INTRODUCTION

1. The need of the thesis

Currently, through the result predicted by the design regarding displacement due to deep excavation pits (HĐS) often deviate against actual observation results. There is a need of studies raising value correctness of input geotechnical parameters served for forecasting the behavior of ground around pits. It is in order to orient modeling experiments as close as possible to working conditions of ground under the impact of HĐS construction and using of ground models suitable with them to improve accuracy, efficiency of the forecast. The thesis hopes with its own result to contribute a new method in a range of many common used methods currently for predicting the behavior of the ground in works related to construction of deep excavations.

2. Research targets and scopes

• Research targets are ground behaviors around pits when carrying out excavation.

• Research scopes of the thesis

- Geological environment adjacent to pit walls in affected parameters of excavation impacts, often to distance equal to four times the depth of the pit;
- Excavated pits constructed in conditions of populated areas, high building densities, vertical walls, considerably quick execution, not much influence on pore water pressure and soil moisture of cohesive soils;
- The research focuses on cohesive soils that may take samples for tri-axial experiments to identify number of input parameters for designing deep excavation projects.
- The research focuses on horizontal displacement behaviors impacted from surrounding ground to insides of excavated pits.

3. Objectives

- Develop forecasting methods on horizontal displacements of ground on pit walls in the direction of modeling actual working conditions of the ground during the excavation of pits;

- Develop the forecasting program on the proposed ground behavior under finite element method;
- Develop procedures of designing and constructing deep excavations, synchronously from site surveys to mathematical calculation models.

4. Defended viewpoints

- Tri-axial compresion test for relief of horizontal stresses properly simulate stress-deformation states of land mass around excavated pits and create different results against traditional tri-axial pressing experiment increased vertical stress. It can be easily improved traditional tri-axial pressing experiment devices to use for horizontal stress relief tests.
- Combined uses on ground improved model Lade and geotechnical testing models using a three-axis horizontal stress relief equipment had relatively consistent results with actual measurements.

5. New science points

- Tri-axial compresion test for horizontal stress-relief that identify some particular properties of ground served for designing deep excavations, are feasible and simulate inn accordance with actual working models of ground areas around excavated pits;
- Using improved Lade model with input parameters determined from tri-axial compresion test for horizontal stress-relief can predict horizontal ground displacement of pit walls that are relatively close to the actual implementation.

6. Science and practical contributions

The thesis result contributes a new testing method on tri-axial compression machines simulated more realistic working conditions of the ground under impacts of deep excavations. It is also a method, new procedure on predicting horizontal ground displacements across pit walls to improve project quality having deep excavation.

CHAPTER 1. LITERATURE REVIEWS ON RESEARCHES AND ASSESSMENTS OF GEOTECHNICAL CONDITIONS OF DEEP EXCAVATION PITS

1.1. Related research situations to geotechnical conditions served for designing deep excavation pits:

1.1.1. Characteristics and scopes of researches on deep excavation pits

+ Research scopes of the thesis on deep excavation pits

There were many researches on geotechnical conditions relating to deep excavation such as: Bjerrum and Eide (1956) [24], Bentler (1998) [22], Clough and Hansen (1981) [32], Hashash (1992) [37], Mana (1978) [45], Mana and Clough (1981) [46], Ou and Shiau (1998) [49], Ou (2006) [47], Peck (1969) [51], Wong (2009) [56]… Do Dinh Duc (2002) [1], Chu Tuan Ha (2011) [3], and other researches. However, there are not many researches involved the description of ground behaviors around excavated pits on construction progresses of deep excavation.

In accordance with Hans-Georg Kempfert and Berhane Geobreselassie (2006) [38], there are many ground stress states as shown on Figure 1.1,

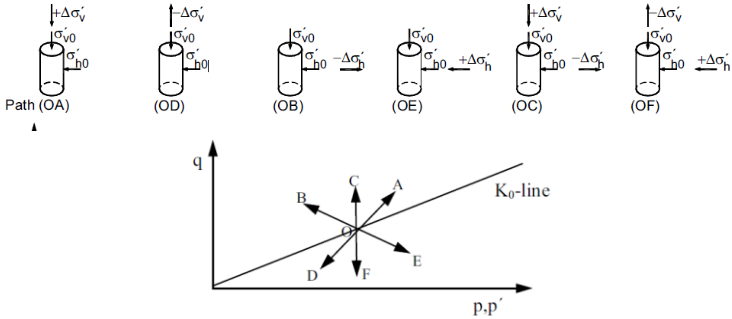
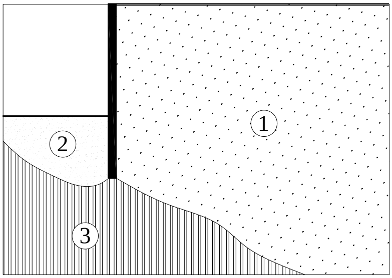


Figure 1.1. Different stress schemes on one excavated pits

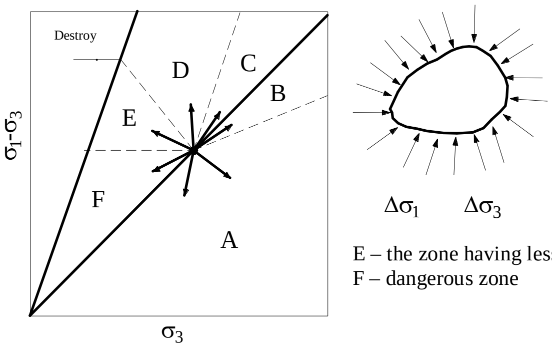
Stroh 1974 [38] divided zones with different load-bearing schemes and stress-deformation relationships for deep excavation projects (Figure 1.2).



