# Dispersivity, collapsibility and microstructure of a natural dispersive loess from Iran

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**ABSTRACT**

A new type of collapsible soil was encountered in Southern Iran and caused some serious technical problems including subsidence, collapse and sinkholes during the construction of Zahedan-Chabahar railway. Field observations indicated that *in-situ* soil contains excessive amount of salts resulting in dispersive features in response to seepage forces in addition to its collapsibility. Therefore, a systematic research plan including field sampling and laboratory testing was carried out to investigate the observed geotechnical features. Results of physio-chemical tests revealed the dominance of Sodium in excess of 70% relative to total dissolved salts, which results in high dispersive potential. In addition, intact soil was observed to show a significant collapse potential of 16% upon wetting because of its low dry density. Compacted soil at the same dry density, on the other hand, showed even higher collapsibility at lower stress levels because the lack of structural bonding provided by calcite in the intact soil. More interestingly, the collapse potential was shown to be dependent on pore water salinity. A reduction in salt concentration in pore water can increase collapse potential to more than 4% because of an increase in the thickness of diffuse double layer. The observed macroscopic behavior was assigned to microstructural features supported by SEM photos.

**Keywords:** dispersive loess; collapse; water salinity; microstructure; natural soils

## 1 INTRODUCTION

A problematic soil was encountered during constructing parts of the national megaproject railway line connecting Chabahar port to Zahedan and hence to the international railway network. The studied site is located 18 km far from the Chabahar main station and 10 km apart from the Gulf of Oman along the Mokran coastline. The observed geotechnical problems were divided into two main categories: (a) the occurrence of deep vertical dispersive sinkholes down to several meters underground, and (b) local and general collapse and subsidence all around the construction site (Fig. 1). These undesirable ground conditions were believed to be the consequence of pounding the area in wet seasons after constructing the Lipar dike in recent years. More important factor is the metastable nature of soil strata which have been deposited during an aeolian geological process (Assallay et al. 1997), making the in-situ soil susceptible to hydro-mechanical loading (Ng et al. 2016) due to loss of suction and true bonding forces.

Moreover, there is extensive research on the influence of pore water salinity on several aspects of hydraulic and mechanical behavior of clayey soils including volume change (Xu et al. 2014), shear strength (Zhang et al. 2016), and swelling potential (Zou et al. 2018). However, there is still a lack of knowledge on the influence of existing salt in soil water on collapse potential. Therefore, a series of physical, chemical, geotechnical and microstructural tests were planned to first characterize both dispersive and collapse potential and to second explore the role of pore water salinity on collapsibility of the studied soil.


Fig. 1. Examples of (a) dispersive sinkhole, and (b) hydro-mechanical collapse.

## 2 FIELD INVESTIGATIONS

A two-step field survey including preliminary reconnaissance and undisturbed *in-situ* sampling was carried out sequentially. General details of field investigations are presented in this section.

### 2.1 Study site

The study area is located 18 km east of Chabahar and 10 km north of Mokran coastline in Southeast Iran

(Fig. 2). The reconnaissance trip provided very useful information on types of geotechnical problems as summarized in Fig. 1. Local people being resident in nearby regions for centuries calls this area "salty land" historically. A parallel borehole drilling revealed no sign of water table down to 15 m below ground surface. Encountering such relatively deep vadose zones necessitates the use of deep re-filled tensiometry for rigorous monitoring of long-term seasonal variations in pore water pressure for subsurface flow analyses (Sadeghi et al. 2018). Eventually, based on technical evaluations of site conditions during the first visit, block sampling was selected as the most suitable method in dry season.


Fig. 2. Site location with reference to Iran South-East boundaries.

### 2.2 Block sampling

Block samples were retrieved from a test pit at study area where the ground was bare and there was no sign of damage caused by collapse or piping. The pit was dug down to 1 m and three cubic block samples were carefully carved with hand tools to the target dimension of about 0.3 m. They were wrapped in cling and plastic membrane and covered by three alternative layers of paraffin wax and cloth. Samples were eventually preserved inside wooden boxes equipped with inside woven dampers. Further details on procedure of block sampling can be found in Sadeghi (2016).

