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DEVELOPMENT OF A NEW TEST TO CHARACTERIZE DISPERSION OF SOIL

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The "Crumb Test" as ASTM standard[1)] permits a simple classification of soils depending on sensitivity to dispersion thanks to qualitative visual observations. We propose here to modify the equipment and improve the test protocol by the development of an "Enhanced Crumb Test". Testing the latter on reference configurations (soil texture and nature of immersing fluid) shows the great potential of this new test to better characterize the sensitivity to dispersion of soils. This could be of a great efficiency for determining reliable assessment on dispersion/erosion risks towards earth works.

Key Words : *dispersibility, clayey soils, crumb test, test procedure, parametric study, erosion*

1. INTRODUCTION

Recent catastrophic floods occurred among others in France (French county Aude in November 1999 or Gard in September 2002) clearly show the great vulnerability of embankments and dikes to internal erosion and overtopping. In most cases, road and railway embankments are washed away after breaching. Damage is caused by turbulence as flood water flowed over and in the embankment scouring out the soil layers and eating back into the earth structure. However, this erosion process depends strongly on the sensitivity of soils to dispersion. In the literature, many authors have studied the problem of this sensitivity by laboratory tests in order to explain and characterize the phenomenon[2,3,4)]. For the identification of soil sensitivity to dispersion, different tests were standardized by ASTM: "Double Hydrometer Test" [5)], "Pinhole test" [6)] or "Crumb Test" [1)].

The "Crumb Test" is a simple, quick and convenient test that can be used both in the laboratory and on field. It is an easily practicable test but with limited capacity because of interpretations based on visual observations. The results obtained are of a qualitative nature. Moreover this test does not fit for testing soils with a low or medium plastic index but commonly used for earthworks like road or railway embankments.

In this paper, we propose to enhance the crumb test by modifying the equipment and improving the testing procedure. This allows us to have quantitative results and a better characterization of the dispersion of a wide variety of soils. In section II, basic features of the ASTM standard "Crumb Test" are summarized. Section III describes the limit of the latter test and the development of the "Enhanced Crumb Test". In section IV, we present results on reference soils immerged in fluids with different properties. In section V, tests on typical soil textures are conducted and commented. Section VI gives a conclusion.

2. DESCRIPTION OF ASTM "CRUMB TEST"

The "Crumb Test" involves placing a small cube of remolded soil (15 mm) on the bottom and next to the wall of a cylindrical dish containing a large

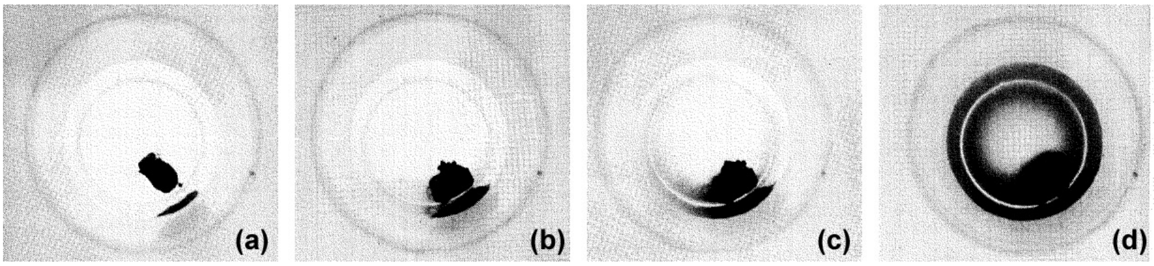

Fig. 1 Typical results from standard "Crumb Test" [7]. (a) Grade 1: non-dispersive. (b) Grade 2: intermediate. (c) Grade 3: dispersive. (d) Grade 4: highly dispersive.

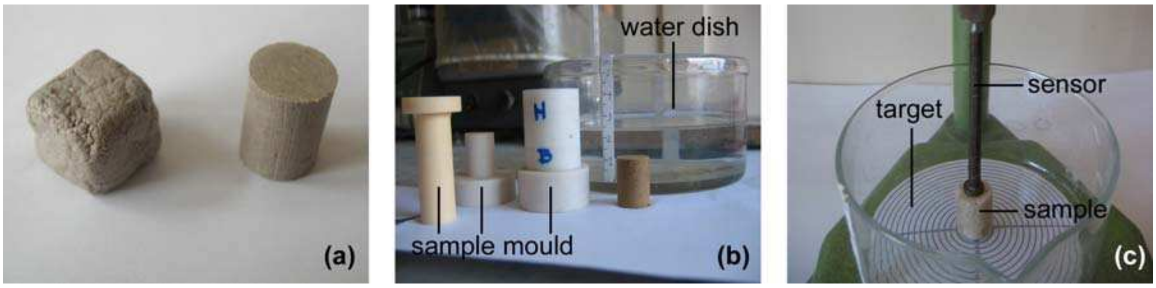

Fig. 2 "Enhanced Crumb Test". (a) Comparison between classical sample and new one. (b,c) Experimental set-up.

