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Erodibility of Granular Materials Models

Ari Sentani[1*], Didier Marot[2] and Fateh Bendahmane[2]

[1]*Universitas Islam Sultan Agung, Jl. Raya Kaligawe km.4 Semarang 50112, Indonesia*
[2]*Universite de Nantes, 58, rue Michel Ange 44600 Saint-Nazaire, France*
* *Corresponding author:* arisentani@unissula.ac.id

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Abstract: Two means physical processes are involved in failure of a dams structure: either a mechanical failure by sliding, or a hydraulic failure by erosion. The causes of failures are internal erosion (23 cases between 44), or external erosion (20 cases of overtopping) and 1 case of sliding. In consequence, internal erosion is the most frequent cause for all the water retaining structures. A series of test are needed to develop models that can describe the internal erosion. This research uses two kinds of tests. They are The Consodilated Drained (CD) Triaxial test and The Erodibility test with triaxial erodimetre. These two tests uses mixture between Kaolinite Proclay (25%) and Fontainebleau Sand (75%) with 9% of water content. The result shows that confinement pressure increase, time for obtained maximal deviatoric also increase. When deviatoric stress is increase, percentage of deformation is also increase. And also the volume variation of specimen is decrease in function of deformation. For the second test, the result shows after the loss of fine particles in the soil, the original dilative stress-strain behavior changes to be contractive and the peak stress is decreases. Comparing the results of Chang & Zhang in 2011, the curves rank in a coherent way for the stress-strain curve although it used different speciments.

Keywords: internal erosion; triaxial test; erodibility; fontainebleau sand; kaolinite proclay

1. Introduction

All over the world, dams are important infrastructure for human life. Dams are widely used for flood control, irrigation, and water supply. The main treat for Dams is failure. These failures have caused immense property and environmental damages and have taken thousands of lives. The fundamental problems relating to the design of dams in soft materials are related to stability.

Two means physical processes are involved in failure of a dams structure: either a mechanical failure by sliding, or a hydraulic failure by erosion Fry et al [1]. According to the data collected from February 2010 to April 2012, it is obvious that erosion is the major cause of failure. More than 97% of failures between 44 known cases were induced by erosion. The causes of failures are internal erosion (23 cases between 44), or external erosion (20 cases of overtopping) and 1 case of sliding, caused by the very severe Tohoku earthquake. Fry et al [1] But today, the probability of accidents is minimal, because the choice of the site, the construction and the surveillance of the dams are the subject of rigorous controls. If it still remains, the risk, the sudden and complete failure of a dam is extremely low. In case of breakage, it is more likely to be a progressive rupture due to the evolution of a crack in the structure.

And if these origins of the breakage of a dam are now well known, that is to say the mathematical representation of the parameters that describe these phenomena, it would better predict, even if their modeling is extremely delicate.

Internal erosion is one of the main threats to water retention structures such as dikes and dams. This phenomenon is produced by the gradual filtration of fine particles that are torn off and transported by the fluid through the porous medium. This leads to an increase in the porosity of the soil and the deterioration of its mechanical properties.

A series of tests are necessary to make models that be able to describe the erosion and the degradation of the mechanical properties of soils that being eroded. One of them is studying the possibilities of characterizing the erodibility of this type of material using a triaxial erodimeter. The phenomenon of erodibility has been studied by Marot et al [2]. This study propose diferent specimen to get comparison with Chang and Zang [3] experiment

2. Methods and Testing Procedure

2.1. Principle of the consolidated drained (CD) Triaxial Test.

The main purpose of Consolidated drained test is investigating the soil mechanical resistance before erosion. The specimen preparation phase was divided into three steps ; production of the specimen, saturation, and finally consolidation. For produced the specimen Fontainebleau Sand and Kaolinite Proclay are mixed. After 1 minute with moisture content of 9% added in to the mixture. Then, while mixing continues, powder clay is progressively added and mixing is then carried on for an additional 10 minutes. After ensuring homogeneity of the grain size distribution, the installation of specimens inside the cell required preliminary forming. The specimens were prepared using a single layer semi-static compaction technique. The mixture was placed in a mould of 50 mm diameter and 100 mm height and subsequently compressed under the action of two pistons until the initial fixed dry density (before consolidation) was reached. This initial dry density value was 16 kN/m3.

The saturation phase begins when 20 kPa of confinement pressure is applied to prevent any preferential leakage between the specimen and the membrane. Carbon dioxide was used to improve dissolution of gases into water, and finally saturation is completed by demineralized and deaerated water. The whole saturation phase requires approximately 24 hrs.

