EFFECT OF INITIAL SURCHARGE ON SWELLING CHARACTERISTICS

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ABSTRACT: Swelling characteristics of expansive soils, namely, swell potential and swelling pressure depend on various parameters such as initial water content, dry unit weight and surcharge pressure. It is important to correctly understand the effect of these parameters on swelling characteristics. This paper discusses the effect of surcharge pressure on swelling characteristics of expansive soils. Swell potential and swelling pressure were studied of samples subjected to varying initial surcharge pressures. The paper focuses on the need to consider the effect of initial compression on swell potential and swelling pressure. It was found that the actual values of swell potential and swelling pressure obtained when initial compression was considered were higher than the values of swell potential and swelling pressure when initial compression was ignored.

1. INTRODUCTION

1.1 Swelling Characteristics

Swell potential and swelling pressure can be either directly determined in the laboratory or indirectly predicted from classification index properties such as plasticity index, clay content, Free Swell Index (FSI), activity, and shrinkage index which have only an indirect bearing on the degree of swelling (Seed et al. 1962, Phanikumar 1997, Rao et al. 2004).

Swell potential (S%) is defined as the ratio of increase in thickness (ΔH) to the initial thickness (H) of the soil sample compacted at optimum moisture content in a consolidation ring and soaked under a token surcharge of 6.9 k Pa (Seed et al. 1962) so that the sample undergoes free swell. It is expressed as,

\[ S = \left( \frac{\Delta H}{H} \right) \times 100 \]  

(1)

Swelling pressure (σs), as determined by free swell method, is defined as the pressure required to recompress a completely swollen soil sample to its original unloaded volume (Jennings 1963; ASTM 1996, D4546A). It is obtained from e-logσ curve as the pressure corresponding to the initial void ratio. Swell potential and swelling pressure depend on placement conditions also such as initial dry unit weight and initial water content. Swell potential and swelling pressure increase with increasing initial dry unit weight and decrease with initial water content. Volume changes of expansive soil samples depend upon the applied surcharge pressure also (Gens & Alonso 1992, Wheeler et al. 2003). Stress acting on the soils prior to inundation is an important parameter, because it governs the values of swell potential and swelling pressure. Hence, swell potential and swelling pressure need to be determined considering the effect of initial surcharge pressure. This paper presents laboratory one-dimensional swell-consolidation test results on remoulded expansive soil samples. Swell potential and swelling pressure were studied with reference to the effect of surcharge pressure. The paper emphasises the need to consider the equilibrium void ratio at the end of compression undergone by the soil sample under the initial surcharge pressure as the reference void ratio for obtaining swell potential and swelling pressure.

1.2 Focus of the Paper

When expansive soils are subjected to surcharge pressures, compression takes place and the initial thickness, H, of the specimen (or, the field stratum) decreases and becomes equal to (H−?H1) where ?H1 is the amount of compression under the applied initial surcharge pressure. When swelling occurs due to wetting, the change in thickness (or, increase in thickness due to swelling), ?H, is to be referred to the new reduced thickness (H−?H1) of the clay stratum resulting due to the application of surcharge pressure and not to the initial thickness H because the initial parameters that control swell have now changed. Hence, swell potential is to be obtained as (?H)/(H−?H1) and not as (?H)/(H). An experimental investigation was conducted to study the effect of initial surcharge pressure on swell potential and swelling pressure, considering the reduced initial thickness of the stratum.

2. EXPERIMENTAL INVESTIGATION

An experimental investigation was carried out on a remoulded expansive soil sample collected from Amalapuram, Andhra Pradesh, India.
Pradesh, India. It was highly swelling clay with a Free Swell Index (FSI) of 250%.

2.1 Quantities Determined and Variables Studied

Swell potential and swelling pressure were determined by swell-consolidation method, which is a free inundation method. Swell potential and swelling pressure were determined at the following placement conditions:

(i) initial water content, $w_i$ (%): 0; (ii) initial dry unit weight, $\gamma_d$ (kN/m$^3$): 12.20; (iii) initial surcharge, $q_i$ (kPa): 5, 25, 50 and 100

Oven-dry soil samples (initial water content = 0%) were used in order to obtain measurable swell potential and swelling pressure.

