figure II)(Fell et al. 2008; Concepts 2015).

Then the phenomenon of coupling of the flow with the consolidation of the soil induces locally overpressures and an excess of shear stress which would favor surface erosion.The shear stress increases with the overpressure of the dam, so the rate of erosion becomes very important when the overpressure increases. The rate of erosion is equal to the mass of eroded soil per unit area and time. It is then possible to classify the soil erodibility as a function of erosion rate.

In this work, we are interested in the conditions of initiation of the piping phenomenon as they can appear in a real structure dam. The aim is, on the one hand, to characterize by numerical modeling the effects of variation of the reservoir of water and the permeability on the maximum porosity induced by erosion, on the

other hand, to calculate the rate of erosion within a dam in order to avoid its rupture. Only the stage associated with suffusion is examined and the soil is considered as a continuous medium composed of three phases: the skeleton, the interstitial fluid and the fluidized particle generated by erosion.
Numerical difficulties arise when the finite element method in its classical version is applied in order to integrate directly the coupled system formed by the equations of consolidation and of suffusion erosion with the transport of the erosion product. A resolution method that assumes a partial decoupling is considered in this study. Thus, the problem of consolidation will be solved initially by ignoring the internal erosion part before secondly determining the porosity of the soil as it is affected by the erosion phenomenon. The model has been integrated into the Comsol Multiphysics version 3.4 environments. The conditions favoring the initiation of the piping phenomenon are then discussed.
The physical model is obtained by coupling the following equations:

- ✓ The law of Darcy expressing the flow in the porous medium for which the permeability is supposed to obey the law of Kozény-Carman;
- ✓ The mass conservation law of the interstitial fluid phase containing the fluidized solid;
- ✓ The elasticity relations in-plane deformations with a harming flexible comportment of the soil;
- ✓ A standard law of internal erosion.

The figure III describes the geometry of the model adopted in this study for the dam. Three areas are involved: the dam water, the dam structure, and the permeable soil traversed by the flow.

The structure of the dam is assumed to be rigid and impermeable. The action of the water of the reservoir is schematized by the simple pressure it exerts on the bottom.

The flow of the liquid phase is supposed to obey Darcy's law. The permeability is assumed to follow Kozény-Carman's law. It is further assumed that the eroded particles and the fluid have the same velocity and that erosion is described by a classical law, (Papamichos & Stavropoulou 1998) and (Andreatti 2014) which directly connects the variation of the porosity to the flow of the fluid. Lastly, the mechanical comportment of the soil is dealt under the supposition of plane strains. We then show that the equations of the problem are written:

Law of Darcy

$$\frac{\partial}{\partial x}\left[\frac{k_0\varphi^3}{g[\rho_w(1-c)+\rho_s c](1-\varphi)^2}\frac{\partial p}{\partial x}\right]+\frac{\partial}{\partial y}\left[\frac{k_0\varphi^3}{g[\rho_w(1-c)+\rho_s c](1-\varphi)^2}\frac{\partial p}{\partial y}\right]=-(1-\varphi)\left[\frac{\partial^2 u}{\partial t\partial x}+\frac{\partial^2 v}{\partial t\partial y}\right] \quad (1)$$

Soil balance

$$\frac{\partial}{\partial x}\left[\frac{E_0(1-\varphi)(1-\upsilon)}{(1-2\upsilon)(1+\upsilon)}\frac{\partial u}{\partial x}\right]+\frac{\partial}{\partial y}\left[\frac{E_0(1-\varphi)}{2(1+\upsilon)}\frac{\partial u}{\partial y}\right]=\rho_s g+\frac{\partial p}{\partial x}-\frac{E_0(1-\varphi)}{2(1-2\upsilon)(1+\upsilon)}\frac{\partial^2 v}{\partial y\partial x}$$

(2)

$$\frac{\partial}{\partial x}\left[\frac{E_0(1-\varphi)}{2(1+\upsilon)}\frac{\partial v}{\partial x}\right]+\frac{\partial}{\partial y}\left[\frac{E_0(1-\varphi)(1-\upsilon)}{(1-2\upsilon)(1+\upsilon)}\frac{\partial v}{\partial y}\right]=\frac{\partial p}{\partial y}-\frac{E_0(1-\varphi)}{2(1-2\upsilon)(1+\upsilon)}\frac{\partial^2 u}{\partial x\partial y} \quad (3)$$

