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Review

State of the art: Mechanical behavior of soil–structure interface

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Abstract

The monotonic and cyclic behavior of a soil–structure interface has a significant effect on the mechanical response of a soil–structure interaction system. Thus, the behavior of the interface should be investigated with focusing on the individual characters different from other geomaterials. A brief introduction and critical review are presented on the state of the art of monotonic and cyclic behavior of soil–structure interface, including the test device and measurement techniques, fundamental rules and deformation mechanism, constitutive models and their applications in the numerical simulations. The tendencies of the investigation on the interface are also predicted in this paper.

Keywords: Interface; Soil; Mechanical behavior; Test; Constitutive model; Numerical analysis

1. Introduction

The monotonic and cyclic behavior of a soil–structure interface plays an important role in the static and dynamic analysis of soil–structure systems, such as high embankments, pile foundations, high railways and underground structures. For example, FEM analysis results of several high concrete-faced rockfill dams showed that the stress and deformation of the face slab are significantly affected by the behavior of the interface between it and the cushion layer. According to the observations of systematic tests, a soil–structure interface can be thought as a composite of the structural surface and a thin-layer soil nearby [1]. Although the interface involves a few general properties of soil, such as dilatancy, it exhibits a significantly different response with loading application from that of the neighboring soil by the constraint effect of nearby structure. Namely, significant deviation may be induced if a constitutive model of soil is simply extended to a soil–structure interface. Thus, the behavior of the interface and its accurate description should be investigated using the test and theory approaches.

The investigation process of the soil–structure interface is closely related to the developments of test techniques and theories in geotechnical engineering. It can be approximately divided into three stages as follows.

(1) The first stage (before 1960s): In this stage, the investigation was focused on the strength behavior as a result of the requirements of practical applications. For example, the wall friction in the Coulomb earth pressure formula can be regarded as a strength parameter of the soil–wall interface. The interface had not been especially investigated as an individual material.

(2) The second stage (1960–1980s): The stress–strain relationship of the interface became a great concern in this stage, accompanied with rapid achievements of numerical techniques and increasing requirements for such a relationship from those involved in the design of large-scale projects. Further investigation was possible owing to the significant development of test and measurement techniques. Therefore, except for the

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strength, the nonlinearity and elasto-plasticity behavior of the interface had been investigated using a diverse range of test devices. A few constitutive models had been proposed to describe the behavior of the interface. These models were also applied to the numerical analysis of a soil–structure system by the interface elements. The main investigation objective of this stage is the macroscopic tangential stress–displacement relationship of the interface.

(3) The third stage (since 1980s): The behavior of a soil–structure interface has been systematically investigated with a few important progresses obtained, including: (1) the coupling of tangential and normal stress–displacement relationship has been concerned, rather than the tangential stress–displacement relationship in the early study; (2) the response under complicated paths, e.g., cyclic loading, has been investigated; (3) the microscopic measurements have been employed, accompanied with significant progress in the macroscopic measurements; (4) the microscopic deformation mechanism, including physical state evolution, has been considered for a profound understanding of the stress–strain relationship; (5) the interface types have been extended to an extensive range, involving different structures and soil from gravel to clay; (6) new phenomena and rules have been discovered for various types of interfaces, for example, the response dependent on the shear directions; (7) the constitutive models have been improved to describe the nonlinear, elasto-plasticity response; (8) many types of numerical methods, comprising different interface models, have been proposed and widely used in practical projects.

The objective of this paper is to give a brief introduction and critical review on the state of the art of monotonic and cyclic behavior of soil–structure interfaces. The presentation includes the test device and measurement techniques, fundamental rules and deformation mechanism, constitutive models, and their applications in numerical simulations.

2. Test device and measurement technique

Understanding of the behavior is derived mainly from the systematical tests of the soil–structure interface. Therefore, it is of great concern to establish an effective testing and measuring system.

2.1. Improvements of traditional test devices

Almost all the types of soil shear test devices have been modified for the soil–structure interface, and the direct shear type and simple shear type devices are the common ones (Figs. 1 and 2). The sample size can be maintained constant by both shear devices through the modification that the size of structural material is larger than that of the adjacent soil sample. The simple shear device may be used to approximately separate the slippage displacement on the interface and the deformation of soil according to the tangential displacements of different rings. Such separation can also be obtained in the direct shear tests using microscopic measurement of the tangential displacement distribution of soil near the structure.

