Influence Of Angularity Of Grains On Suffusion Process In Clayey Sand

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Abstract- About 46% from 136 dysfunctions of surveyed dams has related to internal erosion. Internal erosion is a phenomenon that is not fully understood, although it's makes dysfunctions in dam's structure. Two main phenomena responsible for erosion of particles in soil are backward erosion and suffusion. This report deals with suffusion process, which takes place inside the soil matrix. In suffusion, finer particles of a soil migrate within its own pore spaces be-tween the larger particles. These fine particles can be cohesionless particles or clay particles.

With the objective to study the effect of angularity of coarse fraction grains on suffusion, a series of tests was performed on different clayey sand. Five sand types samples were tested which are different angularity of grains and same grain size distribution. Two experimental devices were used: one to characterize the grain shape and the second to quantify the influence of the grain shape on suffusion. Mechanical method was used to characterize the grain shape.

By using a triaxial erodimeter, the suffusion sensitivity of five mixtures of kaolin-aggregates was determined. Results clearly demonstrate that suffusion process depends on the grain angularity of coarse fraction. With a constant flow, angularity of coarse fraction grains contributes to increase the suffusion resistance.

Keywords: *internal erosion, suffusion, triaxial erodimeter, angularity*

1. Introduction

Among 11,192 surveyed dams (Foster et al. 2000), there are 136 dysfunctions, which are divided up as 5.5% related to sliding, 48% related to overtopping, and 46% to internal erosion. Although it's makes dysfunctions in dam's structure, internal erosion is a phenomenon that is not fully understood (Fell and Fry, 2007; Gutiérrez et al., 2008).

Internal erosion occurs when water flows through a cavity, crack, and/or other continuous void within the embankment. The two main phenomena responsible for erosion of particles in soil are backward erosion and suffusion (Fell, 2007). In backward erosion, particles are detached from the downstream surface of the structure by the seepage forces in the soil. In suffusion, the process is similar, but the coarse particles form a matrix and erosion is only of the finer particles in the pore space between the larger particles.

Indeed, under the influence of water flow, particles constituting the soil within the earth's structure. The grains are possibly detached and transported that affects the strength of the structures and maybe the cause of phenomena such as backward or suffusion. The grains shape and angularity become an important factor to determine internal erosion. It's an intrinsic characteristic, and grain shape is known to have a main function in the mechanical behaviour of the granular medium (Voivret, 2008). In fact, just few studies have been conducted to quantify and determine its exact impact.

The purpose of this study is to propose a quantification of grain shape and angularity on the basis of tests on the flow time of different materials and their mechanical properties. There are five aggregates was used in this study: Loire Sand, Fontainebleau sand, glass bead, mixture of Fontainebleau sand with glass beads and Loire Modified sand. The influence of the grain shape on the suffusion process was studied for mixtures composed by one sand with clay, and also mixture between glass beads and Fontainebleau sand with clay.

2. Methods and Test Procedure

2.1. Methods

The mechanical method consists in carrying out test, on one hand by direct shear box, and on the other hand by gravitating flows with a sand angulometer.

2.1.1. Sand Angulometer

The angulometer is constituted by a standardized funnel and the test consists in measuring the flow duration (Ecm) of various materials. The more grains are angular, the more duration is important. These tests were carried out in conformity with standard [NF EN 933-6, 2002]. The angularity index (IA) is the ratio of the flow duration of an aggregate to the flow duration of mixture of glass beads with an identical grain size distribution.

2.1.2. Direct Shear Test With Cassagrande

The shear test were carried out on dry aggregates, with density index Id near to 1 (Id=[emax-e]/[emax-emin]) where emax, emin are the maximum and minimum values respectively of the void ratio. For various aggregates of the same grain size distribution, the internal friction angle obtained by this test depends on the form and the coarseness of the grains. The used testing method is described by standard [NF P 94-071-1, 1994]. The normal force applied is 50 KPa, 100 KPa and 150 KPa.

