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Analysis of the modification of piping channels on kaolinitic clayey samples in the pinhole test

Juan Carlos Ruge[1#], Henry Giovanni Martínez[2], Eliana Martínez Rojas[2]

Article

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Dispersivity
Pinhole test
Piping
Internal erosion
Double hydrometer test

Abstract

Dispersivity is a severe pathology that occurs mainly in clay soils and is usually catastrophic in geotechnical structures susceptible to this damage. Hundreds of dams worldwide have failed due to quality problems, mainly by piping in the body, foundation, spillway, culvert, and other peripheral structures. The pinhole test is currently considered the most accurate test for detecting the dispersivity of clay soils. However, it presents problems when objectively evaluating the dispersivity of a material due to the qualitative nature of the estimation of results. In particular, the methodology for determining turbidity has been identified. This document studies different piping paths in the sample, which *a priori* may be more realistic than the single path in the current test. A kaolinitic clay, widely studied through index and mineralogical tests, is used as the base material. Regarding the detection of dispersivity, a specialized test package was used to reduce the uncertainty of the results. Natural samples were analyzed using ASTM D4647-13. A modification of the pinhole test was proposed based on the imposition of additional artificial channels. The results revealed that this modification can make the test more realistic because when the dispersive front advances in the soil, it does not travel along a single path but instead looks for different erosive paths. The details of this assertion are discussed throughout the paper.

1. Introduction

In dispersive materials, the interstitial structure contains many exchangeable sodium ions that affect the segregating behavior of the soil. The sodium molecules act as dispersing agents that increase the thickness of the diffuse double layer. Under saturated conditions, the clay assemblages, often called "tactoids", repel each other, undergo lamellar deflocculation, and transform into individual colloidal suspensions (Zorluer et al., 2010). This water-induced removal process creates internal erosion and tubular formation (piping), the degree of which is a function of sodium content, mineralogy, textural chemistry, dissolved salt level and pore size distribution (Zourler, 2003). In simpler terms, dispersivity occurs in cohesive soils when the repulsive forces between particles exceed the attractive forces, facilitating the segregation phase and movement in the suspension. Soils with significant dispersive spectra generally have low permeability, porosity, and bulk density (Ouhadi & Goodarzi, 2006).

Several traditional and modern approaches have been proposed to optimize the standard experimental procedures for identifying dispersive clay. Generally, conventional laboratory index tests such as visual categorization, gradation, specific gravity or Atterberg limits do not allow for deeply defining the internal erosion suitability of soil (Belarbi et al., 2013). There are three tests most frequently performed to determine the numerical framework of dispersivity: the crumb test (Emerson, 1967), the pinhole test (Sherard et al., 1976a) and the Soil Conservation Service (SCS) laboratory dispersion test (sometimes called double hydrometer test) (Decker & Dunnigan, 1977), commonly used in combination to obtain more reliable results. However, there are many critical empirical tests and adaptations of chemical nature (Ladd, 1960; Heinzen, 1976; Coumoulos, 1977; Forsythe, 1977; Sargunan, 1977; Jones, 1981). Similarly, Shoghi et al. (2013), Abbaslou et al. (2016), and Singh et al. (2018), provide a detailed summary of many of these measurement techniques.

Through preferential flow paths, the pinhole technique indicates the development of tubular formations in dispersive materials with high and low sodium ion content and soils with liquefaction potential. In some cases, the Pinhole method has a variable degree of suitability for identifying dispersive soils (Reeves et al., 2006; Ismail et al., 2008) or tunneling processes (Vacher et al., 2004). However, the

[#]Corresponding author. E-mail address: juan.ruge@unimilitar.edu.co
[1] Universidad Militar Nueva Granada, Programa de Ingeniería Civil, Bogotá, Colombia.
[2] Universidad Piloto de Colombia, Programa de Ingeniería Civil, Bogotá, Colombia.

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shortcomings of pinhole test for being qualitative and not effectively identifying accurate soil dispersion (Jermy & Walker, 1999) have generated numerous refinement proposals that provide a more quantitative measurement rather than the typical assessment based on visual examination. Maes (2010), evaluated the susceptibility of the pinhole mechanism to internal pipe routing and the effect of tunnel development on internal soil structure resistance across different hydraulic pressures.

This study proposes modifying the pinhole test by the imposition of multiple tubing channels on the cross-section of kaolin samples. The number of induced channels is presented under two different configurations to explore the effects on the dispersivity paths. The results will be analyzed mainly by comparing the mechanics of the conventional pinhole test with the modification proposed in this investigation.