## 3 EXPERIMENTAL PROCEDURE

### 3.1 Physical and chemical tests

Physical tests were carried out for soil classification according to the ASTM standards. In addition, some supplementary tests including double hydrometer and crump tests were run for identifying dispersive features. A more comprehensive set of chemical tests on saturated water extract were also conducted to analyze the composition of salts and other chemical compounds in natural soil.

### 3.2 Collapse potential and double oedometer tests

Two types of collapse potential tests were carried out. The first type was wetting-induced collapse tests on three intact specimens compressed to target vertical stress levels of 50, 100, and 200 kPa and inundated afterwards (Ng et al. 2017b). The second type included three double oedometer tests on statically compacted soil with the same dry density as of intact one. The first test was run under constant water (CW) and the other two under saturated conditions but with different water salinity. Indeed, one saturated test was conducted with natural salt concentration while the other one with a reduced salinity. Measurements of electrical conductivity reveled that soil water salinity reduced to one third of the specimen with natural salt by six cycles of saturating/dewatering inside the oedometer cell.

### 3.3 Scanning electron microscopy

Scanning electron microscopy (SEM) tests were conducted on freeze-dried intact and compacted soil specimens to explore their microstructure qualitatively.

## 4 INTERPRETATION OF TEST RESULTS

### 4.1 Classifying a new type of collapsible soil

Results of index tests in addition to comparisons with literature on loess classification (Gibbs and Holland 1960) revealed that the natural soil is a lean clayey loess with more than 70% fine particles. This can be a further confirmation on the wind-blown origin of *in-situ* loess strata. As sodium is known to be the most important element contributing to the dispersive potential of clays, the sodium percent in total dissolved salts (TDS) was determined from a saturation soil-water extract. The TDS is the summation of four metallic cations of sodium, potassium, calcium, and magnesium in terms of mequ/liter. Results are summarized in Table 1. The natural loess with sodium percent and TDS of 75 and 229, respectively, has a high dispersive potential according to the classification of dispersivity in Fig. 3.

Table 1. Summary of chemical tests.

| Chemical element/compound/property | Measured value |
|---|---|
| $CaCO_3$: % | 19.0 |
| CaSO4.2H2O: % | 1.8 |
| pH | 8.3 |
| Sodium: mequ/liter* | 171 |
| Potassium: mequ/liter | 8 |
| Calcium: mequ/liter | 31 |
| Magnesium: mequ/liter | 19 |
| Total Dissolved Salts, TDS: mequ/liter | 229 |
| Sodium: % | 75 |

* Obtained from saturation extract

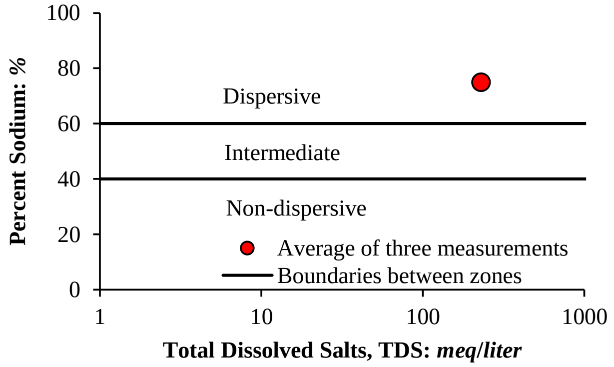


Fig. 3. Categorization of dispersive potential.

This feature of soil explains the occurrence of vertical deep sinkholes due to the vertical hydraulic gradient imposed in wet seasons all through the Lipar upstream. Moreover, deep-seated failure can be expected in cross section of the railway embankment if water pound forms in one side of the embankment.

