PHYSICAL DISPERSIVITY PHENOMENON AND IT’S EVALUATION CRITERIA IN COHESIONLESS SOILS

H. Rahimi¹, N. Abbasi² & H. Davarzani³

¹Professor, Irrigation and Reclamation Eng. Department, Tehran University, Iran
²Associated Researcher, Iranian Agricultural Eng. Research Institute (IAERI) Karaj,Iran
³MS. Student, Tehran University, Iran

ABSTRACT

Physical dispersivity is a phenomenon which causes the soil grains to be dispersed in presence of water and carried away by the flow. This phenomenon can cause many problems in hydraulic structures founded on the soils of such property. Many regions may face this problem especially in places where wind blown sand and silt prevails. The main objective of this research is to investigate the dispersivity potential of such soils and to determine the parameters which have the most influence on the phenomenon. For the purpose of investigation, samples were taken from Saveh plain as well as Chamran project in Khoozestan province of Iran. The samples were tested for determination of their physical properties, including dispersivity. Some specimens were also prepared using physically and chemically dispersive soils to determine the grain size distribution range of the stabilized samples. All samples taken from the field as well as specimens made in the laboratory were tested for grain size distribution, compaction, Atterberg limits as well as in pin hole tests. Based on the overall results, the two major factors affecting the dispersivity potential were found to be the portion by weight and plasticity of the fine grain material in the samples. The average size of sand particles in the samples was also found to be an important factor regarding dispersivity. The greater the percentage of the finer portion of the soil and its plasticity, the less is the dispersivity potential. Based on these factors, a relationship was found for evaluation of physical dispersivity potential. A new testing method was also developed based on the time required for collapse of a compacted, standard size specimen which, placed in water. This experiment resembles the Crumb test, somehow, but can be quantified easily.

1. INTRODUCTION

Difficult soils are responsible for destruction of hydraulic structures in many countries. This group of soils is categorized as soluble, liquefiable, collapsible and dispersive. There are many examples that show hydraulic structures, specially irrigation canal linings, founded on such soils, have been damaged or destroyed in many projects in Iran. Dispersive soil, as a kind of difficult soils, have caused problems in many parts of Iran specially in places where wind blown sand and silt prevails. Dispersivity is a phenomenon which causes the soil particles to be dispersed in presence of water and carried away by a small seepage force. In cohesive soils, it’s nature is chemical and occur when repulsive force between clay particles exceed their attractive force. But in cohesionless soils, particles are dispersed due to lack of attraction between particles which is known as physical dispersivity. Therefore, when a structure is founded on dispersive soil, the foundation soil is vanishes due to piping, following a severe damage to the structure. Normally, chemical dispersivity is evaluated in most fine grained, but physical dispersivity, which can cause lots of damages to the structures is not evaluated because it’s unknown nature. Destruction of the main canal linings in Saveh (central province) as well as Chamran project in Khoozestan province are typical examples of this phenomenon. Because of wide spread locations of this types of soil in many regions of the world, especially in Iran (Khoozestan, Kerman, Yazd, south of Khorasan and central provinces), and also the needs for construction of hydraulic structures in these areas, it was necessary to investigate the methods for their recognition and evaluation. In present research, dispersivity potential of cohesionless soils and it’s affecting factors have been investigated.

2. LITERATURE REVIEW

Chemical dispersivity (in clayey soils) has been investigated by many researchers in the world and different methods, which have physical and chemical nature, have been developed for their recognition
and stabilization. Unfortunately, dispersivity in cohesionless soil has not been well studied and there is no standard method for its evaluation.

Middleton (1930) for the first time introduced the dispersivity term as one of the effective factors in erosion of fine grained soils, and found that high percentage of sodium ions is responsible for the phenomenon. Volk (1938) indicated that dispersivity is the main reason for destruction of small earth dams and embankments. Wood and Atchison (1965) investigated the effects of soil type, sodium absorption ratio (SAR) and amount of total dissolved salts in pore water on piping. Their studies were focused on samples taken from damaged dam sites and for the first time found that dispersivity has been the main cause for the destruction of the dams.

Sherard et al (1971) proved that the rate of damage is related to the amount of salts present in the soil and developed a diagram for evaluation of dispersivity potential using the results of soil chemical analysis. Arulanandan (1975) designed and constructed an apparatus for evaluation of dispersivity of soils. Sherard (1976) initiated an apparatus for direct measuring of piping rate for fine grained soils. His apparatus and test method is known as Pin Hole is now the most creditable and common method for evaluation of dispersivity potential of soils.

