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Collapse Potential of Compacted Silty Sand and Silt

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Abstract. Collapse is a phenomenon that occurs when unsaturated soil is inundated with water under steady vertical stress, causing it to densify. Due to their sensitivity, structures built on collapsible soil pose a major threat. In the present study, an attempt has been made to study the collapse potential of two locally available soil in Trivandrum and the influence of placement conditions. Samples of silty sand and silt of medium compressibility were collected from locations prone to collapse in the city. The effect of initial soil conditions and vertical stress on the collapse behaviour was investigated by conducting single oedometer tests. The collapse behaviour of the soil was experimentally established for different dry densities and at different water contents. With an increase in fine content, the susceptibility of the soil to collapse is reduced. The results suggested that increasing water content and dry density of the soil also reduce the collapse potential of the soils.

Keywords: Collapse potential, Silt, Silty sand, Dry density, Water content.

1 Introduction

Water content changes in the soil lead to volumetric instability. This can lead to the collapse or swelling of soil. Low void ratio and a high clay content tend to cause swelling of soil. Factors that encourage collapse are high void ratio and an open soil structure in which some of the individual void spaces are relatively large [1,2]. The use of compacted fills in many civil engineering applications, such as earth dams, highway embankments and compacted fills raises serious concerns about soil collapse [3]. Collapse is defined as the densification of the soil on inundation with water at constant vertical stress. At low water contents, collapsible soils may endure relatively high applied vertical loads with only minor settlements, while the same soils can experience significant settlements when wet without an increase in applied vertical stress.

Early studies had shown that silts and sands are where the collapse phenomena occurred. However, recent research has revealed that, under specific circumstances, collapse may happen in all types of compacted soils including in pure clays like montmorillonite and kaolinite [4]. The collapse of soil may be due to different factors. But the susceptibility of soil to collapse is determined using a parameter called collapse potential which is determined from oedometer tests. The effects of initial dry density, water content, clay content, and vertical stress on the collapse behaviour of compacted soils are well known [3-11]. At the same external stress, the amount of collapse decreases with an increase in the dry density of the compacted soils [11-12]. The collapse potential of compacted soil decreases with an increase in water content, and the collapse potential increases with the increase in vertical stress. Maximum Collapse potential was recorded at approximately the compactive prestress of the compacted soil specimen or apparent pre-consolidation stress obtained from Casagrande method [4,5,8].

Lawton et al. [3] have described the role of the clay fraction in controlling the collapse behaviour of compacted soils. According to them, the amount of clay present in compacted soil has a great bearing on the soil structure and its collapse behaviour. At low clay contents, few macropeds develop and the clay acts as a binder between the coarser silt and sand particles. When wetted, the clay binders soften and lubricate the intergranular contacts, thereby facilitating collapse. With increasing clay content in the low range, more macropeds develop. Greater swelling occurs from the increased number of clay particles, but this swelling is more than offset by softening and distortion of the macropeds, so the net result is an increase in collapse potential. At some higher clay content, the maximum collapse potential is reached, and at clay contents greater than this, swelling of the clay particles counteracts the collapse, and collapse potential decreases. At high clay contents, swelling predominates over the collapse.

The soil deposits in the Thiruvananthapuram District are usually unsaturated because of the presence of alternate dry and wet seasons. However, these unsaturated soils would be vulnerable to an increase in moisture content due to artificial or natural causes (leakage from pipes or watering of lawns and plants). The main objective of this study is to determine the effect of various characteristics on the collapse behaviour of soil samples from the Thiruvananthapuram District. Such studies are crucial as they identify the important compaction parameters (dry density and water content), soil composition, and applied stress level that the fill designer has to control to reduce wetting-induced collapse.

2. Experimental work

2.1 Characterization of soil

Representative soils were collected from two locations in Trivandrum city and the soil was characterized as per IS standards. The two soils, S1 and S2 were identified as silty sand and silt of medium compressibility and their properties are given in Table 1.

2.2 Test Program

The Collapse potential of the soil was determined from Single Oedometer tests. The tests were conducted as per ASTM D 5333[13]. Two types of soil collected from different locations in Thiruvananthapuram city were used in the test program. The soil was compacted at 80% and 90% Maximum dry density (MDD) and at three different water contents of 6%, 9% and 12%. The Collapse potential of the soil was determined at vertical stress of 200 kPa, 400 kPa and 800 kPa.