2.2 Sample Preparation and Test Procedure

The air-dried soil passing 4.75 mm was oven-dried at a temperature of 105°C to reduce the water content to 0%. The sample was allowed to cool down to the room temperature and statically compacted in the consolidometer ring (H = 20 mm thickness and D = 60 mm diameter) in 4 layers, each of 5 mm thickness, to the predetermined dry unit weight of 12.20 kN/m$^3$. A filter paper and a porous stone were placed at each end of the sample. This unit was placed in the oedometer and the loading pad positioned centrally on the top porous stone. The predetermined initial surcharge pressure (5, 25, 50 and 100 kPa) was applied on the specimen after setting the dial gauge reading (initial reading) to zero. Initial compression ($\Delta H_1$) was noted after leaving the surcharge pressure on the specimen for 24 hours. Swell potential ($S_i$) and swelling pressure ($p_s$) were determined by free inundation method in which the sample is completely inundated with water and allowed to swell freely under the applied surcharge. Dial gauge readings were taken up to equilibrium swell (no further change in the dial gauge reading). The increase in the thickness ($\Delta H$) of the sample from $\Delta H_1$ was noted. Swell potential (Seed et al. 1962) is generally determined as $S = ([\Delta H/H] \times 100)$, where $\Delta H$ is measured from the initial height of the specimen (H).

But, in this paper swell potential was determined as $S = ([\Delta H/(H-\Delta H_i)] \times 100)$ where $\Delta H$ was measured from the compressed height (H- $\Delta H_i$) of the specimen. Swelling pressure is generally read from the e-log $p$ curve as the pressure corresponding to the initial void ratio (Jennings 1963) corresponding to placement dry unit weight. In this paper swelling pressure was measured as the pressure corresponding to the void ratio corresponding to the reduced thickness obtained by the specimen due to the application of surcharge pressure. At reduced void ratio or thickness, the sample obtains higher dry unit weight and consequently yields higher swell potential and swelling pressure depending upon the magnitude of surcharge.

3. DISCUSSION

Figure 1 shows the general pattern of rate of heave in the form of heave (mm)—time (mins) plots for identical samples ($w_i = 0\%$ and $\gamma_d = 12.20$ kN/m$^3$) subjected to varying initial surcharge pressure (5, 25, 50 and 100 kPa). All the samples were allowed to swell up to 3 days during which equilibrium heave was obtained indicating that all the samples were saturated. However, there was a notable reduction in heave with increasing surcharge pressure. The magnitudes of heave for the surcharge pressures of 5 kPa, 25 kPa, 50 kPa and 100 kPa were respectively 2.26 mm, 2.06 mm, 0.86 mm and 0.20 mm. Further, there was a notable variation in the primary heave as the surcharge pressure varied.

The heave curves were plotted neglecting the initial compression undergone by the samples at higher surcharge pressure, though the initial compression was allowed to take place completely under the applied surcharge pressures. Water was allowed into the specimens only at the end of initial compression. The first point in Figure 1 corresponds to the point of time at which water was allowed into the specimen. Thus, the volumetric changes (or, changes in thickness) in the specimens caused by the surcharge pressure were not shown. But, if the rate of volumetric changes in the specimens affected by surcharge pressures in the form of initial compression should also be taken into consideration, the heave pattern changes.

Figure 2 shows rate of heave of samples considering the initial compression undergone by them under the applied surcharge pressure. The heave pattern shown in Figure 2 is the actual heave pattern, which shows the rate of volumetric change (initial compression), undergone by the specimens under surcharge pressure prior to inundation. The heave curves for samples that underwent initial compression were below the X-axis. For the samples that underwent initial compression, the total heave is the difference between the points indicating initial compression and final heave as shown in Figure 2. If heave is to be calculated according to the pattern shown in Figure 1, it would not reflect the amount of initial compression and also the effect of reduced void ratio on the final heave. In the case of samples that undergo initial compression under initial surcharge pressure, actual swell potential would be different from the swell potential reported in practice, which ignores the initial compression. Actual swell potential is that referred to the reduced thickness of the sample due to initial
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Figure 2: Actual Heave Pattern