volume of distilled water (250 ml). The tendency of soil particles to disperse in a colloidal suspension is estimated by observing cloud formation at 2 minutes, 1 hour and 6 hours. Depending on the turbidity of the cloud, soil is classified into one of four grades (**Fig. 1**):

- Grade 1, non-dispersive: no reaction. The soil could crumble or spread out but there is no turbid water. All particles settle during the first hour.
- Grade 2, intermediate: slight reaction. There is the formation of a barely visible colloidal suspension causing turbid water near portions of soil.
- Grade 3, dispersive: moderate reaction. A cloud of suspended clay is easily visible around the soil surface and can extend till 10mm away from the soil sample.
- Grade 4, highly dispersive: strong reaction. A dense cloud of colloidal suspension is observed on the entire surface of the dish.

3. PROTOCOL IMPROVEMENT AND APPARATUS MODIFICATION OF THE ASTM "CRUMB TEST": "ENHANCED CRUMB TEST"

Using the "Crumb Test" as described in ASTM (see preceding paragraph), we were confronted with many difficulties in terms of protocol and interpretation of results.

(1) Sample preparation

The sample preparation recommended in the "Crumb Test" standard presents a number of difficulties and limitations of repeatability or reproducibility compare to the custom prevailing in standardized laboratory test such as triaxial test. The manual cube compaction for remolded sample is a sensitive and low reproducible (and even low repeatable) step of the procedure. Thus, it is done according to perpendicular directions and the soil has a tendency to crack and weaken during the sample compaction. In addition, the sample preparation must be done in a short time in order to reduce the water evaporation and it is so difficult to obtain exact dimensions: cube facets are uneven and the side width varies. Finally, the manual preparation gives results differing inevitably from one operator to another. This results in varying sample dimensions and compaction rate.

For these reasons, we have developed an "Enhanced Crumb Test" with cylindrical samples statistically recompacted at a given volume and at a water content defined by a standard Proctor test[8]. A cylindrical mould (1.5 cm in diameter and 2 cm height) was produced and used (**Fig. 2ab**). In addition, the sample is placed in the middle of the water dish to avoid wall effects.

(2) Test procedure and measurements

If, in the "Crumb Test", visual observations are suitable for a qualitative classification of the soil but

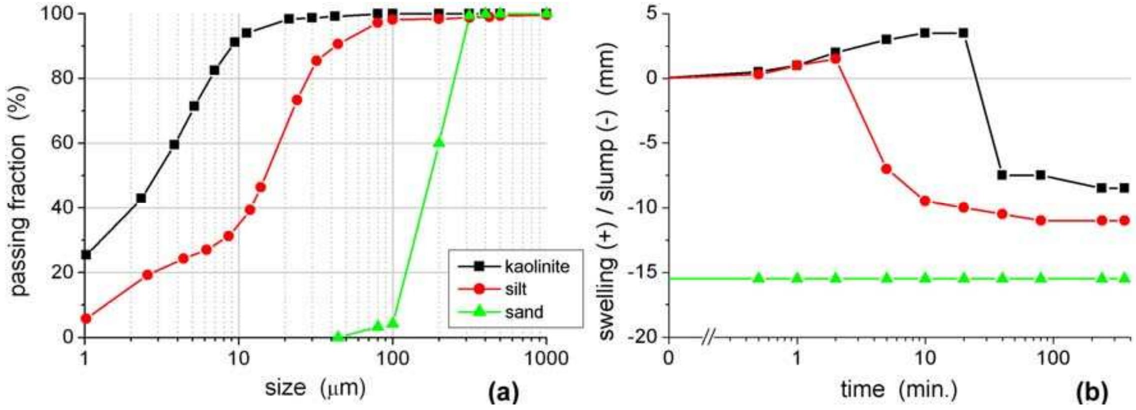

Fig. 3 Tests on reference soils. (a) Grading. (b) Swelling/slump curves.