Zone 1 – Vertical stresses remain while horizontal stresses gradually reduce when excavating
Zone 2 – Vertical stresses reduce due to excavation and horizontal stresses increase due to wall displacements
Zone 1 – Vertical stresses reduce due to excavation and horizontal stresses remain gradually

Figure 1.2. Locations of load-bearing zones

Zone E is the area that Wong (2009) [56] indicated to have lacking of appropriate.



E – the zone having less research
F – dangerous zone

Figure 1.3. Stress line on the ground

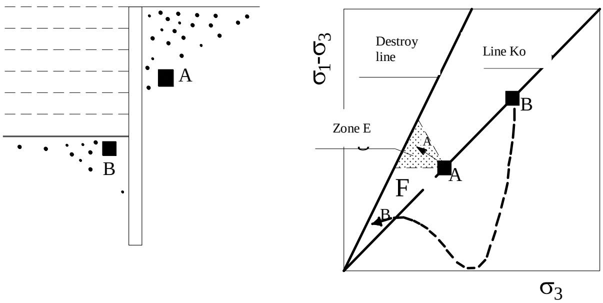


Figure 1.4. Stress line on excavated pits

To study the ground working states behind the wall, it should have appropriate experimental equipment. Using tri-axial test considered on load decreasing (σ3) is the direction in which this thesis followed. After having testing data, it will conduct building calculation models and software for excavated pits to suit with this data.

1.1.2. Geotechnical phenomena happen after excavating deep pits

While constructing deep excavation in large urban areas, mainly adjacent construction, geotechnical phenomena mentioned above all can occur, but the phenomenon of ground movement is consider dangerous because it can cause destruction not only excavated pit structures but also for neighboring buildings. These movements happen mainly on ground areas behind pit walls and pit surrounding ground areas. Currently, there are many studies on these areas. However there are not many uniformed and completed studies to apply on designing and constructing deep excavation. Therefore, it should have more appropriate researches for this area.

1.1.3. Stress states of ground materials

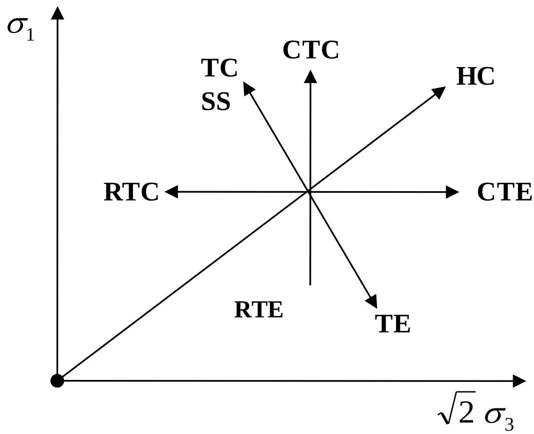


Figure 1.6. Reflected diagram for different stress lines on three-direction plan

Reduced Tri-axial Compression Stress Path (RTC) In this type, materials are under initial hydrostatic stress states, then chamber pressures gradually reduce while the stress standing σ1 remains.

1.1.4. Calculation and design for deep excavated pits

There are three methods commonly applied in calculating deep excavation, including simple method, elastic-ground bearing beam method and finite element method.

Ground model on finite element analysis consists of common used models to design as follows:

a. Linear elastic model;
b. Mohr-Coulomb model;
c. Hyperbol model;
d. Improved Cam-Clay model.

1.1.5. Assessing advantages and disadvantages of some ground models

Ground models outlined above are all using Mohr-Coulomb destructive surface therefore can estimate load bearing capacities of the ground depending on working conditions. However, in addition to determine ground bearing capacities, geotechnical problems also require estimating deformation, excessing pore water pressures, consolidated processes etc. Each model may suit with a certain condition of the problem and basically correspond to one or more computing requirements.

Above models, in the case of reducing stress σ3, model results are not described correctly characteristics of stress-deformation relationship of the ground.

Therefore, there should be one model that can describe the change in the stress line on reduced stress σ3, more suitable with the actual deep excavation problem.

1.2. Relevant researches on surveys on geotechnical data served for designing and constructing deep excavations

According to the summary, through design documents, geological survey reports, measurement and observatory data of pit movements and other materials collected from many other researches and practices show that forecast designing data on deep excavation displacements is not much accurate with many differences compared with field measurements.

1.2.1. Geotechnical experimental methods

There are many geotechnical experimental methods. Experimental methods are used depending on requirements of the design and construction organized methods. With designs of deep excavation pits, tri-axial experiments for deep excavation problem are very important. Due to characteristics of conventional tri-axial equipment currently used, ground samples are saturated and experimental scheme is gradually increased vertical stress, horizontal stress does not change and not appropriate to describe behaviors of the ground behind pit walls.

