III-516 BUCKLING OR KINKING OF PLASTIC DRAINS IN SOFT CLAYS

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1. INTRODUCTION: Many of the soft soils that exist in coastal lowlands of the world are highly compressible. Installation of plastic drains to accelerate consolidation of and piles to carry surcharge loads through soft clays, are two of the common methods of treating these soils. Amongst the various problems that arise during the installation and performance of plastic drains, the problem of buckling or kinking (Fig. 1) (Ali, 1991; Miura et al, 1991), needs study because, their functional utility gets reduced significantly. Similar problem is faced in the design of piles subjected to downdrag or negative skin friction.

2. FORMULATION: Soft soils being highly compressible, undergo significant consolidation settlements. If the settlement of the soil is more than that of the drain or the pile, the drain/pile would be subjected to downdrag. The axial force, P(z), in the drain/pile at any depth, z, from the top is

$$P(z) = \int_0^z \tau(z)\,.\,p.\,dz \qquad (1)$$

where $\tau(z)$ is the shear stress mobilised at the interface and p- the perimeter of pile/drain cross section. The total axial force, P_m, at the tip, ie. at z=L, is

$$P_m = \int_0^L \tau(z)\,.\,p.\,dz \qquad (2)$$

where L is the length of the drain/pile. The tendency for bending by the drain/pile is resisted by the soil surrounding it and is modelled as a Winkler medium (Fig. 2), whose horizontal coefficient of subgrade reaction k_{sh} varies with depth. Treating the drain/pile as a beam-column, the governing equation for their response following Davisson (1963) is

$$EI\frac{d^4w}{dz^4}+P(z)\frac{d^2w}{dz^2}+P(z)\frac{dw}{dz}+(k_{sh0}+m(z/L))w=0 \qquad (3)$$

where EI is the flexural stiffness of the drain/pile, w- lateral displacement, and B- width/diameter of the drain/pile. The variations of the axial force, P(z), and $k_{sh}(z)$ cosidered are

$$P(z)=P_m(z/L)^{np}$$
$$k_{sh}(z/L)=k_{sh0}+m(z/L)^{nh} \qquad (4)$$

where k_{sh0} is the coefficient of subgrade reaction at the top, n_p, m, n_h - are parameters. For simplicity, P(z) and $k_{sh}(z)$ are considered to vary only linearly with depth, ie. $n_p=1$ and $n_h=1$. In such a case, Eq. 3 after simplification becomes

$$\frac{d^4w}{dZ^4}+\lambda Z\frac{dw^2}{dZ^2}+\lambda\frac{dw}{dZ}+(\beta+\mu Z)w=0 \qquad (5)$$

where $\lambda = P_m L^2/EI$, $\beta = k_{sh0}L^4/EI$, $\mu = mBL^4/EI$, and $Z=z/L$. The drain/pile is considered to be hinged at both ends. That is at z=0 and z=L, w=0 and $EId^2w/dz^2=0$. Discritising the drain/pile into n elements each of size, L/n, Eq. 5 in finite difference form (Madhav and Davis, 1974) is

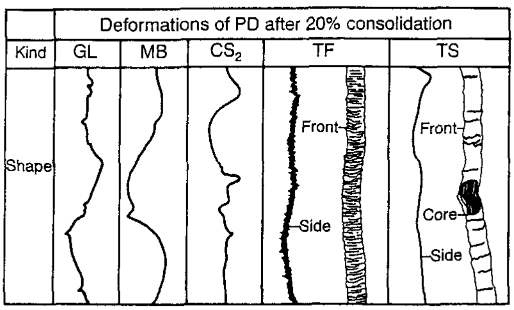

FIG. 1 Shape of Plastic Drains after Deformation (after Miura et al, 1991,

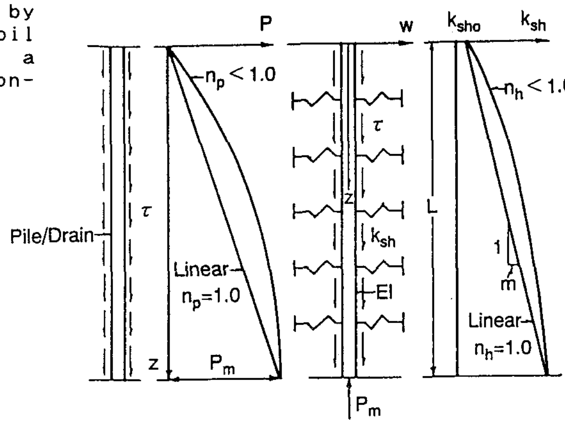

FIG. 2 Model and Definition Sketch

$$(w_{i-2}-4w_{i-1}+6w_i-4w_{i+1}+w_{i+2})+(\lambda Z_i/n^2)(w_{i-1}-2w_i+w_{i+1})+(\lambda/2n^3)(w_{i+1}-w_{i-1})+(\beta+\mu Z_i)n^4.w_i=0 \quad (6)$$