The consolidation process begins when the isotropic confining pressure (σ3) was increased in steps in conformity with standard NFP 94-074 [4] procedures to reach 100 kPa. The consolidation process phase requires approximately 12 hrs. After consolidation, a deviatoric stress was applied with the piston of triaxial cell into the specimen and measured it with the dial gauge. And then increasing the speed of the triaxial's plate constantly until the specimen ruptured. Different confining pressure: 50 kPa, 100 kPa and 200 kPa are used to investigate the soil resistance before erosion.

The materials uses for this research is fontainebleu sand mixed with kaolinite proclay, with the physical properties in table 1:

Table 1. Physical properties of the speciments

Physical Properties	Value	Unit
Water content	9	%
Gamma d	16	kN / m^3
Initial volume of the sample in	0.00020	m^3
Total mass of the dry sample	320.24	g
Dry mass of Fontainebleu Sand	240.18	g
Clay mass (25%)	80.06	g

Amount of water (9%)	28.82	g
Total wet mass of the sample	349.07	g
Height of the sample	100	mm
Diameter of the sample	50	mm

2.2. Principle of the triaxial erodimetre

The purposes of Erodibility Test are to investigate the initiation and development of internal erosion and to study the stress-strain behavior of the soil experiencing internal erosion. The apparatus allows independent control of hydraulic gradient and stress state. A triaxial erodimeter was designed to apply downward seepage flow on intake soil sample or on reconstituted soil specimen (Fig. 1).

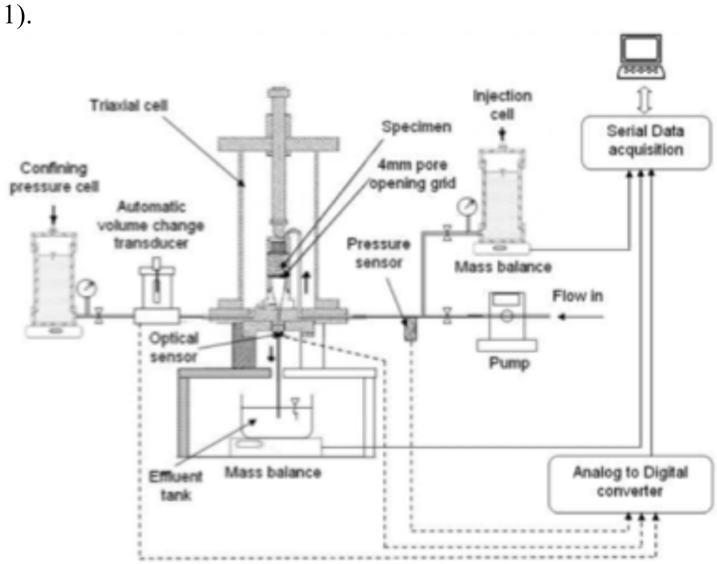

Fig 1. Schematic Diagram of Triaxial Erodimetre

The testing device comprises a modified triaxial cell which was designed to saturate the sample in upward direction, to consolidate it under isotropic confinement and finally to force fluid through the sample in downward direction. The system to generate seepage flow under constant hydraulic gradient comprises a pressure sensor and an injection cell connected to air/water interface cylinder. Injection cell is continuously weighed in order to determine injected flow rate. The system to generate seepage flow in flowrate-controlled conditions comprises a gear pump connected to a pressure sensor.

The eroded soil is measured using a soil collection system and a multichannel optical sensor. A multichannel optical sensor was placed at the end of the draining pipe and soil collection system was placed after optical sensor. This optical sensor measures instantaneously the transparency of the fluid coming from the glass pipe, which decreases with the increase of soil particles in the effluent. The measurements can be used to study the erosion rate, variations in soil permeability, and soil deformation during the erosion process.

This research used the GDS to control volume and containment variations. The amount of eroded particles can be very small. Thus, the measurement by weighing or by visual observation is not precise enough to detect the initiation of internal erosion. Therefore, this triaxial device has been equipped with an optical sensor. The optical sensor is placed at the end of the drain pipe at the base of the triaxial set up. The small dimensions of the apparatus make it possible to place vertically close to the base of the sample and this positioning makes it possible to avoid any deposition of eroded particles between the sample and the optical sensor. The optical sensor makes it possible to measure the concentration of clay, C, inside the fluid which is expressed by the ratio between the mass of the clay particles and the mass of water inside the fluid. We recovered the effluents with beakers. Data acquisition is automatic with Visual basic professional software developed by Bendahmane [5]

3. Results and Discussion

3.1. Results of the consolidated drained (CD) Triaxial Test.

Three speciments with different deviatoric stress are being tested. The result shows that confinement pressure increase, time for obtained maximal deviatoric also increase. The maximal deviatoric stress that being obtained are 96.36kPa for 50 Kpa which corresponds to a deformation of 14.33%; 232.81kPa for 100 kPa which corresponds to a deformation of 22.25%.; 448.61kPa for 200 kPa which corresponds to a deformation of 26.61%.

