CHAPTER 1
GENERAL PRESENTATION

The rupture of an earth dam by (rénard) tunnel erosion can be divided into some phases. Blais (2003) [2] and Pascal (2004) [3] divided this phenomenon into three principal phases,

1. The development of the conduit of erosion, i.e. progressive increase in the diameter of the gallery crossing the earth dam, governed by the law of erosion.
2. The collapse of the roof of the conduit (tunnel) when the diameter of this one becomes too important
3. The widening and/or the deepening of the trapezoidal breach created by this collapse.

Hunt and *Hanson* [4] divide the process of erosion of a cohesive earth dam by overflow based on the experimental observation. This type of collapse of the earth dam is not a case of (rénard) tunnel erosion. However, they made an assumption of the widening of a breach where the result shows that the rate of the widening of a breach is controlled only by the shear stress. From these assumptions, we try to check and find the parameters which support the collapse using numerical simulation.

1.1 Collapse of cavities: the phenomenon

The collapse of the soil remains one of the very important risks in the geotechnical field. It is an abrupt subsidence which makes expensive accidents, dangerous, with a rather important probability (collapse can occur in any type of soil). Because of the change of volume and depression during dryings and dampings, the soil loses its stability which is then followed by collapse. Cavities or undersoil galleries resulting from the human industrial activity (for example: mines) or naturally formed by the water circulation in soluble solid masses of rocks can also cause this phenomenon.

We can from now on distinguish various types of collapses according to its main cause and its size [5].

Table 1 Various types of collapse

Type	Cause	Remarks
Depression	• Symptomatic phenomenon of the undersoil autoeers (badly embanked)	• Flexible deformation without rupture • Slow progression
Stripping	• Gravitating drive	• Is often in the solid masses

	• The massive water circulation • The circulation of material of filling of a cavity	lime stones • Deformation in small zone (a few m^2)
Subsidences	• Rupture of the roof of a cavity • Damage of the old works	• Upward force like "a bell" going up towards surface makes a funnel or a crater • Rather fast phenomenon with the rather important dimension of accident
Generalized collapses	• Chain breakage of the pillars of the exploitation	• Fast phenomenon with major damage • At the same time violent and spontaneous lowering of surface (sometimes in several hectares and several meters of depth)
The suffusion	• Entrainment of the particles (initially rather fine) in the mass of soil because of fast pore water circulations. • Caused by a natural circulation of water or timid soil pipes	• Affect mainly sands and silts • At the time of the voids in the soil are rather important, of brutal collapses of soil can occur with disorders on the surface.

1.1.1 Example of mode of rupture of a cavity

We take the case of a subsidence which shows the evolution of collapse when a cavity exists in the soil. The phenomenon of a subsidence occurs in some stages. First of all, the roof fissures then breaks with fall of blocks in an existing cavity. Then, the vault goes up because of the successive falls of blocks of the roof. When a tunnel "cone" starts to be formed, we notice the beginning of formation of a "bell" of subsidence. The "bell" of subsidence continues to develop towards surface. The cone fills the undersoil cavity. The subsidence then emerges on the surface. Following the deterioration of the surface soils, the subsidence takes the shape of stable funnel [6].

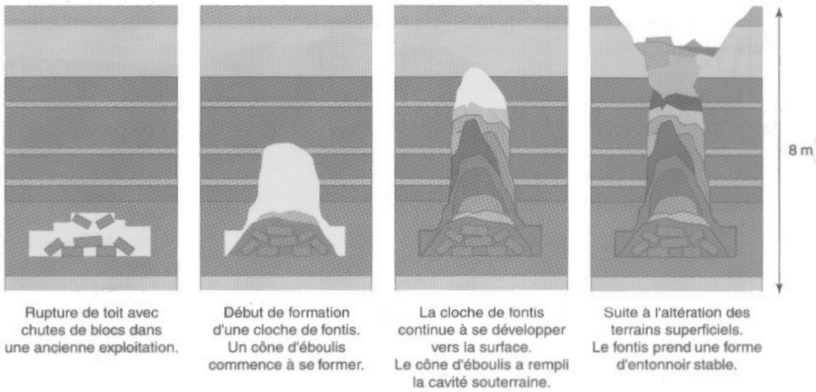

Figure 1 Formation of a Cavity (LCPC INERIS)