2. Background

As mentioned in the abstract, many dams worldwide have failed due to piping problems. In the US alone, 20% of dams have revealed incidents related to internal erosion driven by seepage. This pathology has often been identified in hydraulic-geotechnical structures such as levees, dikes, dams, embankments, and spillways, caused by different aspects such as animal burrows, roots of some plant species, fissures or by some intrinsic condition of a soil susceptible to this anomaly (ASDSO, 2023). In the rest of the world, most cases are divided between overtopping and quality problems, covering 80% of the total cases. Of these events, 58% of quality problems are related to piping in the body or foundation. Data about piping are not shown when it is due to dispersivity or erodible soils detonated by an external factor (Zhang et al., 2007).

Caldeira (2018) mentions that the erosive (dispersive) path has a retrogressive tendency because the detachment of particles at the path's end reveals the pathology's triggering mechanism. Such detachment is exacerbated through the porous medium when the critical gradient is greater than the threshold that the material physically supports, according to its intrinsic properties. The gradient necessary to initiate erosion must be very high in fine soils that cross the sieve 200 and have a plasticity index greater than 7. The opposite is true for non-plastic soils (NP), particularly with a plasticity index of less than 7. Schmertmann (2001) reported that the minimum gradient generating the detachment in the soil is very low, of the order of 0.08. While the speed required for longitudinal scour in a dispersive path is between 40 and 90 times that for piping processes. It is essential to understand this process, according to *ibid.* Schmertmann (2001), as a detachment condition in zones of effective stress and, therefore, of zero shear strength (vide Figure 1).

This aspect can be understood in Figure 1, which shows the onset of erosion for non-plastic soils according to the value discussed in the previous paragraph. As the hydraulic

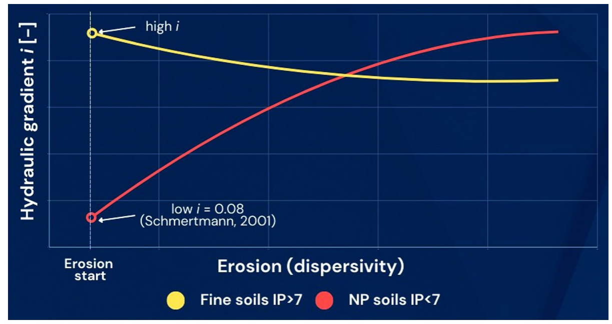

Figure 1. Hydraulic gradient versus erosion.

gradient increases, erosion is assumed to increase in these soils. In contrast, a high hydraulic gradient – i – is required to initiate erosion in fine soils. The hydraulic gradient should remain constant or, at most, decrease slightly to maintain constant erosion in such soils.

The dispersive mechanism of cohesive soils is complex. Some researchers, such as Wei et al. (2007), rely on acidity theory, using the *pH* value to explain the reasons for dispersivity. Mineral and cation theories are sometimes applied to answer this behavior in fine-grained soils (Wang et al., 1999). Although many of these theories have conceptual bases, they still need to be completed in application fundamentals, and to ensure proximity to the intrinsic behavior of dispersivity, numerous experimental archetypes are developed. The pore water-soluble cation test developed by Edgar (1991) and the exchangeable sodium percentage test (Sherard et al., 1973) follow execution protocols similar to the criteria for dispersion potential classification. Fan et al. (2013), propose a quantitative method that interprets the results of those tests. Systems similar to SCS with different limits were patented by Gerber & von Maltitz (1987) and Walker (1998). Likewise, Muttuvel (2008) modeled an analytical device for the simulation of internal erosion and piping processes, which incorporates the stress-strain characteristics of the soil and validates the results employing uniaxial tensile tests. Other studies (Camapum de Carvalho et al., 1999; Camapum de Carvalho & Gitirana, 2021) have evaluated in tropical non-plastic soils that discontinuity in particle size distribution can strongly influence tubified erosion.

More current equipment, such as the Jet Erosion Test (Hanson & Cook, 2004), the Hole Erosion Test (Fell & Wan, 2002; Wan & Fell, 2004a, b) and the Slot Erosion Test (*op cit.* Fell & Wan, 2002), allow modeling of internal tubular erosion rate and shear stress using the measured flow rate and hydraulic gradient. Modifications of these devices and simple numerical methods to analyze the collected data are extensive (Lim, 2006; Farrar et al., 2007; Bonelli & Brivois, 2008; Mercier et al., 2012; Karamigolbaghi et al., 2017; Lüthi, 2011; Lüthi & Millar, 2011; Marot et al., 2011; Regazzoni & Marot, 2018). It has recently been possible to determine the potential for pipe formation through true triaxial testing under a broader range of confining stresses and hydraulic gradients (Richards & Reddy, 2010). Tomlinson & Vaid (2000) developed a test to assess the effect of uniaxial stress on the piping phenomenon. Valdes & Liang (2006) adjusted the performance of industrial filters in various modes of internal tubular behavior of soils.