The direct test device has been used in a large quantity of tests of the interface between different structures and soil [2–10]. With this type of device, the strength, stress–displacement relationship, and their influence factors were discussed under different loading conditions. Many simple shear tests have also been conducted to investigate the behavior of the interface [10–15]. Uesugi and Kishida

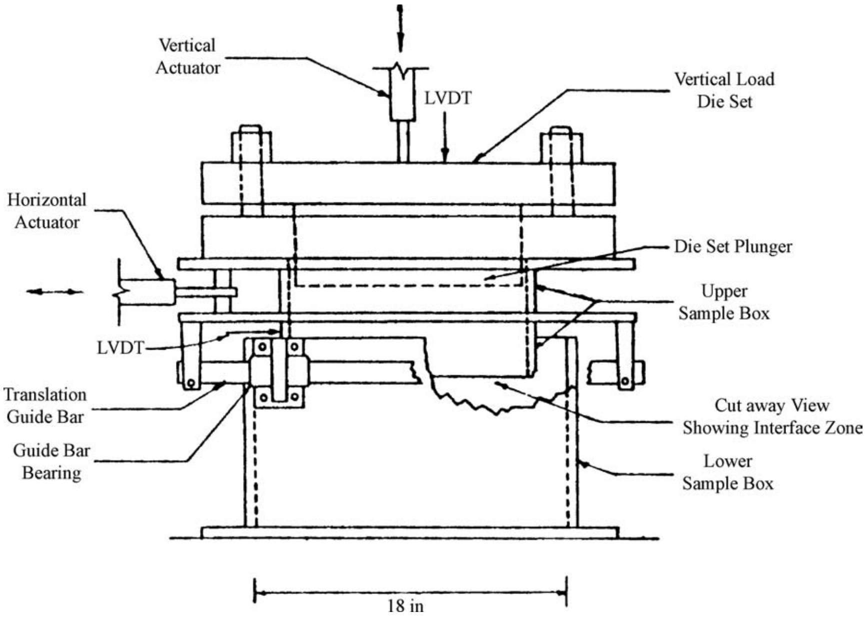

Fig. 1. A direct shear type test device of the interface, CYMDOF [10].

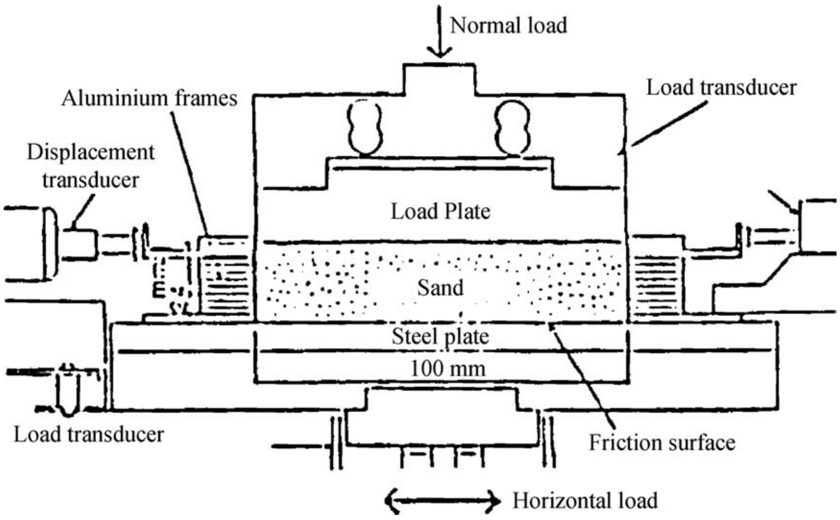

Fig. 2. A simple shear type test device of the interface [12].

firstly developed a simple shear test device for cyclic test of an interface (Fig. 2) [13].

The main disadvantage of these devices is the stress concentration at the ends of the interface, namely nonuniform distribution of the stress or strain along the interface [16]. The test results indicated that the qualitative rules are consistent when using both types of the devices, for example, the shear stress of the steel–clay interface decreases with increasing number of shear cycles [10]. However, the tangential displacement between a structure and soil cannot be definitely determined in the simple shear test; thus, the stress–displacement relationships obtained from these devices may be significantly different quantitatively.

Except for the direct and simple shear type test devices, the ring torsion device was used to investigate the behavior of a sand–steel interface [17,18]. The major advantage of this type of device is that the stresses and strains within the specimen are nearly uniform. However, a special technique such as X-irradiation should be employed to measure the deformation of the interface. The difficulties in preparing specimen and in measuring deformation preclude this type of device from broad application. Other test devices, such as annular shear device [19] and triaxial shear device [20], had ever been used to the test of a soil–structure interface.

