Effects of curing temperatures on the strength of cement-treated peat

Yuichiro KIDO, Satoshi NISHIMOTO, Hirochika HAYASHI & Hijiri HASHIMOTO
Civil Engineering Research Institute for Cold Region, Sapporo, JAPAN

ABSTRACT: Trencher mixing is a soil improvement method involving cement, and uses a backhoe as its base machine. The low weight of backhoes removes the need for a sand mat to ensure trafficability, but the lack of such a mat causes temperatures at the surface of cement-treated ground to become lower than the external temperature, thus affecting the solidification of the cement. As this is a problem for construction in winter, the influences of the curing temperature and the strength of cement-treated soil were studied in a laboratory test. Peat was used as the cement-treated material for its characteristics as a soft soil found widely in cold regions. The results indicated that the strength of cement-treated soil decreased with reduced temperatures. The decrease was especially remarkable at sub-zero temperatures.

1. INTRODUCTION

The strength of soil improved using cement is affected by factors such as soil texture, curing temperature, type of cement, binder content and mixing time. Of these factors, the curing temperature is often not controlled, as it is not economical to do so. However, its influence on the strength of cement-treated soil has been pointed out for winter soil improvement in cold, snowy regions. It has been reported that the strength of cement-treated soft clay becomes lower than the strength developed at a curing temperature of 20 degrees Celsius (Babasaki, 1996 and Hosoya, 1996). The curing temperature of 20 degrees is the value provided by the Japanese Geotechnical Standard for laboratory mixing tests.

The trencher mixing method uses a backhoe (a lightweight heavy machine) as its base machine, making it unnecessary to install a sand mat to ensure trafficability before construction.

It has been reported that the lack of a sand mat causes the surface of cement-treated soil to be affected by external air in winter construction (Hashimoto, 2006). A study of changes in curing temperature and strength was therefore conducted, and the causes of changes in strength were discussed.

2. EXPERIMENTAL CONDITIONS AND MEASUREMENT ITEMS

2.1 Cement-treated soil

Peat was used as the material to be treated with cement due to its characteristics as a soft soil found extensively in cold, snowy regions. Peat was collected in the Horonobe area of Hokkaido, Japan. Table 1 shows the results of the soil test.

Table 1 Engineering properties of peat tested

<table>
<thead>
<tr>
<th>Properties</th>
<th>Hironobe peat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural water content (%)</td>
<td>550</td>
</tr>
<tr>
<td>Density of soil particles (g/cm³)</td>
<td>1.854</td>
</tr>
<tr>
<td>Ignition loss (%)</td>
<td>66</td>
</tr>
</tbody>
</table>
2.2 Test piece preparation method

Test pieces were prepared in accordance with the Japanese Geotechnical Standard Practice for Making and Curing Stabilized Soil Specimens without Compaction (JGS0821-2000, The Japanese Geotechnical Society, 2000), which lists soil improvement provisions. The mixing time for the cement and soil was 10 minutes, as provided in the standard. The strength of the cement-treated soil was evaluated in an unconfined compression test. The curing periods were 7 and 28 days.

2.3 Types of binder

Two types of cement were used. One was blast furnace cement, which was chosen as a binder because it is generally used in ground improvement. The other was a special cement developed specifically for strengthening peat.

In Japan, special cement products are sold for use with soil types where sufficient strength cannot be achieved with ordinary cement.

2.4 Binder content

The binder content is defined as the ratio of the weight of cement to the wet unit weight, and is set at 20, 30 or 40%.

2.5 Electron microscopy

It has been reported that, when improving peat using special cement, the strength of the resulting soil is affected by the production of ettringite, a type of cement hydrate (Hayashi, 2005). Electron microscopy was used to visually confirm the relationship between the curing temperature and ettringite production only for the case where special cement was used. This was conducted in accordance with the Japanese Industrial Standard General rules for scanning electron microscopy (JISK0132).

2.6 X-ray diffraction test

To ascertain the effect of cement-treated ground on the unconfined compressive strength at low temperatures, cement hydrate of test pieces were observed by X-ray in accordance with the Japanese Industrial Standard General rules for X-ray diffractometric analysis (JISK0131). Test pieces with a special-cement binder content of 40% were evaluated at uniform curing temperatures of 20, 5, 0, -5 and -20 degrees Celsius.

3. RESULTS

3.1 Effect of curing temperature on the strength of cement-treated soil (blast furnace cement)

To ascertain the effect of curing temperature on the strength of cement-treated soil, curing was conducted for a fixed period at uniform temperatures of 20, 5, 0, -5 and -20 degrees Celsius. Test pieces cured at 0, -5 and -20 degrees could not be compared with other cases since they were frozen. They were tested after defrosting at 5 degrees the day before the unconfined compression test.

Figure 2 shows the relationship between the unconfined compressive strength and curing temperature after curing for seven days.

Compared with the strength of cement-treated soil cured at 20 degrees, the strength of the test pieces cured at -5 and -20 degrees was less than half, while the strength of those cured at 0 and 5 degrees was at least 60%.