Table 1. Soil Properties

Property		Value	
		S1	**S2**
Specific gravity		2.59	2.55
Grain size distribution			
Gravel fraction [4.75-20mm] (%)		19	6
Sand fraction [0.075-4.75mm] (%)		38	36
Silt fraction [0.002-0.075mm] (%)		29	35
Clay fraction [<0.002mm] (%)		14	23
Soil Classification (USCS)		SM	MI
Atterberg Limits (%)			
Liquid limit		56	47
Plastic Limit		33	34
Plasticity Index		23	13
Compaction Characteristics			
Light Compaction	OMC (%)	15.6	13.25
	MDD (g/cc)	1.725	1.854
Heavy Compaction	OMC (%)	20	20
	MDD (g/cc)	1.56	1.694

2.3 Single Oedometer test

This is the most widely used test method for the determination of collapse potential. The statically compacted specimens were set up in standard consolidation assemblies and then incrementally loaded up to a specific stress level without inundation. On attainment of equilibrium under the applied stress, the compacted specimens were inundated with inundating fluid. The final deformation after 24 h is however used while calculating the collapse potential of specimen in order to allow for any residual collapse [10]. Additional loading is then applied with the specimen remaining saturated. A typical single oedometer test result is shown in Fig. 1. The collapse potential for a single oedometer test is given as:

$$\textit{Collapse potential},\ i_e = \frac{\Delta e}{1+e_i} \qquad (1)$$

Where Δe and e_i is change in void ratio upon saturation and void ratio at the beginning of saturation, respectively.

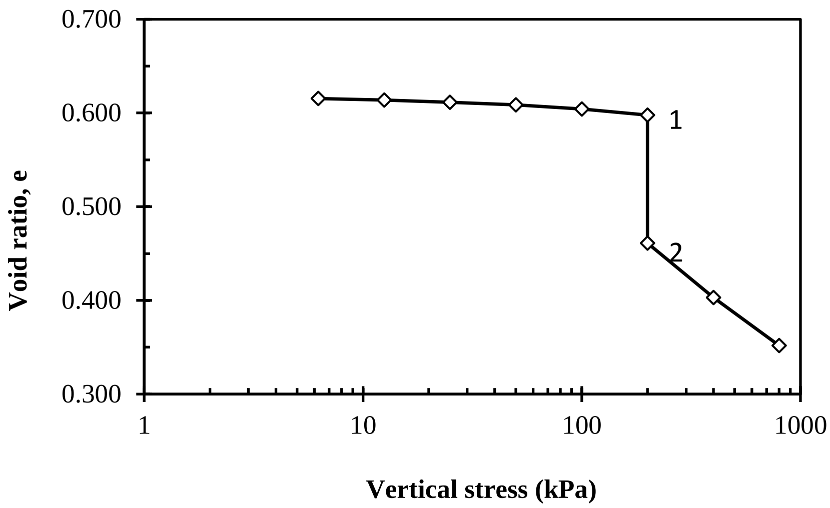


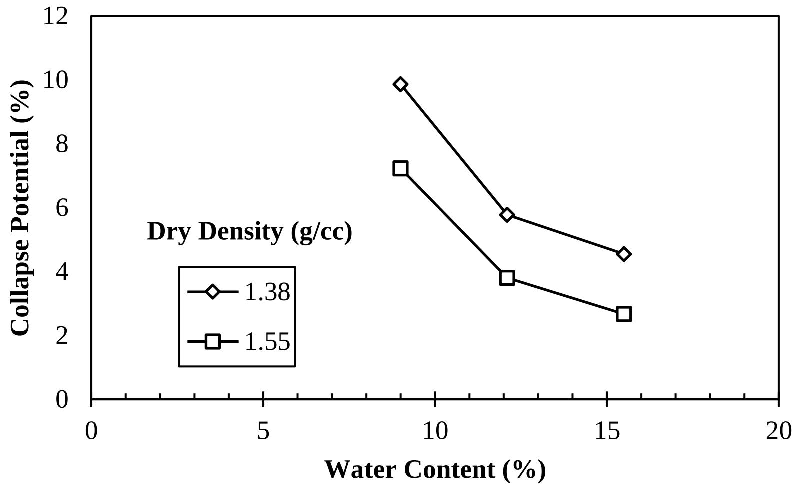
Fig. 1. Typical single oedometer test result