Law of internal soil erosion

$$\frac{\partial\varphi}{\partial t}=\rho_S\frac{1}{\tau_{er}}\left(1-\frac{\varphi}{\varphi_0}\right)|q|+\frac{\partial^2 u}{\partial t\partial x}+\frac{\partial^2 v}{\partial t\partial y} \quad (4)$$

Evolution of the concentration of eroded particles

$$\varphi\frac{\partial c}{\partial t}-\frac{k_0\varphi^3}{g[\rho_w(1-c)+\rho_s c](1-\varphi)^2}\left[\frac{\partial c}{\partial x}+\frac{\partial c}{\partial y}\right]\left[\frac{\partial p}{\partial x}+\frac{\partial p}{\partial y}\right]=(1-c)\left[\frac{\partial\varphi}{\partial t}-(1-\varphi)\left(\frac{\partial^2 u}{\partial t\partial x}+\frac{\partial^2 v}{\partial t\partial y}\right)\right] (5)$$

x is the coordinate along the vertical downward axis, y is the coordinate along the horizontal axis, t is the time, u vertical velocity, v horizontal velocity, p water pressure, φ soil porosity, c concentration of eroded particles, q flow rate, τ_{er} soil resistance to erosion, g gravity acceleration, k_0 the initial soil permeability, E_0 the Young's modulus of the soil, υ its Poisson's ratio, ρ_s the density of the solid grains of the soil and ρ_w the density of the water. These equations are classical(Morland & Sellers 2001; Germain et al. 1983).
To integrate problem (1)-(4), a finite element model is developed using the commercial software Comsol Multiphysics version 3.4 when initial and boundary conditions are specified.

Figure IV presents the geometric model developed under Comsol.
For the parametric study carried out below, it is assumed that consolidation under the weight of the reservoir dam and water has been completed. We are only interested in the effect of increasing the level of restraint on internal erosion that may develop under the dam; the term $\rho_s g$ is therefore omitted from the second term of equation (2).
The simplified model proposed in this study assumes that the water in the reservoir acts as a simple static pressure exerted on the AB side, that the dam is water resistant and dimensionally stable so that it acts on the part CD only by a static field of stresses. The initial and boundary conditions associated with the system formed by the consolidation equations (1) - (3) are written in Table I.
∇ denotes the gradient operator and p_{in} the overpressure.

III. RESULTS AND DISCUSSIONS

We are interested in the effect of increasing the level of the retention p_{in} on the internal erosion which can develop under the dam and this, in terms of the permeability k_0. The erosion resistance τ_{er} will be assumed constant: $\tau_{er} = 10^5$ usi. The two parameters p_{in} and k_0 are linked to the particle size and type of permeable soil present under the dam. The other settings utilized in the modeling are:

$$\rho_s = 2650\, kg.m^{-3},\ \rho_w = 1000\, kg.m^{-3},\ g = 9.8 m.s^{-2},\ E_0 = 5.10^8\, Pa,\ v = 0.2\ and\ \varphi_0 = 0.36$$

The parameters k_0 and p_{in} are regarded as changeable.

It can be observed that the concentration c, in the equation (5), does not include in equations (1) - (4). These equations can, therefore be integrated in a decoupled way of equation (5). Once the solution of the system (1) - (4) is obtained, it can be used to integrate equation (5) and obtain the spatial and temporal distribution of the concentration of eroded particles. However, the difficulties are not overcome because equations (1) - (5) cannot be directly integrated by using the method of the finite elements in its classic version Bubnov-Galerkin because the problem obtained is very badly conditioned. Numerical instabilities in fact pollute the solution and prevent any calculation of the model. Considering the practical case of the initiation of the piping phenomenon, it can be seen that the porosity generally undergoes only small variations around its initial value φ_0. It may then be assumed that the porosity remains constant, $\varphi = \varphi_0$ in equations (1) - (3) assuming that erosion does not directly affect the solution of the consolidation problem. This partially decouples the problem and integrates the system (1) - (3) and the erosion equation (4) separately. The latter integrating analytically once the solution of the problem of consolidation is calculated.