The pinhole test, as an indicator for dispersive soils, was first expounded by Sherard et al. (1976b) to distinguish and refine the understanding of dispersive, sodium ion-rich, fine-grained, highly erodible soils. The test procedure described in ASTM (2013a) is based on extensive testing and observational experience, so it is not intended to be used as a quantitative test capable of accurately measuring subsurface erosion rates (Figure 2). This method is discussed extensively by Maharaj (2010) and Maharaj & Paige-Green (2010), and numerous approaches are intended to inform the procedure of this test for dispersive problem-solving (Leonards et al., 1991; Tosun, 2000; Botschek et al., 2002a, b; Vacher et al., 2002; Batog et al., 2007; Nadal-Romero et al., 2011a). In all these reports, the susceptibility of various soil types to dispersion or tubular ingrowth is reported through physicochemical parametric measurements before and after the test.

The evident importance of the interaction between electrical conductivity and exchangeable sodium in the numerical description of clay dispersion and piping (Turner et al., 2008) has exposed the pinhole methodology to modifications in order to address its operation under quantitative principles. Also, Arulanandan & Heinzen (1977) used a rotating cylinder and weight loss to measure erosion within the Pinhole device. In the same way, Zhang (1981) proposed discriminating soil dispersion by the molar rate of sodium ions in the pinhole test. Fan et al. (2004) adopted the pinhole mechanism for different test-weighted values, which provided a more reasonable and reliable synthetic discrimination method to isolate soil dispersion (Chen et al., 2017). Similarly, Rahimi & Abbasi (2008) developed a metal disk with a short conical inlet tube that prevents erosion inside the pinhole device.

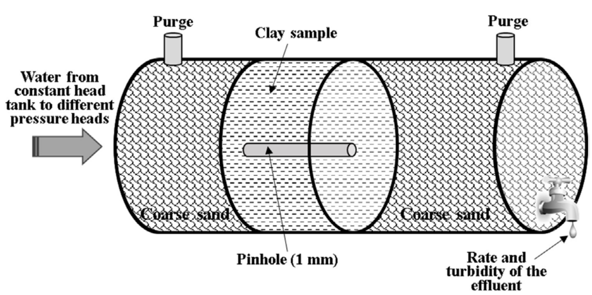

Figure 2. Schematic of the chamber housing the sample in the pinhole test.

3. Materials and methods

3.1 Material characterization

The study was carried out with kaolin, a hydrated aluminum silicate. The particle size distribution (PaSD) was obtained using the ASTM D7928-1 standard procedure under hydrometric processes. Figure 3 shows the particle size curve for kaolin. The test used a deflocculant (sodium hexametaphosphate) to obtain values for particles with diameters less than 0.002 mm. An essential aspect of the PaSD of this material is the intrinsic contour of the curve, which extends primarily from 0.075 mm to 0.002 mm, indicating the dominance of a silty soil.

Table 1 summarizes the clay's physical properties and classification parameters, analyzed considering the coefficient of variability between samples.

The use of X-Ray fluorescence (XRF) spectral data was carried out in order to know the chemical compositions of the minerals present in the clay. On the other hand, the changes in the mineralogical information of kaolin were focused using X-Ray diffraction (XRD) through the positions of the basal reflections. The data provided in Figure 4b show that alumina and silica oxide are present in significant proportions, while the other compounds are present in trace amounts. Excluding the quantitative estimation phase, the XRD patterns indicate the presence of quartz, kaolinite and illite as the main minerals (Figure 4a).

3.2 Proposed modification to the Pinhole test

The pinhole test alteration includes adding four tubing channels in modification type I and eight for modification type II, arranged crosswise in the x-y and x'-y' plane with the center at the main hole, as shown in Figures 5 and 6.

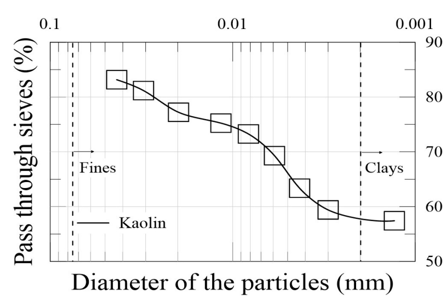

Figure 3. Particle size distribution of the kaolin.

Table 1. Physical properties of kaolin.

