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A REVIEW OF SOIL CONSTITUTIVE MODELS FOR SOIL STRUCTURE INTEREACTION ANALYSIS

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ABSTRACT: Soils are multiphase materials comprised of mineral grains, air voids and water. Soils are not linearly elastic or perfectly plastic for external loading. Various constitutive models are available to describe the various aspects of soil behaviour. But no single soil model can completely describe the behaviour of real soil under all conditions. This paper attempts to compare various soil models and suggest a suitable model for the Soil Structure Interaction analysis especially for Kochi marine clay.

INTRODUCTION

In recent years, a number of studies have been conducted in the area of soil-structure interaction, modelling the under laying soil in numerous sophisticated ways. Soils are not linearly elastic and perfectly plastic for the entire range of loading. In fact, actual behaviour of soil is very complicated and it shows a great variety of behaviour when subjected to different conditions. Various constitutive models have been suggested by different researchers to describe various aspects of soil behaviour in detail. This paper attempts to compare various basic soil models and suggest a suitable model for the Soil Structure Interaction analysis especially for Kochi marine clay.

SOIL CONSTITUTIVE MODELS

The complexity in the behavior of soils has led to the development of many models of soil based on the classical theories of elasticity, plasticity and visco-elasticity for the analysis of Soil-Structure interaction problems. The elastic property of the soil is represented using a spring, the plastic property of the soil is represented using a slider and the viscous property of the soil is represented using a dashpot.

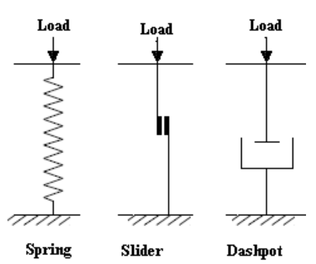

Fig.1. Basic components of soil models[1]

Elastic Models

In this type of model, soil behaviour which exhibit purely elastic characteristic is considered. The simplest type of idealized soil response is to assume the behaviour of supporting soil medium as a linear elastic continuum. Here the deformations are assumed as linear and reversible. Extensive research has been done to obtain exact and approximate solutions of these models so that they can be used in soil-structure interaction problems. The basic elastic models are Winkler model and Continuum model.

Winkler Model

In Winkler model soil is assumed as a system of identical but mutually independent, closely spaced, discrete, linearly elastic springs. The characteristic features of this representation of soil medium are the discontinuous behaviour of the surface displacement. According to this idealization, deformation of the soil medium due to the applied load is confined to the loaded region only. The surface displacement of the soil medium at every point is directly proportional to the stress applied to it at that point and completely independent of the stresses or displacements at other or even immediately neighbouring point of the soil-structure interface.

Fig.2 shows the physical representation of Winkler model of soil-structure interface.[2]

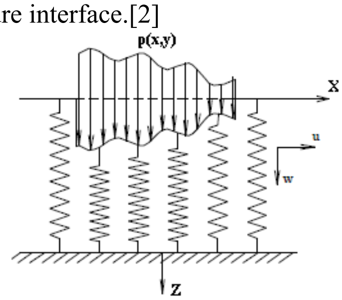

Fig.2. Winkler Model

The response function for the Winkler model is,

$$p(x,y) = k\, w(x,y) \tag{1}$$

where, $p(x,y)$ is the applied stress at a point, $w(x,y)$ is the deflection at that point and k is the sub grade modulus with units of stress per unit length.
In this model displacement occurs immediately under the loaded area and outside the region the displacements are

zero. Applicability of Winkler model is limited to such soil media which possesses cohesion or transmissibility of applied forces.

Elastic Continuum Model

In elastic continuum model the continuous behaviour of soil is idealized as three dimensional continuous elastic solid. In this case the soil surface deflections due to loading will occur under and around the loaded region.

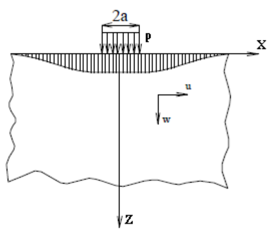

Fig.3. Elastic continuum model

The above figure shows the typical surface displacement profile of a soil medium subjected to a uniform load ‘p’ of radius ‘a’. The distribution of displacements and stresses in such media remain continuous under the action of external force system. In this case some continuous function is assumed to represent the behaviour of soil medium.

In continuum idealization, soil is assumed to be semi infinite and isotropic for the sake of simplicity. However, the effect of soil layering and anisotropy may be conveniently accounted for in the analysis.