This approximation of the erosion problem makes it possible to solve the problem of the numerical instabilities which characterizes the strongly coupled problem. It is not very restrictive because it can be verified that the conditions of Initiation of the piping phenomenon are effectively associated with a porosity which remains near to the initial value. Moreover, studies of Vardoulakis et al.(Vardoulakis et al. 1996), and then Papamichos et al. (Papamichos et al. 2001) in the context of the problem of silting encountered in production of heavy oils, have shown that a partially decoupled model makes it possible to account for majority of the experimental remarks. The model, they used, assumes that the fluid flow and erosion occur in a matrix that remains rigid at time t so that the deformation of the skeleton does not directly have any effect on them. The solid structure distorts in a practically static way under stresses. The initiation of piping phenomenon is characterized by a sudden local variation in the porosity which is demonstrated by the resolution of the system (1)-(4). The development of the piping phenomenon cannot be grasped through this simple system which assumes that the soil is homogeneous. The development phase of piping phenomenon can be analyzed in a simplified way using the concept of the remaining time until breach formation, Bonelli et al. (Stéphane et al. 2007)

We then carry out, under Comsol, the transient simulation of the consolidation problem governed by the three differential equations with partial derivatives (1)-(3) when they are liable to the initial conditions (6) and the boundary conditions (7) to (10). Then the erosion equation (4) is solved. The results obtained then make it possible to plot under Comsol the isovalues of the porosity. Table II summarizes the value of the maximum porosity in terms of k_0 and p_{in} and Figure V shows the porosity's isovalues for $k_0 = 10^{-6}$ *and* $p_{in} = 5.10^4$.

IV. CONCLUSION

The modeling of initiation of the piping phenomenon was carried out in this work. The dam is also modeled taking into account the effect of Darcy's flow and the axisymmetric elastic deformations of the porous medium. The consideration of the internal wall's displacement of the dam induces a localization of the stresses which appears in the zone affected by the piping phenomenon. Soil erosion is not uniform throughout the inner wall of the dam infected with hydraulic piping. Overpressures then appear on the wall of the dam. The erosion rate augments with pressure, ruggedness and argil concentration. A simplification of the equations obtained has been considered in order to eliminate the problem of numerical instabilities which affect the finite element resolution of the highly coupled issue. Quantitative estimation of the effect of this approximation is not currently available but elements recovered in the literature allow arguing of its adequacy. Parametric studies were then carried out on initiation of piping phenomenon in terms of the variation of the level of the reservoir of the dam and of the permeability of the sol that stands it. It has been possible to verify that the proposed erosion model always predicts an initiation to the discontinuity of the dam foundation, where the hydraulic gradients are the strongest. The hydraulic piping is difficult to detect and evolves very quickly, which leaves little time to act against it. When it happens, it's often too late. The calculation of the time required to evacuate a dam before destruction is very important. . The erosion coefficient can be used as an indicator to evaluate this time available before rupture.

REFERENCES

[1]. Andreatti, F.C.P.C.A.B., 2014. A two-phase flow model of sediment transport : transition from bedload to suspended load. J. Fluid Mech, (1967), pp.1–20.

[2]. Bendahmane, F., Marot, D. & Alexis, A., 2008. Experimental Parametric Study of Suffusion and Backward Erosion. Journal Of Geotechnical And Geoenvironmental Engineering © Asce, (January), pp.57–67.

[3]. Biot, M.A., 1955. Theory of Elasticity and Consolidation for a Porous Anisotropic Solid. , 182, pp.1–5.

[4]. Bonelli, S. et al., 2011. Piping flow erosion in water retaining structures : inferring erosion rates from hole erosion tests and quantifying the failure time Piping flow erosion in water retaining structures : inferring erosion rates from hole erosion tests and quantifying the fa. In IECS 2010, 8th ICOLD European Club Symposium Dam Safety - Sustainability in a Changing Environment, Sep 2010, Innsbruck, Austria. ATCOLD Austrian National Committee on Large Dams, 6 p., 2010.

[5]. Bonelli, S. & Marot, D., 2008. On the modelling of internal soil erosion St ´ ephane Bonelli , Didier Marot To cite this version : In The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG) 1-6 October, 2008 Goa, India.

[6]. Bonelli, S. & Nicot, F., 2013. Erosion in Geomechanics Applied to Dams and Levees Libgen Lib. S. Bonelli & F. Nicot, eds., Wiley-ISTE.

[7]. Charles, J.A., 2002. Internal erosion in European embankment dams. , pp.378–393.

[8]. Concepts, K., 2015. IV-4 . Internal Erosion Risks for Embankments and Foundations. In dam safety, risk, BestPractices. pp. 1–134.