The sample is placed in a box consisting of two parts which can slide horizontally one over the other. The sample normal force (N) applied vertically, by means of a piston. A shearing force (T) applied horizontally, by moving the lower half box. A comparator measures the sample change in height.

2.2. Test Procedure

2.2.1. Tested Materials and Specimen Preparation

As the sensor accuracy allows a fairly precise detection of clay particle erosion, several suffusion tests were performed using clayey sand samples. With such type of gap-graded soils, the coarse fraction is composed of sand grains and the fine fraction corresponds to the clay fraction. Tests were performed on different mixtures of 10% of kaolin and 90% sand. Liquidity and plasticity limits of kaolin are 55% and 22%, respectively. Five aggregates types were tested, the first is a Fontainebleau sand (grain size distribution within the range 80 µm – 425 µm, (D50=239.74 µm; grain density=26.5 kN/m3). This grading is being used to make grading percentage for other aggregates. The second aggregate, referred to as Loire sand, has a different grain size distribution (grain

size distribution within the range 80 µm- 800 µm, D50=178.96 µm, grain density=26 kN/m3). The third aggregate is glass beads (grain size distribution within the range 80 µm-800 µm, D50=263.94 µm, grain density=24.6 kN/m3). The fourth aggregate (i.e. modified Loire sand) has the same range for grain-size distribution as the glass beads, but it is composed of grains from the Loire sand (grain size distribution within the range 80 µm-800 µm, D50=212.19 µm). The last is mixture between Fontainebleau (41.4%) and Glass beads (58.6%). From the total 500 gram for a specimen, the range of grain size distribution of this mixture is 212 µm consists of 293 gram of glass beads, and then 80 µm, 300 µm, 425 µm, and 800 µm consists of 207 gram of Fontainebleau, with D50 = 250.18 µm. Figure 1 shows assessing internal instability of graded using Wan&Fell method, all aggregates is in unstable zone.

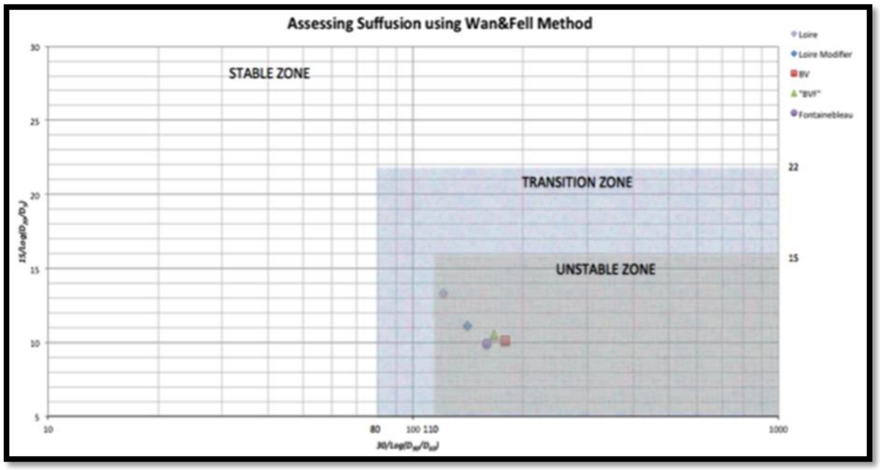

Fig.1. Assessing of potential of suffusion using Wan and Fell (2008)'s method.

2.2.2. Testing Program

The specimen preparation phase was divided into three steps: production of the specimen, saturation and finally consolidation. The sand grains are first mixed with kaolin for 1 minute. Water progressively added and mixing is then carried on for an additional 10 minutes, and stop every 5 minutes to mixed it manually. After ensuring homogeneity of the grain size distribution, the installation 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 50 mm height and subsequently compressed under the action of two pistons.

In the triaxial erodimetre, the specimen was placed on a 4 mm pore opening grid. This pore opening allows the migration of all particles of sand and clay. A smaller pore opening grid would prevent the migration of sand grains, which in turn, would limit the initiation of suffusion process (Marot, 2009).