This approach provides much more information on the stresses and deformations within soil mass than Winkler model. However this idealization has a major drawback of inaccuracy in reactions calculated at the peripheries of the foundation. It has also been found that, for soil in reality, the surface displacements away from the loaded region decreased more rapidly than what is predicted by this approach.

Elastic-plastic Models

In soil-structure interaction analysis, nonlinear behaviour of soil mass is often modelled in the form of an elasto-plastic element. Here deformations occur linearly and proportional to the applied stress up to a certain stress level. This behaviour may be represented by an ideal reversible spring.

Mohr-Coulomb Model

It is an elastic-perfectly plastic model. The set of parameters adopted to represent the model are: young’s modulus, poisson’s ratio, friction angle, cohesion and the dilatancy angle[3]. For each sublayer a linear variation of the young’s modulus has been assumed. As the model does not allow to change the soil stiffness within the strain level, a reduced static stiffness has been adopted during the preliminary costruction stage.

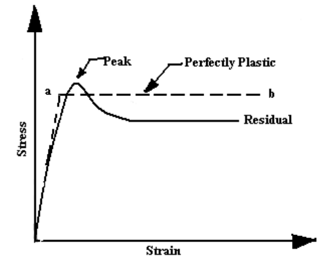

Fig.4. Elastic-Perfectly plastic assumption of Mohr-Coulomb model

Mohr-Coulomb model is a simple model applicable to three dimensional stresses with only two strength parameters to describe the plastic behaviour. Researchers have indicated by means of triaxial test that stress combinations causing failure in real soil samples agree quite well with the hexagonal shape of failure contour.

This model is applicable to analyse the stability of dams, slopes, embankments and shallow foundations.

St.Venant’s Model

St.Venant’s model is formed when an elastic element is connected in series with a plastic element. Use of such a single element generally shows an abrupt transition from elastic to plastic state. The use of large number of St.Venant’s units in parallel represents the Elasto-Plastic behaviour of soil more accurately.

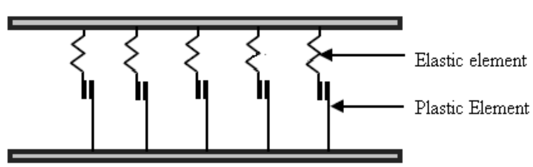

Fig.5. St.Venant’s Elasto-Plastic unit

Use of a number of springs helps to facilitate the simulation of the gradual transition of soil strain from elastic to plastic zone. The following expression may be used in terms of strain modulai for elastic and plastic strains respectively.

$$\varepsilon_{ep} = M_e\,\sigma + M_p\ \log[\ \sigma/(\sigma_u-\sigma)\ ] \qquad (2)$$

Where M_e is the elastic strain modulus of soil, M_p is the plastic strain modulus of soil and σ_u is the ultimate load that can sustain.

Conceptually, the above mechanical model may appear to be useful enough. But the problem occurs in the proper adjustment of such springs at the base of the structure.

Viscoelastic Models

The real deformation characteristics of fine grained soil media under the application of any load are always time dependant to some extend depending on the permeability of soil media. Loading applied to a saturated layer of clay, at the first instance, causes an increase in pressure in the pore water of soil. With time the pore water pressure will dissipate resulting in progressive increase of effective stress in soil skeleton. This leads to time dependent settlement of foundation. Here are numerous instances of rheological processes in the foundation leading to large and non-uniform settlement.

The mechanical models represent the rheological properties of the soil skeleton by a combination of elastic, viscous and plastic elements. These models are generally formed by a combination of springs and dashpots in series.

Displacement of retaining walls and the instability of slopes are two classical examples apart from the time dependent settlement of framed structures. Various models are available to describe the rheological properties of clayey soils.

Generalized Maxwell's Model

It is the most general form of the linear model for viscoelasticity. In this model a spring and a dashpot are connected in series and subjected to loading. For better results a number of such arrangements in parallel may be used.

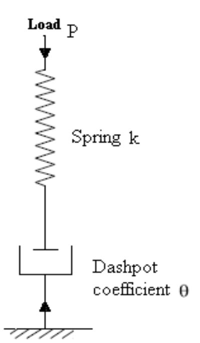

Fig.6. Generalized Maxwell Model

Kelvin's Model

It is a viscoelastic model having the properties of elasticity and viscosity. It is named after the British physicist and engineer William Thomson, 1st Baron Kelvin. It can be represented by a purely viscous damper and purely elastic spring connected in parallel as shown in fig.7[4].

