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Individual penetration of aggregates into soft seabed and the effects of geosynthetics

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ABSTRACT: The construction of structures on soft seabeds can pose major problems due to the very low bearing capacity of some marine deposits and the problems caused by the penetration of individual aggregate/rock particles into the seabed. Even when the overall bearing capacity of the marine seabed is adequate, a geosynthetics layer might still be required to prevent the penetration of individual aggregate particles into the seabed. A research programme has been undertaken to study the penetration of aggregate, used as embankment material, into soft marine deposits. Included in the research was the development of a new test procedure to determine the susceptibility of aggregate penetration into the seabed. The results of the research show that the size of aggregate and the presence of a geosynthetic are important parameters in controlling the penetration of aggregates into the seabed. The results of tests using different geosynthetic materials show that non-woven or woven geosynthetics perform better than geogrids. For the cases without a geosynthetic layer, an empirical curve is presented to correlate the height of embankments, liquid limit of the marine deposits, aggregate size and its penetration into the seabed.

1 INTRODUCTION

The bearing capacity mechanism associated with the construction of embankments on soft ground has been discussed by Jewell (1996). However, the construction of structures on a soft seabed can pose more difficult problems due to the very low shear strength of some marine deposits, Kurumada *et al* (1992). Problems can be ameliorated at an early stage of construction by forming a thin layer of embankment material on the top of soft soil with or without a geosynthetic layer, Tan *et al* (1994).

The following subjects need to be considered when assessing the constructability of embankments over soft soils:

1. The yield stress and viscosity of the seabed, Fakher *et al* (1999).
2. The bearing capacity mechanism of the seabed, overlaid by a thin layer of embankment materials with or without a geosynthetic layer, Fakher and Jones (1996).
3. The anchorage behaviour of a geosynthetic layer (if used) at the interface of the seabed and the first layer of the embankment, Fakher and Jones (1997).
4. The penetration of individual aggregate/rock particles into the seabed.

The latter has not been fully investigated and can be a critical case where large size aggregates are used to construct embankments. Even when the overall bearing capacity of the seabed is adequate, the penetration of individual aggregate particles into the seabed needs to be studied as a geosynthetic layer might be required to prevent penetration of aggregate particles into the seabed.

2 EXPERIMENTAL STUDY

A research programme has been undertaken to study the penetration of aggregates, used as embankment materials, into soft marine deposits. Included in the research was the development of a new test apparatus and test procedure.

2.1 *Apparatus*

The test apparatus consists of a steel cylinder, a perforated steel loading plate and a loading system, Fig. 1. The steel cylinder, with an internal diameter of 100mm, and the loading system are the same as that used for the conventional California Bearing Ratio (C.B.R.) test. As a result the proposed apparatus can be assembled easily in most soil mechanics laboratories. The diameter of the perforated steel loading plate is 2mm less than the internal diameter of steel cylinder to ensure ease of movement; the loading plate is 20mm thick and has four perforations, each 5mm wide. The loading plate is rigidly screwed to the load piston of the C.B.R. test apparatus.

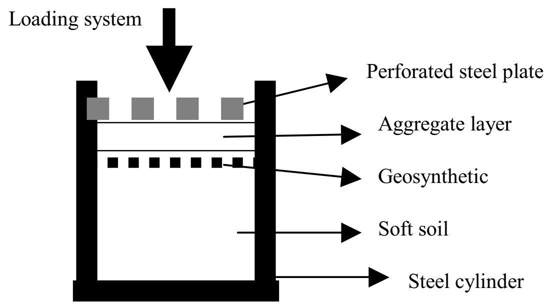


Figure 1. Test apparatus

It should be noted that the proposed test is not the same as model loading test used to determine bearing capacity. In a model testing to determine bearing capacity, the action of loading plate is to create a failure mechanism of foundation. In the proposed test the action of the loading plate is to push aggregate into the soft clay and create “mud cakes”. The test is conceptually similar to a consolidation test where deformation is studied. Therefore the diameter of the loading plate is almost equal to the internal diameter of steel cylinder.

2.2 *Material and sample preparation*

The shear strength of very soft soil such as marine clay has been shown to be a function of the liquid limit and water content, Fakher *et al* (1999). The soft soil used in the test was prepared by mixing fine soil (classified as CL have a LL of 39.3 and PL of 19.5) with water for 20 minutes at 25°C to produce a water content equal to the liquid limit. The shear strength of the material was measured using a laboratory shear vane.