2.2. Specialized equipments

Several professional test apparatuses had been developed to observe and measure the response of a soil–structure interface in more detail. For example, Desai et al. developed a new device, CYMDOF, to conduct both the direct and the simple shear tests of the interface [10]. This device was further modified to introduce and measure pore water pressure in the interface due to shear application [21]. Fakharian developed an automated apparatus for three-dimensional monotonic and cyclic tests of the soil–structure interface (Fig. 3) [14]; the response due to the application of different stress paths can be observed.

A large-scale shear test apparatus, CSASSI, was developed to investigate the monotonic and cyclic behavior of a soil–structure interface, with the focus on the interface between a structure and gravelly soil (Fig. 4) [22]. An invariable sample size, 50 cm long and 36 cm wide, is provided by this test apparatus. Three kinds of normal boundary conditions, namely constant stress, constant stiffness, and constant displacement, can be directly applied to the interface with high accuracy through the new design of soil container and structural plate. An automated hydraulic loading system is equipped with high capacity up to 200 kN in both the directions tangential and normal to the interface. Except for the automatic measurement of the stress and displacement, the movements and crushing of soil particles near the structure can be observed in microscopic way. The investigation capacity was recently expanded to three dimensional, with the development of a new test apparatus that can apply monotonic and cyclic loading in three perpendicular directions [23]. The load control and measurement systems were also improved significantly. Therefore, large-scale monotonic and cyclic tests can be realized with various complex loading paths.

2.3. Measurements

For many test devices, the acquisition of data including stress and displacement of the interface in both directions, tangential and normal to the interface, is fully computerized. The measurement accuracy is continuously improved with increasing level of hardware and software.

To investigate the deformation mechanism of a soil–structure interface, there have been a number of attempts to measure the deformation from a microscopic point of view, rather than the traditional macroscopic perspective. For example, in a large-scale direct shear test, Yin et al.

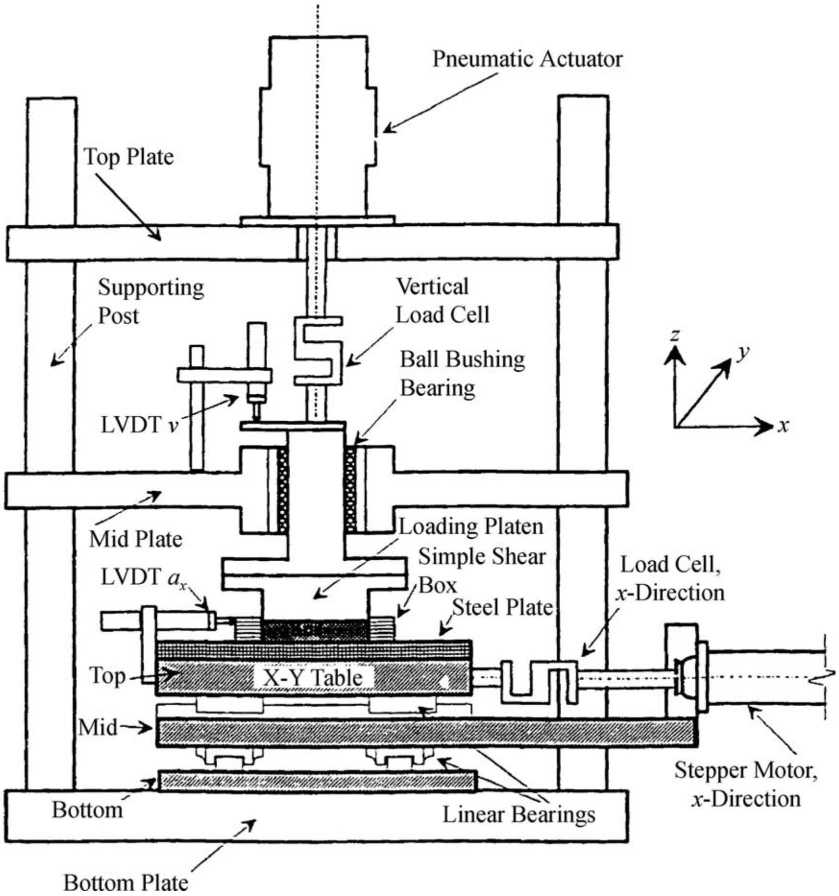

Fig. 3. A three-dimensional shear test device of the interface [3].