[9]. Fell, R. et al., 2008. Guidelines for landslide susceptibility , hazard and risk zoning for land-use planning. Engineering Geology, 102(3–4), pp.99–111. Available at: http://dx.doi.org/10.1016/j.enggeo.2008.03.014.

[10]. Fjar E., Holt R.M., Horsrud P., Raaen A.M., R.R., 2004. Petroleum related rock mechanics Elsevier.,

[11]. Foster, M. & Fell, R., 2001. Assessing Embankment Dam Filters That Do Not Satisfy Design Criteria. J. Geotech. Geoenviron. Eng, (May), pp.398–407.

[12]. Foster, M., Robin, F. & Spannagle, M., 2000. The statistics of embankment dam failures and accidents. Can. Geotech. J, 37(1992), pp.1000–1024.

[13]. Fry, J. et al, 1997. Context and framework of the report of the European working group on internal erosion.

[14]. Germain, P., Suquet, P. & Nguyen, Q.S., 1983. Continuum Thermodynamics. , 50(December 1983).

[15]. He, X.Y. et al., 2009. Temporal and spatial distribution of dam failure events in China. International Journal of Sediment Research, 23(4), pp.398–405. Available at: http://dx.doi.org/10.1016/S1001-6279(09)60010-X.

[16]. Mattsson, H.J.G.I.H.& T.S.L., 2008. On Internal Erosion In Embankment Dams,

[17]. Morland, L.W. & Sellers, S., 2001. Multiphase mixtures and singular surfaces. International Journal of Non-Linear Mechanics, 36(June 1999), pp.131–146.

[18]. Papamichos, E. & Stavropoulou, M., 1998. An Erosion-mechanical Model for Sand Production Rate Prediction. Int. J. Rock Mech. Min. Sci., 35(4), pp.531–532.

[19]. Papamichos, E.R. et al., 2001. Volumetric sand production model and experiment. Int. J. Numer. Anal. Methods Geomech, 808(January 2000), pp.789–808.

[20]. Stavropoulou, M., Papanastasiou, P. & Vardoulakis, I., 1998. Coupled Wellbore Erosion And Stability Analysis. International Journal For Numerical And Analytical Methods In Geomechanics, 769(March 1997), pp.749–769.

[21]. Stephane, B., Brivois, O. & Benahmed, N., 2007. Modelling piping erosion and interpretation of the hole erosion test. In HAL archives - ouvertes.

[22]. Stéphane, B., Olivier, B. & Damien, L., 2007. The scaling law of piping erosion. In 18ème Congrès Français de Mécanique Grenoble. pp. 27–31.

[23]. Vardoulakis, I.., 2004. Fluidisation in artesian flow conditions : Hydromechanically stable granular media. Géotechnique, (2), pp.117–130.

[24]. Vardoulakis, I., Stavropoulou, M. & Papanastasiou, R., 1996. Hydro-Mechanical Aspects of the Sand Production Problem. Transport in Porous Media, 22(2), pp.225–244.

[25]. Zhang, L. M., & Chen, Q., 2006. Seepage failure mechanism of the Gouhou rockfill dam during reservoir water infiltration. NII-Electronic Library Service, 46(5), pp.557–568.

Figures:

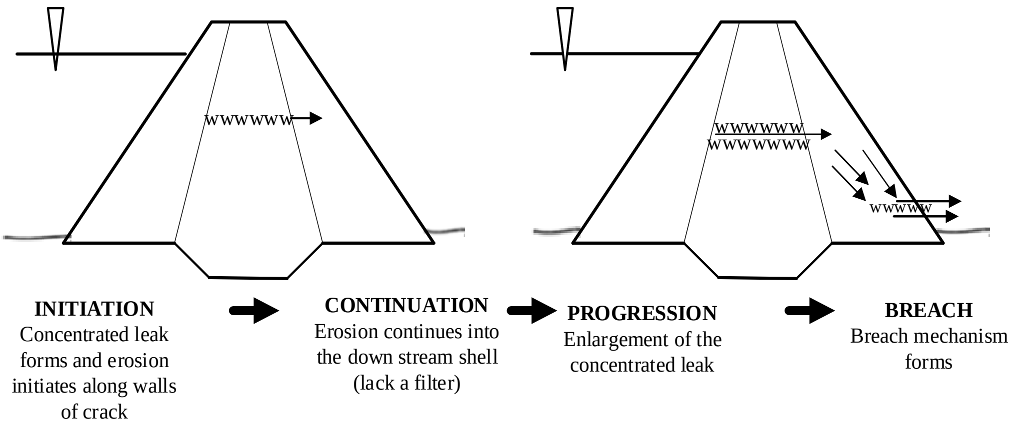

Figure I: Internal Erosion through the Embankment Initiated by a Concentrated Leak (adapted from Fell et al. 2008)

