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Finite Element Modelling of Soil-Structure Interaction

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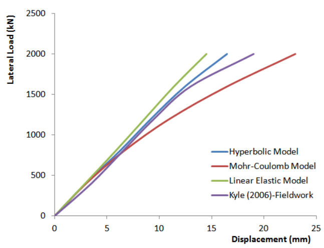
Graphical abstract



Abstract

This paper presents background information relevant to the modelling of soil-structure interaction. The interaction between the structural element (i.e. pile foundation or abutments) and the soil medium is believed to have the potential to alter considerably the actual behaviour of any structure. Modelling of the structural element is rather simple and straightforward when compared to modelling the structure in interaction with soil. It is known that the structural analysis simplifies soil behaviour, while geotechnical analysis simplifies structural behaviour. The choice of an appropriate soil constitutive model may have significant influence on the accuracy of soil-structure interaction analyses. A 2D finite element analysis on a pile-cap-pile-soil model replicating actual field work was performed in this paper using OASYS SAFE to further substantiate the choice of an appropriate soil constitutive model for the purpose of soil-structure interaction modelling.

Keywords: Soil-structure interaction, constitutive model, interface element, finite element method

1.0 INTRODUCTION

The interaction between the structural element (i.e. pile foundation or abutments) and the soil medium is believed to have the potential to alter considerably the actual behaviour of any structure. The properties of the soil medium which can influence the behaviour of the structure are: - soil density, internal friction angle, soil-structure friction and backfill angle [1]. Modelling of the structural element i.e. superstructure and foundation piles, in isolation is rather simple and straightforward when compared to modelling the structure in interaction with soil. This is due to the non-linearity properties of the soil medium. While structures are usually satisfactorily modelled with linearly elastic, homogeneous and isotropic materials, modelling of soils is extremely complex as its heterogeneous, anisotropic and nonlinear force–displacement characteristics [2] need to be accounted for. [3] has highlighted the need for appropriate material and structural modelling especially for soil-structure interaction of integral bridges (which is a classic case of soil-structure interaction).

2.0 CONSTITUTIVE MODEL

As stated by [2], soil constitutive models are simplified idealizations of soil characteristics and an essential feature for practical applications. Constitutive models provide a qualitative description of the material behaviour and the material parameters further quantify this behaviour [4]. The choice of an appropriate soil constitutive model may have significant influence on the accuracy of soil-structure interaction analyses. A good constitutive model is known to be able to predict the response of the soil under critical combinations of load by taking into account the actual characteristics of the soil under these critical loads [5]. Therefore, it should be possible to obtain the constitutive models' material parameters in a simple manner through conventional or standard laboratory soil tests [6]. It is important that the chosen constitutive soil model should be able to replicate the actual behaviour of the soil medium for a reasonably wide range of conditions.

2.1 Mohr-Coulomb Model

The Mohr – Coulomb Model being a linear elastic – perfect plastic model is the most used constitutive model used in modelling soil mediums. The Mohr-Coulomb model is one of the simplest soil constitutive models with only two strength parameters needed to describe plastic behaviour. Researchers have indicated that, by means of tri-axial tests, stress combinations causing failure in real soil samples agree well with the hexagonal shape of failure contour found with the Mohr-Coulomb model [4]. It is also known that the Mohr-Coulomb model neglects the effects of intermediate principal stress; however, this does not significantly influence plain-strain or plain-stress analysis.

2.2 Duncan-Chang Hyperbolic

The Duncan-Chang Hyperbolic constitutive model [7] is one of the most popular constitutive models used for the modelling of soil behaviour. The advantages of this hyperbolic constitutive model, which is based on the stress-strain relationship of the soil, stem from the simplicity and its successful use in analysing a number of different practical problems [8] [9]. It is capable of modelling the non-linear, stress-dependent and inelastic behaviour of cohesive and cohesion less soils. The capabilities and limitations of the formulation are thoroughly documented and well understood.

2.3 Drucker-Prager Model

Drucker-Prager model is a simplification of the Mohr-Coulomb Model. The existing corners and singularities in the Mohr-Coulomb model are reduced in this model with a smooth failure surface. . Generally, it shares the same advantages and limitations with the Mohr-Coulomb model but the latter model is still preferred over this model [4] [10].

2.4 Modified Cam-Clay Model

The Modified Cam-Clay model is an extension of the Cam-Clay model which was developed in the sixties at Cambridge University [4]. The Modified Cam-Clay model is an elastic plastic strain hardening model where the nonlinear behaviour is modelled by means of hardening plasticity. It is reported that this model is suitable to describe deformation compared to failure for normally consolidated soft soils [10].

3.0 MODELLING OF SOIL-STRUCTURE INTERACTION

Resistance of ground to the stress and forces induced by structural movement may transmit additional forces back to the structure. This counter-action activity between soil and adjacent structure may continue until the equilibrium of the whole soil-structure system is achieved or until the soil and/or the structure fail [11]. The behaviour of a structural element and the soil medium are known to be profoundly different. Therefore, the modelling and analysis of these two elements varies significantly. As far as the structural analysis is concerned, the modelling addresses the variety in structural build-ups, geometrical variations i.e. linear to nonlinearity and the structural response under various loading conditions.