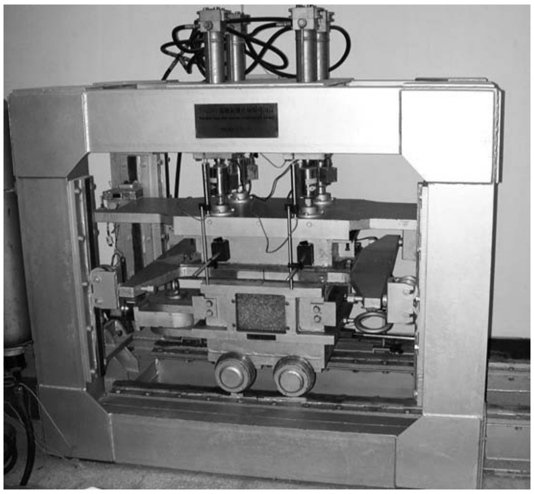

Fig. 4. A large-scale test device of the interface, CSASSI [22].

observed soil particle movement along the interface using a device that resembled a periscope [6]. Guler et al. measured soil particle movement near the structure via the image analysis of photographs [24]. Hu and Pu observed the displacement distribution in the soil near the structure using photographs and discussed the thickness of a sand–steel interface [8]. On the basis of the image analysis theory, a new microscopic measuring system, including equipment and analyzing software, was established for observing and measuring the movement of soil particles during a soil–structure interface test [25]. With this system, the soil particles can be tracked using the high-resolution image series that are recorded during the interface test, and the measurement accuracy can reach sub-pixel class.

There is clearly a recent trend to combine macroscopic and microscopic observation approaches to achieve a better understanding on the behavior of a soil–structure interface. The apparatus development should aim at a comprehensive device with higher load capacity, more complex stress paths, and accurate measurements with a combination of macroscopic and microscopic approaches.

3. Behavior

3.1. Stress–strain relationship

A typical description of a soil–structure interface is the hyperbola relationship between shear stress and tangential displacement under constant normal stress condition, obtained from direct shear tests [3]. This formulation is widely used so far in the numerical analysis for its simplicity. However, Brandt indicated that there is a progressive failure in the direct shear test, which has a significant effect on the observations [5]. An ideal rigid plasticity failure mode was, therefore, suggested to describe the tangential stress–displacement relationship. Volumetric change behavior of the interface has been investigated using a few tests [12]. Three-dimensional monotonic and cyclic response of stress–displacement relationship of a sand–steel interface was investigated using a simple shear apparatus, C3DSSI [26,27]. It was shown that stress path and normal boundary condition significantly affect the stress–displacement relationship. Desai and Rigby investigated the stress–displacement response of a steel–clay interface, using a new technique to introduce and measure pore pressure in the interface [21].

A new interesting feature was discovered from the cyclic test results of the interface between a structure and gravelly soil. The mechanical response of the interface, including shear strength and normal displacement, is dependent strongly on the shear direction [1]. This feature is defined as "aeolotropy of interface", and the normal displacement exhibits more significant effect than the shear stress for most interfaces. A main reason that the aeolotropy of interface comes into being is probably the initial shear application, as this brings about structural aeolotropy of the arrangements and dip directions of the soil particles near the structure due to the constraint of the structure. The initial shear history is also preliminarily confirmed as a main factor influencing the aeolotropy extent [1].

3.2. Deformation mechanism

Great efforts were made also on the observations of microscopic deformation of a soil–structure interface during the tests. For example, the photographs were used to observe the behavior of the soil particle near the structure, showing the formation of a shear zone with a thickness [28]. Such shear localization along the interface was also found from the numerical analysis results [29]. The systematic test results indicated that a thin-layer soil near the structure may exhibit a significantly different response to loading application from that of the neighboring soil due to the constrain effect of the structure [1]. In this sense, the soil–structure interface can be thought as a composite of the structural surface and a thin-layer soil nearby. This indicated that the interface has a thickness. The thickness can be determined using the movements of soil particles near the structure. The movements of different rings can also be employed to estimate the thickness in the simple shear test. A few test results indicated that the thickness of the interface between a structure and coarse grained soil is mainly dependent on the soil grain size, although it is affected by other factors such as the roughness of the structural surface and the normal stress. For example, this thickness can be estimated as five-times average soil grain size [1,8].