1.2.2. Ground specialized parameters on the problem of deep excavation pits

1. Mohr-Coulomb model: $E, \upsilon, c, \varphi, \Psi$

2. Improved Cam-Clay model: $M, \Gamma\ \lambda\ \kappa\ p_c\ \nu$

3. Hyperbol model: $K_L, K_{ur}, n, R_f, c, \varphi$

1.3. Comments

1. Characteristics of ground surrounding excavated pits is that vertical stresses remain while horizontal stresses decreases gradually through excavation processes. And within surveying scopes of excavation pits, ground soils always exists initial deflected stress states.

2. Ground parameters taken from current experimental data do not closely reflect actual ground conditions on construction of excavated pits. Thus this poses a problem to select an testing model for determining suitable ground parameters with designing and constructing deep excavation pits.

3. In the case of horizontal stress reduction (σ3), the result on these models is described incorrectly in term of characteristics on stress-deformation relationship of the ground. Therefore, there should be one model that describes the change in the stress line of the mass ground behind the pit walls as reduced horizontal stress (σ3).

CHAPTER 2. TESTS FOR INDENTIFY CHARACTERISTIC PARAMETERS OF THE GROUND ON HORIZONTAL STRESS-REDUCED TRIAXIAL MACHINES

2.1. Introduction

a. States of ground soil under tests:

Triaxial experiments provide much input parameters data for designing deep excavation problems. In order to measure changes in volumes of soil samples, they must be saturated. The process of sample saturation may cause them deforming in comparision with initial conditions that the result is not close to reality. Triaxial stress-reduced testing model could describe non-saturated soil samples and horizontal pressure droping throughout excavation while vertical pressures remaining.

b. Theoretical foundations of conventional triaxial testss:

Pressures from all directions applied to samples during experiment σ3 are kept constantly.

c. Theoretical foundations of horizontal stress-reduced triaxial tests:

Axial pressure is kept constantly, pressures from all directions applied to samples during the experiment σ3 decrease gradually and formulate deflection stress P / A = σ1 - σ3.

Comparison on principles between conventional triaxial tetss and horizontal stress-reduced triaxial tests is shown in Figure 2.1.

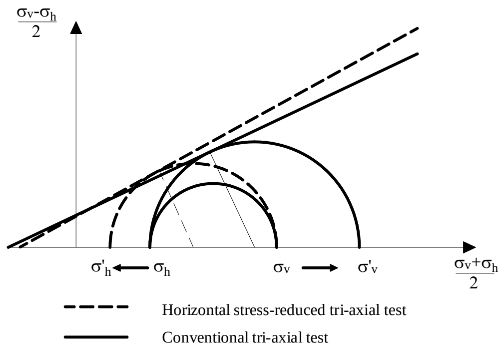


Figure 2.1. Destructive boundary diagram Mohr - Coulomb

2.2. Current testing methods defined input parameters for designing and constructing deep excavation pits

There are many testing methods, including laboratory tests and field tests. In particular, triaxial test for deep excavation problem is very important.

2.2.2. Tri-axial compression test

Triaxial compresion test (TCT) was conducted to determine the shear strength on undisturbed soil samples. The test can be performed for many different scheme in accordance with the actual working conditions of under loading ground.

2.3. Model of horizontal stress-reduced tri-axial test

1. Content of testing method

The principle of this method involves determining the shear strength of soil samples under side pressure pressures decreasing gradually, while under the effect of constant axial load.

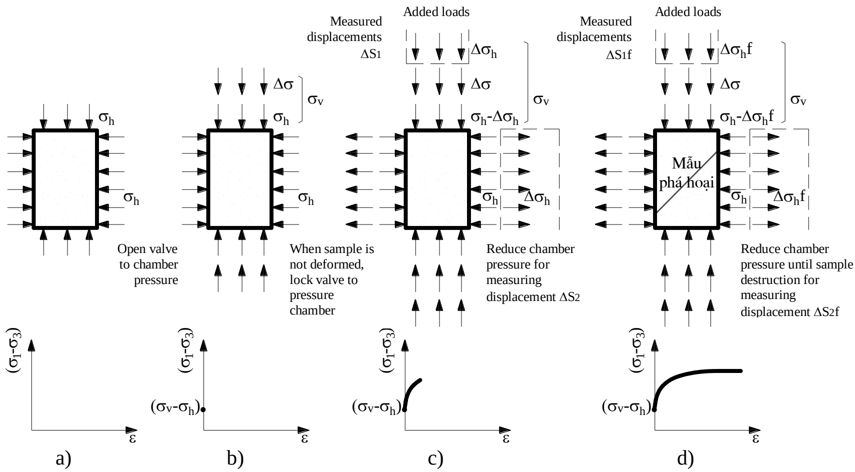


Figure 2.4. Testing progress scheme

(a) Step 1: Create chamber pressures up to the value σh;

(b) Step 2: Create a vertical deflection stress σv = σh + Δσ; Keep chamber pressure until stabilization of soil samples without distortion. Lock on pressure valve with pressure chamber;

(c) Step 3: Descend gradually chamber pressures on each level, subsidize vertical loads on each level, ensure constant vertical load during the experitesting processes;

(d) Step 4: Reduce chamber pressures until deflection prossures are large enough to can cause destruction.

2. Testing equipment and tools

(1) Pressure chamber; (2) Box for creating and maintain pressures; (3) Axial-force generated equipment; (4) Chamber pressure- reduced equipment; (5) (6) Deformation measured equipment; (7) Equipment for measurement of vertical load volume

(loadcell); (8) Equipment for measurement of chamber pressure; (9) Equipment for recording data (Data logger TDS 530).