### 4.2 Dependency of collapsibility on water salinity

Fig. 4 shows results of wetting-induced collapse tests on intact soil. Collapse potential is evaluated as:

$$C_p = \Delta\varepsilon_v = \frac{e_{CW} - e_{Sat}}{1+e_0} \tag{1}$$

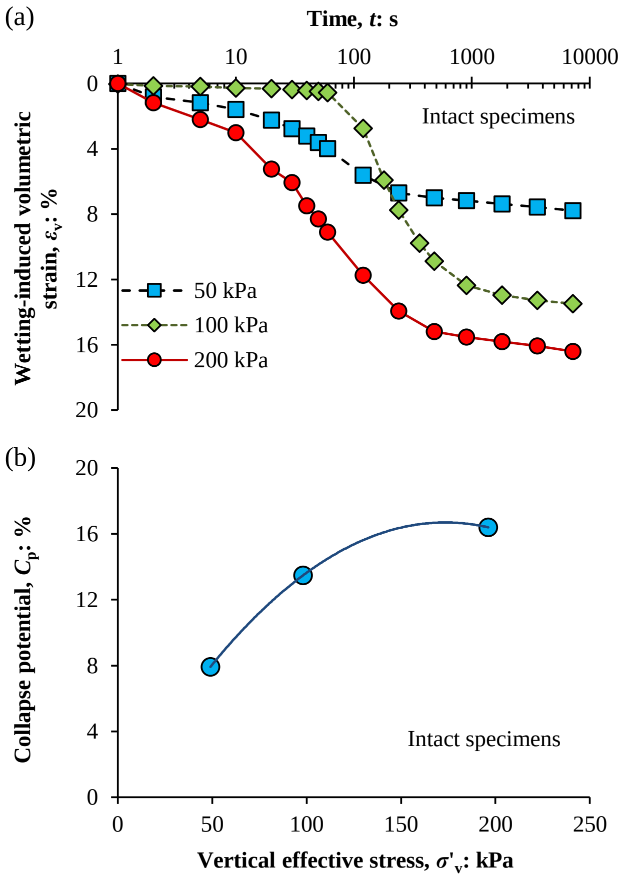


Fig. 4. Wetting-induced collapse tests on intact soil (a) consolidation stage, and (b) collapse potential

where $e_0$, $e_{CW}$, and $e_{Sat}$ are void ratio at initial state, after constant-water compression, and after consolidation, respectively. Fig. 4(a) shows variations in volumetric strain during the consolidation stage. Results in terms of collapse potential ($C_p$) versus effective stress are presented in Fig. 4(b) where the maximum $C_p$ of 16% was recorded under 200 kPa effective stress. Therefore, the natural loess lays in a category with “severe trouble” of foundation conditions for geotechnical design and construction purposes.

Fig. 5 compares results of collapse tests carried out on intact and compacted soils. Larger collapsibility was measured in most cases for compacted soil compared to the intact one. Although the initial dry density was very similar for both types of specimen, compacted soil may not have the natural structure of intact soil provided by inter-particle calcite bonding (Table 1). It is noted that a yield stress as much as 40 kPa was evaluated for intact soil from the results of a separate oedometer test following the Casagrande’s graphical method. Of particular interest is the dependency of $C_p$ on soil water salinity which has been rarely reported in the literature. According to Fig. 5, compacted loess with reduced salinity has a higher collapse potential compared with that having natural salinity. A possible reason is reduction in the thickness of diffuse double layer with an increase in salinity, resulting in less collapsibility.

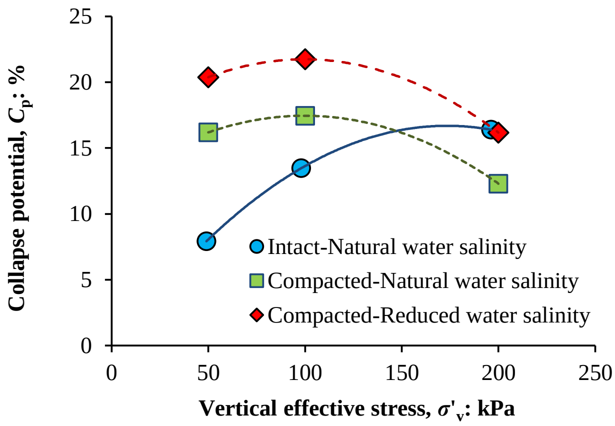


Fig. 5. Collapse potential of intact and compacted specimens with different salt concentration in soil water