Rahimi et al (1993), indicated that the Sherard diagram is not valid for soils of high salt contents with a TDS (total dissolved Salts) of more than 50 meq/lit. They proposed a new approach for evaluation of dispersivity potential using chemical properties of soils such as ECe, SAR and pH. As mentioned before, all previous researches have been focused on chemical nature of dispersivity and not its physical nature.

3. MATERIALS AND METHODS

The main objectives of this research were to find a rational relation between dispersivity potential of cohesionless soils and their index properties as well as to determine the parameters which have the most influence on the phenomenon. As there is no standard test and apparatus for evaluation of piping in silts and fine sands, Pin Hole and Crumb methods were used with some modifications improve their capabilities for measuring of dispersivity potential. The soil samples used for the investigation were taken from field and were prepared artificially.

3.1 Samples Preparation

For the purpose of this investigation, samples were taken from Saveh plain in the central province of Iran as well as Chamran project in Khoozestan province. Furthermore, seven samples were prepared artificially with the known gradations as presented in Table 1. As it can be seen in Table 1, samples A, B, C and D are uniform and the others that were prepared from mixing of uniform samples of different gradations are non-uniform. All samples were tested for determination of their physical and chemical properties, including grain size distribution, compaction, Atterberg limits as well as dispersivity potential.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Diameter range</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mesh No.</td>
<td>Opening size (mm)</td>
</tr>
<tr>
<td>A</td>
<td>100-200</td>
<td>0.075-0.149</td>
</tr>
<tr>
<td>B</td>
<td>50-100</td>
<td>0.149-0.297</td>
</tr>
<tr>
<td>C</td>
<td>30-50</td>
<td>0.297-0.595</td>
</tr>
<tr>
<td>D</td>
<td>10-30</td>
<td>0.595-2.0</td>
</tr>
<tr>
<td>AB</td>
<td>50-200</td>
<td>0.075-0.297</td>
</tr>
<tr>
<td>ABC</td>
<td>30-200</td>
<td>0.075-0.595</td>
</tr>
<tr>
<td>ABCD</td>
<td>10-200</td>
<td>0.075-2.0</td>
</tr>
</tbody>
</table>

Table 1. Gradation of samples
Then highly dispersive samples were selected to investigate the factors affecting their dispersivity. These samples were mixed with various amounts of fines having different plasticity. The fine proportion of the samples were: 5, 10, 15, 20, 25, 30 and 40 percent by weight. The plasticity properties and chemical dispersivity potential of all samples are depicted in Table 2.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Liquid Limit</th>
<th>Plasticity Index</th>
<th>Dispersivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35</td>
<td>18</td>
<td>ND</td>
</tr>
<tr>
<td>2</td>
<td>43</td>
<td>21</td>
<td>ND</td>
</tr>
<tr>
<td>3</td>
<td>55</td>
<td>31</td>
<td>ND</td>
</tr>
</tbody>
</table>

Several artificial samples were obtained by mixing various types and different contents of fines with physically dispersive sands. These samples were subjected to physical and chemical tests to determine their index properties and their dispersivity potentials were measured using Pin Hole apparatus.

3.2 Pin Hole Test

Pin Hole test is normally used as standard method (ASTM - D4647-87) for evaluation of dispersivity of clayey soils. In this test three criteria are used for evaluation of dispersivity potential namely: turbidity of out-flow, final diameter of the hole and discharge of flow. Although these criteria are very suitable for clayey soils but they are improper for sands and silts. Therefore, it was necessary to modify both the apparatus and the criteria. Since in a sandy specimen, water flows through the total cross section instead of the hole, therefore, the inlet of the apparatus was modified as shown in Fig1 in such a way that water is forced to flow through the hole in the center of the specimen. The suggested criteria for modified test are: movement of particles and collapse of the specimen, that are determined by direct observation. For physically dispersive samples, piping takes place by 50 mm pressure head and the specimen is washed away completely at the very beginning of the test. For non-dispersive samples, there was no indication of piping under 1020 mm pressure head at the end of the test. The rate of the dispersivity is classified by the pressure head which causes the particles to move.

![Fig 1. Modified pinhole apparatus](image)

3.3 Slackening Test

This test that has been developed in this research is similar to Crumb test. Unlike the crumb test for clayey soils, where turbidity of water is the main qualitative criterion for dispersivity evaluation, in this test the time period for slackening of the specimens is used as a quantitative measure.

In the suggested method, the specimen is prepared with optimum water content and maximum dry density using Harvard Miniature compaction mould. Then the specimen is covered with a No. 4 wire mesh, and
is placed into one liter of distilled water up to a half depth as shown in Fig 2-a. The time period for complete collapse of the specimen is determined and used as a measure for quantitative evaluation of dispersivity potential (Fig 2-b).

