Field and Laboratory Observations of Expansive Soil Heave

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Synopsis

Various approaches have been used by different investigators to observe and measure the heave of an expansive soil and to predict its volume change. Field observations always give realistic ground heave measurements. In this paper observed ground movements of expansive soil in the field are presented. Observations included movements with depths after long term flooding of two sites. The results are directly or indirectly related to the soil response to moisture, loads and permeability of the soil. However ground heave was found to decrease exponentially with depth. Parallel laboratory tests were performed to study soil response to volume change under controlled moisture increase. Ordinary swell under load tests were also performed. The results were compared with the actual measured heave in the field. The swell under a load equivalent to the overburden pressure was found to overestimate the heave.

Introduction

Heave of an expansive soil is an important parameter for quantitative characterisation of the expansive soil.

- Different methods and techniques have been used for the measurement and prediction of expansive soil heave. These methods include, the oedometer tests, soil suction approaches and empirical approaches.

- The empirical equations are prediction methods based on the correlation between laboratory or field measurements and soil indices such as the liquid limit and the plasticity index.

- The oedometer methods for measurement and prediction of heave are the most widely used methods. These consist of direct and indirect measurement of heave. The direct measurement is made by measuring the soil heave at a certain initial surcharge load. The indirect measurement is made by using the oedometer test data and applying either the effective stress principle and/or revised consolidation theory (Sullivan & McClelland (1969), Jennings et al (1962))

- Different methods have been used for prediction of heave using soil suction data. The methods differ according to the method adopted for suction measurement.

- In this paper the results of heave measurements conducted at two locations lying within the expansive soil zone in Sudan are presented and analysed. The measurements were made following a long term flooding of the sites.

In addition, laboratory experiments were also conducted on soil samples brought from the two sites to measure the percentage swell for different stress and suction conditions. The different methods of laboratory testing were assessed for heave prediction.

Field and Laboratory Heave Observations

Observations in the Field:

- Heave measurements were conducted at two locations, located on the expansive soil zone in Sudan Fig. (1)

Fig (1) LOCATION OF SITES WHERE THE FIELD EXPERIMENTS WERE PERFORMED

- The subsoil conditions were revealed by sinking boreholes at the two sites and taking soil samples for testing at the laboratory. The soil profiles and properties are summarised in Fig. (2). However, wide shrinkage cracks exist at site (1) during the dry season
- The set-up used to observe heave of subsoils consisted of 152mm diameter steel plates welded to steel rods 19mm in diameter and placed at 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 & 4.0 meters below ground level.

- After drilling the holes up to the specified depths, the plates were located and the space above the plates was filled with sand to represent the overburden load. Steel plates (254x254mm) were provided on the ground surface to prevent direct penetration of water. The steel rods were designed with a projection of 250mm above the ground level to facilitate heave observations. Heave was observed using a precise level accurate to 0.05mm.

- The sites were covered by 100mm thick sand blanket to minimize the rate of evaporation and to allow for better distribution of water. The spatial distribution of the plates and their setting are shown on Fig. (3).

- Concrete slabs were placed on the ground surface to allow ground surface heave measurements. Heave observations were made before and after flooding of the sites. Flooding started in mid-March (1986) and continued till July of the same year. The first heave observations were made after 15 days of continuous wetting. The second, third and fourth observations were made one, two and three months after the first observations were made respectively.

- Fig. (4) and Fig. (5) show the observed ground heave after surface wetting for site (1) and site (2) respectively. Moisture profiles before and after wetting are shown on Fig. (6) and Fig. (7) for site (1) and site (2) respectively.
to be equivalent to the corresponding field overburden pressure. The percentage swell measured in the laboratory was the maximum volume change observed when the sample was completely soaked in water.

Table (1) shows the results of the percentage swell measured for samples from Site (1) and Site (2).

<table>
<thead>
<tr>
<th>Site</th>
<th>Depth (m)</th>
<th>L.L.</th>
<th>P.I.</th>
<th>I.M.C. Load %</th>
<th>Swell %</th>
<th>Free swell %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>2.0</td>
<td>64</td>
<td>35</td>
<td>20</td>
<td>38</td>
<td>5.65</td>
</tr>
<tr>
<td></td>
<td>4.0</td>
<td>63</td>
<td>32</td>
<td>17</td>
<td>76</td>
<td>6.05</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>70</td>
<td>37</td>
<td>20</td>
<td>94</td>
<td>5.15</td>
</tr>
<tr>
<td></td>
<td>6.0</td>
<td>65</td>
<td>34</td>
<td>16</td>
<td>115</td>
<td>6.50</td>
</tr>
<tr>
<td>Site 2</td>
<td>1.0</td>
<td>73</td>
<td>34</td>
<td>18</td>
<td>34</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>71</td>
<td>34</td>
<td>24</td>
<td>38</td>
<td>16.1</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>69</td>
<td>37</td>
<td>24</td>
<td>36</td>
<td>5.05</td>
</tr>
<tr>
<td></td>
<td>4.0</td>
<td>64</td>
<td>33</td>
<td>24</td>
<td>76</td>
<td>4.10</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>70</td>
<td>35</td>
<td>23</td>
<td>97</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>6.0</td>
<td>68</td>
<td>34</td>
<td>20</td>
<td>118</td>
<td>4.10</td>
</tr>
</tbody>
</table>

The free swell:
The swelling potential of the soil samples from Site (2) was assessed using this test. A vertical pressure of 1 kPa was applied to the samples and the corresponding heave was observed. The results of these tests are presented on Table (1).