Figure 3 displays the strength of peat treated with blast furnace cement and cured for 28 days. Compared with the strength of the test piece cured at 20 degrees, the strength of those cured at 0 and 5 degrees was 60%, which was similar to the case of 7-day curing. Those cured at -5 and -20 degrees had a strength of less than one-third that of the piece cured at 20 degrees. The strengths of the test pieces with the same binder content in Figs. 3 and 4 were compared. After 28-day curing at a temperatures of 0, 5 and 20 degrees, the strength increased by a factor of between 1.3 and 2 over that found in the case of 7-day curing. The strength of test pieces cured at -5 and -20 degrees showed almost no increase even if the curing period was extended. Additionally, the strength at a curing temperature of -20 degrees did not increase even when the binder content was increased.

In the case of soil improvement using blast furnace cement, almost no soil improvement effect can be expected at curing temperatures of -5 and -20 degrees, and the strength will not increase even after 28 days of curing.
3.2 Effect of curing temperature on the strength of cement-treated soil (special cement)

Figure 4 shows the strength of soil treated with special cement after curing for seven days. The strength achieved at 0 and 5 degrees was 20 to 40% of that at a curing temperature of 20 degrees, indicating a greater decrease in strength development due to the influence of curing temperature compared with the cases using blast furnace cement. At -5 and -20 degrees, almost no improvement effect was observed compared with the case of 20 degrees.

Figure 5 shows the strength of cement-treated soil after 28-day curing. Compared with the strength achieved at 20 degrees, test pieces cured at 0 and 5 degrees developed a strength of up to 60% in contrast to the case of 7-day curing. At -5 and -20 degrees, however, almost no improvement in strength was observed. Comparing the test pieces with the same binder content shown in Figs. 5 and 6, the strength after 28-day curing at 0 and 5 degrees increased by a factor of 3 to 6 over the strength after 7-day curing. The increase in strength brought by extending the curing period was greater than in the cases using blast furnace cement. At curing temperatures of -5 and -20 degrees, the strength improvement in the case of 28-day curing was almost same as that of 7-day curing.

At curing temperatures of -5 and -20 degrees, almost no soil improvement effect was observed, and no increase in strength was expected even after 28 days of curing.

For both types of binder, no improvement effect was expected at curing temperatures of -5 and -20 degrees. For curing temperatures of 0 degrees or higher, the strength of cement-treated soil can be designed as approximately 60% of that achieved at 20 degrees.

3.3 Elements that affect the strength of cement-treated soil (special cement)

Special cement that is effective in the improvement of peat contains more gypsum than ordinary cement. These elements cause production of a large amount of ettringite in an acicular crystalline form. This process absorbs water from the soil for crystallization, thus reducing its water content.
The strength of peat is also increased, as its voids are filled with ettringite crystals. For the above reasons, ettringite production at different curing temperatures was photographed using an electron microscope to ascertain its influence on the strength of cement-treated soil.

Figure 6 show that the soil improved at curing temperatures of 20 and -20 degrees, respectively, for seven days with a binder content of 40%. The acicular crystals seen in the two photos are ettringite (Et). Ettringite crystals at a curing temperature of 20 degrees are longer and produced in larger amounts than those at -20 degrees. The soil improved at -20 degrees had plate-like anhydrite (Anh), which wasn’t observed at 20 degrees.

It was presumed that ettringite production was restricted by low temperatures, resulting in a decrease in unconfined compressive strength.

![Figure 6 SEM photo of treated Horonobe peat using Special cement at curing of 7 days (Left: Curing temperature -20℃, BC 40%, Right: Curing temperature 20℃, BC 40%)](image)

3.4 Relationship between ettringite production and the strength of cement-treated soil

Ettringite cannot be measured quantitatively with an electronic microscope. Ettringite production was therefore measured in an X-ray diffraction test. Figure 10 shows the ettringite production and unconfined compressive strength after 7-day curing. The quartz index indicates ettringite production, which was smaller at lower curing temperatures. The X-ray diffraction test confirmed that strength development became smaller because ettringite production was restricted by low temperatures.

![Figure 7 Relation of Amount of ettringite and 7 days for curing Unconfined compressive strength (Special cement)](image)

4. CONCLUSION

After a curing period of 28 days, the improvement in unconfined compressive strength at curing temperatures of 0 and 5 degrees Celsius was approximately 60% of the strength achieved at 20 degrees. This was proved for both blast furnace cement and special cement.

Almost no improvement in strength from cement use was observed when the ground surface was exposed to external air of -5 degrees or lower. It is important to prevent freezing of cement-treated ground using covers with soil or other insulation-based curing methods.

Ettringite production in peat mixed with special cement is restricted by low temperatures, resulting in a lower improvement effect.

REFERENCES


Hayashi, H. and Nishimoto, S., 2005, Strength Characteristic of Stabilized Peat using Different Types of Binders, Deep Mixing 05, pp.55-62, 2005