Suffusion potential assessment by self-filtration criteria

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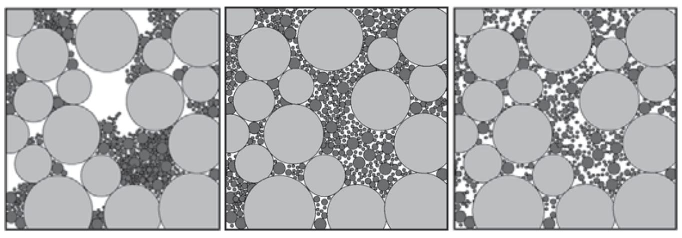
Introduction

a) Dam dysfunction b) Sinkhole

Figure 1: Some frequent consequences of suffusion.

Suffusion - a major type of internal instability of soils - is a frequent sub-surface risk for earth structures and foundations of structures placed on ground (Fig. 1). Suffusion occurs when fine soil particles are loosened, mobilised, and transported by seepage flow through series of pores and pore constrictions formed by soil primary fabric. The removal of these particles increases porosity and hydraulic conductivity, which enhance again the transportation (Fig. 2). At a critical porosity, soil is restructured at a micro scale to create larger void for the transportation of larger particles and/or to spark other type of internal instability, such as concentrated leak erosion. Therefore, suffusion also is often considered as the early step of many other types of internal instability of soils.



a) Stable state b) Mobilisation c) Particle loss

Figure 2: Development of suffusion at particle scale.

Gap of knowledge

Traditional suffusion assessment methods focus on *particle size distribution* (PSD). This is a wrong target. In a metaphorical perspective, soil porous structure is a building and pores are rooms where loose particles – furniture – are stored. The deciding factor for furniture removal should not be the wall size, i.e. coarse particle sizes, but the door sizes, i.e. pore constriction sizes (Fig. 3). The new assessment method created by this study focuses on the *constriction size distribution* (CSD) formed by soil primary fabric.

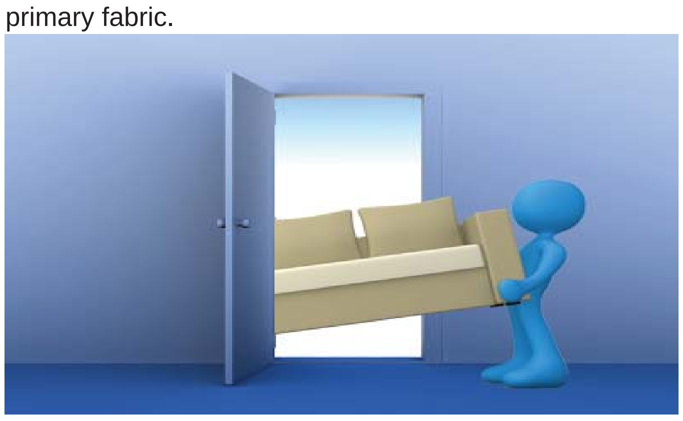
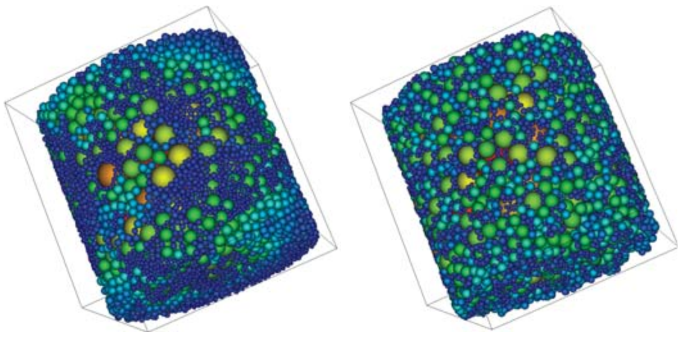


Figure 3: Deciding factor for the removal of loose particles (furniture) should be not the larger particle size (wall size), but the pore constriction size (door size).

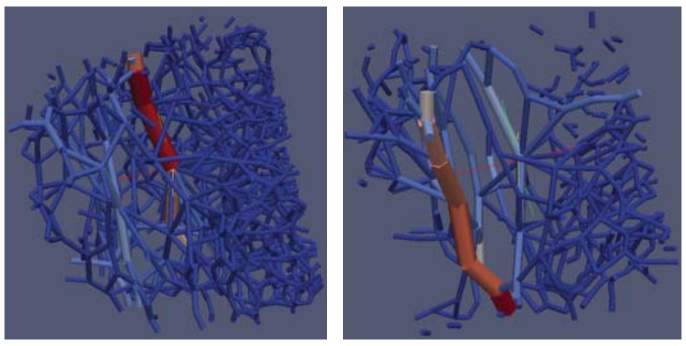
Numerical discovery

However, the determination of primary fabric is not necessarily clear. Because soil particles are too small to attach stress sensors on, a numerical approach has been selected. A new sequential particle packing method has been created in order to facilitate the study of particle arrangements (Fig. 4). Soil specimens are compacted under zero gravity to neglect the impact of particles' weight on stress distribution (Fig. 5). The contact analysis showed that regardless whether soils are narrow-graded or wide-graded, segregated or homogeneous, there is always an overlapping zone by particle size between the primary fabric and loose particle fractions (To et.al., 2014).



a) Layer-wise arrangement b) Random-wise arrangement

Figure 4: Particle arrangement. Layer-wise arrangement simulates segregated soils, such as soils dumped from trucks.



a) Layer-wise arrangement b) Random-wise arrangement

Figure 5: Contact force illustration. Loose particles are pushed out of force chains because they do not transfer load neither weight of above particles.