The curves have a pronounced maximum beyond which they decrease more and more slowly. The maximum of the curve corresponds to the stress that must be applied to cause the disentanglement of grains in the plane of rupture.

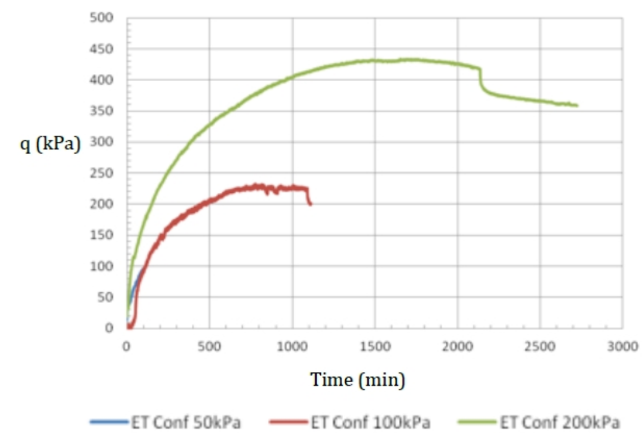

Fig. 2 Relations between Deviatoric Stress with Time

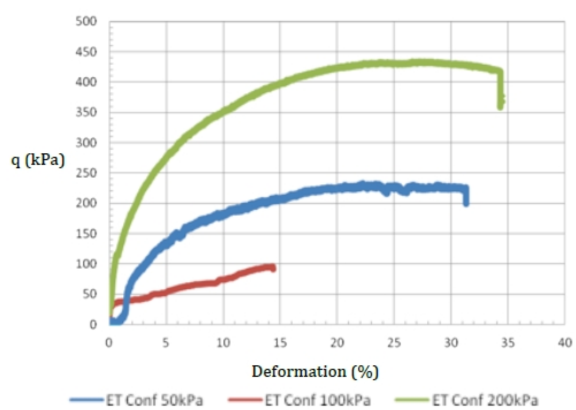

Fig. 3 Deviatoric Stress in function of deformation

The volume variation curves for the 100kPa and 200kPa confinement tests show the volume decrease during deformation. This voluminal deformation indicates a loose character of the sample. This decrease in volume is called contractance.

However, for the 50 kPa confinement test, the volume variation curves show an increase in the volume fraction during the deformation and then a decrease. This increase in volume is called dilatancy and the decrease in volume is called contractance. This is due to the overconsolidation of the sample

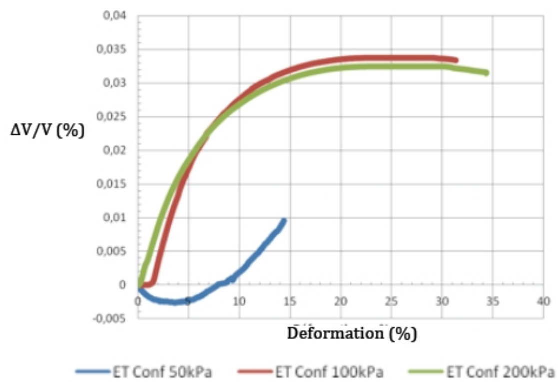

Fig. 4 Variation volumic in function of deformation

3.2. Results of the triaxial erodimetre

The test is try to obtain the effect of erosion in soil resistance. The table below shows the representativeness of test results on samples made of 25% kaolinite Proclay using the triaxial erodimeter.

Tabel 2. Characteristics of imposed hydraulic gradient tests

Sample Reference	Mixture	Test of hydraulic gradient i (m/m)	Confinement (kPa)	Time (h)	Phenomena observed
E1	K25F75	10	100	5	No Erosion
E1	K25F75	18	100	1,67	No Erosion
E1	K25F75	25	100	1	No Erosion
E1	K25F75	100	100	1	Erosion

The test used different hydraulic gradients. At the beginning of the process,the test used a hydraulic gradient of 10. When it started the erosion test process, fine particles began to erode for 1 hour and afterwards there were no eroded particles . Until 5 hours and after increasing the hydraulic gradient to 18 and 25, it increased to 100. During saturation, there was a lot of clay that was eroded.

During hydraulic gradient 18 and 25, there was no erosion. Afterwards, hydraulic gradient adjusted to 100. This value corresponds to an injection pressure of 100kPa. Therefore, the injection pressure is the same as the 100 kPa confining pressure applied to the sample, the fine particles begin to erode but, it's just a small amount.

The mass eroded by weighing for i = 10m / m is zero, likewise for i = 18m / m and 25m / m. The mass eroded by weighing for i = 100m / m is equal to 46.00mg or 0.060% clay mass, and the mass eroded by optical sensor is equal to 38.11mg or 0.047% clay mass. The results obtained show an evolution of the eroded mass which increases according to imposed hydraulic gradient.