Sample	G_s (.)	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)	Hydraulic conductivity (cm/s)	Specific weight γ (g/cm^3)
1	2.58	42.2	24.3	19.7	0.000043	1.50
2	2.56	42.2	25.2	17.0	0.000041	1.57
3	2.53	43.0	24.3	18.7	0.000038	1.58
Variation (%)	1.0	1.0	2.0	7.0	6.0	3.0

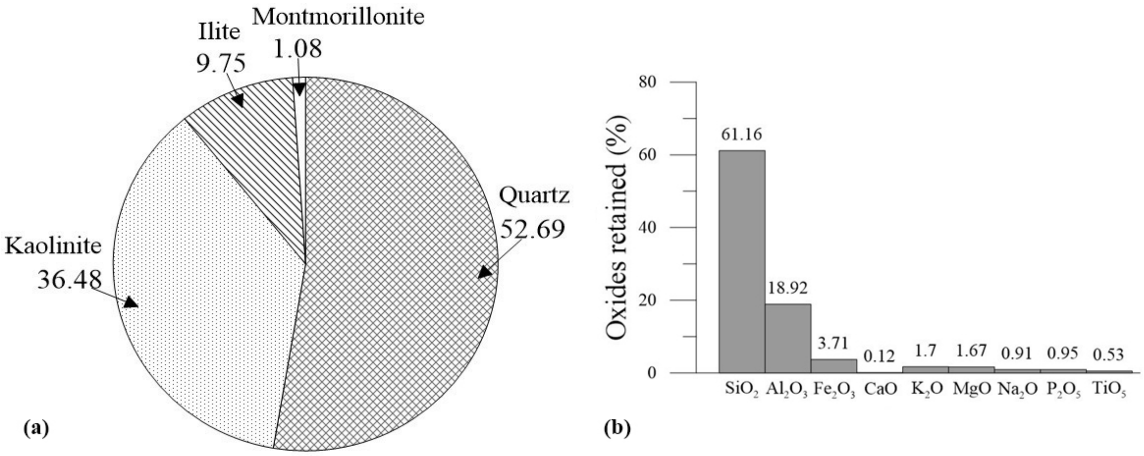

Figure 4. Results of: (a) XRD; and (b) XRF.

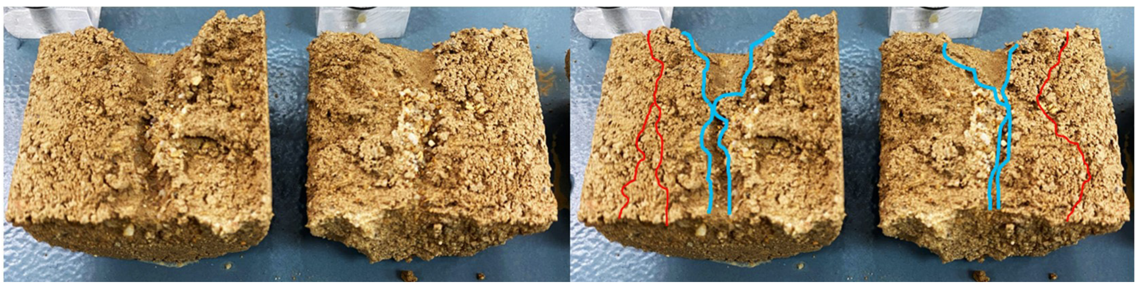

Figure 5. Different natural and induced paths in the pinhole sample.

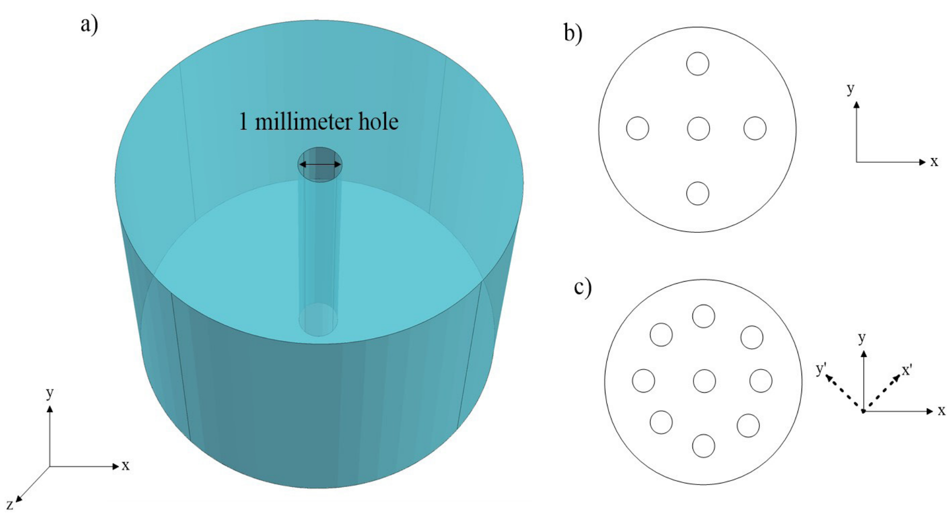

Figure 6. (a) Pinhole apparatus chamber; (b) Modification I; (c) Modification II.