Combining Eq.6 for the nodes 2 to (n-1) with the boundary conditions, a set of equations for the drain/pile system are obtained as

$$[A]\{w\}+\lambda[C]\{w\}=0 \quad (7)$$

where [A] and [C] are square matrices of size (n-1). Premultiplying Eq.7 with $-[C]^{-1}$, the negative inverse of [C], one gets

$$[A^*]\{w\}=\lambda\{w\} \quad (8)$$

where $[A^*]=-[C]^{-1}[A]$. Eq.8 is of the standard form, the eigenvalues of which give the buckling loads. The smallest eigenvalue λ_{cr} is the load at which the drain may buckle or get kinked.

3. RESULTS: A value of 10 for n is found to give results of sufficient accuracy, similar to Madhav and Davis(1974). Fig.3 presents the variation of buckling load, λ_{cr}, with the parameters μ and β. If k_{sh0} (β) is zero, the drain/pile acts as a laterally unsupported column and the buckling load for a hinged column with linearly varying axial load is obtained. The minimum load at which the drain/pile could buckle increases with the nondimensionalised coefficient of subgrade reaction, β. For β increasing from 1 to 1000, the nondimensional buckling load increases from 0.9 to about 89 for μ=1. The buckling load is sensitive to the parameter, μ, which signifies the rate of variation of k_{sh} with depth. For μ increasing from 1 to 10, the buckling load increses from 12.8 to 31.2 for β=1000.

4. CONCLUSIONS: A simple model is proposed to explain the formation of kinks in a plastic drain installed in soft clay during consolidation. The axial force and the coefficient of horizontal subgrade reaction are considered to vary with depth. A design chart for the estimation of the load at which a drain may buckle or get kinked, is presented. The same chart can be used for predicting the buckling load of a slender pile in a consolidating soft clay.

5. REFERENCES: (i)Ali, F.H.(1991)'The Flow Behaviour of Deformed Prefabricated Vertical Drains, Geotext. and Geomemb., V.10, pp.235-248. (ii)Davisson,M.T.(1963) 'Estimating Buckling Loads for Piles', 2nd Pan Am. Conf. SMFE., Brazil, Vol.1, pp.351-371. (iii)Madhav, M.R. and Davis, E.H.(1974)'Buckling of Finite Beams in Elastic Continuum', J. Engrg. Mech. Div., ASCE,V.100, EM6, pp.1227-1236. (iv)Miura, N., Park,Y-M, and Fukuhara,S.(1991) 'Experiment on the Drainage Properties of Plastic Drains', Proc. 26th JSSMFE Annual Meeting, Nogano, pp.2009-10.

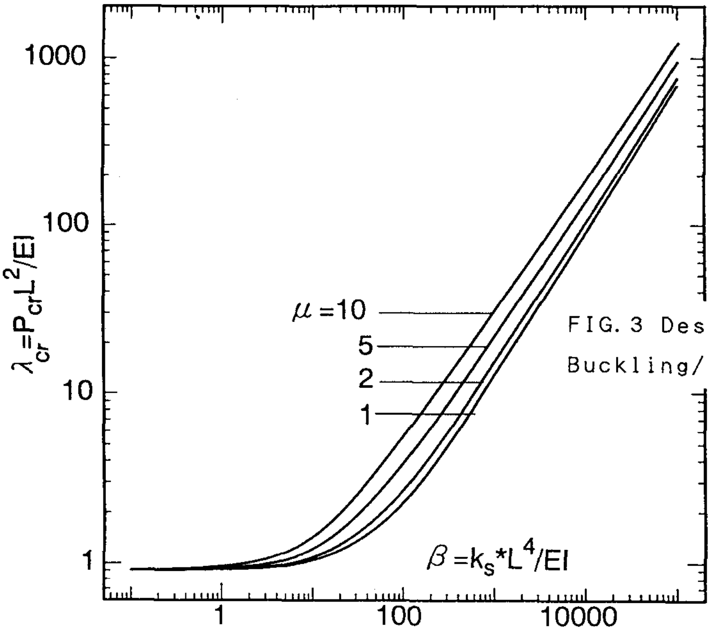

FIG.3 Design Chart for Predicting Buckling/Kinking of Plastic Drains