Figure 3 shows the variation of actual swell potential and reported swell potential with the initial surcharge pressure. There was a significant difference between the actual and reported swell potential values. The actual swell potential was higher than the reported swell potential. The difference between the two increased with increasing surcharge pressure within the range of surcharge pressure used in the test programme. When heave is referred to the reduced thickness obtained by the specimen due to surcharge, as is done in the case of actual swell potential \((\Delta H/H)\times 100\), the denominator is reduced increasing the value of actual swell potential. This is irrespective of the heave, \(\Delta H\), in the numerator. Thus, the increase in actual swell potential compared to the reported swell potential can be given a numerical explanation. Further, when the void ratio of the sample is reduced due to initial surcharge, the dry unit weight of the sample rises compared to the placement dry unit weight. Thus, on inundation, the repulsion between the soil particles would be more in the case of samples which do not undergo initial compression. This is the explanation that can be given from the mechanics point of view. In actual field situations, if a building is designed based on the reported swell potential, it can be subjected to detrimental damage owing to actual swell potential which is higher than the design swell potential. Hence, it is necessary to consider in building design the initial compression undergone by the expansive clay and the consequent increase in heave and reduction of thickness in clay layer.

Considering e-log \(p\) curves (which are not shown here), \(e_o\) was the initial void ratio for the specimen that did not undergo initial compression. However, for the specimens that underwent initial compression under the applied surcharge, the initial void ratio \((e_i)\) was less than \(e_o\). The actual swelling pressure \((\sigma_s)\) is, therefore, the pressure required to bring back the swollen specimens to the respective initial void ratios at which inundation took place, namely \(e_i\). These would be higher than the swelling pressure determined without considering initial compression.

From the foregoing discussion, it appears important to consider the void ratio at which the sample is inundated, which governs the actual values of swell potential and swelling pressure. For the samples which undergo initial compression due to the application of surcharge pressures, the reduced void ratio at which water is allowed into the specimen to cause swelling plays an important role. The values of swell potential and swelling pressure also depend upon the value of surcharge pressure. This paper defines a parameter called coefficient of swellability \((C_s)\) which is the ratio of void ratio at inundation \((e_i)\) to the initial surcharge pressure \((q_i)\). This parameter plays a significant role in governing the swelling behavior of expansive clays. Figure 5 shows the variation of actual and reported swell potential with coefficient of swellability \((C_s)\).
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Both the actual and reported values of swell potential showed a rapid increase initially with increasing coefficient of swellability and after a certain value of $C_S$, both actual and reported values of swelling pressure decreased. At low values of $C_S$, swell potential was low because of higher initial surcharge and hence the value of swell pressure was also low.

Figure 6 shows the variation of actual and reported swelling pressures with coefficient of swellability ($C_S$).

<table>
<thead>
<tr>
<th>$C_S$ (kPa)</th>
<th>$S%$ (reported)</th>
<th>$S%$ (actual)</th>
<th>$p_{s0}$, kPa (reported)</th>
<th>$p_s$, kPa (actual), kPa</th>
<th>Coefficient of swellability ($C_s$)</th>
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</thead>
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<tr>
<td>5</td>
<td>11.3</td>
<td>11.3</td>
<td>128</td>
<td>128</td>
<td>0.24</td>
</tr>
<tr>
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<td>128</td>
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<td>4.33</td>
<td>128</td>
<td>200</td>
<td>0.0116</td>
</tr>
</tbody>
</table>

While the reported swelling pressure was the same for all the specimens because the initial compression was not taken into consideration the actual swelling pressure was high at low values of coefficient of swellability and decreased with increasing values of coefficient of swellability. As the initial void ratio was low at low values of coefficient of swellability, the resulting actual swelling pressure was high.

4. CONCLUSION

Swelling behaviour was studied under varying surcharge. Swell potential and swelling pressure were determined with reference to the reduced thickness or void ratio. They were compared with those obtained ignoring the effect of reduced thickness or void ratio. In the case of samples that undergo initial compression under initial surcharge pressure, actual swell potential would be different from the swell potential reported in practice, which ignores the initial compression. The actual swell potential was observed to be higher than the reported swell potential. There was a significant difference between actual and reported swelling pressure values. The actual value of swelling pressure is higher than the reported value. The difference between the actual and reported values of swelling pressure increased with increasing surcharge pressure. Both the actual and reported values of swell potential showed a rapid increase initially with increasing coefficient of swellability and after a certain value of $C_S$, both actual and reported values of swelling pressure decreased. The reported swelling pressure was the same for all the specimens, but the actual swelling pressure was high at low values of coefficient of swellability and decreased with increasing values of coefficient of swellability.

REFERENCES