The flow injection is performed through the induced conduits using a 1 mm diameter pipe. It is important to describe that the distance between the eccentric holes and the sample chamber is at least 10 mm. The objective of this proposal is to evaluate the dispersive potential of the soil, using a more realistic approach to internal piping behavior in compacted materials, since generally, erosion processes co-occur in numerous channels parallel and perpendicular to the flow and are not directed through a single circulation pathway as established by the original test.

As seen in Figure 5, a sample of the pinhole test reveals a cross-section made at the end of the test showing a blue line representing the erosive path induced by a 1 mm diameter probe before starting the test. Although other piping channels were not induced, they are identified in the sample. Therefore, modification of the test by imposing new pinholes is justified, as illustrated in Figure 7.

Inducing various artificial conduits allows for obtaining more approximate dispersivity values and testing whether including these new channels affects the mechanics of the

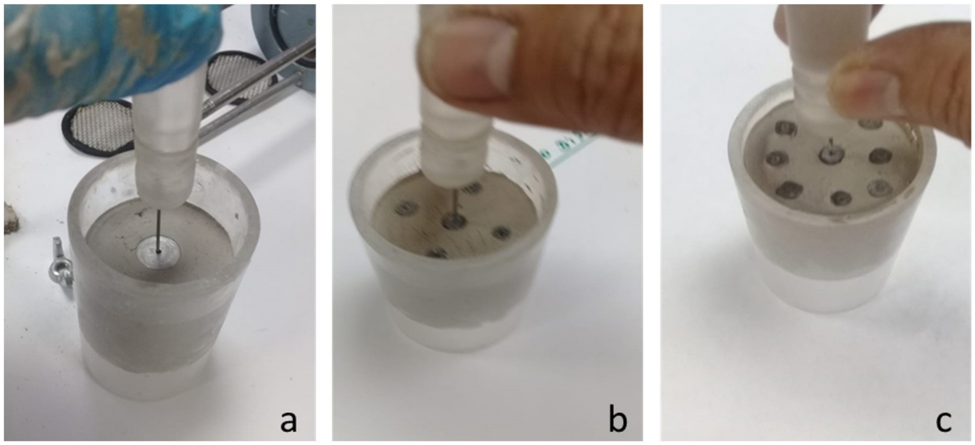

Figure 7. Pinhole test modification: (a) NM, flow direction; (b) Modification I, flow direction; and (c) Modification II, flow direction.

results in soils with index values of dispersivity obtained through the original pinhole test (Figure 7).

3.3 Testing program

Thirty (30) dispersive and non-dispersive soil samples were prepared to provide dispersivity measurements using the new mechanical modifications of the Pinhole test. Since the natural samples obtained are non-dispersive, artificial dispersivity will be imposed in order to reduce the uncertainty of false negatives in the crumb (ASTM, 2013b), pinhole (ASTM, 2013a), and SCS test (ASTM, 2018).

Taking as a reference the SCS test methodology, better known as double hydrometer, where a comparison is made between samples tested with a deflocculating agent and without a deflocculating agent; the methodology proposed by Galvis (2020) and Galvis et al. (2021) is replicated. In this study, the samples are artificially dispersed, trying to simulate the natural dispersive behaviour of the samples. With this, it was possible to advance the research by obtaining first-hand dispersive samples due to the impossibility of obtaining them *in situ*.

Each of the specimens was compacted in three separate layers using a small hammer as a compaction tool in a bottomless mold, with eight blows per layer according to the standard energy calculation required for the volume of the specimens. The optimum moisture content for all layers is close to 28%, with a maximum dry unit weight of 1.36 g/cm^3. The layers have a thickness of 13 mm for parallel flow through the synthetic tubing channels. The dispersive samples contain 4% sodium hexametaphosphate added to the compaction water of the specimens. This method is analogous to that used in the double hydrometer test.

For the pinhole test, a 1 mm diameter hole is drilled through the 40 mm long and 35 mm diameter cylindrical soil samples, using the geometric distribution for each modification (Figure 2). Distilled water is percolated under pressures of 50, 180 and 380 mm water column, using a reservoir. For the loading values, the effluent flow rate is recorded at a controlled time of 60 and 300 seconds to observe the qualitative condition of the water after the pinhole test.