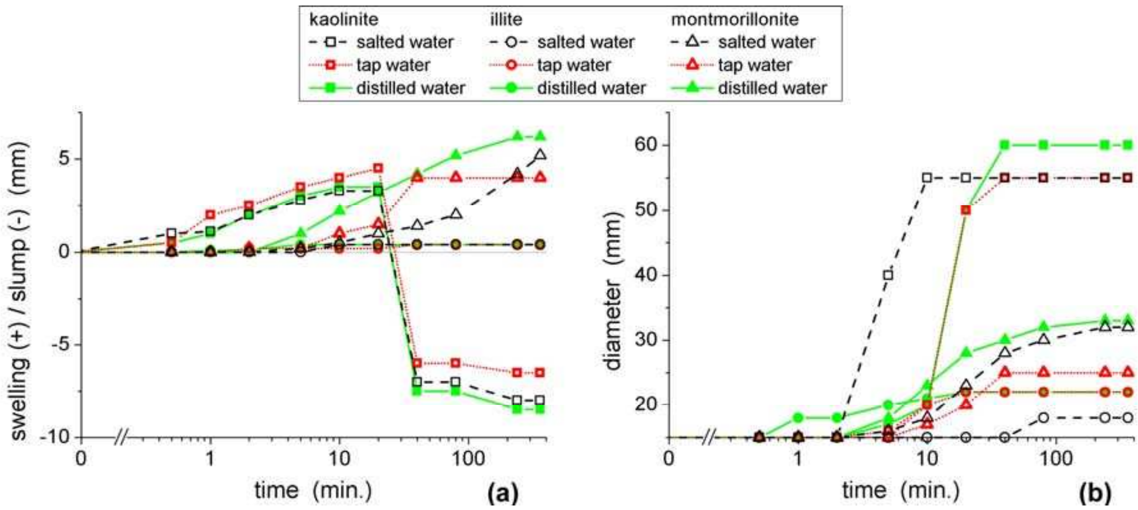

Fig. 4 "Enhanced Crumb Test" on reference configurations. (a) Swelling/slump curves. (b) Expansion curves.

these observations are not sufficient to obtain quantitative results. In this perspective, and in order to have more repeatable tests, we developed a device that allows us to measure geometric properties of the sample over time (**Fig. 2c**). A sensor is used to measure the swelling or the slump of the sample while a target placed at the bottom of the container is used to measure the expansion of the sample (i.e. its diameter). Swelling/slump and enlargement of the sample are measured at 30 seconds, 1, 2, 4, 5, 10, 20, 40, 80 minutes, 4 and 6 hours. The total duration of the test is thus identical to the one of the original "Crumb Test".

4. "ENHANCED CRUMB TEST": RESULTS ON REFERENCE CONFIGURATIONS

(1) Swelling/slump curves

Fig. 3b represents the swelling/slump curves of three reference soils: kaolinite clay (armorican), silt (Goberville) and Fontainebleau sand. Note that the y-axis shows the vertical position of the sample upper interface, the origin source being the initial position of this interface.

Fig. 3b shows the typical behavior of these three textures:

- for sand, granular and not clayey soil, there is no phase of swelling and the slump is immediate (note that this type of soil is not usually tested with standard "Crumb Test"),
- for silt, fine but few clayey soil, after a first phase where strains are maintained by the suction generated during the static compaction, there are a quick slump phase and a significant dispersion,
- for clay, there is schematically four phases: first, an hydration phase, then a swelling specific to clay, followed by a slump phase caused by crumbling and the final dispersion.

First observations show that the slump seems to depend largely on the cohesion of soil particles and /

Table 1 Properties of tested soil textures.

N°	soil type	dry weight %			water	dry	liq/plastic limits			G_{CT}*	*dh_f*
		clay	silt	sand	%	density	w_L (%)	w_P(%)	I_P (%)		*(mm)*
1	sand	10	20	70	11	1.9	13.6	-	-	1	*12.5*
2	sandy silt	15	45	40	11	1.9	14.6	12.7	2	1	*10.1*
3	clayey sand	25	5	70	11	1.9	13.5	-	-	1	*10.5*
4	clayey silt	25	60	15	11	1.9	25.5	21.2	4.3	1	*12.1*
5	sandy clay	35	25	40	11	1.9	19.6	13.9	5.7	1	*9.1*
6	silty clay	45	40	15	14	1.8	26.9	20.4	6.5	1	*9.9*
7	clay	65	5	30	19	1.6	26.1	21.7	4.4	1	*6.2*
8	clay	70	20	10	23.5	1.5	35.2	30	5.2	1	*7.8*

*grade determined with standard ASTM "Crumb Test"

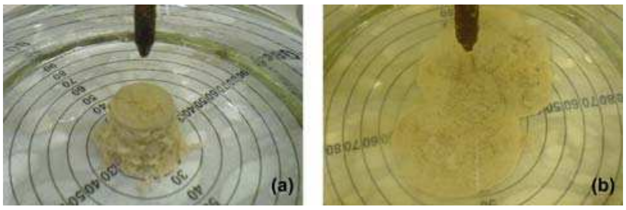

Fig. 5 Pictures from "Enhanced New Crumb Test" at 6h (end of the test). (a) In distilled water. (b) In water with dispersing agent.