3. Results and Discussion

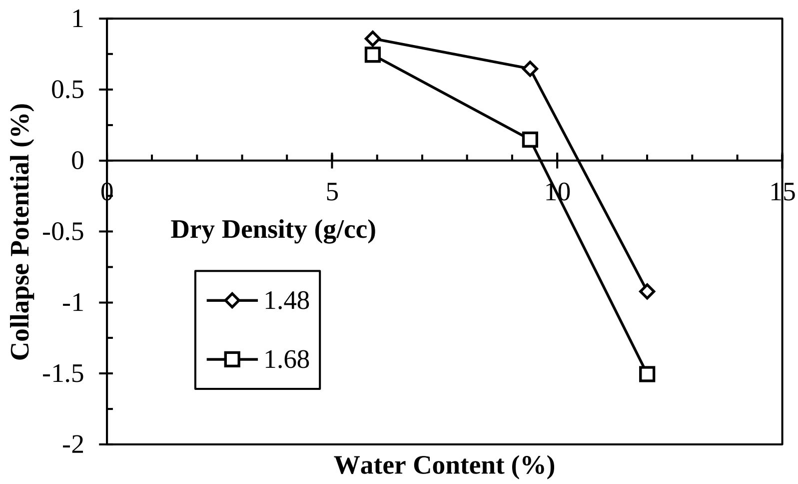
The results of single oedometer tests are presented and discussed to bring out the effect of placement conditions like water content, dry density, and vertical stress on the collapse potential of two different types of soil

3.1 Effect of water content

Fig. 2 presents the variation of collapse potential with water content for compacted specimens at vertical stress of 200 kPa S1 and S2 soils. S1 soil had a collapse potential of 9.8% at a water content of 9% and dry density of 1.38 g/cc, which reduced to 5.78% and 4.54% at a water content of 12% and 15.5% respectively at the same dry density. At any given dry density, the collapse potential of compacted specimens decreased with an increase in water content in both the soils. The reason for the decrease in collapse potential is attributed to the higher compressibility of soil with the increase in water content.



(a)



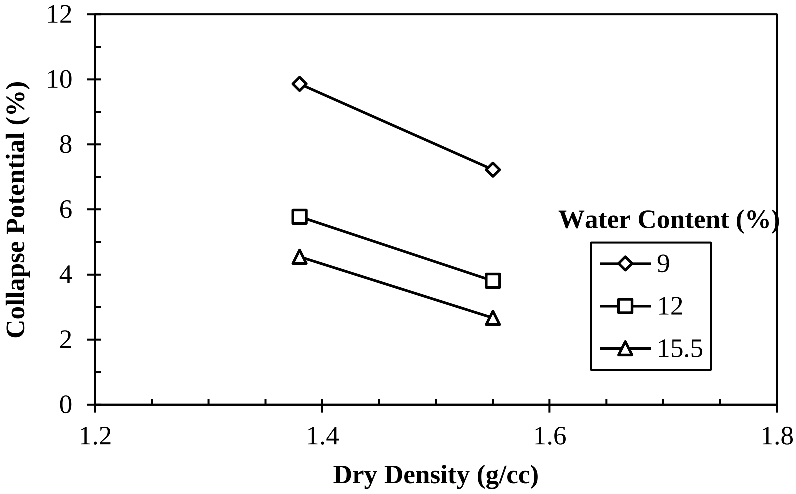
(b)

Fig. 2. Variation of collapse potential with water content of specimens compacted to different dry densities and inundated at vertical stress of 200 kPa a) S1 soil b) S2 soil

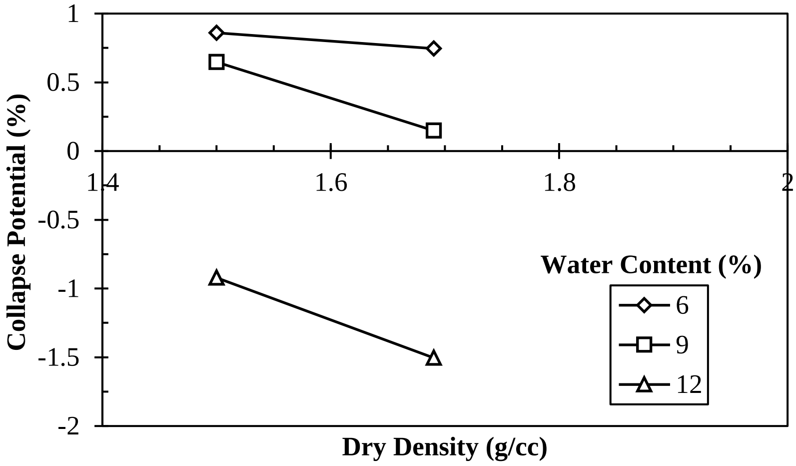
At 200 kPa vertical stress (Fig. 2b) the S2 soil exhibited notable negative collapse potential(swell) at higher water content. This is due to the influence of clay content in MI soil. Works carried out by Tadepalli and Fredlund [10] have shown inverse linear relations for the variation of collapse potential with water content at a given dry density in the investigated range of vertical stress. It can be inferred from the plots that the relationships between collapse potential and water content are not linear for the soil studied here and the values depend on the vertical stress.