The saturation phase begins when a small 15 kPa 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 de-aerated water. The whole saturation phase requires approximately 24 hrs.

With the objective to recover grains which could fall in the funnel-shaped draining system during the specimen preparation, a very small quantity of water was injected with low pressure by a lateral pore situated under the 1.5 mm pore opening grid and it was recovered by the effluent tank. Finally, the specimen was subjected to a hydraulic flow in a downward direction using demineralized and deaerated water in order to keep the injected fluid characteristics identical. flow constant was used to tested, the flow value is 2 ml/min.

3. Results and Discussion

3.1. Mechanical Methods

The values of the internal friction angle (φ) were: 34.91° for glass beads (BV), 36.66° for the Fontainebleau sand (F), 33.22° for the Loire sand (L), 31.37° for the modified Loire sand and 29.15° for the mixture between glass beads and Fontainebleau (BVF).

The angulometer measurements first consisted to measure the average flow duration during the test (Ecm). The flow durations for glass beads, Fontainebleau sand, Loire sand, modified Loire sand and mixture glass beads and fontainebleau were respectively: 17.03s, 20.32s, 21.24s, 21.86s, 18.34s. So the corresponding values of IA were 1, 1.19, 1.25, 1.28 and 1.08. The Table below is presenting the result of Mechanical method.

Tabel 1. Result of mechanical method of five aggregates

	Ecm (s)	**I_A**	**Φ (°)**
BV	17.03	1	34.91
BVF	18.34	1.08	29.15
F	20.32	1.19	36.66
L	21.24	1.25	33.22
LM	21.86	1.28	31.37

3.2. Characterization of Suffusion Erodibility

The Results for the maximum concentration were 2.59 mg/g for Loire Sand; 1.5 mg/g for Modified Loire Sand; 2.84 mg/g for Glass Beads; 3.2 mg/g for Fontainebleau; and 2.43 mg/g for mixture between Glass Beads and Fontainebleau. Glass Beads has a highest value. The value of Loire Sand is higher than Glass Beads. When the value of concentration is increasing, it is a phase of erosion and filtration. And when the value is getting decrease, it is a phase when filtration and clogging. The results of concentrations are plotted in figure 2.

Figure 3 shows that the hydraulic conductivity decreases with time, and in this case of kaolin Loire sand specimens the minimal value of hydraulic conductivity occurred well after the maximum value of eroded clay concentration was observed. Figure 4 shows that the result of hydraulic gradient is under the limit of confinement, except Modified Loire Sand and few of Loire Sand. The lowest value of hydraulic gradient is Fontainebleau Sand. When the hydraulic conductivity is decreasing and the hydraulic gradient is increasing, the phase of filtration is happening.