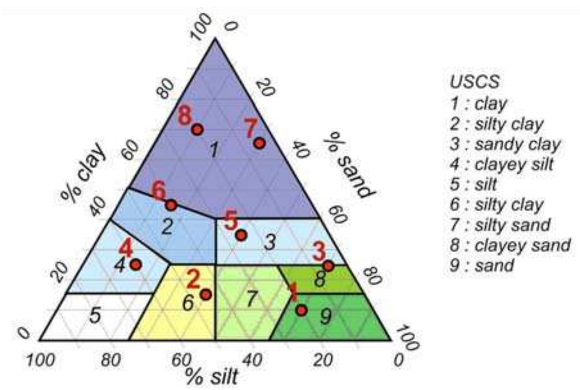

Fig. 6 Different tested soil textures.

or the impermeability of the sample. Much of the cohesion is due to the presence of clay, the latter playing a main role in the slowdown of the slump process, while the sand, without cohesion, tends to accelerate the crumbling and hence the slump.

(2) Influence of the clay type

To study the influence of mineralogical nature of the clay on the dispersion, three different types of clays were used: kaolinite, illite (both known as non-expanding) and montmorillonite (known as expanding). The tests were also conducted with three types of fluid: distilled water, tap water from public network and salted water (NaCl concentration: 0.6 mol.L-1).

The results are shown on **Fig. 4ab**. The soil samples with illite and montmorillonite clays have a behavior which differs from the sample with kaolinite. The latter is the one that swells the earliest but is also the only one to slump (**Fig. 4a**). The sample with illite is fairly inert, whereas the sample with the montmorillonite swells relatively slowly but during the entire test. These global observations are stable independently of the used fluid.

The enlargement (diameter) of the sample on the bottom is measured with a target drawn to the bottom of the container (**Fig. 2c**). The expansion of the sample with kaolinite clay is the largest, independently of the fluid, followed by samples with montmorillonite or illite (**Fig. 4b**).

Till the end of the test, the sample with kaolinite clay totally disperses, the one with montmorillonite is only partially dispersed whereas the one with illite does not. In consequence, this test discriminates efficiently the nature of the clay.

(3) Influence of the fluid properties

a) Tests in salted water

The presence of sodium chloride ions reduces the thickness of the double layer of clay particles and thus decreases the force of repulsion between particles[9]. The "Enhanced Crumb Tests" realized in salted water give an enlargement lower than in distilled water (**Fig. 4ab**). The dispersion of soil is therefore limited in a salty environment.

b) Tests in the water with dispersing agent

By contrast with salt, adding a dispersing agent (sodium hexametaphosphate, used for the "Double Hydrometer Test") enhances the dispersion of clay. Tests realized in water with dispersing agent show an increase of the expansion in comparison to the one measured in distilled water (**Fig. 5ab**).

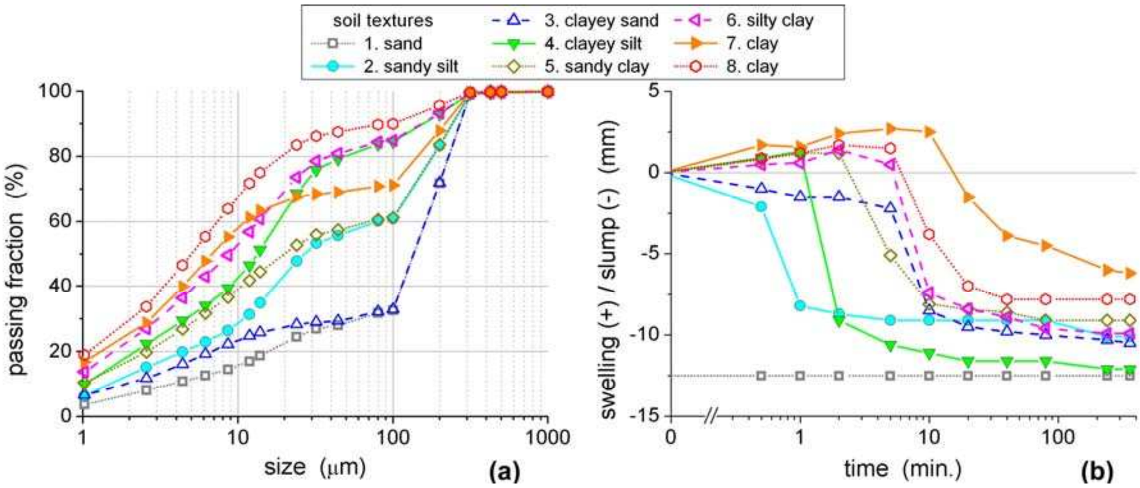

Fig. 7 Tests on different soil textures. (a) Grading. (b) Swelling/slump curves.