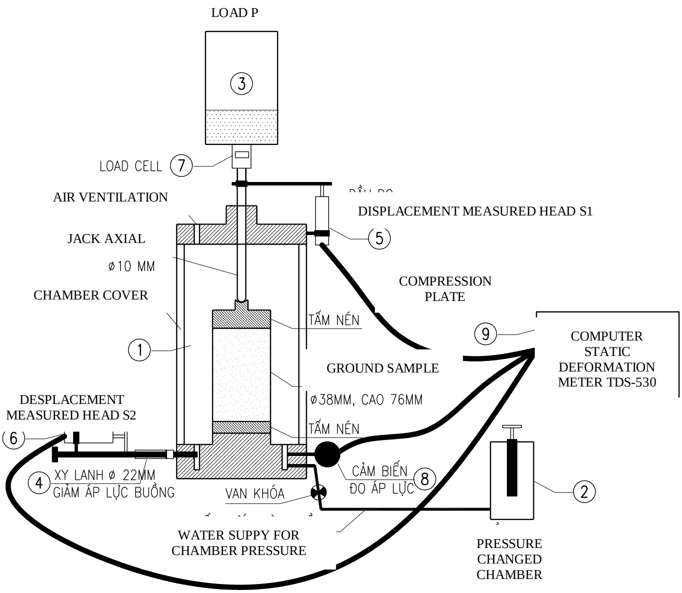


Figure 2.5. Machine diagram for horizotal stress-reduced experiments

3. Testing procedures

Testing procedures are conducted in accordance with similiar steps of conventional triaxial tests with diagram CU.

4. Unloading

5. Calculation and reporting of testing results

6. Initial level of loading

To ensure closely description of ground working processes, it should determine the initial level of loading appropriately.

The assumption is the ground in its natural state to have existance of two components: σv and σh in which: $\sigma_v = \sum\gamma_i h_i$ is the column volume of above ground or stratigraphic pressure $\sigma_h = K_0.\sigma_v$ with K_0 - coefficient of static earth pressure.

7. Analysis of testing data

8. Testing results

1. National Institute of burn project, Tan Trieu commune, Thanh Tri, Ha Noi.

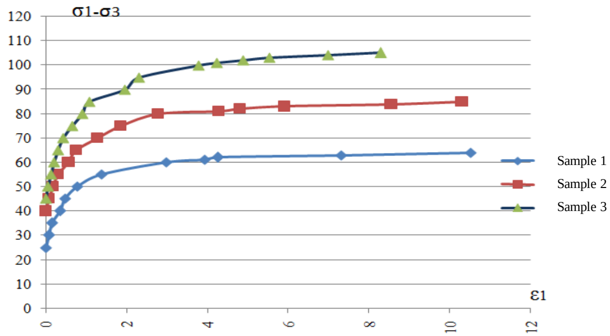


Figure 2.19. Interrelated diagram between stress deflections and axial deformations

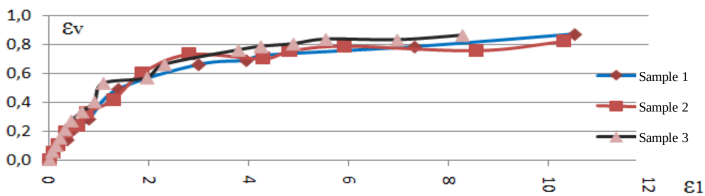


Figure 2.20. Interrelated diagram between volume deformations and axial deformations

Compare tri-axial testing results completed for the project:

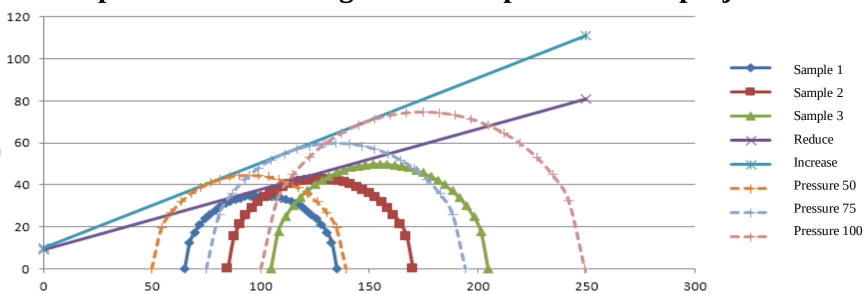


Figure 2.21. Mohr circle diagram of horizontal stress tests and compare with conventional tri-axial tests

2. Business, office and apartment project at 505 Minh Khai, Vinh Tuy, Hai Ba Trưng, Ha Noi.

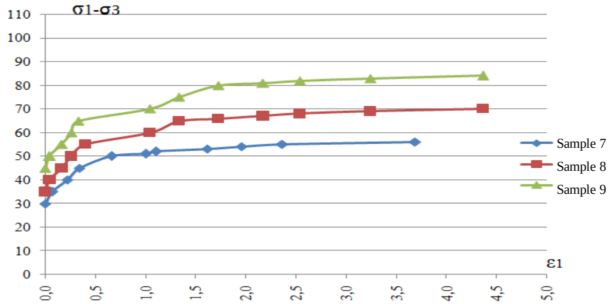


Figure 2.25. Interrelated diagram between stress deflections and axial deformations

