multidirectional shaking, one should be more
careful when such situation prevails.

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MODEL TESTS IN RELATION TO A METHOD TO
REDUCE NEGATIVE SKIN FRICTION
BY TAPERING A PILE

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ABSTRACT
As one method to reduce negative skin friction on a pile it can be considered that the pile is tapered. This principle is based on the fact that, when the surrounding soil settles down relatively faster than the pile, it separates off from the pile surface. In order to verify this fact, model tests of negative skin friction were done, using four piles having the following kinds of taper; 10 to 1,000, 5 to 1,000, 1 to 1,000, and 0 to 1,000, i.e. straight.
For those tests a small steel bin was used where a base plate supported by piston cylinders was lowered as slowly as possible so that the sand filled there could settle down, developing negative skin friction on the pile surface.
As a result, it could be concluded that the negative skin friction could be reduced by roughly 90% for 10 to 1,000, 80% for 5 to 1,000, and 50% for 1 to 1,000 in comparison with a straight pile.

Key words: pile, negative friction, model test, sand (IGC: E 4)

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INTRODUCTION

Theoretical or experimental investigations of negative skin friction on piles have been so far made remarkable progress. Furthermore, development of reduction methods of negative skin friction and their evaluation has been also getting on. For example, the following methods are available; slip layer method where a thin layer of asphalt is applied on a pile surface to cut the negative skin friction, or pipe sheathing method where a pile is covered by a sheathing pipe which suffers negative skin friction in its place.

And there are also other uncommon methods where a pile is filmed by bentonite slurry or where an electric current is applied between a pile and the surrounding soil. Besides, reduction of total negative skin friction on a pile group by making the pile spacing narrower has been so far recognized.

This paper will report about a reduction method of negative skin friction by tapering a pile.

PRINCIPLE

Negative skin friction develops along a pile surface when the surrounding soil settles down faster than the pile. Our experience shows that the magnitude of relative displacement required for negative skin friction is only one or two centimeters.

Judging from this fact, it can be easy to understand that, if the surrounding soil separates from the pile surface when the soil settles down relatively faster than the pile as shown in Fig.1, very few negative skin friction will develop. This may be possible when a pile is tapered.

Indeed, when the surrounding soil is clayey, some tension may take part of negative skin friction because the soil tears off from the pile surface, but it can not develop whole along the pile length at the same time. Thus, if any, total negative skin friction will be relatively smaller.

If a sand layer is deposited on a consolidating clay soil, negative skin friction developing in the sand layer tends to become greater when the pile is not tapered i.e. straight. In that situation, a tapered pile may be applied effectively.

It goes without saying that such a tapered pile should have enough bearing area at the tip because it can be used as bearing piles not friction piles. So, from the economical point of view, the choice of degree of taper will depend on how much negative skin friction on a pile should be reduced. This report is to introduce the results of experiments on negative skin friction of model tapered piles.

Fig. 1. Principle to reduce negative skin friction

Fig. 2. Schematic illustration of experiment
Table 1. Physical properties of sand

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>maximum size (mm)</td>
<td>4.76</td>
</tr>
<tr>
<td>uniformity coeff.</td>
<td>2.5</td>
</tr>
<tr>
<td>specific gravity</td>
<td>2.70</td>
</tr>
</tbody>
</table>

**EXPERIMENT**

Tests were done in a steel bin $105 \times 80 \times 70$ cm in size as shown in Fig. 2. A base plate which is supported by four piston cylinders can be lowered down by releasing the oil jack. Four model piles were put on the respective load cell on the bottom, passing through the halls opened on the base plate. The capacity of the load cells is 0.5 kN.

The spacings between the pile surface and the wall or the wall and the bin wall were covered by thin vinyl sheets so that the sand would not drop out. The piles have four kinds of taper; 10 to 1000, 5 to 1000, 1 to 1000, and 0 to 1000 i.e. straight. The piles were fabricated by aluminum thin plate whose thickness is 1 mm, their cross-section being square, and being instrumented with five wire strain-gages on each side of the pile surface confronted. The length of the piles is 75 cm.

The perimeter at the midst of the length is the same, that is, 8 cm, so that the circumferential area is also the same. Sand paper was attached on the pile surface to make the friction much greater. Tests were done as follows; dry sand was filled in the bin after the piles were situated at the proper location as vertically as possible, keeping the base plate at high level.

The property of the sand is tabulated in Table 1. After filling, the sand was compacted by a vibrator to a density of 1.67 g/cm$^3$. At first, the load cells and strain-gages were measured and then the base plate were lowered as slowly as possible, and finally again the load cells and strain-gages were measured. The total settlement was 27.5 mm.

**RESULTS**

The negative skin friction which was measured by load cells was plotted in Fig. 3.

![Fig. 3. Magnitude of negative skin friction](image)

![Fig. 4. Axial thrust distribution](image)
against the degree of taper. From this figure it can be seen that negative skin friction is totally 0.25 kN for straight pile, about one half of it for 1 to 1000, about one seventh for 5 to 1000, and about one ninth for 10 to 1000, which means roughly 50%, 80%, and 90% reduction respectively.

The reason why some part of negative skin friction remained even in tapered piles seems to be due to the fact that some sands dropped into the gaps which have been formed between the pile surface and the surrounding sand. Fig. 4(a) to (d) show the distribution of axial thrust induced by negative skin friction on the piles which was calculated from strain-gage measurement. These data also indicate the result that negative skin friction decreases as the degree of taper increases.

CONCLUSION

Consequently, it can be concluded that the tapering pile is effective for decreasing negative skin friction and that negative skin friction decreases as the degree of taper increases. In future this effect should be verified in clayey ground also.