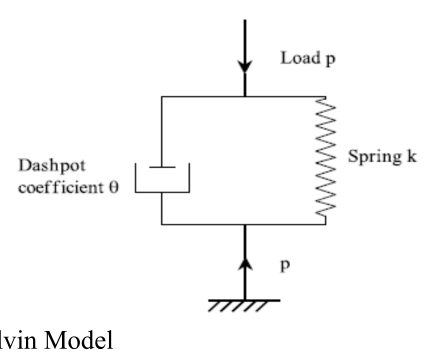

Fig.7. Kelvin Model

Since the two components of the model are arranged in parallel, the strains in each component are identical:

$$\varepsilon_{total} = \varepsilon_D = \varepsilon_S \tag{3}$$

Where ε_D is the strain the dashpot and ε_S is aht strain the spring. Similarly, the total stress will be the sum of the stress in each component.

$$\sigma_{Total} = \sigma_D + \sigma_S \tag{4}$$

From these equations we get that in a Kelvin model, stress σ, strain ε and their rates of change with respect to time *t* are governed by equations of the form:

$$\sigma(t) = E\ \varepsilon(t) + \eta\ [d\varepsilon(t)/dt] \tag{5}$$

where, E is a modulus of elasticity and η is the viscosity. The equation can be applied either to the shear stress or normal stress of a material.

INTERFACE ELEMENTS

Interface elements are numerical entities used in finite element technique for modeling geometric discontinuities that are present in some boundaries of structures. An interface element should be able to account for the relative motion along the interface and thus to accurately simulate the deformations and physical behavior of geomaterials. In finite element analysis of civil engineering structures a large variety of applications for interface elements is present. Interface elements can be used to model soil-structure interaction effect in a pile foundation surrounded by soil media.

In numerical practice two types of interface elements are used. The first class of elements contains the continuous interface elements (line, plane and shell interfaces). It is a reduction from a classical volume finite element (thin layer interface element) and the second class of elements contains the nodal or point interface elements, which to a certain extend are identical to spring elements. It is also called a surface element which is a zero thickness joint element.

Zero-thickness Interface Element

It was developed by Goodman et al. in 1968. In this element the nodes at the contact surface are separated and some normal and tangential springs are used to connect them. Later, however, rheological elements were used in the form of springs and dashpots operating between the nodes of the interface elements.

These rectangular element posseses four nodes and eight degrees of freedom as shown in fig.7.

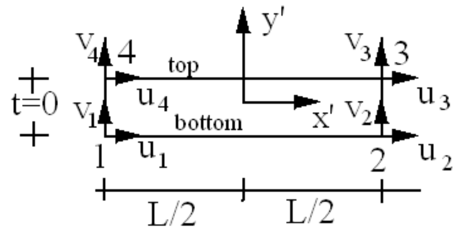

Fig.7. Goodman's Interface Element

Thin Interface Element

It was suggested by Desai and Nagaraj. In this element it is assumed that only a thin element of the weaker material at the contact undergoes a highly localized shear strain along the contact surface. The formulation of this element fits well in the context of finite element method and can easily be used to include the nonlinearity and/or plasticity of the behavior of material and yield more realistic results.

Line interface Element

This special isoparametric element has been developed (Beena 1994) with a view to represent the friction between soil and reinforcement. The geometry of the present element is such that it is a line with four nodes. The element has four nodes and zero thickness as assumed by Goodman et. al., a linear variation of displacement along the length of the element is assumed. Relative displacement between the top and bottom notes is taken as the corresponding strain in the element[5].

CONCLUSIONS

The review of the different categories of the soil models as applied in the soil-structure interaction analysis leads to the following broad conclusions.

(1) The effect of soil-structure interaction is to be considered for the accurate estimate of the design force quantities. To obtain the same realistic and simplified modelling of the soil-structure system is absolutely necessary.

(2) Winkler hypothesis yields reasonable performance and it is very easy to exercise. So for practical purpose this idealization may be used.

(3) The clayey soil having low permeability possesses time dependent behaviour under sustained loading. in such time dependent process of soil-structure interaction, critical condition may occur at any time during the process in some situation. Under such circumstances, modelling soil as viscoelastic medium can only provide the crucial input for the design.

(4) The strength and limitations of some basic models and interface elements in different categories are discussed and it will help to select the suitable model and interface element based on the need of the problem in hand.

(5) For the particular problem which uses Kochi marine clay as the soil medium one of the suggestion for modelling is to use the Winkler model to start with and any one of the viscoelastic model to do the detailed soil-structure analysis.

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