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Numerical study on behaviour of saturated clay embankment reinforced with GHD

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1. Introduction

Behaviour of saturated clay embankment reinforced with Geosynthetic Horizontal Drain (GHD) has been studied numerically. Effect of drainage capabilities of geosynthetic reinforcement, its vertical spacing, and rate of embankment construction/loading on its deformation pattern have been examined.

2. Numerical Modelling of Embankment

DACSAR finite element program developed by Iizuka and Ohta (1987) which incorporates critical sate soil model proposed by Sekiguchi and Ohta (1977) has been employed in this study. Elasto-plastic soil model is used to represent clay elements while GHD is modelled by bar elements.

Fig. 1 shows the typical mesh used. Half part of symmetric embankment of 3 m high and 19.8 m width is analysed assuming plane strain condition. Length of GHD used is 4.8 m and front face slope is 1 horizontal for 2 vertical. Displacement boundaries specified in analysis are also shown in Fig. 1. Embankment is assumed to have a base on solid foundation.

Properties of soil used correspond to reconstituted Tokyo Bay Clay, and are determined by laboratory triaxial and oedometer tests (Table 1). Modulus of GHD and its in-plane permeability are adopted from manufacturer's catalogue. Thus real material properties are used in analysis so as to simulate the behaviour of actual embankment.

Table 1 Material properties used in analysis

Material properties	Symbol	Value
a. Soil		
critical state parameter	M	1.3
coefficient of dilatancy	D	0.052
compression index	λ	0.188
recompression index	κ	0.017
initial void ratio	e_0	1.54
coeff. of earth press. at rest	K_0	0.6
permeability (cm/sec)	k	1×10^{-7}
poisson's ratio	ν'	0.375
bulk unit weight (kN/m^3)	γ	16.7
b. GHD		
elastic modulus (MPa)	E	400
cross-sectional area (cm^2/m)	A	13.11
horz. permeability (cm/sec)	$k_{h(GHD)}$	10

Saturation condition of embankment is simulated by providing initial pore water pressure equal to the height of centre of element for each element constructed.

To model the drainage effect of GHD, thin soil elements of thickness 10 mm are provided immediately below GHD with permeability equal to the in-plane permeability of GHD (drained case). Pore water can cross the embankment boundary through these elements. Remaining properties of these thin soil elements are the same as that of other soil elements. In case of geosynthetic which does not have water drainage function (undrained case), permeability of these thin soil elements are kept equal to the permeability of the soil.

Embankment construction is achieved at the rate of 0.33, 0.5 and 1 m/day. At the end of embankment construction, surcharge load equivalent to 2 m height of the embankment is given with the same loading rates as embankment construction. Effect of vertical spacing of GHD in embankment deformation is examined by providing GHD at 30, 60 and 90 cm interval.

3. Result and Discussion

Fig. 2 compares the displacement vectors for drained and undrained cases at the end of loading. Total vertical displacement of a soil element consists of consolidation settlement and plastic deformation whereas lateral component of displacement is caused mainly by plastic deformation. For undrained case, horizontal component of displacement is significantly larger while the vertical component is smaller.

Fig. 3 compares the displacement path of a node '*A*' near toe (see Fig. 1) during construction/loading for drained and undrained cases. Its clear that there is much larger horizontal deformation for undrained case, which ultimately leads the embankment to failure. This additional deformation is caused by accumulated pore water pressure in the embankment.

Front face movement of the embankment for drained case as a ratio of undrained case is shown in Fig. 4. One can see that lateral deformation at front is reduced by more than 50% (for loading rate of 0.5 m/day), if geosynthetic with sufficient in-plane permeability is provided.

Effect of rate of loading for 0.33 and 0.5 m/day is also compared in Fig. 4. Front face deformation decreases by about 25% if the loading rate is slowed down from 0.5 to 0.33 m/day. This shows the significance of loading rate in embankment stability.

Effect of vertical spacing of GHD in front face movement is shown in Fig. 5. Although the spacing are different, total cross-sectional area of GHD provided is the same for all three cases. For wider spacing, drainage paths are longer so the rate of pore water dissipation is slower, therefore lateral movements are larger. For the case analysed, for example, lateral displacement increased by more than 40 % when the vertical spacing is increased from 30 cm to 90 cm.