1.1.2 The case of Situ Gintung

The collapse of an earth dam implying the creation of the (rénard) tunnel erosion is always happen and makes a news topic. The case of Gintung Situ is one of the illustrations. It is a dam earth located in Tangerang, close to Jakarta (Indonesia) which broke on March 27th, 2009. This catastrophe was probably assigned by the formation of (rénard) tunnel erosions to the level of the outfall [7]. The number of victims was catastrophes: 99 people deceased and more than 150 people are disFigureed, since the earth dam is in a residential zone which is very dense one.

The event begins on March 26th, 2009 in the evening (with 23:00), with precipitations of rain of about 113,2 mm/jour (in 2007, the maximum value was 275 - 300 mm/jour) [7]. The catastrophe starts about midnight when the citizens living close to Situ Gintung heard noises which occurred close to the earth dam. Finally with 3:00 of the morning, the earth dam broke (Figure 2 and Figure 3).

We notice that the earth dam “warned” the citizens by noises, which should have encouraged with an immediate evacuation of the population before the earth dam crumbles completely.

Figure 2 Tragedy of Situ Gintung (seen above)

Figure 3 Collapse of Gintung Situ

1.1.3 Objectives of research

The purpose of our study is to understand the causes of such a collapse and what can facilitate it. We will be interested in the phenomenon of (rénard) tunnel erosion, which occurs in the middle of the earth dam, which remains still a field of research. The collapse of the earth dam because of the formation of the (rénard) tunnel erosion will be thus analyzed to see its evolution and to define the parameters which supports it.

We will model in this report the stage of collapse of the soil which constitutes the phenomenon of (rénard) tunnel erosion in undrained condition. A model of earth dam with a cavity of size given is calculated to see with which value of cohesion one reaches the rupture. This is a simplification of a real case which is done normally by the enlarging of a cavity and cohesion of the fixed soil.

1.2 Characteristics of the soil

1.2.1 Soil mechanics properties

At first we assume that a soil is a compressible material and elastic, which follows the law of Hooke. Because of these characteristics, we consider modules or mechanical properties which explain the nature of the soil, for example the Young modulus, the module of Poisson, the module of compressibility, etc [8].

1. The Young's modulus

This modulus, also known as the elastic longitudinal modulus, is a constant which connects the tensile stress and the deformation for an isotropic material. This module is expressed like a relationship between the tensile stress applied to a material and the deformation which results from it (a relative lengthening), as long as this deformation remains small and that the elastic limit of material is not reached.

$$E = \frac{\sigma}{\varepsilon} \tag{1.1}$$

2. The Poisson's ratio

This coefficient, characterizes the deformation of material perpendicular to the direction of the force applied.

$$\nu = -\frac{\varepsilon_{transversal}}{\varepsilon_{axial}} = -\frac{\varepsilon_x}{\varepsilon_y} \tag{1.2}$$

3. The modulus of rigidity (Shear Modulus)

This module characterizes the shear strength of a material. It is connected to the modulus of elasticity (E) and to the Poisson's ratio (ν),

$$G = \frac{E}{2(1+\nu)} \tag{1.3}$$

4. The module of compressibility

It is the module which connects the constraint to the rate of deformation of an isotropic material subjected to an isostatic pressure. The general equation is expressed as follows,

$$K = -V\frac{\partial p}{\partial V} \tag{1.4}$$

Where V is the volume of subjected material a value of pressure p.