To quantify the effect of internal erosion on soil shear strength, drained shear tests were performed from the stress states applied during the erosion tests. The results show that shear strength is affected by internal erosion because the maximum deflector decreases by 12.97% for i = 2 and by 21.80% for i = 100.

Comparing the results of our tests with those of Chang and Zhang [3], the curves rank in a coherent way for the stress-strain curve.

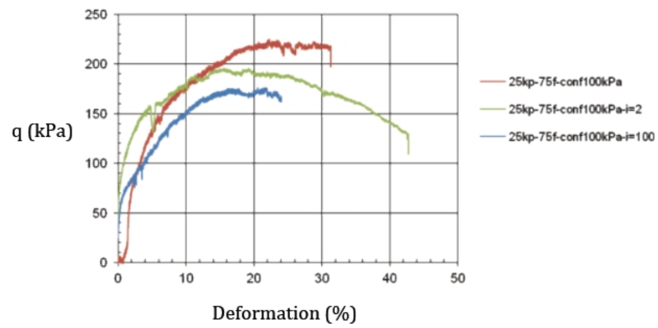

Fig. 5 Comparation of deviatoric stress in function of deformation before erosion and after erosion

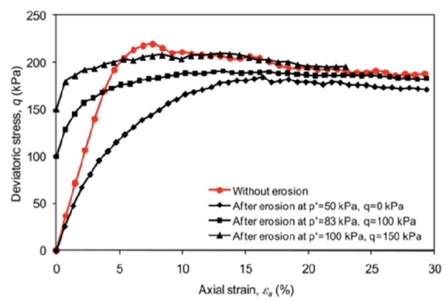

Fig. 6 Deviatoric stress in function of deformation from Chang&Zhang (2011)

From Figure 7, during saturation, fine particles were significantly eroded. It is almost identical with the beginning of the erosion process. This granulometric curve means that since the beginning of erosion with i = 2, the most eroded particles are clay. At the end of this process, some clay and sand have been eroded. The curve shows that the fraction of fine particles eroded at the beginning of the erosion process is nearly 20% more than in the end of the erosion process.

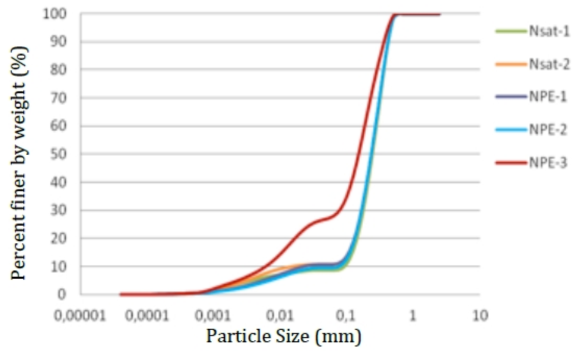

Fig. 7 Grain Size Distribution of eroded particle with gradient hydraulic=2

For the second sample, during the saturation there is little eroded fine particles, according to figure 8. For i = 10, at the beginning of the erosion test there are many particles eroded more than 30% by compared to that of saturation. And for i = 100, just a few fine particles has eroded during particle size analysis, the darkness value is equal to 2 while it must be between 5 and 30 so the curve look different from others.

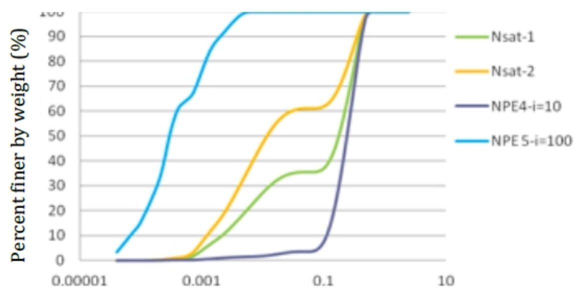

Fig. 8 Grain Size Distribution of eroded particle with gradient hydraulic=10-100

4. Conclusions

Erodibility with granular materials models has main purpose to investigate the initiation and development of internal erosion and to study the stress-strain behavior of the soil experiencing internal erosion. The results of consolidated drained tests shows that confinement pressure increase, time for obtained maximal deviatoric also increase. The curves have a pronounced maximum beyond which they decrease more and more slowly. The maximum of the curve corresponds to the stress that must be applied to cause the disentanglement of grains in the plane of rupture.

The triaxial erodimetre test is try to obtain the effect of erosion in soil resistance. The test used different hydraulic gradients. The results obtained show an evolution of the eroded mass which increases according to imposed hydraulic gradient. To quantify the effect of internal erosion on soil shear strength, drained shear tests were performed from the stress states applied during the erosion tests. The results shows that shear strength is affected by internal erosion because the maximum deflector decreases by 12.97% for i = 2 and by 21.80% for i = 100. Comparing the results of Chang and Zhang [3], the curves rank in a coherent way for the stress-strain curve although it used different speciments.

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