4. Analysis and results

Detecting a dispersive anomaly in soil is fundamental to the lifetime of a geotechnical structure—particularly those with hydraulic stresses, as discussed above. The timing of anticipating the dispersive potential of the material is critical at the geotechnical design stage.

4.1 Pinhole test

Tests based on the unmodified pinhole method, *i.e.* conventional testing, are developed using ASTM Standard Method A. This method is designed for samples suspected of being dispersive. The samples are initially known as non-dispersive. However, the planned set of tests is performed on them. Method A must be tested by imposing all pressure heads and measuring the flow rates encountered.

Table 2 shows the dispersivity results for the originally non-dispersive samples, considering the modifications in the flow channels of the specimen, as shown in the methodology. It is important to note that the modified samples, imposing more piping channels (*a priori* more realistic), present a different classification according to the ASTM D4647-13 standard (ASTM, 2013a). However, regarding dispersivity values, the qualitative mention is the same, i.e., the samples are also classified as non-dispersive. Nevertheless, the standard already identifies a difference between ND1 and ND2. In principle, this is a minimal distinction based only on the change in the effluent rate flow, which begins to reveal the consequences of the modification, even in naturally non-dispersive samples.

The samples conventionally used according to the reference standard reveal a No dispersive - ND1 classification for a single artificial piping channel. However, the modified samples (I-II), although also classified as non-dispersive, have the ND2 symbology added to them. This aspect means they

Table 2. Classification of non-dispersive samples.

Sample	Modification	Max. head reached (mm)	Flow rate (mL/s)	Hole size after test (mm)	Classification Method A	Qualitative effluent turbidity
1	NM	1020	1.73	1.0	No dispersive - ND1	Clear
2	NM	1020	1.75	1.0	No dispersive - ND1	Clear
3	NM	1020	1.78	1.0	No dispersive - ND1	Clear
1	I	1020	3.37	1.0	No dispersive - ND2	Clear
2	I	1020	3.45	1.0	No dispersive - ND2	Clear
3	I	1020	3.42	1.0	No dispersive - ND2	Clear
1	II	1020	3.90	1.0	No dispersive - ND2	Clear
2	II	1020	3.78	1.0	No dispersive - ND2	Clear
3	II	1020	3.95	1.0	No dispersive - ND2	Clear

Legend: NM, No Modification; I, Modification I; II, Modification II.

present a higher flow rate, which is strongly influenced by the proposed modification. In all three cases, the flow turbidity was completely clear. The difference between clays that are referenced as non-dispersive ND1 and ND2, their difference lies in the flow rate, which must be less than equal to and greater than 3.0 mL/s, respectively.

The only differentiated aspect in the proposed modification for the non-dispersive samples, i.e. I and II, is the flow rate increase, which, although it seems obvious, is a point of interest before evaluating the dispersive samples, as analyzed, according to the observation in Figure 5.

The results are interesting concerning the samples with imposed dispersivity (Table 3), in which a traditional deflocculant is used, as in the particle size distribution test for the fine fraction of a material. As expected, the unmodified (NM) sample with induced dispersivity changes its dispersive response. It is shown that at a pressure head of 380 mm, it is already dispersive, and its category reveals that it is classified as Slightly Dispersive - ND3 for method A and Dispersive – D for method B since the turbidity of the source was described as dark and cloudy, respectively.

This aspect already shows a disparity in criteria that generates uncertainty in the analysis of the pinhole test. At this point, the singular process demonstrated that dispersing the soil by adding salt with sodium ions allows the test to reflect a true positive. Of course, this only explains some things. Although the samples are not naturally dispersive, they present a high susceptibility to this pathology when infiltrated by humidity with sodium salts.

This description will be incomplete without describing the response obtained in the dispersive samples with modifications I and II. Consequently, the samples with modifications type I and II (five and nine pinholes) in the first instance exhibit a lower pressure head at which dispersivity was achieved (180 mm) and a logical increase in flow rate, as explained above in the analysis of the non-dispersive samples. The pinhole orifice remains constant between 5 and 6 mm, and the turbidity description remains dark or cloudy, depending on the method approach.

Here, referring to the change shown in the dispersivity classification is necessary according to the reference standard. It is evident that in the specimens without modification (NM), the description for method A resulted in Slightly dispersive - ND3 and for method B, Dispersive D. After subjecting the samples to modification I and II, the classification changes from Slightly dispersive - ND3 to Moderately dispersive - ND3. In other words, the modifications generate a change in the dispersivity of the material. It is important to note that the samples are dispersive for method B in all cases. However, method A, which is considered more accurate due to the ASTM D4647-13 standard (ASTM, 2013a), reveals an apparent change, which is not small, since the change from one step to another in the degree of dispersivity implies a variation in the parameters of pressure head, flow rate, orifice size and effluent turbidity (see Figure 8). A summary of the results obtained is illustrated in Figure 9.