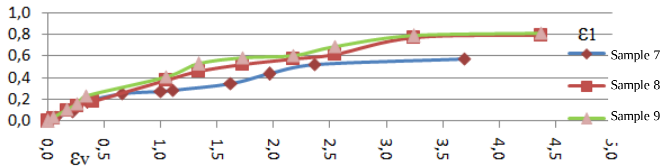


Figure 2.26. Interrelated diagram between volume deformations and axial deformations

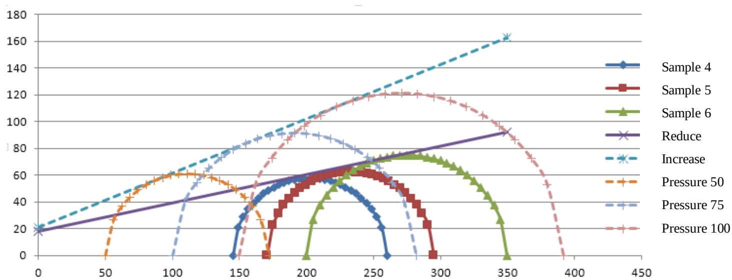


Figure 2.27. Mohr circle diagram of horizontal stress tests and compare with conventional tri-axial tests

Comparison of elastic modules

Reduced σ_3		Increased σ_1	
σ_3 (kN/m^2)	E_i (kN/m^2)	σ_3 (kN/m^2)	E_i (kN/m^2)
80	60720	50	5882
110	61748	75	6711
135	71025	100	8928

3. Central Military Hospital 108 project, No. 1 Tran Hung Dao, Hai Ba Trung, Ha Noi.

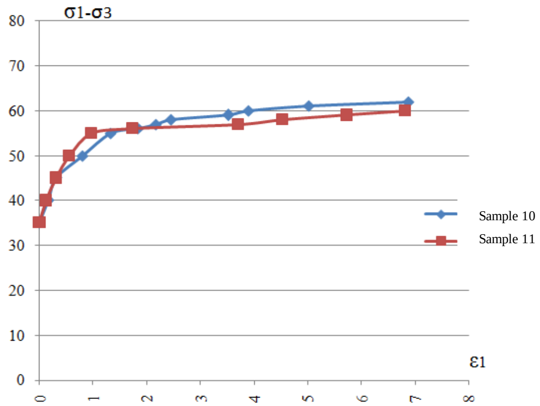


Figure 2.30. Interrelated diagram between stress deflections and axial deformations

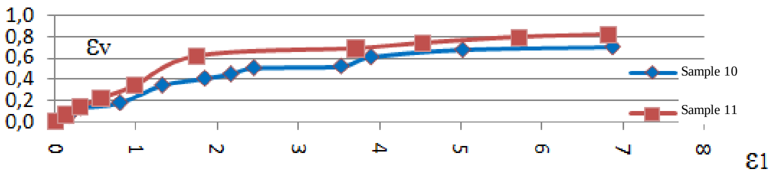


Figure 2.31. Interrelated diagram between volume deformations and axial deformations

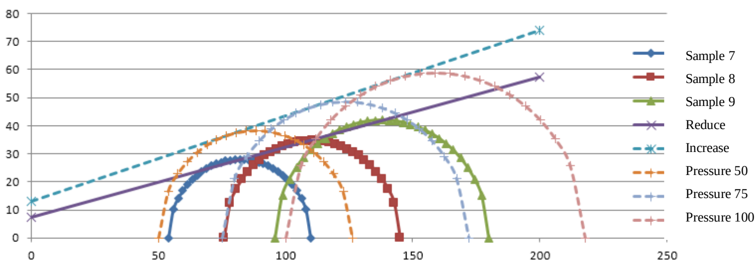


Figure 2.32. Mohr circle diagram of horizontal stress tests and compare with conventional tri-axial tests

COMMENTS FOR CHEPTER 2

+ Testing equipment and procedures, in terms of theorical aspects, allow a full description of ground behaviors surrounding excavation pits under excavated progresses such as existence of initial deflection stresses and gradual reduced stresses over excavated progresses.

+ Ground behaviors beside excavated pits during testing progresses of conventional tri-axial testing scheme against tri-axial horizontal stress-reduced testing scheme are different, particularly follows:

- The value obtained as c, φ of tri-axial stress-reduced testing scheme scheme CU differs with conventional tri-axial tests due to pore water pressures vary for each different stress path;

- The elastic module E of horizontal tri-axial stress-reduced tests are larger than conventional tri-axial tests.

CHAPTER 3: USING LADE IMPROVED MODEL FOR DEEP EXCAVATION PROBLEM

3.1. Ground behaviors

Ground behaviors are represented by stress-deformation relationships and mathematical models described characteristics of this relationship are known as the ground model substrate.

3.2. Lade ground model

3.2.1. Reason for selection of Lade model

Compare with other computational models described ground behaviors on geotechnical problems, Lade model has following advantages:

- To build on results of tri-axial compression tests that are realities consist of effects of intermediate stress components.

- There is only one plastic flow surface, one destructive surface and one unique expression of potential energy plastic deformation. With this advantage, when establishing the expression of plasticity matrix do not encounter difficulties on dealing with intersections between compression flow surface and shearing flow surface as other models.

- Can describe behaviors of re-durable or re-softening [40] [41] [42].