However, for geotechnical analyses, these are the following concerns;

i. Appropriate soil constitutive model
ii. Coupling of adjacent mechanisms with soils
iii. Modelling of special boundary conditions
iv. Time dependent processes: Consolidation and creep

Therefore, the approach employed to model the soil-structure interaction should be able to complement each other to provide reliably accurate analytical results. Generally, it is known that the structural analysis simplifies soil behaviour, while geotechnical analysis simplifies structural behaviour. There are three finite element modelling approaches commonly employed by researchers in the area of soil structure interactions namely i) Winkler Spring approach known as a field elimination method where the soil media is represented by a spring element, ii) Finite element model is also known as a continuum model. It is a conceptual approach for dealing with boundary distances and loaded areas. Compared to other models, finite element analysis may provide more information on the stresses and deformations within the analysis of soil deformations, stability and the influence of the soil on surrounding structures. However, one of the disadvantages of this approach could be its failure in representing the physical behaviour of soil to higher degree of accuracy [2]. And iii) Integrated modelling is a finite element approach combined with either one of the followings; spring element, dash pot element, thin layer element or zero thickness elements. This modelling technique is also known as a coupled soil-structure interaction system incorporating the interface elements [11].

4.0 MODELLING OF SOIL-STRCUTURE INTERFACE

Reliably accurate modelling of the interface element (see Figure 1) for monotonic and/or cyclic behaviour is known to be an important aspect in trying to understand the behaviour of soil-structure interaction.

Therefore, choosing an effective modelling technique and constitutive model of a soil-structure interface has become a great concern in recent years due to the rapid developments in numerical methods. Increasing demand for a reliably accurate model from those involved in the design of large-scale structures may also contribute to this.

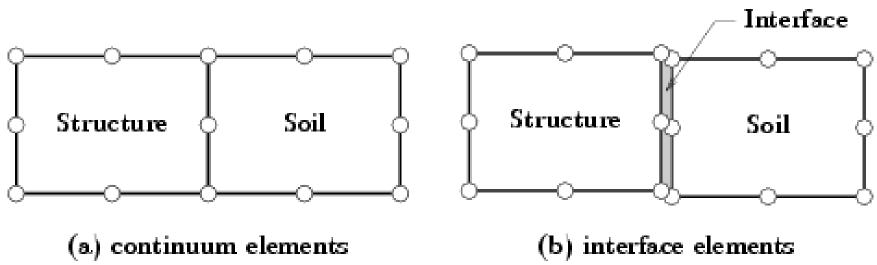


Figure 1 Modelling of soil-structure interface element

4.1 Interface Modelling

Interface elements mainly include two-node elements, continuum (node to node element) with finer meshing, zero thickness elements and thin-layer elements. Two-node elements may take the form of dashpot elements or node to node spring elements. Node to node spring elements has been a common choice to model interface behaviour.

According to [12], for certain problems, interface behaviour may be possibly modelled by simply refining a conventional finite element mesh in the vicinity of the interface and by assigning suitable properties. This method is also known as continuum meshing where the elements in the model are jointed node to node. The principles of the conventional finite element method are well documented and well established. A major disadvantage of this method is the insufficient capability to clearly replicate the failure or slip plane when two different materials are sandwiched together [13]. [12] stated that in an analysis using conventional finite elements with refined meshing, failure may occur at the nearest stress point in the weaker of the two materials sandwiching the interface (i.e. refined vicinity). Therefore, researchers or analysts should take extra care when using this method.

[14] stated that the interface element derived from the relationship of relative nodal displacement and stresses proposed by Goodman are one of the most commonly used interface elements. It is a four node element, without thickness and is known as a zero thickness element. However, zero thickness elements have their own disadvantages, i.e. they are prone to errors in normal stress and deformation calculations. [15] found that zero thickness interfaces are more appropriate to model solid-on-solid contact in finite element analyses.

Another approach is to consider the soil – structure interface as a thin continuum or thin layer element. Thin-layer elements are better than zero thickness elements since both simple shear tests and field tests show that there actually exists a transition zone along the interface of two bodies with different stiffness. Concerns over the determination of a thin-layer thickness have been highlighted in the literature [14] [15]. It is feared that a small change of thickness could produce large differences in the calculated results. [16] suggested that a simple shear test can be carried out to determine the thickness of the thin-layer interface.

5.0 NUMERICAL ANALYSIS

A finite element model was developed considering an approach suggested by [17] of a field testing arrangements by [18], who investigated the cyclic lateral load behaviour of a pile, pile cap and backfill. Models using OASYS SAFE packages were developed to replicate this field testing reported by [18]. Generally finite element computational efficiency is influenced by the number of elements considered. Therefore, reduced bandwidth through renumbering process [19] within the software capabilities were used to select an appropriately suitable number of elements to represent the soil. Figure 2 shows the model used in this study. The material properties and backfill soil types considered in this model are shown in Table 1 and 2 .