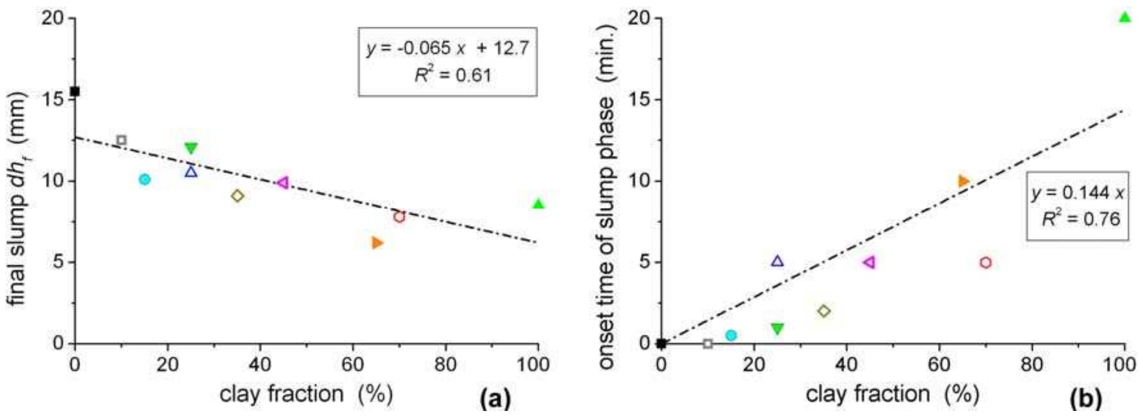

Fig. 8 "Dependency on with clay fraction. (a) Final settling. (b) Initiation time of the slump phase.

5. INFLUENCE OF SOIL TEXTURE ON SENSITIVITY TO DISPERSION

(1) Characterization of soil textures

We tested different texture of soil in order to cover a wide variety of situations. The textures are made from a mixture of sand, silt and kaolinite clay (grading on **Fig. 3b**), to which is added a water content corresponding to 95% of Normal Proctor Optimum. Kaolinite was used as it is a common type of clay in France. These soil textures are positioned on the ternary diagram of USCS classifications (**Fig. 6**). The physical characteristics are reported in **Table 1** and the grading is shown on **Fig. 7a**. These textures cover a wide range from the clayey to the sandy soils. For each "Enhanced Crumb Test" at least two or three repeatability tests has been done.

(2) Effect of texture on dispersion

Fig. 9b represents swelling / slump curves obtained for all tested textures. Very varied behaviors are obtained although standard classification by "Crumb Test" [1)] does not underline any difference: all tested textures are classified in the same grade (**Table 1**).

For textures composed mostly of sand (> 50%) and with less than 30% of clay, it is observed that the behavior of the specimen does not present a swelling phase and that the sample slumps quickly. Conversely, an increasing swelling and a decreasing final slump are noticed for textures with increasing clayey fraction. The dispersion phase (characterized by a slow slump) is also larger for clayey textures. The value of the final slump dhf and the onset time of the slump phase seem to be directly related to the percentage of clay (**Table 1**, **Fig. 7b**, **8ab**).

The curvature of the grading curve due to the silt fraction in the texture has also a strong influence (**Table 1**, **Fig. 7ab**). At constant sand fraction, decreasing clay proportion and substituting clay by silt (texture 6 to 4, or 5 to 2) eliminates the swelling phase and leads to a rapid slump. At constant clay fraction, decreasing sand proportion and substituting sand by silt (texture 7 to 8, or 3 to 4) also decreases the onset time of the slump phase.

6. CONCLUSIONS

Thanks to changes to the set-up as well as improvements to the testing protocol, the “Enhanced Crumb Test” permits a better characterization of the sensitivity to dispersion of soils in comparison to the ASTM standard. Thus, it is perfectly suited to discern the nature of the soil clay fraction, its proportion and the influence of immersing fluid. Using the “Enhanced Crumb Test” in a variety of fluids promoting the dispersion (dispersing agent), or limiting it (salted water) shows the test potential to study the dispersion in conditions as diverse as rainfall erosion on a slope or river erosion on estuary. Thus, the results obtained with the “Enhanced Crumb Test” could be used to establish reliable diagnostics on sensitivity to dispersion.

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