3.2.2. Lade model

Parameters of Lade Model

Table 3.1. Parameters of Lade model

Parameters	**Description**
M, λ, ν	Elastic characteristics
η_1, m	Destructive standard level
μ, ψ_2	Potential energy plastic expression
h, α	Plastic standard level
C, p, b	Re-durable and re-softening

3.3. Lade improved model

1. Background for establishing Lade improved model

Lade improved model is established by the author based on the original model Lade that taken into account for stress-reduced path σ_3 and can be applied for stress-reduced path σ_1 and stress paths of other conventional tri-axial compression tests. Characteristics of Lade improved model include elastic characteristics, destructive surface, melting plastic surface and plastic deformation potential energy expression. Improved contents include:

- Add the characteristic of unit cohesive force into the expression of Lade model to describe the behavior of clay type soil.
- Develop the relationship between internal friction angle and unit cohesive force with specific parameters on destructive surface of the original Lade model.
- Develop the relationship between expansion characteristics of the ground and parameter the specific parameters of plastic deformation potential energy surface of original Lade model.
- Develop new plastic flow surface in accordance with plastic deformation under different stress paths including stress reduced path.

Reduced σ_3 tri-axial tests in Chapter 2 and a number of tri-axial testing results under different stress paths are used to establish ground improved Lade model.

2. Elastic characteristics

The value of elastic modulus for the ground should not be determined by initial slopes of stress-deformation relationship curves. It should be determined by small deformation elastic modulus or unloading-loading elastic modulus. Values of elastic modulus along stress paths are summarized on the following table:

Tests	**E (kN/m^2)**
Reduced σ_3	59766
Remained I_1	21715
Increased σ_1	9434

3. Destructive surface

Destructive surfaces on Lade model have been studied in Lade [40], [41] and proven in many studies. Therefore, this destructive surface is used in Lade improved model. However for users' convenience, parameters of destructive surfaces should be converted to intensity characteristics of the ground as friction angles and unit cohesive forces.

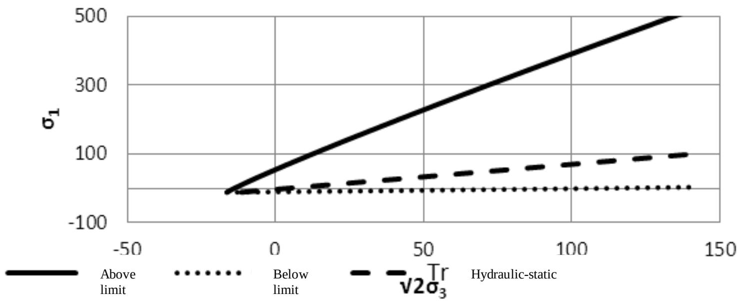


Figure 3.5. Destructive surface on deflection plan

4. Potential energy plastic deformation surface

5. Flow plastic surface

For the Lade ground model fit with stress-reduced path σ_1, or reduced σ_3, researchers have established a new plastic flow surface like Figure 3.13. With this new plastic flow surface, in its original state on hydrostatic axis, stress path towards any direction also occurs plastic deformation. The magnitude of off-axis hydrostatic plastic flow surface depends on the magnitude of the plastic deformation due to sliding shear loads. When unloading, plastic deformation constant volume and plastic flow surface do not grow in size in accordance with the hydrostatic axis, but only develop in size towards destructive surfaces. When loading, plastic deformation stress due to increased volume and delivery of further plastic flow origin hydrostatic axis.

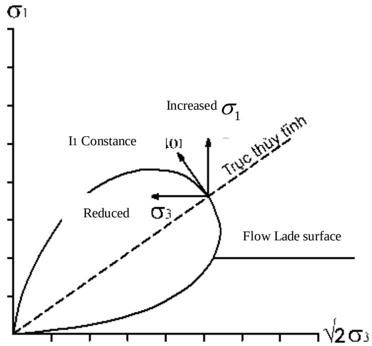


Figure 3.12. Stress path of tri-axial compression test and flowing surface Lade

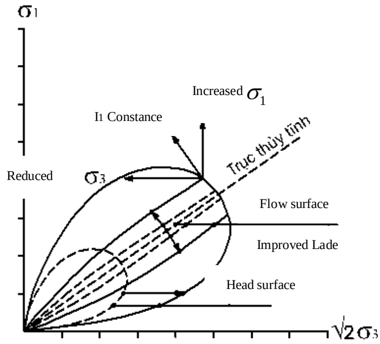


Figure 3.13. Improved plastic flow surface Lade

6. Definition of characteristics for improve Lade model

Characteristics of improved Lade model is presented in Table 3.2 as follows:

Table 3.2. Parameters of improved Lade model

Parameters	Description
E_0 , ν	Elastic characteristics
c , φ	Destructive standard level
μ , ψ_2	Potential energy plastic expression
h , α , β	Plastic standard level
C , p	Re-durable and re-softening

7. Evaluation of the reliability of improved Lade model

Tri-axial testing results in many different stress paths, including reduced σ_3 as shown on Figure 3.16 and relationship curve between volume deformation and axial deformation of testing samples as shown in Figure 3:17 by Costanzo et al [34] implemented.