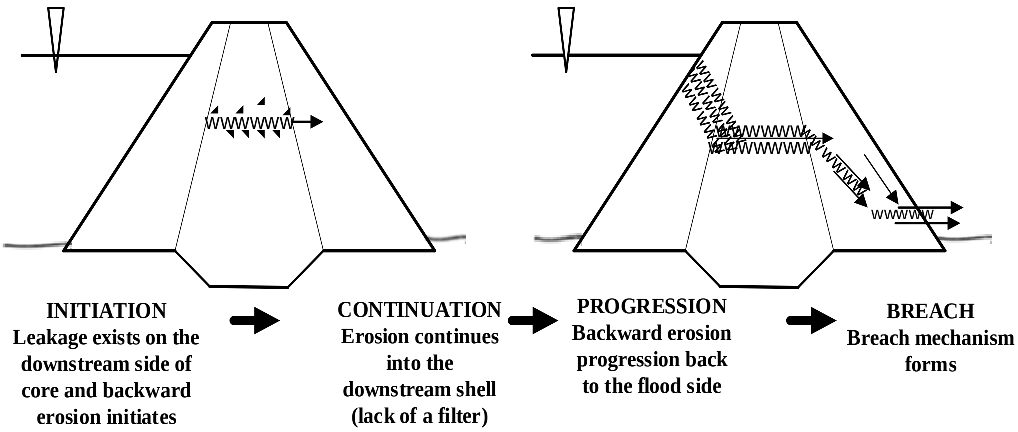

Figure II: Internal Erosion across the earthwork introduced by Erosion toward the back (adapted from Fell et al. 2008)