3.2 Effect of dry density

Fig. 3 represents the variation of collapse potential with dry density for compacted specimens at a vertical stress of 200 kPa. The collapse potential of compacted specimens decreased with the increase in dry density in both soils.



(a)

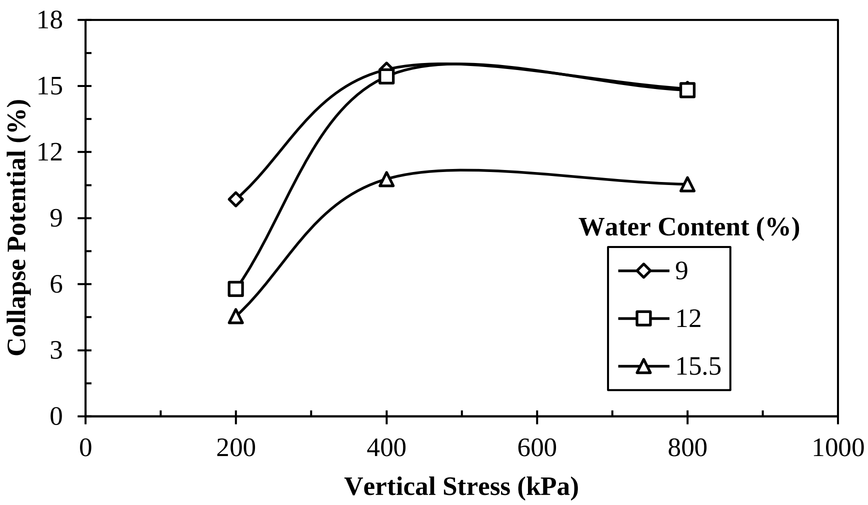


(b)

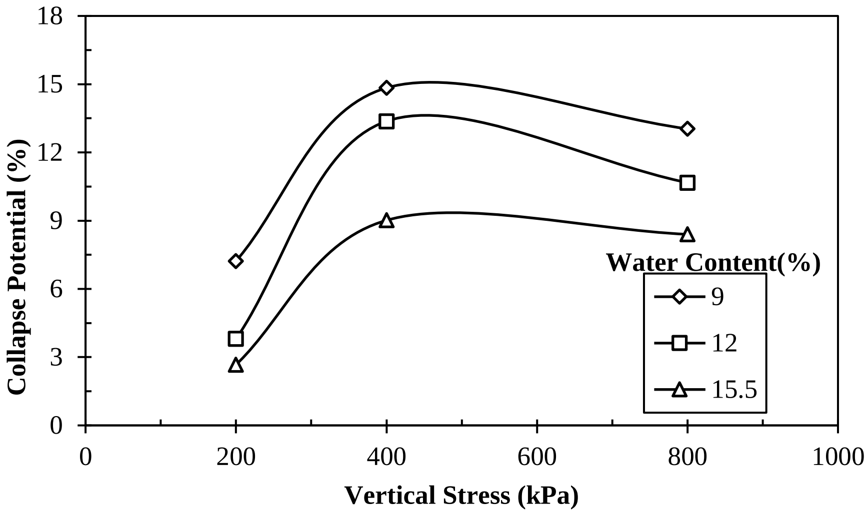
Fig. 3. Variation of collapse with water content of specimens compacted to different dry densities and inundated at vertical stress of 200 kPa. a)S1 soil b)S2 soil

3.3 Effect of vertical stress

Fig. 4 and 5 compare the variation of collapse potential with vertical stress of specimens compacted at different water contents and constant dry densities. In S1soil at both dry densities, the collapse potential first increased up to vertical stress of 400 kPa and beyond which it decreased, complying with the observations reported in the literature. The collapse potential increase with the increase in vertical stress and reaches a maximum value, beyond which it decreases [3]. With the increase in vertical stress, the curves become flatter, especially for specimens compacted at OMC where the effect is more prominent. This behaviour can be attributed to lower values of compactive prestress for the specimens compacted at OMC. Also, the decrease in collapse potential at 800 kPa at 1.55 g/cc is more significant than 1.38 g/cc. This is also due to the more densification of the specimen at 1.55 g/cc. In MI soil(Figure 4.9,4.10), at both dry densities specimens swelled at flooding pressures of 200 kPa and significantly collapsed at vertical stresses larger than 200 kPa. This is due to the higher percentage of clay content in the MI soil.