The deformation mechanism had been discussed based on the measurement results in both macroscopic and microscopic ways. Gao et al. indicated that the tangential displacement of the interface can be divided into the deformation of soil itself and the slippage along the contact surface that is mobilized when the shear stress reaches the strength [30]. Zhang et al. discovered the deformation mechanism of the interface between a structure and coarse grained soil by combining macroscopic and microscopic measurement results [1]. They demonstrated that the tangential displacement of the interface is composed of two indispensable components: one is due to slippage on their contact surface and the other is the deformation of the soil constrained by the structure nearby (Fig. 5), and the normal displacement is mainly induced by the latter component except for the application of normal stress. The proportion of the two components varies according to shear and is affected by a few factors, such as the structure roughness and the normal stress. This mechanism again demonstrates that the behavior of the interface is significantly different from that of the neighboring soil.

The physical state was discussed in the interface between a structure and gravelly soil using cyclic shear tests [1,31]. It was found that there is significant evolution in physical state of the soil near the structure due to shear application, including particle crushing and soil compression. This evolution governs the evolution of behavior from the initial state to a stable state during the shear application. In addition, the volumetric change due to dilatancy can be divided into an irreversible and a reversible dilatancy component according to different mechanisms, rules, and influencing factors [1]. The reversible dilatancy component is characterized by its reversibility and dependency on the magnitude and direction of the current shear strain. The irreversible dilatancy component is characterized by its irreversibility and dependency on the shear history. This division can be used to explain and describe the volumetric change due to dilatancy in a reasonable way. Significantly, the irreversible dilatancy component can be used as a measure to the evolution extent of the interface during loading application [31].

3.3. Influence factors

The factors that influence the behavior are of great concern in test investigation of a soil–structure interface. Potyondy studied the influence of surface roughness of the

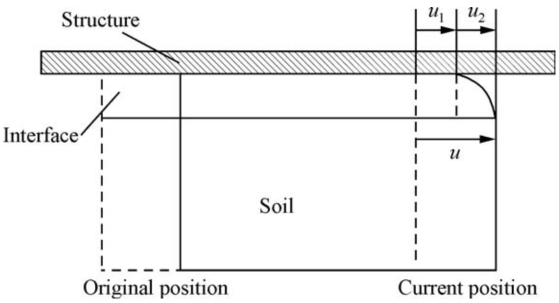

Fig. 5. Components of tangential displacement of an interface [1]. u: tangential displacement; u_1: tangential displacement due to slippage; u_2: tangential displacement due to deformation of soil constrained by the structure.

structure on the behavior of a sand-structure interface using a series of direct shear tests considering different structural materials including steel, concrete, and wood [2]. A series of monotonic and cyclic simple shear tests were conducted on the behavior of a sand–steel interface [11–13]. Their results showed that the surface topography is a key factor to the friction behavior; similar conclusions were also drawn based on other test results [32–35]. Desai et al. performed many cyclic shear tests and indicated that shear stress of a sand-concrete interface can be expressed as a function of normal stress, tangential displacement, number of loading cycles, and initial soil density [10]. A few test results showed that the strength of soil-geogrid interface was not affected significantly by cyclic loadings [36]. Comprehensive investigations on the influence factors have also been carried out using other types of tests [4,7,18–20,37].

The interfaces of practical soil–structure system may be more complex than the interface tested in laboratory. The behavior of such interfaces may be significantly affected by the construction and operating conditions. For example, there is often the slurry layer in the interface between the concrete cut-off wall and soil around because of the construction procedures. The primary test results showed that the thickness of slurry layer has a significant effect on the behavior of such an interface [38].

The existing tests mainly focused on a two-dimensional behavior of the interface and systematical tests are needed on the interface considering the application of a three-dimensional shear, including a complex stress path. These test observations can significantly promote the understanding of mechanism and rules of a few important characteristics of the interface, e.g., dilatancy and evolution of physical state.

4. Constitutive model

4.1. Approaches of modeling

Three approaches have mainly been used to establish a model of a soil–structure interface, as follows:

(1) An empirical formula of the stress–strain relationship is proposed using the fit or interpolation methods based on the test results. Such type of model is fairly simple and easily accepted by the engineers; however, it is unable to accurately capture the response of the interface with the application of a complex stress path. Thus, such a model should often be used in a limited range of soil–structure interaction analysis.