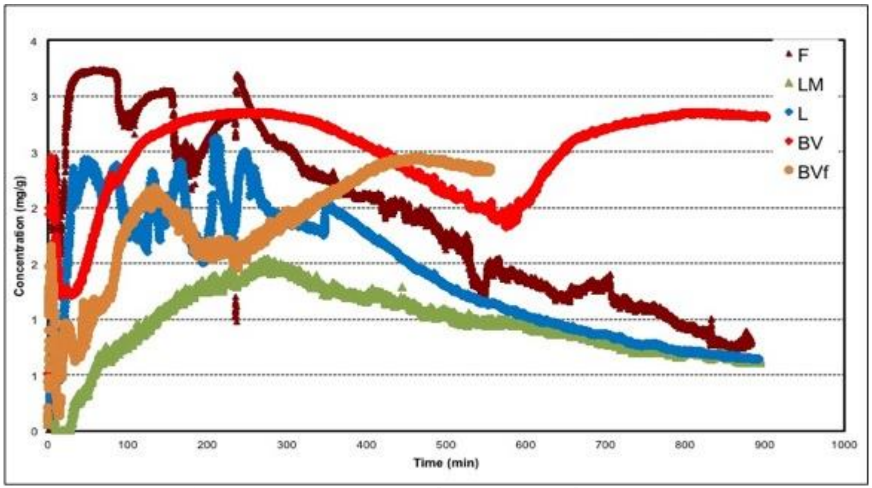

Fig.2. Concentration with Constant Flow

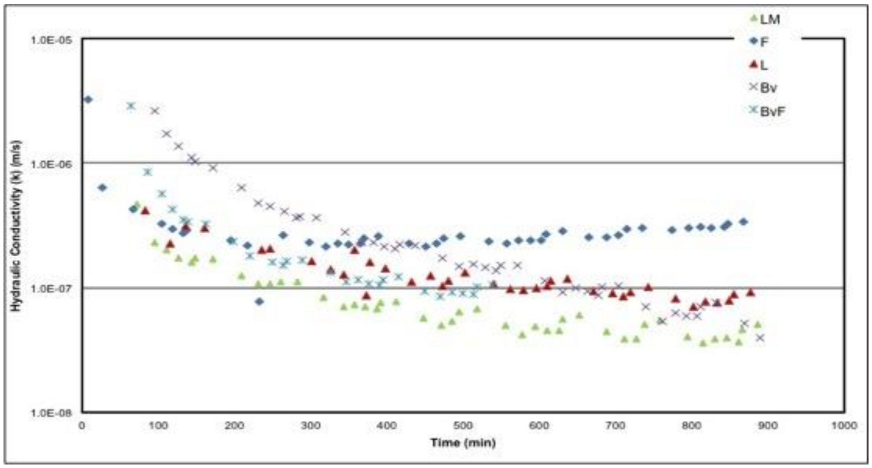

Fig.3. The Results of Hydraulic Conductivity

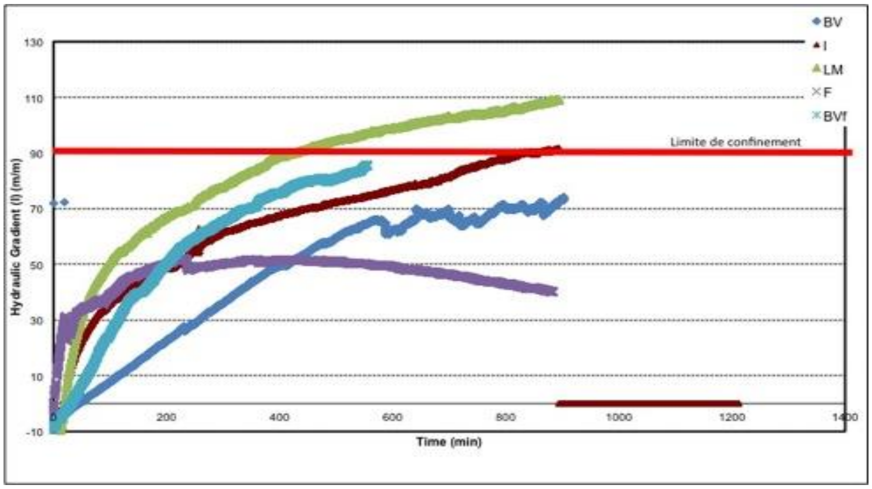

Fig.4. The Results of Hydraulic Gradient

3.3. Grading Analysis

Laser apparatus were used to get grading analysis. Grading comparison of Fontainebleau used Laser Granulometri and Sieve analysis was used to determine grading analysis. Figure 5 shows that the result is not too different. Curve from Fontainebleau Sifraco also used to get better comparison, it is curve from the manufacture of Fontainebleau Sand.