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References

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Keywords: GHD, Saturated embankment, Elasto-plastic soil model, Finite element analysis, Drainage effect, Loading rate

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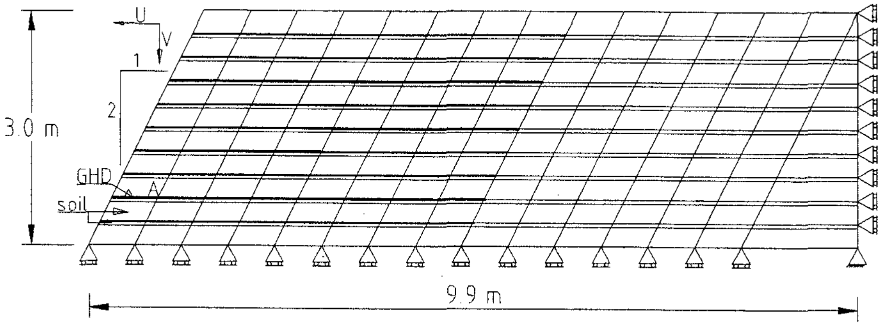

Fig. 1 Typical finite element mesh used in analysis

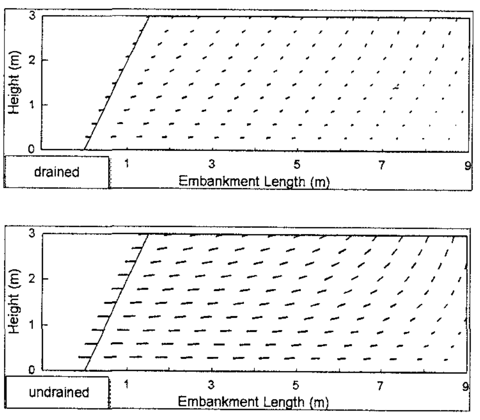

Fig. 2 Displacement vectors at the end of loading for drained and undrained cases

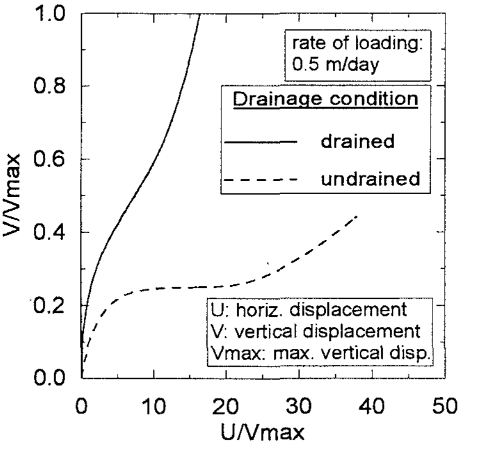

Fig. 3 Displacement path of a soil element near toe

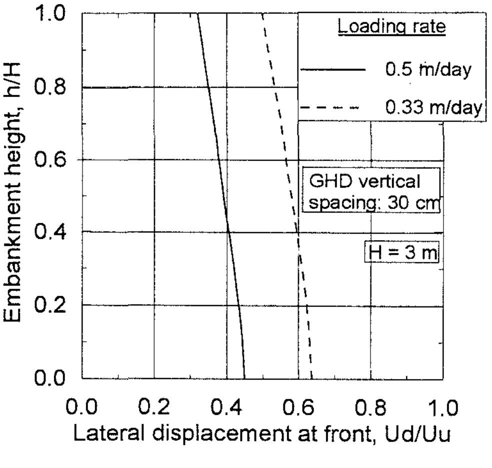

Fig. 4 Effect of loading rate on front end movement of embankment

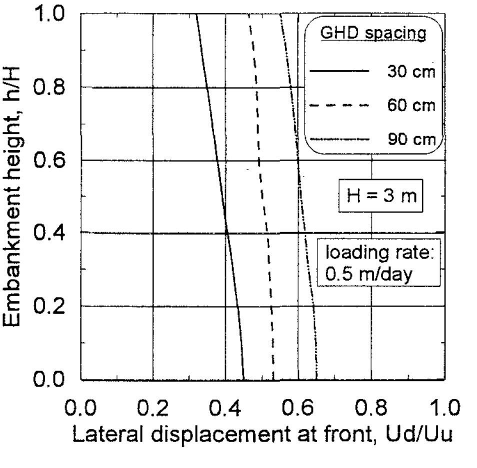

Fig. 5 Effect of vertical spacing of GHD on front end displacement of embankment

(U: lateral displacement; d: drained case; u: undrained case; H: embankment height)