(2) The constitutive model of soil is applied to the interface directly because the similarity between the behavior of soil and interface. Sometimes, a modification was conducted for a proper characterization of the interface. Such type of model is widely used in the numerical simulation of many soil–structure systems; however, it cannot reasonably describe the individual features of the interface.

(3) A specialized model is derived on the basis of the deformation mechanism analysis from test results of the interface. Such type of model has been the leading one for describing behavior of a soil–structure interface, and a diverse range of models had been proposed by considering different aspects of the interface.

4.2. Model categories

Constitutive models of a soil–structure interface are generally of four types: (1) ideal models, (2) nonlinear elasticity models, (3) elasto-plasticity models, and (4) damage models.

The ideal models, such as an elasto-ideal plasticity model and a rigid plasticity model, are commonly referred to as "Mohr–Coulomb model" because the model's strength criterion is usually formulated using the Mohr–Coulomb criterion. For example, Brandt proposed a rigid plasticity model according to direct test results [5]. Such models have been used for the interface in many commercial FEM programs yet.

A typical nonlinear elasticity model was proposed through assuming a hyperbolic tangential stress–displacement relationship under constant normal stress condition [3]. Desai et al. modified the Romberg-Osgood model to describe cyclic tangential stress–displacement relationship of an interface [10]. Lu and Bao presented a coupled model of the interface [39]. Luan and Wu proposed a nonlinear elasto-perfect plastic model of interface [40]. These models are widely used in the numerical analysis because of their simplicity. However, the plastic deformation and volumetric changes cannot be described reasonably.

Ghaboussi et al. proposed one of the first elasto-plasticity interface models using a cap yield surface [41]. In addition, the concept of critical state and bounding surface, which has been successfully used in the modeling of soil behavior, was used for constitutive models of the interface in the framework of generalized plasticity [42,43]. A series of elasto-plasticity models have been developed for the interface on the basis of various assumptions [44–49]; however, these models have not been widely used in the numerical modeling, which may be attributed to the complexity in the formulation and in the parameters determination.

Desai et al. proposed a new "Disturbed State Concept" (DSC). They assumed that an intact material is induced to damage with the application of loading. In other words, a material corresponding to a stress–strain state can be regarded as a composite of two types of materials: one is an intact material that can be described using elasto-plasticity model, the other is a material at the critical state that undergoes hydrostatic pressure only. A few models using the DSC or other damage concepts have been established to predict the behavior of a soil–structure interface [8,50–52]. It should be noted that the evolution rule of these damage models are mainly assumed according to the macroscopic observations of stress–strain relationship, the microscopic mechanism of the damage has not been illustrated. In other words, the damage rule is an assumption of theory rather than an objective understanding.

Zhang and Zhang proposed an evolution rule of physical state based on the comprehensive analysis on the macroscopic and microscopic observations [53]. Thus, the damage concept is extended to describe the evolution of physical state and the resulting evolution of behavior. A new elasto-plasticity damage model, the EPDI model, was accordingly established [31] based on the test observations and a few assumptions, including: (1) respectively formulating the two plastic strain components due to shear and compression using a two yield-surfaces concept; (2) introducing a bounding surface scheme to compute the plastic shear strain due to shear application; (3) proposing a dilatancy equation to compute the volumetric strain due to dilatancy. It was confirmed by comparing model predictions with test results (e.g., Fig. 6) that this model unitedly captures the four main features of the interface between a structure and gravelly soil: (1) monotonic and cyclic behavior; (2) tangential stress–strain relationship, normal stress–strain relationship, and their coupling; (3) microstructure aeolotropy and resulting aeolotropy of interface; and (4) evolution of physical state and resulting evolution of behavior.

There is a clear tendency that a reasonable interface model should be based on the combined understandings of the microscopic deformation mechanism and macroscopic rules of stress–strain relationship. It is preferred if a model, which can describe the monotonic and cyclic behavior simultaneously, involves the features of reasonable physical concepts, simple mathematical formulations, and easy parameters determination. On the other hand, the rigorous models sometimes need to be simplified according to different concerns on the features, for the effective application of practical projects.

5. Numerical format

The numerical format of the interface provides an effective approach for the application of constitutive model to soil–structure interaction analysis. The development of numerical format promoted investigation of the interface models significantly. Many numerical formats have been developed and can be classified into three main categories.

