Heave Failure as a Fourth Type of Seepage-Induced Internal Instability Problems Associated With Granular Soils

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Abstract: Internal instability problems associated with granular soils involves washing out of the fine grains within the voids of the coarse grains. This movement may involve one or more of the following, mass loss, volume change, and permeability change. Leading to the occurrence of one of these possible cases, namely, suffusion (involves mass loss with no volume change), suffusion (involves mass lose with volume reduction) , fluidization (involves volume change without mass loss). These three cases are well defined in the literatures; however the authors of this paper have found a fourth case (heave failure) was not taken in consideration. Heave failure involves both mass lose and increment in volume of the granular soil. Deep understanding of this case will prevent failure of geotechnical and hydraulic structures. Here in this paper the conditions that lead to the occurrence of heave failure are defined and illustration is made based on some experimental studies . Also it is found that the applied stresses on the soil can change the mode of internal instability failure from suffusion to suffusion / suffusion failure mode. editor

Keywords: suffusion, suffusion, heave failure, internal instability

I. INTRODUCTION

Internal erosion process involves washing out of loose fine particles, under the effect of seepage forces, through the voids of the primary soil. Internal instability takes place when the seepage forces are large enough to move the fine particles, and when the fines are smaller than windows those formed among soil larger soil particles, Dallo and Wang (2016).

Internal erosion instability problems may occur in both man-made and natural soil deposits, they may occur even in the granular filters that were constructed of internally unstable materials, Dallo et al. (2014), renders those filters coarser, and accordingly decreases their ability to protect the core or foundations materials, Wan and Fell (2008).

Internal instability problems, associated with cohesionless soils, were investigated by many studies, among others Kézdi (1979), Kenney and Lau (1985, 1986), Lafleur et al. (1989), Burenkova (1993), Skempton and Brogan (1994), Ahlinhan et al. (2010), and Dallo et al. (2013), Ni et al. (2018).

Coarse widely graded or gap-graded soils are susceptible to undergo suffusion, Wan and Fell (2004), also soils with a grain size distribution, GSD, curve concaved upward, while linearly graded soils or soils with a GSD curve concaved downward are believed to be internally stable, Lafleur et al. (1989).

Various methods were proposed to assess the internal stability of soils. one of the earliest methods was the method of kezdi (1979) which was based on modifying the granular filter design criteria. Later Kenney and Lau (1985, 1986) proposed a method based comparing the diameter of the fine particles with the diameter of the constriction size and it was verified with experimental tests. The latter method was adopted by many researchers due to its good accuracy and simplicity.

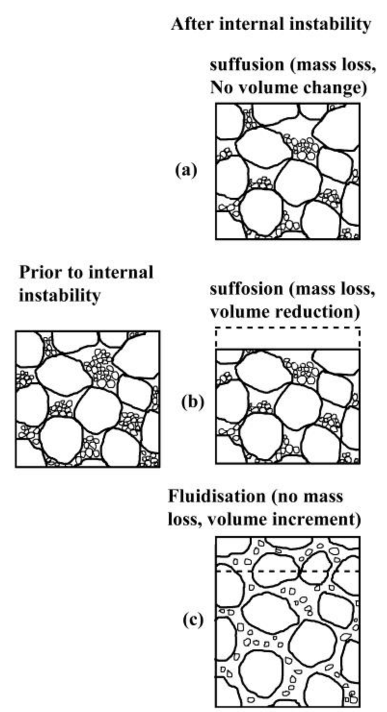

Fig. 1 Schematic illustration of internal instability phenomena: (a) suffusion; (b) suffosion; (c) fluidization (based on Fannin and Slangen (2014))

There are many forms of internal instability problems, namely: suffusion, suffusion, fluidization, and heave failure. Recently, Fannin and Slangen (2014) made a clear definition of the first three terms, as shown in Fig.1. Suffusion is

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characterized by mass loss and permeability increment with no volume change, suffusion is characterized by mass loss, permeability change, and volume reduction, while fluidization is characterized by permeability increment, volume increment, and no mass loss. However, the heave failure wasn't taken in consideration in Fannin and Slangen (2014) study. The definition of heave failure is presented in this paper.

II. HEAVE FAILURE CONDITIONS

Fannin and Slangen (2014) have defined three types of seepage-induced instability phenomena, namely: suffusion, suffosion, and fluidisation. Actually there is a fourth case, heave failure, which is characterized by ($\Delta m>0$, $\Delta V/V>0$, and $\Delta k>0$). Such a case was observed by Li (2008) for the experimental test labeled (HF05-50-U) , see Fig. 2a . The soils were tested in a transported cylinder and vertical stress is applied to the soils see Fig. 2b] and the hydraulic head was gradually increased and the volume change and mass loss was observed .