The soft marine sample was placed in the test cylinder and depending upon the test overlain with a geosynthetic material.

Layers of aggregates were prepared and placed in the steel cylinder in two stages. The aggregates were first rained from a small height of 50mm onto a plastic plate placed on the top of the steel cylinder. The plastic plate was quickly removed in a horizontal direction and the aggregates fell on the top of soft soil or geosynthetic in the steel cylinder. Seven sizes of aggregates were used in the research, Table 1. Three types of geosynthetic materials were used, Table 2.

Table 1. Results of consolidation tests

Aggregate number	D10	D30	D50	D60
	(percentage of aggregate passing)			
1	19.6	21.0	22.2	23.0
2	16.0	17.0	17.4	18.0
3	5.8	8.0	10.0	11.4
4	4.1	4.2	4.4	4.5
5	3.4	3.6	3.7	3.8
6	2.9	3.0	3.1	3.2
7	2.1	2.2	2.4	2.5

In a number of tests, a geosynthetic layer was used on the top of soft soil. Table 2 shows the geosynthetic materials used.

Table 2. Geosynthetic materials used in the test

	Geosynthetic 1	Geosynthetic 2	Geosynthetic 3
Form	nonwoven fabric	geogrid	woven fabric
Thickness under 2kPa loading (mm)	4	3.3	1.5
Tensile strength (kN/m)	Length: 10 Width: 5	7.7	-----
Maximum strain at failure (%)	Length: 10 Width: 12	20.2	-----
Aperture size (mm)	-----	Length: 8 Width: 6	1
Puncture resistance (N)	1200	-----	-----

2.3 *Test procedure*

Once the test had been assembled, the perforated steel plate was placed on top of the upper layer of the aggregate and pushed downward, Fig. 1. The force required to push the plate and the underlying aggregate into the soft soil was recorded and the test was terminated when soft soil material was seen to extrude through the perforations in the loading plate. After the test, the samples were examined and the penetration of the sand into the soft soil was established.

3 RESULTS AND DISCUSSION

A set of typical results are presented in Fig. 2. In all tests, a gradual increase of pushing force resulted in an increasing downward displacement of the loading plate. A number of tests were repeated to study the repeatability of results. It was observed that the divergence of results was less than 20% which is considered as a representative value of maximum uncertainty. The repeatability of the test was improved for fine aggregates.

Visual inspection of the samples showed that a layer of sand with or without a geosynthetic layer can be used to create a layer of "mud cake", identified as a mixture of sand and marine clay, which prevents penetration of large aggregates

The effect of a geosynthetic layer on the increase of resistance to penetration of aggregate into the soil is apparent, Fig. 2. The effect of aggregate size is shown in Fig. 3. The penetration resistance decreased when the aggregate size increased. However, the displacement did not increase with an increase of aggregates size. Large sized aggregates have a larger void space so a large vertical displacement of the loading plate is required for the voids to be filled by the soft soil.

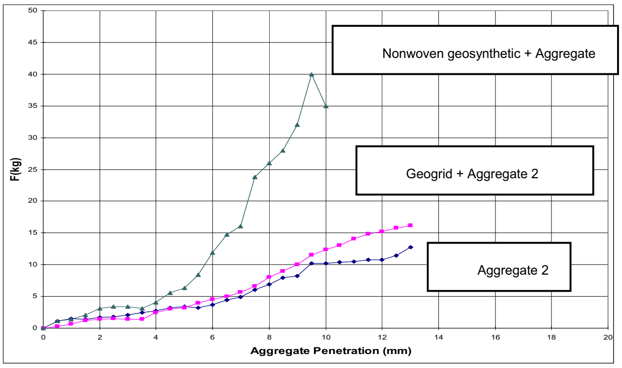
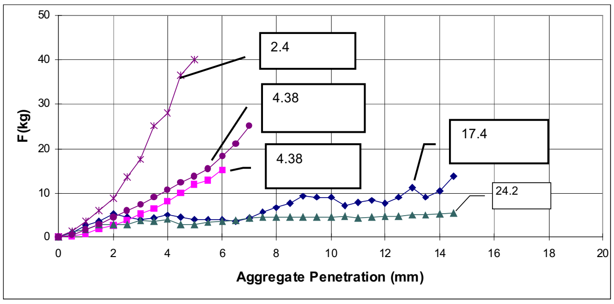