5.1. Surface condition

The first type of numerical format regards the interface simply as a surface of soils. Thus, the analytic or numerical solutions can be derived for the relationship between soil pressure against the structure and the corresponding soil–structure displacement under specified conditions, which is thought as the stress–strain relationship of the soil–structure interface. Based on the Lamb solution, Reissner (1936) derived the first analytic solution of the impedance of the soil due to vertical vibration application of circular rigid plate [54], and then a few impedance functions were derived. For example, Gazetas et al. derived a series of impedance functions of soil due to a few types of vibration applications of a semi-buried foundation in level linear elastic soil [55–58]. The impedance functions of soil with different types of loads by pile foundation have also been

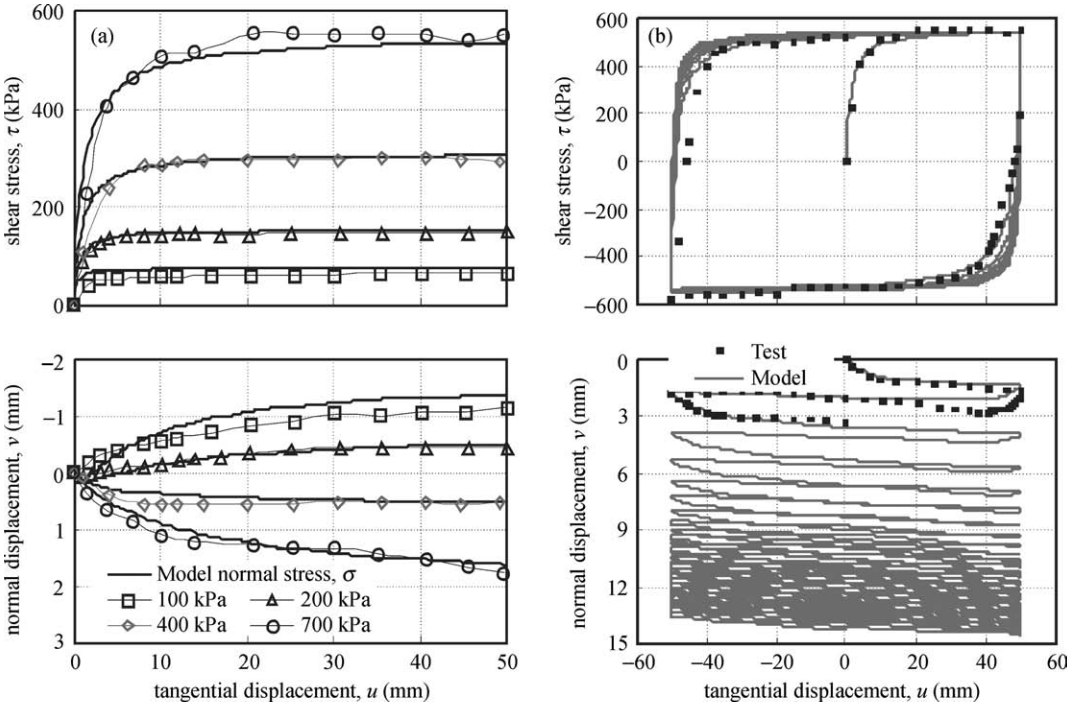

Fig. 6. Comparison of model predictions and test results of interface between a steel plate and gravel under constant normal stress condition: (a) monotonic shear and (b) cyclic shear (normal stress: 700 kPa) [31].

suggested using theory derivation or numerical analysis [59–62]. However, this type of method has to treat the soil as ideal material, which is an oversimplification of the behavior of the soil. In addition, many important features of the interface cannot be considered reasonably. Therefore, the surface condition format should be evaluated seriously when it is used to describe a soil–structure interface, especially for the significant deformation problems.

5.2. Contact format

The second type of numerical format, contact format, is based on contact mechanics. This format has been widely used in several famous commercial computing softwares, such as MSC MARK and ANSYS. Many algorithms, such as Lagrange methods and penalty function methods, have been developed to analyze soil–structure interaction. This type of format can capture the contact and discontinuity of the interface between rigid bodies or continuum; however, it is difficult to devise a model that can describe the complex behavior of the interface.

5.3. Interface element

The third type is the interface element [63] that has been widely used in the numerical analysis of soil–structure systems. Such an element can simulate the discontinuity between the structure and neighboring soil at the interface within a continuum-based numerical method, e.g., the finite element method (FEM), with various constitutive models. Yu et al. yielded a three-dimensional formulation [64].