As shown in Fig. 2b, where the suffusion had occurred at an average hydraulic gradient of 15, followed by heave failure at an average hydraulic gradient of 29, and schematic illustration of this process is shown in Fig. 3. Fannin and Slangen (2014) proposed a conceptual framework for seepage-induced instability phenomena, as shown in Fig. 4a. To take the case of heave failure in consideration, we propose to modify the Conceptual framework shown in Fig. 4b.

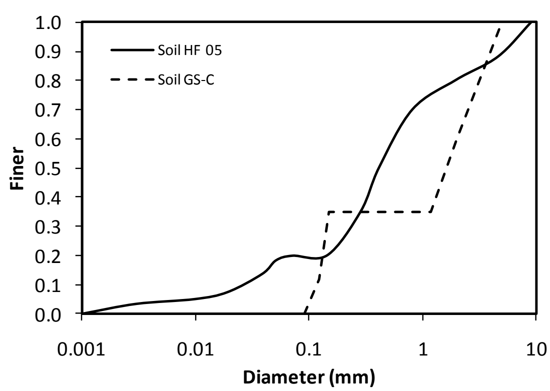

Fig. 2a Grain size distribution of the soils used in the analysis

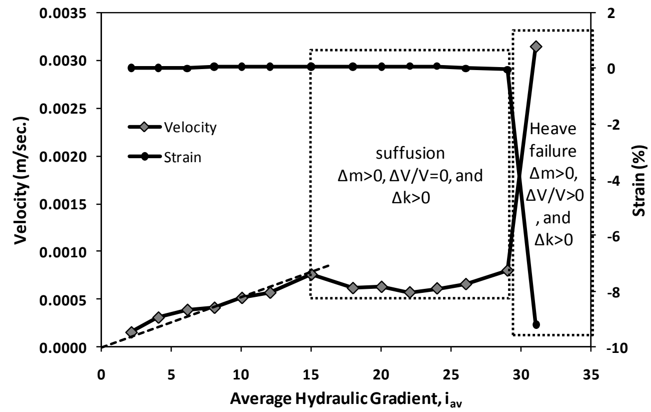

Fig. 2b Seepage-induced instability of soil HF05-50-U (reanalysis of the tests of Li (2008))

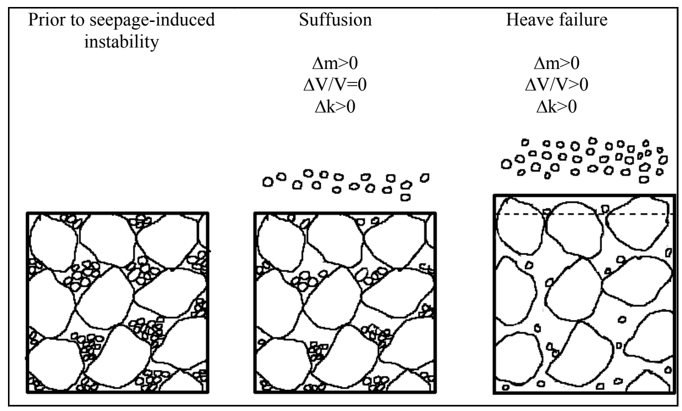

Fig. 3 Schematic illustration of heave failure

III. EFFECT OF CONFINING STRESSES ON THE INTERNAL STABILITY

Chang et al. (2012) investigated the internal instability of a gap-graded soil, and they monitored the amount of eroded soil particles, axial strain and radial strain. The gap-graded soil samples (GS-I-1, GS-C-4, GS-C-5 and GS-C-6) were tested in the triaxial device and subjected to the same confining stress of 50 kPa but the axial stress was the different of 50, 100, 150 and 200 kPa, respectively. Also, different hydraulic heads were applied to these samples.

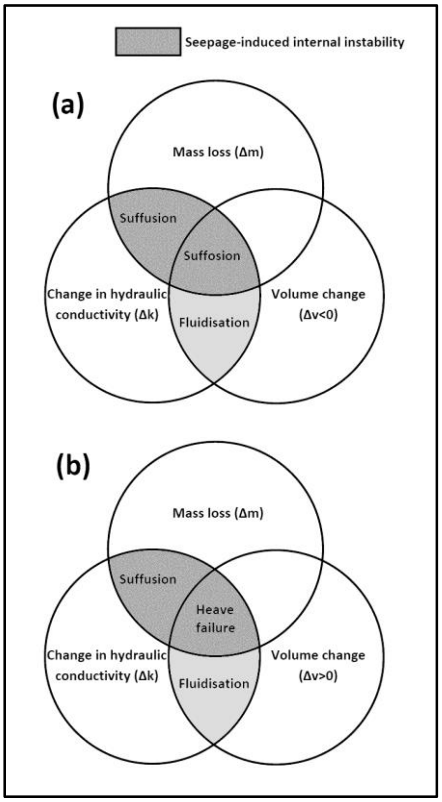

Fig. 4Conceptual framework for seepage-induced instability phenomena (a) ΔV<0 [Fannin and Slangen (2014)], (b) ΔV>0