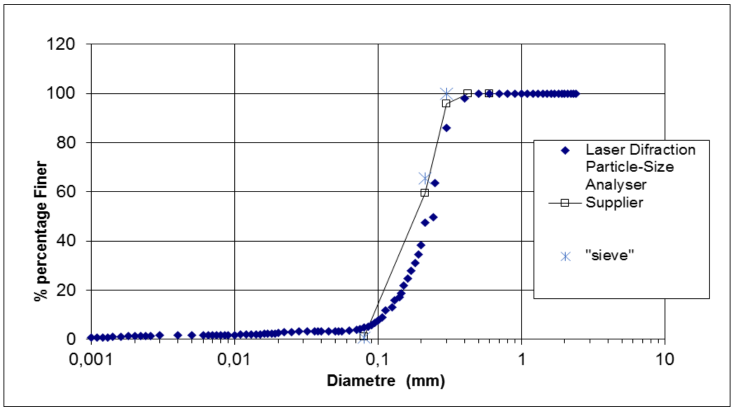

Fig.5. Grading Comparasion of Fontainebleau

After Triaxial Erodimeter test, each specimen was taken and a grading analysis made with laser apparatus. Four kinds sample of each specimen were top, middle, bottom and reference. Each sample represented each part of specimen. Sand mixture was used as reference but didn't used for Triaxial Test. The height of the speciment is 50 mm, so I separate it into three part with 25 mm for each height. Figure 6 shows the result of grading analysis presenting loss of clay. 0.08 mm was taken for examples. There are unusual result for Fontainebleau sand, because the percentage of grains in the top (4.79%) is more than the percentage of grain in the middle (4.58%). But the specimen shows good filtration and separation (figure 7). The four other samples representing the same trend in different value.

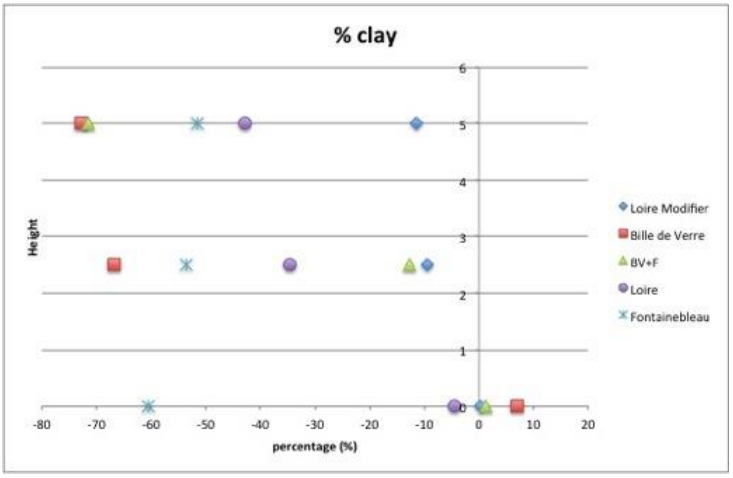

Fig.6. Percentage of loss clay

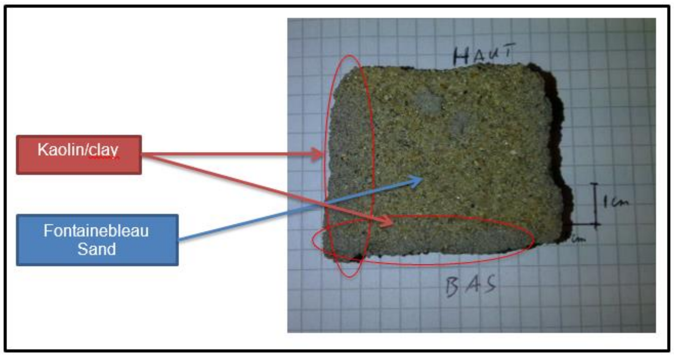

Fig.7. Speciment of Fontainebleau with 10% kaolin after Triaxial test

Figure 8 and 9 shows the grading analysis of effluent. Loire Sand (figure 8) and Fontainebleau Sand (figure 9) were used for comparison. Each effluent took about 40 minutes. For Loire Sand are 7 samples and for Fontainebleau are 4 samples. The results for Loire effluent is not too different, but for Fontainebleau is a little bit different because the time to taken the effluent is longer than Loire.