Having done this analysis, it is worth clarifying one more aspect of the sample modification. The proximity of the chamber can influence the border effect on the eccentric pinholes. Figures 5 and 7, show that the tubing channels are naturally generated around the imposed pinhole. In addition, in Figure 7, the centre of the pinhole is distanced from the chamber wall at a distance ten times the pinhole diameter (1 mm). This distance is considered sufficient to avoid a possible boundary effect.

4.2 Double hydrometer and crumb test

For the complementary crumb and double hydrometer tests, three natural samples and three samples with artificial dispersivity were taken to compare with the pinhole tests developed. Table 4 shows the results of this qualitative test (crumb), which reveals low dispersivity degrees for the natural samples. In contrast, the values of the dispersive reaction are indeed high for the samples with imposed dispersivity. The results are valid for the ASTM D6572-13 standard (ASTM, 2013b).

Table 3. Classification of dispersive samples.

Sample	Modification	Max. head reached (mm)	Flow rate (mL/s)	Hole size after test (mm)	Classification method A / B	Qualitative effluent turbidity
1		380	1.60	6.0	Slightly dispersive - ND3 / Dispersive - D	Dark/Cloudy
2		380	1.92	6.0	Slightly dispersive - ND3 / Dispersive - D	Dark/Cloudy
3		380	2.07	6.0	Slightly dispersive - ND3 / Dispersive - D	Dark/Cloudy
1		180	2.47	5.0	Slightly to moderately dispersive - ND3 / Dispersive - D	Dark/Cloudy
2		180	2.32	5.0	Slightly to moderately dispersive - ND3 / Dispersive - D	Dark/Cloudy
3		180	2.37	5.0	Slightly to moderately dispersive - ND3 / Dispersive - D	Dark/Cloudy
1		180	2.50	5.0	Slightly to moderately dispersive - ND3 / Dispersive - D	Dark/Cloudy
2		180	2.40	6.0	Slightly to moderately dispersive - ND3 / Dispersive - D	Dark/Cloudy
3		180	2.42	6.0	Slightly to moderately dispersive - ND3 / Dispersive - D	Dark/Cloudy

Legend: NM, No Modification; I, Modification I; II, Modification II.

Table 4. Degree of dispersivity for the crumb test.

Solution	Crumb Condition	Time (min)	Dispersivity grade	Dispersivity classification
Distilled water	Air dried (from pinhole)	2	1	Non-dispersive
		60	2	Intermediate
		360	2	Intermediate
Sodium hexametaphosphate	Air dried (from pinhole)	2	1	Non-dispersive
		60	4	Highly dispersive
		360	4	Highly dispersive

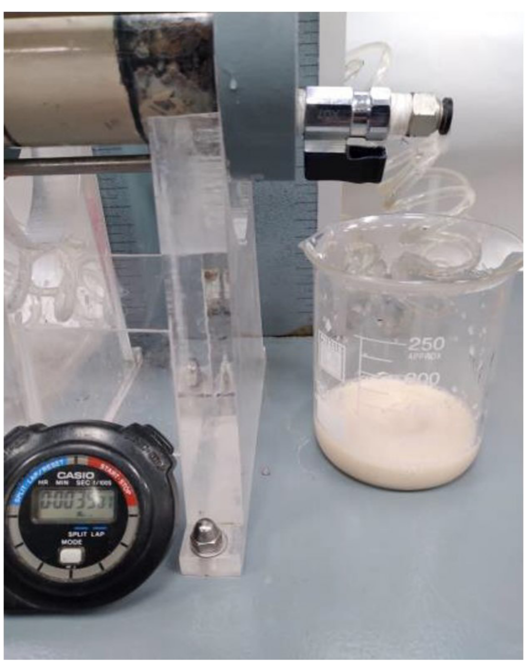

Figure 8. Turbidity classified as *dark* in the effluent for dispersive samples.

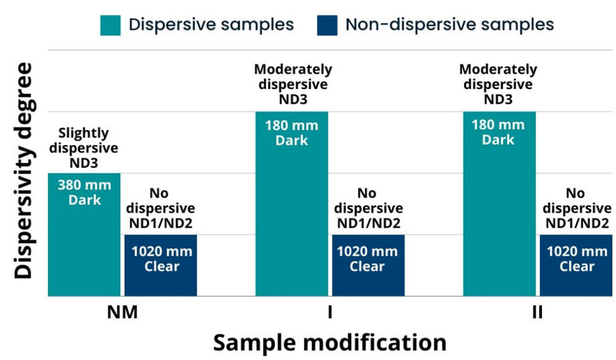

Figure 9. Summary of results of the pinhole tests.