Fig. 2. Slackening test: a - specimen before test  b- specimen after complete collapse

4. RESULTS

4.1 Effect of Grain Size Distribution on Physical Dispersivity Potential

Based on the results obtained from grain size distribution of all samples, it was found that the gradation curves of physically dispersive soil lie in special zone limited to upper and lower bands as shown in Fig. 3.

Fig. 3. Limitation range of gradation curves for physically dispersive specimens

4.2 Effect of Liquid Limit and Percentage of Fines on Physical Dispersivity Potential

The pinhole test was accomplished on all natural and artificial samples. Results obtained from these tests showed that dispersivity rate of samples are decreased with increasing of fine content as well as the liquid limit. Fig. 4 shows the variation of minimum fine content levels necessary to stabilize three types of sands versus their liquid limits.
Fig. 4. Variation of minimum fine contents for stabilization of sand versus liquid limit

4.3 Effect Particle’s Diameter on Dispersivity

Pinhole test results showed that the physical dispersivity decreases with increasing the diameter of particles. In the other hand, the samples with larger particles are stabilized using less fine contents. For example, sample A (between No.100-200 meshes) was stabilized using 35 percent of fines with liquid limit of 43%, whereas sample C (between No.30-50 meshes) was stabilized using 25 percent of the same fines. This is depicted in Fig.4.

4.4 A Diagram for Evaluation of Physical Dispersivity

Based on the results obtained from all tests, it was found that the main effective factors on rate of physical dispersivity potential are:
- Plasticity and fine contents (passing No. 200 mesh) of samples
- Particles diameter

The prime factor that in this research is called cohesion factor, is defined as product of percentage of fines content by it’s liquid limit, and the second factor is expressed by $D_{50}$ as a representative for the diameter of the particles. Based on these two criteria, a diagram was developed for evaluation of physical dispersivity as shown in Fig.5. As it can be seen in Fig. 5, the diagram is divided into three different zones. The A and B zones show physically dispersive and non-dispersive areas respectively, and C indicates the intermediate zone.

Fig. 5. Diagram developed for evaluation of physical dispersivity
4.5 Relationship between Time of Slackening and Physical Dispersivity

The results obtained from slackening test showed that the time of slackening increases as the cohesion factor increases, and decreases with increasing particle diameter for a constant cohesion factor. Fig.6 shows the variation of slackening time versus the fine content of the samples. Referring to Fig. 6, it is found that the time of slackening increases with increasing of fines content as well as the mean particle diameter ($D_{50}$) decreases.

In order to develop a relationship between slackening time and physical dispersivity, the time of slackening was plotted against mean particle diameter ($D_{50}$) for all samples, as shown in Fig.7. This figure is suggested to be used for evaluation of the physical dispersivity potential of questionable soils. In Fig.7, physically dispersive samples will locate under the curve and non-dispersive ones will locate above it.
4.6 Verification of the Developed Criteria

The natural soil samples taken from Saveh and Chamran sites were used for verifying the developed criteria. Chemical analysis of the samples showed that they are not dispersive chemically. These samples were evaluated using the three suggested methods. Results obtained indicate that Chamran samples are physically dispersive based on grain size distribution, cohesion factor and slackening time criteria. This conclusion was in good agreement with the results of pinhole tests. Saveh samples were evaluated using the same methods. It was found that they are grouped in three categories of dispersive, non-dispersive and intermediate, which is verified with pinhole results, successfully.

5. CONCLUSION

Several conclusions can be drawn from the results of the present study that involves the physical dispersivity and its evaluation criteria in cohesionless soils:

1- A range for the gradation curves was found for the soils which are sensitive to physical dispersivity.
2- A diagram was developed for evaluation of physical dispersivity based on fines properties.
3- The Crumb test was extended to cohesionless soils quantitatively.
4- Although suggested criteria can be used satisfactorily for evaluation of physical dispersivity, but it is necessary to conduct various tests and use the engineering judgments.
5- It is suggested to modify the pinhole apparatus, or a new one be developed for this purpose.

REFERENCES

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BIOGRAPHY

Hassan Rahimi, born in 1946 is currently a professor at Irrigation Engineering Department of Tehran University. He is specialized in soil mechanics and construction materials with an emphasize on difficult soils. He is the author of several papers in this area.

Nader Abbasi, born in 1970 is associated researcher of Iranian Agricultural Engineering Institute (IAERI) and currently PhD student at Tehran University. He is studying about geotechnical aspect of hydraulic structures. He focus on determination of consolidation properties of fine soils as his PhD thesis.
Hossein Davarzani, is graduated MSc. student at Irrigation Engineering Department of Tehran University. This paper is a part of his thesis.