The controlled moisture oedometer test:
This is an attempt to simulate actual field conditions in the laboratory. The moisture content of the sample was controlled by adding a controlled amount of water to the sample using two filter paper strings each 1.5 mm wide and attached to the top and bottom of the sample. The final moisture content was aimed to be equal to that of the representative soil layer in the field after flooding. Each test continued for 5-7 days.

- The percentage swell (A% Vol) was computed when all water was absorbed by the sample. Results of these tests are shown in Table (II).

<table>
<thead>
<tr>
<th>Site</th>
<th>Depth (m)</th>
<th>I.M.C.</th>
<th>F.M.C.</th>
<th>A% Vol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>1.0</td>
<td>19</td>
<td>32</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>20</td>
<td>26</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>17</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Site 2</td>
<td>1.0</td>
<td>27</td>
<td>33</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>25</td>
<td>31</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>25</td>
<td>27</td>
<td>3.1</td>
</tr>
</tbody>
</table>

I.M.C. = Initial moisture content
F.M.C. = Final moisture content
Discussion of Field Results

A rapid response of the top soil layers to heave was observed at site (1), Fig. (4). By the end of the first 15 days the ground surface heave showed more than 50% of the total measured heave. The deeper layers at this site allowed rapid penetration of water into the soil. Deeper layers showed heave later and by the end of the wetting period up to 3.50m depth experienced noticeable amount of heave.

The trend of ground heave at site (2) was found to be similar to that of site (1), Fig. (5). Ground heave at site (2) was observed to decrease with depth in a more uniform manner compared to site (1). This is probably due to the homogeneous soil layers and presence of less cracks at site (2).

The rate of ground heave:

In order to study the rate of ground heave and the effects of cracks, the soil profile was divided as shown in Fig. (8). Each layer was chosen to be 1.0m thick. The layers were selected to cover the depth affected by moisture increase.

![Fig. (8) Profile Layer as Divided for Analyses of Heave Results](image)

- Fig. (9) shows the rate of heave of each layer at site (1) and site (2). The heave of each layer is the difference of the measured heave at the top and bottom of the layer. It was clear that layer (1) experienced more than 90% of its maximum observed heave by the end of the first 15 days. The second layer at both sites reached about 70% of its maximum heave by the end of the next 30 days.

- Layer (2) at site (1) showed greater amount of heave than layer (1). This was attributed to the effect of the cracks which existed in layer (1) and reduced its heave. The maximum heave of the layers is shown on Table (III).

![Fig. (9) The Rate of Ground Heave of Soil Layers at Site 1 & Site 2 After Flooding](image)

<table>
<thead>
<tr>
<th>Site No</th>
<th>Layer</th>
<th>Maximum Heave (mm)</th>
<th>% Heave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site (1)</td>
<td>1</td>
<td>40.8</td>
<td>4.08</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>61.5</td>
<td>6.15</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>39.4</td>
<td>3.94</td>
</tr>
<tr>
<td>Site (2)</td>
<td>1</td>
<td>72</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>38.5</td>
<td>3.85</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>39.7</td>
<td>3.97</td>
</tr>
</tbody>
</table>

- The trend of the curves showing the variation of measured heave with depth, Fig. (4) and Fig. (5), was examined using statistical regression and an exponential function.

- If $h_0$ is the maximum measured heave, $h$ the ground heave at depth $d$, and $d_0$ the depth at which no heave was observed the following relationships are obtained, Fig. (4).

For Site (1):

$$d_0 = 1.512 \times e^{-3.088 \frac{d}{h_0}}$$

$\text{do}$ was taken to be 3.50m and a correlation coefficient of 0.91 was obtained.

For Site (2):

$$d_0 = 1.143 \times e^{-3.139 \frac{d}{h_0}}$$

$\text{do}$ was taken to be 4.0m and correlation coefficient of 0.91 was obtained.
Field and Laboratory Observations of Expansive Soil Heave

- The above relationships are shown on Fig. (4) and Fig. (5) for site (1) and site (2) respectively. The fit is similar to Van der Merwe (1966) empirical relationship.

- The maximum ground surface heave given by the above relationships is about 295 mm for both sites. The discrepancies seen on Fig. (4) and Fig. (5) in the top layers are due to the reduction in heave caused mostly by surface cracks. This is more clear for site (1) where wide cracks were noticed to prevail.

Field versus laboratory measurements:
- Fig. (10) and Fig. (11) show comparison between the measured heave in the laboratory and the observed heave in the field. The undisturbed soil samples obtained from 1.0 m, 2.0 m & 3.0 m depths were considered to represent the soil layers shown on Fig. (8).

Conclusions
Shrinkage cracks were found to greatly reduce heave in the cracked zone and hence reduce the accumulated surface heave.

Ground heave was found to decrease exponentially with depth.

The depth of moisture variation due to long term flooding was found to vary between 3.5-4.0 meters.

The results of different oedometer methods used to predict heave were compared with the actual heave values measured in the field. The free swell and swell under overburden load were found to overestimate heave. The results of the oedometer tests designed to simulate actual field conditions were found to underestimate heave by a small extent.

All the methods overestimated heave in the cracked zone.

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