This module can be also expressed according to (ν) and the modulus Poisson's ratio of rigidity (G),

$$K = \frac{2G(1+\nu)}{3(1-2\nu)} \tag{1.5}$$

1.2.2 Criterion of Mohr Coulomb

This criterion delimits the space of the couples (σ', τ) acceptable on any facet of soil. Terzaghi considered that the soil is composed of two coupled mediums, the granular framework and the pore water [9]. In a saturated soil, the total constraints σ are distributed between the solid skeleton (noted effective constraints σ') and the water (isotropic water pressure pore noted U), which is expressed in the *relation of Terzaghi*:

$$\sigma = \sigma' + u \tag{1.6}$$

The criterion of Mohr Coulomb is written then,

$$\tau = c' + \sigma'.\tan\phi' \tag{1.7}$$

With C is cohesion and $Ø'$ is the natural angle of repose.

In the reference mark of principal constraints (example of a triaxial compression test) the criterion is written,

$$\sigma_1 '-\sigma_3 ' = 2c'\cos\phi '+(\sigma_1 '+\sigma_3 ')\tan\phi \qquad (1.8)$$

Which is also shown on Figure 4,

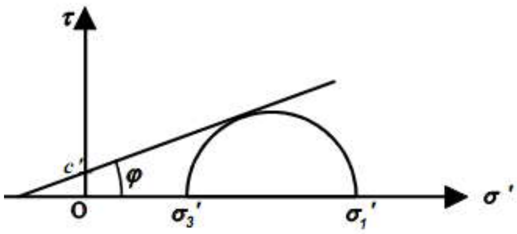

Figure 4 Mohr Circle (with mechanical properties of soil)

Cohesion is a measurement of the forces which attach particles of soil. It also comprises the force of shearing of soil which is independent from inter particle friction. The cohesion of soil is caused by:

- Electrostatic forces (in the case of clay)
- The nature of cementing materials ($Fe2O3$, $CaCO3$, NaCl, etc)
- The negative capillary pressure (which is lost during damping)
- The answer of pressure of pore under the undrained condition (which decreases with time)

The non-cohesive soils are deprived of cohesion (for example: sand). There exist two conditions of cohesion depending on the dissipation of water,

a. Drained cohesion by which the pore water pressures were already dissipated (corresponds to long-term behavior of the soil)
b. Undrained cohesion by which the pore water pressures are not be still dissipated. This corresponds to a short-term behavior.

On this criterion there is also the natural angle of repose (Ø'). This angle (effective) of friction or internal friction gives a measurement of the shear strength of the soils by friction will intra particulate.

1.2.3 The classification of the soils

The taken soils can be described complementary in several ways: according to nature, the proportions and the physical properties their components. Classification makes it possible in a few words to transmit a total image of each soil.

Compared to its granular size [10], we quote this classification of the soils

Table 2 Non-cohesive soils and cohesive soils: characteristics

Soils	granular or granularities	coherent or fine
Particles	Grains	Notable proportion of fine particles to very fine
	Regular form	Irregular form (specific large surface)
	Physicomechanical Alteration	Physicochemical Alteration
Bond particle-water	Low or zero. Interstitial water	Strong. Dependant water. Existence of a layer of adsorbed water
	No influence: • mineralogical nature of the particles • electrolytes of interstitial water	Influence: • mineralogical nature of the particles • electrolytes of interstitial water
Force connection	Dominating forces of gravity	Forces of gravity Dominating attraction forces molecular and electrostatics at short distance.

Some orders of magnitude of various types of soil are quoted in Table 3.

Table 3 Soil mechanics properties

Classify N°	1	2	3	4	5	6
γh (kN/m3)	17	18	19	19	20	20
it (kPa)	10	0	20	0	25	0
Ø' (°)	0	30	5	34	10	38

With,

Classify 1: Cohesive soil (clay and silt) and Lime

Classify 2: Loose granular soil

Classify 3: Slightly stiff cohesive soil and Lime

Classify 4: Slightly compact granular soil

Classify 5: Stiff cohesive soil with very stiff (marl and clay)

Classify 6: Compact granular clay