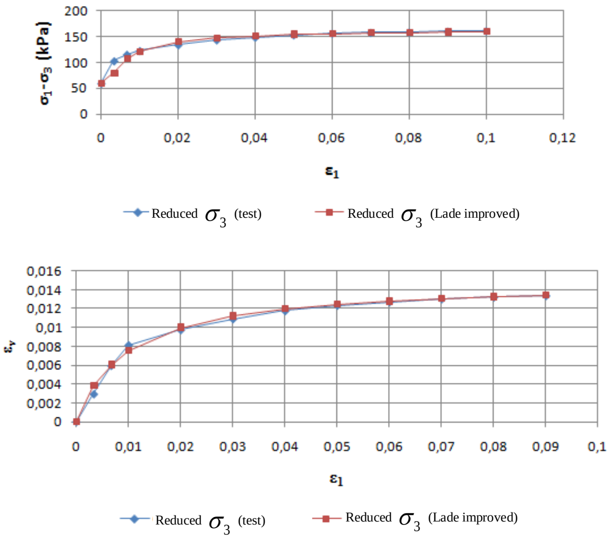


Figure 3.21. Compare on calculation results and stress-deformation relationship results for reduced tri-axial compression tests σ_3

3.4. Calculated software based on selected ground models

Software calculated deep excavation pits LadeDeep is developed by the author from a geotechnical analysis software based on the finite element method that is capable modeling the ground and structural elements. New development contents consist of adding source codes into Lade model improved Lade model, analysis during construction processes of deep excavation pits.

A block diagram of the software is shown in Figure 3.24 to include data entry, loops through construction phases, loops solving nonlinear materials improved Newton-Raphson method. Calculation results of the software include: stress, deformation and displacement of the ground as well as internal forces in supporting systems such as walls, anchor struts.

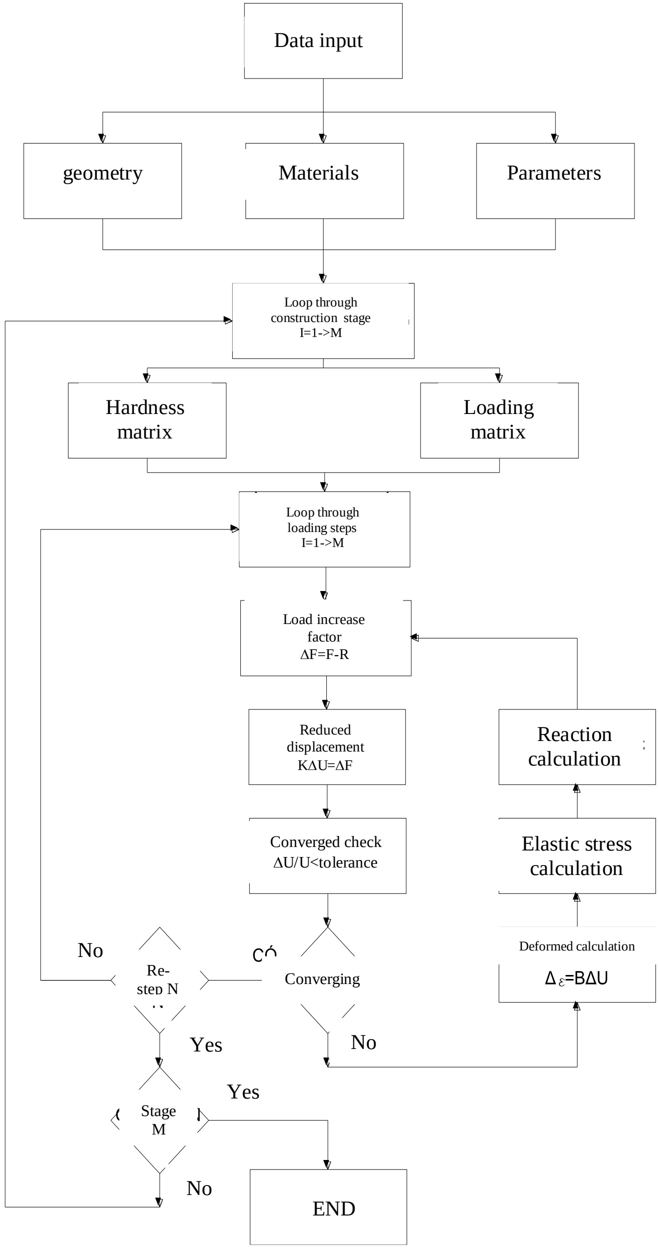


Figure 3.24. Block and loop-solving diagram of LadeDeep software

COMMENTS OF CHAPTER 3

Selection of Lade model for developing a new ground model to include reduced-stress path σ_3. Lade model is the model that is established based on conventional triaxial compression test while improved Lade model is based on reduced triaxial compression test σ_3. The similarity of these two ground models is characteristic parameters of models. The difference of these two models is when reduce σ_3, in certain ground stress state, stress-deformation interrelation for Lade model is elastic and for improved Lade model is soft-elastic. Moreover, improved Lade model concurrently describe stress-deformation interrelationship under conventional triaxial test and under different stress paths.

Initial elastic modulus along stress-deformation interrelationship paths of reduced triaxial tests σ_3, having greater value than conventional triaxial test. For calculation model of deep excavation pits having ground model used initially elastic modulus of conventional triaxial tests will make estimated result greater than the reality.