In the double hydrometer test (SCS), conducted under the standard ASTM D4221-18 (ASTM, 2018), the results of the degree of dispersivity according to the test configuration are presented (Figure 10). The *A/B* ratio denotes the percentage of dispersivity, which correlates qualitatively with the degree of dispersivity. According to note 5 of the reference standard, when the dispersion percentage is 100, the material is said to be fully dispersive. If it is zero, the soil is entirely non-dispersive. The official standard categorises a dispersion

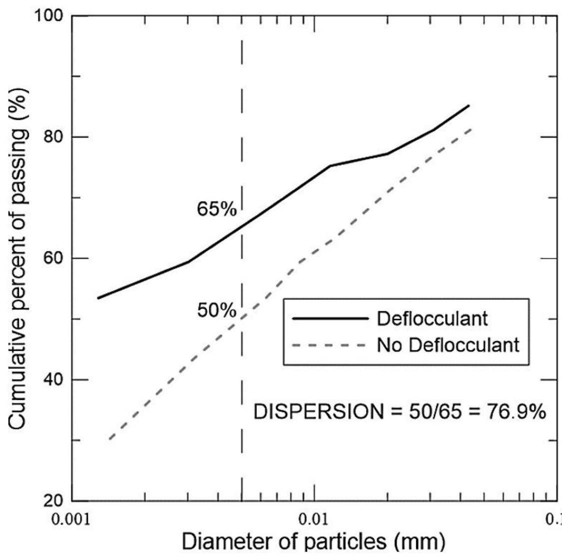

Figure 10. Percentage of dispersivity obtained from the SCS test.

value of 76.9% as a dispersive clay-fraction because the value is higher than 50%.

5. Conclusion

A set of qualitative tests such as pinhole, crumb and double hydrometer is necessary to obtain the reaction to the dispersivity of soil with high reliability. It is recommended to include quantitative tests with a physical-chemical approach (total dissolved salts, pH, exchangeable sodium percentage, and cation exchange capacity). Even analyze the possibility of including less studied tests in the literature, such as the Hole Erosion Test, Jet Erosion test and Inderbitzen test.

Inducing dispersivity in non-dispersive natural samples can be an adequate technique, parallel to the classical procedure, to properly calibrate the pinhole equipment used to evaluate the degree of dispersivity. By imposing artificial dispersivity on the specimen, the whole dispersive panorama that the apparatus is capable of measuring in the standardized test can be obtained.

The proposed variation to the pinhole test based on the ASTM reference standard, which is more realistic through the specimen, reveals that in specimens with induced dispersivity, it is possible to obtain different dispersivity values than those found in the conventional procedure. That is, specimens with more piping channels available have higher dispersivity values. However, further research is required with different degrees of artificial dispersivity of the sample and different sodium salts or other ions that may cause dispersivity in the clay material.

This research demonstrates that the pinhole test can be flawed in accurately assessing soil dispersivity. For highly dispersive samples, evaluated by methods A and B, the difference in typification can be high.

A further corollary is related to modifying the samples by inducing more 1 mm diameter holes in the cross-section, demonstrated in Figure 5, where even new trajectories were spontaneously generated without the need to impose them. This strongly justifies modifying the samples towards a more realistic situation. However, a more extensive test campaign, varying the clay material, is required to obtain more accurate results.

Declaration of interest

The authors have no conflicts of interest to declare. All co-authors have observed and affirmed the contents of the paper and there is no financial interest to report.

Authors' contributions

Juan Carlos Ruge: conceptualization, data curation, writing – original draft. Henry Giovanni Martínez: conceptualization, methodology, validation. Eliana Martínez Rojas: formal analysis, methodology.

Data availability

All data produced or examined in the course of the current study are included in this article.

List of symbols and abbreviations

i	Hydraulic gradient
pH	Potential of hydrogen
ASTM	American Society for Testing Materials
A/B	Dispersion ratio
D	Dispersive
G_s	Specific gravity
I	Modification 1
II	Modification 2
ND1	No dispersive
ND2	No dispersive
ND3	Slightly dispersive (method A)
NM	Unmodified
NP	Non-plastic soils
PaSD	Particle size distribution
SCS	Soil Conservation Service
US	United States of America
XRD	X-Ray diffraction
XRF	X-Ray fluorescence
γ	Specific weight

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