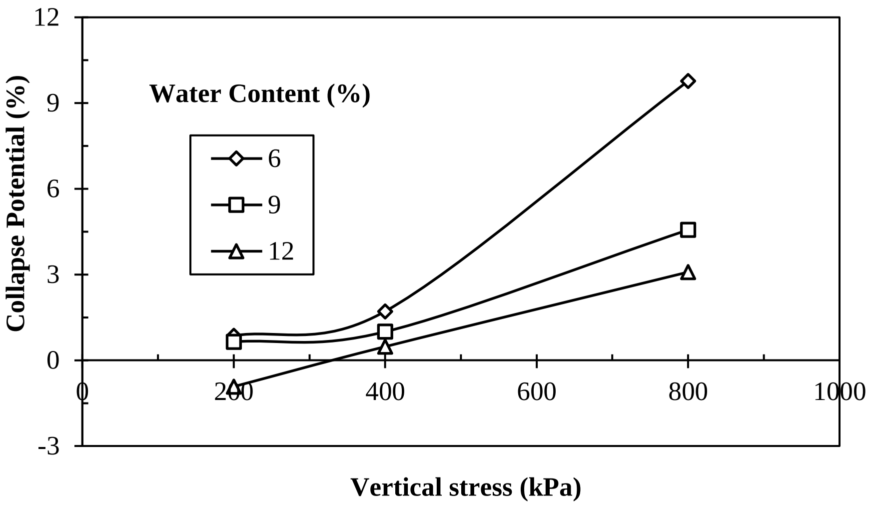


(a)

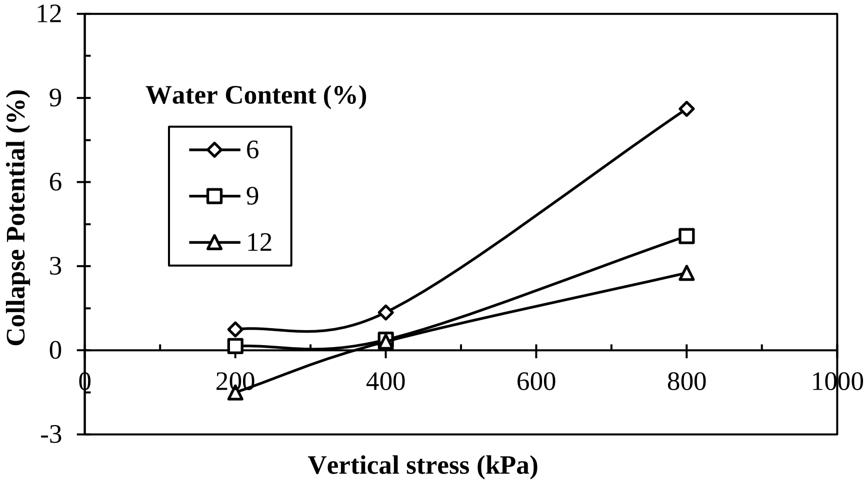


(b)

Fig. 4. Variation of collapse potential with vertical stress at different water content and a constant dry density of (a) 1.38 g/cc (b) 1.55 g/cc



(a)



(b)

Fig. 5. Variation of collapse potential with vertical stress of MI soil at a dry density of (a) 1.48 g/cc (b) 1.68 g/cc

4. Conclusions

The salient finding of the present study is that the two soils of Thiruvananthapuram District are susceptible to significant collapse in the compacted states. Factors such as initial dry density and water content of the soil specimen and vertical stress have a significant bearing on the collapse behaviour of the compacted soil specimens. Oedometer test was performed to find the effect of placement conditions and normal pressure on the collapse behaviour of soils. The other major conclusions arrived at from the study are:

- For both SM and MI soils collapse potential decreased with an increase in water content and dry density
- Compacted soil specimens tended to swell and collapse at the experimental range of densities, water contents and vertical stresses. The collapse potential of SM soil increased with the increase in vertical stress and is maximum at the yield stress, beyond which it decreased. The reduction in collapse potential is due to the densification and increase in the degree of saturation at higher stresses.
- The MI soil specimens swelled at flooding pressures of 200 kPa and significantly collapsed at vertical stress larger than 200 kPa.
- Hence maintenance of the design water content during the construction of these soil fills is essential to minimize wetting-induced volume changes.

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