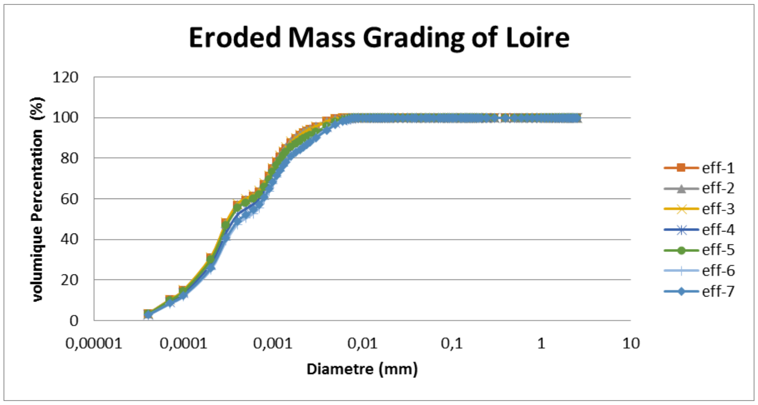

Fig.8. Eroded Mass Grading of Loire

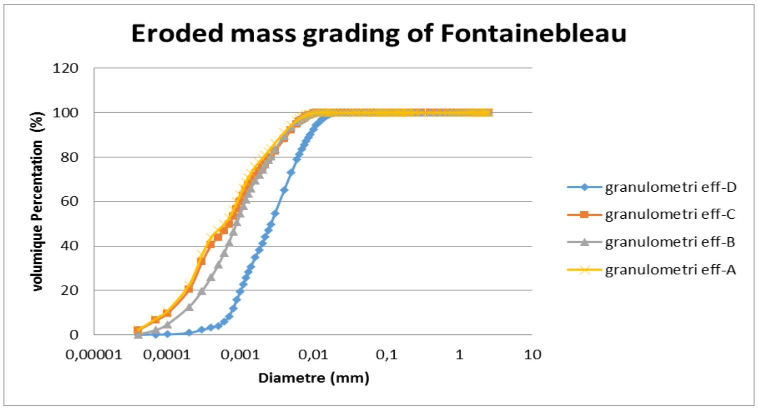

Fig.9. Eroded Mass Grading of Fontainebleau

4. Conclusion

Characterization of the suffusion sensibility of five mixtures of kaolin-aggregates and measurement grain angularity of the different used aggregate were performed by mechanical methods. By using a triaxial erodimeter, the suffusion sensitivity of five mixtures of kaolin-aggregates was determined. Results clearly demonstrate that suffusion process depends on the grain angularity of coarse fraction. With a constant flow, angularity of coarse fraction grains contributes to increase the suffusion resistance.

The values of maximum kaolin concentration in effluent measured during suffusion tests were compared with measurements of grain angularity of coarse fraction. Linear correlations between maximum kaolin concentration and angularity are obtained for the Fontainebleau sand, the Loire sand and the modified Loire sand with the optical method and the mechanical method. When results obtained from mixtures including glass beads are taken into account, such linear correlation is lost. More important values of clay concentration during erosion for coarse fraction composed by glass beads. By comparing the coarse fraction made uniquely with Fontainebleau and the one made of a mixture of glass bead and Fontainebleau sand, it seems that the presence of glass bead has limited the erosion process instead of intensify it. The strange behaviour of glass beads possibly comes from the result of Internal Friction Angle.

However as the mechanical method takes into account the influence of grain shape and also the influence of grain-size distribution, this method seems to be the more appropriated to characterize the influence of the grain shape on the process of erosion by suffusion.

Acknowledgements

I would like to thank my two principal advisers, Prof. Didier Marot and Prof. S. Imam Wahyudi for all the help along the way and for the opportunity to be part of Geotechnique Laboratory of GeM IUT Saint Nazaire. I would also like to thank Dr. Fateh Bendahmane, for all the help along my research in the Laboratory. I am deeply grateful to Dr. Luc Sibille, for his mentorship and for sharing his experience in Soil Mechanic.

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