A closer look at the results of the Chang et al. (2012) enabled us to find that the increasing the axial stresses could change the kind of internal instability mode from suffusion to suffusion/suffusion. Soil sample GS-I-1 underwent very small amount of axial and radial strains of 0.14% and -0.07% respectively, which can be considered as a suffusion failure. However the other soil samples underwent suffusion in the first stage of the tests, up to hydraulic gradient of 2.6 and 2.7 for samples GS-C-4 and GS-C-5 respectively. After that they underwent suffusion (no further volume change while the erosion of the soil particles). Soil sample GS-C-6 underwent suffusion up to hydraulic gradient of 2.2, then it underwent suffusion up to hydraulic gradient of 3.2. while increasing the hydraulic gradient form 3.2 to 4.1 the soil underwent another stage of suffusion, increasing the hydraulic gradient beyond 4.1 causes no more volume change and hence another stage of suffusion had been occurred.

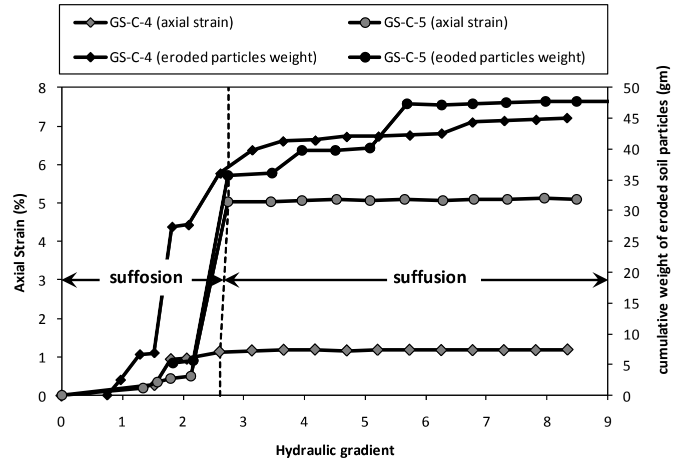

Fig. 5 Axial strain and cumulative weight of eroded soil particles of soil samples GS-C-4 and GS-C-5 (reanalyzing the results of Chang et al. (2012))

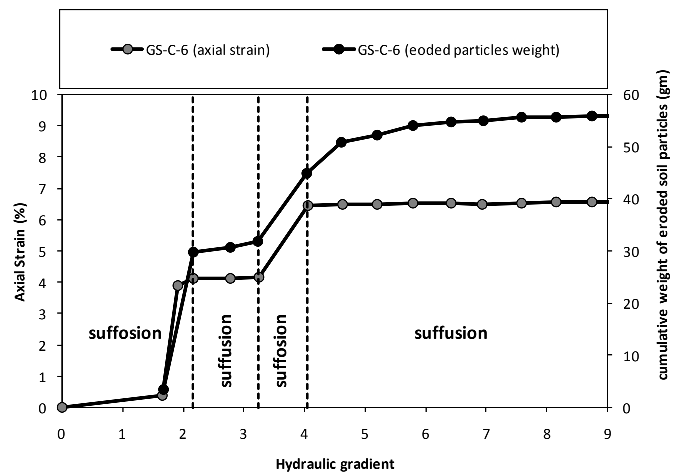

Fig. 6 Axial strain and cumulative weight of eroded soil particles of soil samples GS-C-6 (reanalyzing the results of Chang et al. (2012))

IV.SUMMARY AND CONCLUSIONS

Hydraulic and geotechnical structures maybe constructed on/from granular soils, and some types of these granular soils are internally unstable when they subjected to water flow. For those soils, the fine particles are suffused (i.e. washed out), a malfunctioning or a failure may result-in. To prevent those losses a deep understanding of the internal stability problems is required. And this was done in this paper, where four types of seepage-induced internal instability can be characterized in the granular soils, namely: suffusion, suffosion, fluidisation, and heave failure, and they can be defined as follows:

- Suffusion is the internal instability problem that is associated with mass loss and permeability increment with no volume change.
- Suffosion is another form of internal instability problems, characterized by mass loss, permeability change, and volume reduction.

- Fluidisation is characterized by permeability increment, volume increment, and no mass loss.
- Heave failure is the internal instability problems that associated with mass loss, and increment in both volume and permeability.

The mode of internal instability failure can be effected by the stresses applied to soil sample. Increasing the axial stress while keeping the confining stresses constant can change the mode of internal instability failure from suffusion to suffosion/suffusion failure.

More experimental tests on various grain size distribution will give us more clear idea about the internal stability problems and establishing accurate threshold of suffusion and suffosion. Conducting large scale triaxial tests (say 30 cm in diameter) on granular soil will help to find more accurate relationships between applied stresses and the type of internal erosion failure.

Also testing undisturbed soils using field tests can give us deeper understanding of the internal erosion process. Case studies can also provide valuable information about this process.

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