That means the accuracy of traditional approaches, which separated PSD into those two fractions by an exact delimiting size or a sharp boundary, has to be scrutinised. An approximate separation method is proposed (Fig. 6).

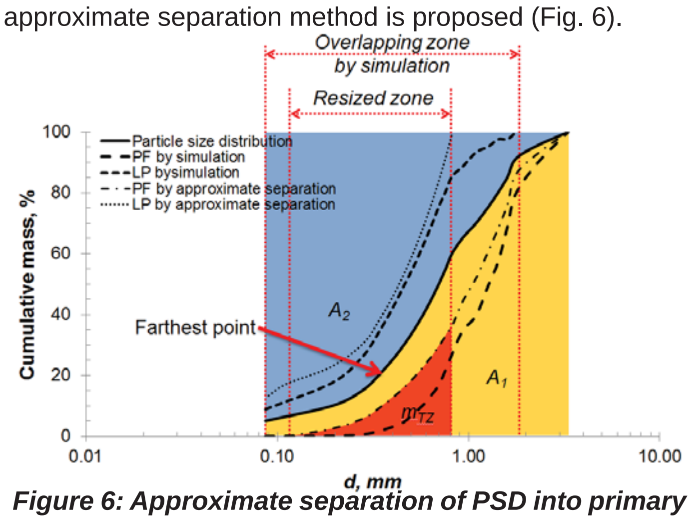


Figure 6: Approximate separation of PSD into primary fabric and loose particles. The overlaping zone is assumed to end at 0.25d_{max}.

The mass of the primary fabric in the overlapping zone is assumed to simulate the mass of soil. The total mass of the primary fabric in this range, m_{TZ}, is calculated as:

$$m_{TZ} = \frac{A_1}{A_1 + A_2}\left(f_{0.25d_{100}} - f_{0.25d_{point}}\right)$$

Note that d_{point} is the coordinate of the farthest point the PSD deviates from its mean line connecting (d_3,3) and (d_{100},100).

Assessment method

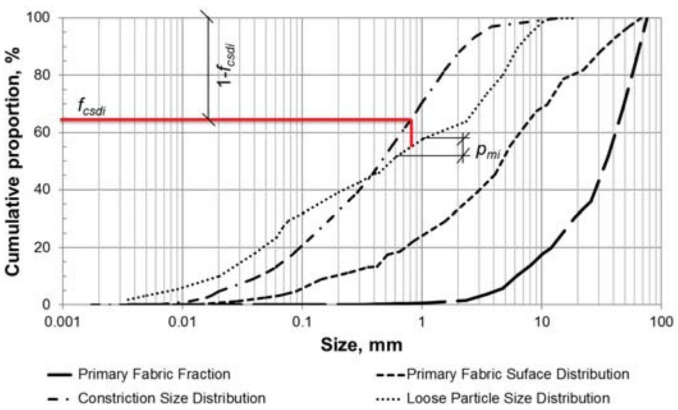


Fig 7: Assessment procedure. The probability of transportation to the next pore for a loose particle is the proprotion of the larger constrictions formed by the primary fabric.

The suffusion potential assessment procedure (Fig. 7) is conducted as:

- The original PSD is divided into the primary fabric and loose particle fractions by the approximate method.
- The CSD formed by the primary fabric is calculated by a statistic of a virtual numerical specimen, which allows arrangement study, or by a probabilistic method, which employs surface distribution of the primary fabric (Fig. 7).
- The PSD of sole loose particles is divided into many small size intervals. The probability of transportation to the next pore for particles in each interval, P_{wi}, is the proportion of pore constrictions larger than the mean size of the interval (Fig. 7).

$$P_w = \sum P_{wi} = \sum_{i=1}^{n} p_{mi}\left(1 - f_{csdi}\right)$$

- The suffusion potential is assessed by the total probability of transportation, P_w:

$$\begin{cases} P_w \le 20\% & \textit{Stable} \\ 20\% < P_w < 50\% & \textit{Transitional} \\ 50\% \le P_w & \textit{Unstable} \end{cases}$$

The new assessment method has been applied on experimental data from some prior studies. The results have been compared with some prior assessment methods.

Methods	Applied soils	Serious errors
Wan & Fell (2008)	38	5 (13%)
Indraratna et.al (2011)	38	6 (16%)
Current method	38	0 (0%)

Note that, when the primary frabric is too widely graded, the virtual specimen might not be created due to the current computational ability. The probabilistic approach for CSD can be applied to any soils, but it still needs to run by a computer program.

Potential applications

- **Other types of internal erosion**: Because the new method focuses on the transportation of particles. It can be applied at some extent to tailing transportation into tailing dams or some other types of internal erosion, such as contact erosion. From contact erosion stand point, the primary fabric works as a filter, while the loose particles are the base soil.
- **Material selection**: In daily engineering practice, designers often use narrow-graded soils or employ inverted filters to reduce internal instability risks. Thanks to the improved accuracy, the current method can help to take advantage of local materials where possible. This circumvents Bill of Materials and deducts excavation, transport, and purchase cost of imported materials. Although an exact saved amount can be provided only for each individual particular construction, the application is promising.
- **Risk assessment**: According to a statistic conducted at UNSW on data from ICOLD (Foster et.al., 2000), internal erosion is related to nearly half of all dysfunctions of dams and embankments. The new method can improve risk assessment for existing and future structures.

A future task of the research is the introduction of other soil parameters to reduce the range of the transitional zone and to improve the applicability of the new method. The author strongly desires to apply the new approach in industrial work.

REFERENCES

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