Figure 2. Typical results and the effect of a geosynthetic layer



Note: figures in boxes refer to aggregate size (mm)

Figure 3. The effect of aggregate size (D50) on the resistance to penetration

The non-woven geosynthetic was more effective in preventing aggregate penetration than geogrid materials, especially in the case of fine aggregates. The effect of the geogrid aperture was investigated using a combination of geogrid and woven jute, and Fig. 4 shows that the presence of woven jute was very effective. Although the in-plane bending stiffness of a geogrid has been seen to be an important factor in construction over very soft soils, Fakher *et al* (1996), the jute geotextile covers the apertures of the geogrid and provides an increase in penetration resistance and a decrease in required vertical displacement.

It is common practice in the design of embankments that the bearing pressure (P) exerted by the embankment should not exceed the bearing capacity of the foundation and in addition should not cause excessive settlements. However, the penetration of individual aggregate particles, used as embankment material at the base of the structure, needs to be considered during design.

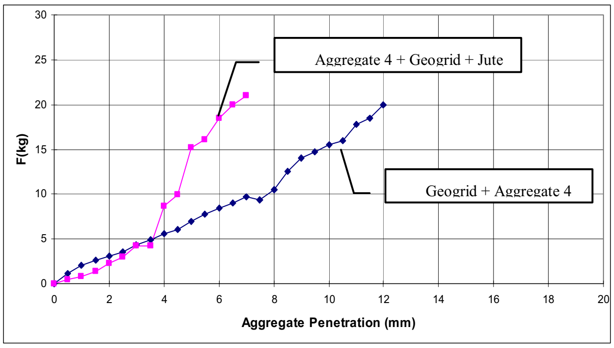
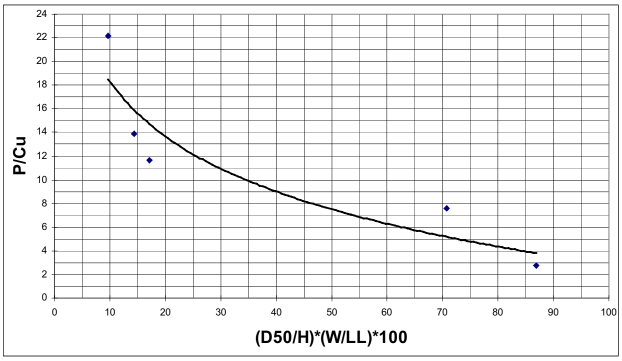


Figure 4. The effect of woven jut on the performance of geogrid

Based upon results of the present research, a dimensionless chart is proposed in Fig. 5 which can be used as an aid in embankment design. If the bearing pressure (P) exerted by an embankment is more than the value of P derived from Fig. 5, then finer aggregates and/or a geosynthetic layer may need to be used at the base of the embankment. Even when the overall bearing capacity of the marine seabed is adequate, a geosynthetic layer may still be required to prevent the penetration of individual aggregate particles into the seabed.



where: C_u = undrained shear strength
H = thickness of the first layer of the embankment (m)
D_i = diameter of aggregate for which i % is smaller (m)
W = water content (%)
LL = liquid limit (%)
P = vertical pressure at the base of the embankment (kN/m²)

Figure 5. Dimensionless curve to check penetration of individual aggregate

4 CONCLUSIONS

The following conclusions can be drawn from the research study:

1. The proposed penetration can be used to simulate the phenomena of aggregates penetration into soft soils.
2. The average stress due to an embankment on the top of a soft foundation should not exceed the value derived from the dimensionless curve, proposed in the paper.
3. Even when the overall bearing capacity of a marine seabed is adequate, a geosynthetic layer may still be required to prevent the penetration of individual aggregate particles into the seabed.
4. Further research is required to study the effect of combination of different aggregates and geosynthetics.

5 NOTATION

Cu: undrained shear strength
H: the thicknes of first layer of embankment
Di: diameter for which i percent of sample is smaller
W: water content
PL: plastic limit
LL: liquid limit
P: stress of embankment on the top of soft clay

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