### 4.3 Microstructural observations

The considerable collapsibility of loess mainly arise from its special honeycomb microstructure with two distinct pore categories of macropores and micropores where the former is very sensitive to hydro-mechanical alteration (Liu et al. 2016). The abundance of macropores with entrance diameter in excess of hundreds of μm is evident in Figs 6(a) and (b) for intact and compacted soils, respectively, although larger macropores formed in compacted soil. This further supports higher $C_p$ for compacted soil compared with the intact one. Loess microstructure also affects other aspects of behavior like dynamic properties (Ng et al. 2017a). A salt grain is demonstrated in Fig. 6(c) supporting the measured large dispersive potential.

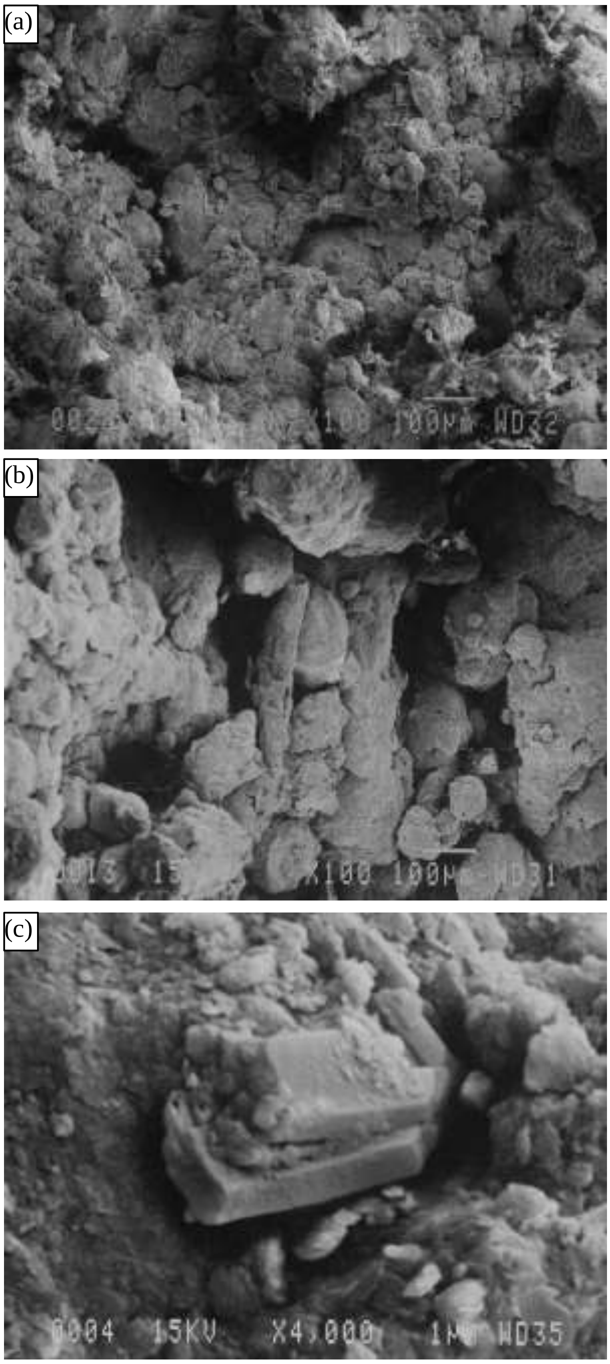


Fig. 6. Microstructure of (a) intact, and (b) compacted soil; (c) a salt crystal being abundant in dispersive loess

## 5 CONCLUSION

A natural dispersive loess occurred close to the North Coast of the Gulf of Oman is introduced and classified mainly based on its collapsible and dispersive features. Deposited close to sea water, the natural soil strata in this region are salt-rich. The existence of salts in soil water is supported by occurrence of *in-situ* deep sinkholes, results of chemical tests, as well as microstructural observations. Results revealed the severe collapse potential induced by wetting. More importantly, a clear dependency of collapse potential on soil water salinity was observed. It is believed that observed phenomenon is due to the interaction between soil water salinity and absorbed water by clay minerals although further studies are needed for a more insightful explanation.

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