The interface element can be divided into two categories according to their configurations: one is shear element and the other is entity element. The shear element considers only three components, i.e., one stress component normal to the interface and two shear stress components tangential to the interface. Significantly, the shear element can degenerate to the Goodman element if the thickness of interface is set to zero. The shear element can be used to reasonably describe the mechanical essentials of a soil–structure interface because the interface is usually very thin and intensively constrained by the structure. This element has been widely used in soil–structure interaction analysis [65–66]. For example, Clough and Duncan discussed the earth pressure problem [3], Plesha simulated the direct tests of the interface [67], Justo obtained the stress–displacement response of a concrete-faced rockfill dam [68], and Gens analyzed the interaction between geotextile and soil [46].

The shear element with a thickness became the main tendency because it can reasonably describe the normal stress–strain relationship, as well as the tangential tress-strain relationship of the interface according to the following reasons: (1) The test results indicated that the soil–structure interface has a thickness [1,8]. (2) A large stiffness in the normal direction should be assumed using the interface element with zero-thickness to ensure nonoverlap between the soil and structure near the interface; this treatment can induce significant error in the normal stress and thus affect the tangential stress–strain relationship of the interface.

The entity element has a uniform element format with the common soil element. Zienkiwicz used the entity element to simulate the interface. Desai et al. performed a further study on the entity element using physical analysis and then definitely brought forward the concept of “thin-layer element”, whose behavior is significantly different from that of the neighboring soil [69]. In other words, the constitutive relationship of the entity element is different from that of soil though their element formats are similar. The entity element was also used in the numerical simulation, including the FEM analysis of earth pressure and pile foundation [69], the simulation of rock joints [44]. The entity element is compatible with the adjacent elements of other materials; however, it may confront a few challenges in practical application, e.g., the determination of the parameters, and the reasonable consideration of the structure restraint.

Sharma insisted that the entity element can degrade into shear element if its thickness became so small that the normal stress components in the tangential direction can be ignored [70]. However, it should be noted that there are significant difference between the two types of elements in the physical understanding, constitutive relationship, and numerical format.

Although the shear element has exhibited significant numerical effectiveness and conceptual rationality, the contact behavior on the interface element in the normal direction cannot be obtained accurately. It may be a valuable attempt to design a contact format involving a constitutive model. In addition, new iteration algorithms of the numerical format should be investigated for better convergence and stability.

6. Conclusions and prospecting remarks

(1) A number of results from laboratory tests, prototype observations, and numerical analysis have indicated that the monotonic and cyclic behavior of a soil–structure interface has a significant effect on the mechanical response of a soil–structure interaction system. Thus, the behavior of the interface should be investigated with focusing on the individual features different from other geomaterials.

(2) The test technique is one of the key issues for the investigation on behavior of the interface. Its developments are advised to aim at a comprehensive device with higher load capacity, more complex stress paths, and accurate measurements with a combination of macroscopic and microscopic approaches. Therefore, a refined monotonic and cyclic test can be conducted for comprehensive understanding of various types of soil–structure interfaces.

(3) A systematical understanding has been achieved on the monotonic and cyclic behavior of the interface between a structure and coarse grained soil, including the deformation mechanism, fundamental rules, and main influence factors. Further researches on the behavior of a soil–structure interface are suggested as follows:
  (i) The investigation should be extended to the interfaces of the practical projects, which may be formed under a complex condition. The behavior of such an interface is significantly different from that of the "pure" interface in the laboratory.
  (ii) The systematical tests are needed on the interface considering the application of a complex stress path or a three-dimensional shear.
  (iii) The discussion should be promoted on the mechanism and rules of a few important characteristics of the interface, e.g., dilatancy and evolution of physical state.
  (iv) The cyclic behavior of the interface between a structure and cohesive soil needs to be concerned, such an investigation depends on a refined test system.

(4) Different types of constitutive models of the interface have been established and applied to a number of numerical analysis of soil–structure systems. A reasonable constitutive model should be based on the combined understandings of the microscopic deformation mechanism and macroscopic rules of stress–strain relationship. It is preferred if a model involves the features of reasonable physical concepts, simple mathematical formulations, and easy parameters determination.

(5) The interface element is an effective numerical format of the interface model. The shear element is recommended because of its numerical effectiveness and conceptual rationality. It may be a valuable attempt to design a contact format involving a constitutive model in the numerical analysis for some interface problems where a large discontinuous deformation needs to be described.

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