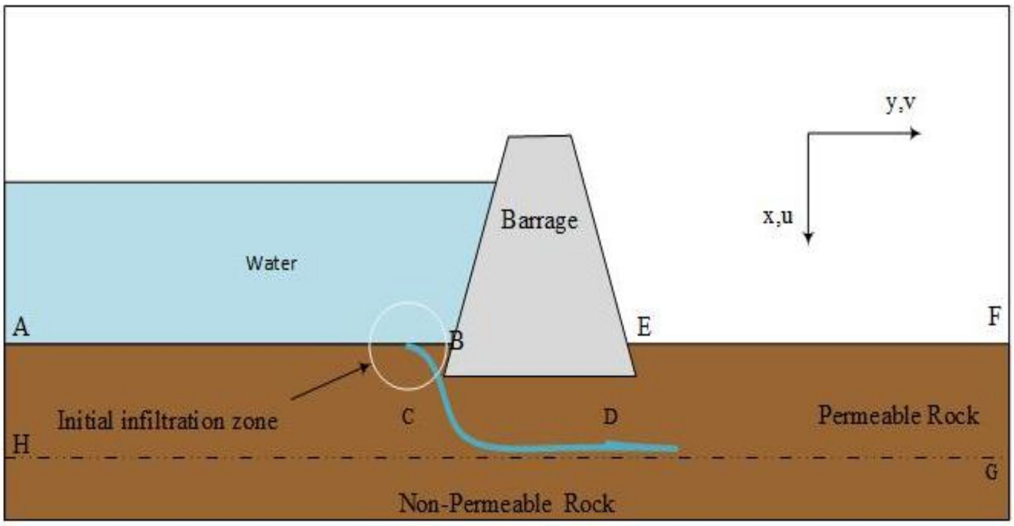

Figure III: Geometric configuration of the dam

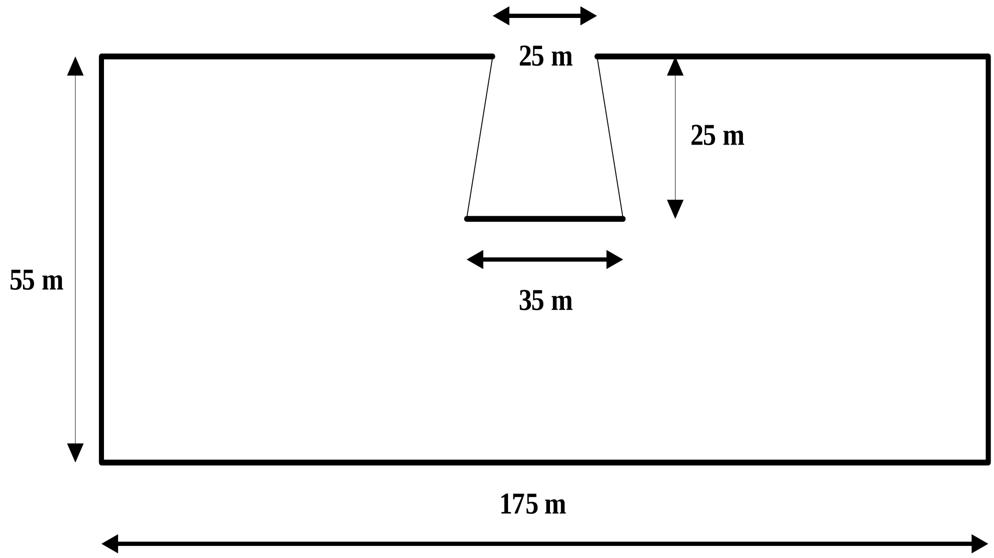

Figure IV: Geometric model Comsol adopted for the problem of the dam

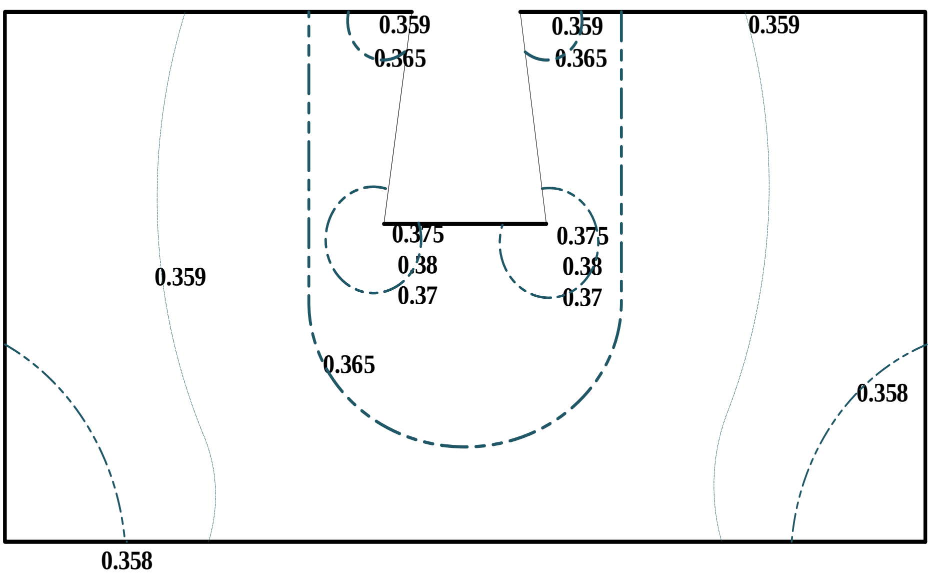

Figure V: Isovalues of the porosity for $k_0 = 10^{-6}$ and $p_{in} = 5.10^4$

Tables:

Initial conditions	p = 0, u = 0, V = 0		(6)
Boundary conditions	$\nabla u = \nabla v = 0,\ p = p_{in}$	on AB	(7)
	$\nabla u = \nabla v = 0,\ p = 0$	on EF	(8)
	$\nabla u = \nabla v = \nabla p = 0$	on BC, DE, CD	(9)
	$u = v = \nabla p = 0$	on FG, AH, HG	(10)

Table I: Summary of Initial and Boundary conditions

Overpressure of the Dam (Pa) p_{in}	Permeability (m.s^{-1}) k_0	Maximum Porosity $\varphi_{\max}$
5.10^4	10^{-6}	0.372
	10^{-7}	0.352
10^5	10^{-6}	0.403
	10^{-7}	0.365

Table II: Maximum porosity values as a function of permeability k_0 and overpressure p_{in}

Drame Aboubacar Sidiki "Modeling Of Internal Erosion And Initiation Of Piping Phenomenon In A Dam "American Journal of Engineering Research (AJER), vol. 7, no. 10, 2018, pp. 57-64