Determining an appropriate soil model to replicate the soil behaviour accurately was one of the main concerns at this stage. Therefore, the effects of different soil constitutive models for clean sand were compared to the field results obtained by [18] to identify an appropriate soil model. On the basis of this study (Figure 3), it was determined that the Duncan-Chang Hyperbolic soil model represented the soil behaviour reasonably accurately. This study also suggests that the Mohr-Coulomb soil model reasonably represents the soil behaviour up to 8mm of displacement. This indicates that at any laterally induced movement less than 10mm, the Mohr-Coulomb soil model can be used to represent the soil behaviour to a reasonable accuracy.

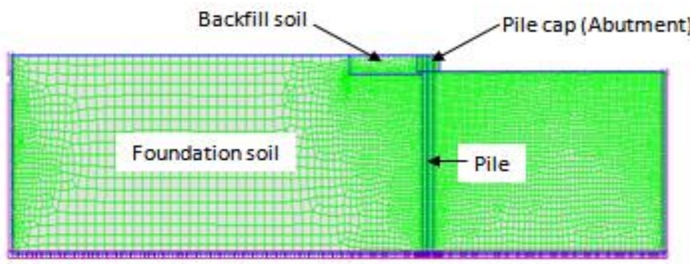


Figure 2 Finite Element Model

Table 1 Properties of model

Parameter	Description
Pile height	12.2m
Pile size	1.1m diameter
Pile cap height	1.12m
Pile cap Width	2m
Soil type	Clean sand

Table 2 Soil properties [21], [18]

Type	γ (kN/m³)	m %	v	c (kN/m²)	φ
Clean Sand	18.4	13.4	0.3	3.83	39
Type	R_f	n	n_{ur}	K	K_{ur}
Clean Sand	0.98	0.81	0.81001	200	530

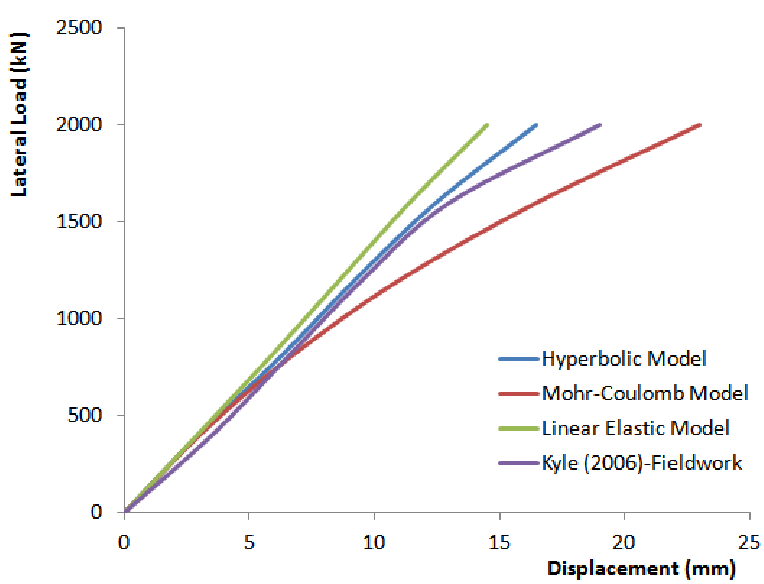


Figure 3 Lateral load-displacement profile for clean sand

6.0 CONCLUSION

The nature of the aggregates present in dilute solution, below the gelation threshold concentration, was investigated using atomic force microscopy (AFM). When the two components were present in a 2:1 (dendrimer:diamine) ratio, rod like aggregates were observed in the AFM The length of these rods was approximately 100 nm, and their diameters were ca. 9 nm (depth ca. 1 nm).

The characteristics and type of color blind has been studied and identified as well as the problem faced by individual that is color blind. A real-time color recognizing system using image processing technique is successfully developed and tested.

A various experiments were performed to test the functionality of the developed application for color deviation and range tests. For the color deviation test, the results showed the deviation on the HSV value of the tested color was small and within an acceptable ranges. The results of the range test showed that the device could recognize color from a range of 20 cm up to 12 m.

In conclusion, this prototype is able to recognize up to four colours such as red, blue, green and yellow as well as their respective variations such as light blue or dark blue. The region with similar HSV value to the designated region is also highlighted. The visual results which is text indicating the object color as well as the boundary line is successfully shown on the LCD monitor. The result of the distance test shows that the hue (H) element is almost consistent whereas the saturation (S) varies by roughly 49.3% and value (V) by 30.5%. As for the range of detection, the minimum range is 12 cm where the maximum range is up to 15 meter. The accuracy of the 4 base colors detection is about 80%.

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