The calculated software LadeDeep based on finite element method for flat problem using a triangular element six nodes, programming language Delphi XE6. Software can describe in detail construction processes such as excavation, strut erection, stretching anchor cables. Linear elastic substrate models , Hardening model, Lade model and improved Lade model are implemented in the software. The software uses graphical interfaces, capable of fast data entry, automaticaly meshing elements. Effected loads can be modelled in the form of distribution or concentration loads at any point. Retaining walls are modeled with beam elements with two nodes. Struts or anchoring systems are described by nonlinear element orchestra under the bar materials or geometry. LadeDeep software can analyze the influence of dual mention of pore water pressure problem undrained analysis of clay.

CHAPTER 4: CALCULATION PRESSURES OF DEEP EXCAVATION IN ACCORDANCE WITH IMPROVED LADE MODEL

4.1. Calculation contents

To assess the reliability of the improved Lade model in finite element method for excavation problem, calculation examples for real works need to be done. This chapter presents calculated examples to be made with actual domestic and oversee projects that have been constructed. Actual data used in the calculations include ground characteristics, retaining structure characteristics, characteristics of construction processes, and field observation data.

Software used in the calculation includes software LadeDeep (Lade model and improved Lade model) and compare with Plaxis software (Mohr-Coulomb model, model Hardening).

4.2. Modeling deep excavation pits

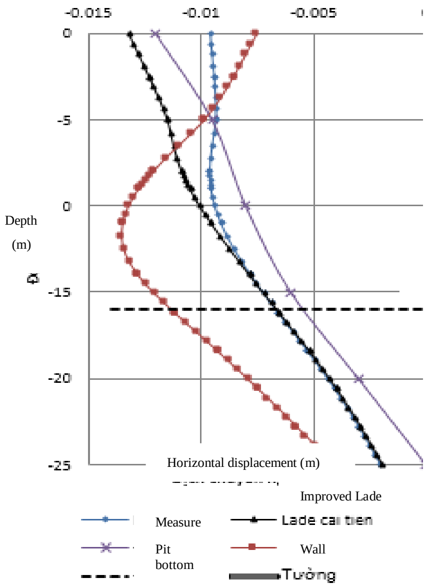
Deep excavation pits include the ground around pits, pit prop structures including retaining walls, struts and ground anchors. Apply to some specific projects:

1. Hospital 108 project;
2. Hoabinh Green City Minh Khai project;
3. Hydraulic power station damp No. 2.

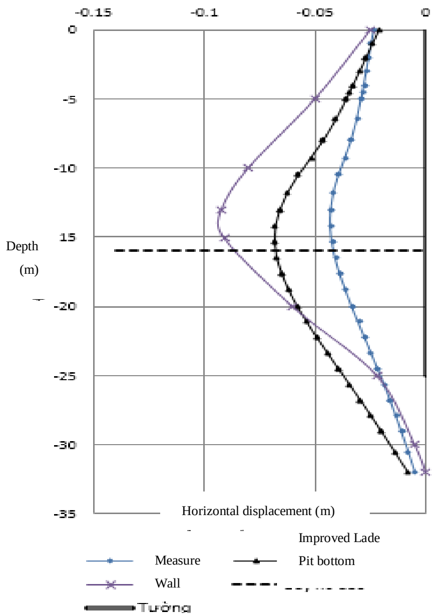
COMMENTS

Behaviors of excavation pits depend on stress-deformation relationship under stress path consistent with reality. That relationship is expressed by specific elastic modulus and the reduced elastic modulus when stress increasing. Improved Lade model and Hardening model creat similar deformation. In improved Lade model, the initial elastic modulus depends on the ground stress path so analysis results are more consistent with the measured results.

Calculation results of excavation behaviors depend very much on defining parameters of ground model and using suitable ground parameters, especially characterized by the elastic valuation close to reality that is more difficult than determining characteristic intensity.



Hospital 108 project



Hoabinh Green City Minh Khai project

CONCLUSIONS AND RECOMMENDATION

1. Conclusions

1.1 Construction of deep excavation pits is ground unloading process together with load up on supporting structural system. Stress and deformation states of the ground behind pit walls change along reduced stress σ_3, σ_1 unchanged. Triaxial tests are currently not suitable to simulate excavation precesses during construction.

1.2 Triaxial compression equipment according schemes of reduced chamber pressure (σ_3) that thesis author had designed and improved based on common triaxial compression equipment has been completed and has been tested with good results.

1.3 Triaxial compression tests according reduced scheme σ_3 are implemented with many different ground types showing some ground characteristics determined from these tests differ with other coomon rules resulted conventional triaxial compression tests such as elastic modulus, friction angle and unit cohesive forces. Elastic modulus E of horizontal triaxial stress-reduced tests is larger than conventional triaxial tests and computational results are approprite with actual measured data.

1.4 Ground model described stress-deformation states had results differing from realities due to not using input parameters that are formulated basing on appropriate stress path. Lade model fits with different stress paths, there should be some changes and improvements to fit with excavation problem such as: establishing relationships with basic ground characteristics like unit adhesive forces and friction angles for easy application in practical calculations, improvement of plastic flowing surfaces for deformation occuring under loading and unloading processes, and characterized initial elastic modulus. Improved Lade model presented in this thesis has met these requirements while using input parameters determined from triaxial compression horizontal stress-reduced tests.

1.5 LadeDeep software has been developed basing on the improved Lade model suitable with unloading stress paths on the back of pit walls. LadeDeep results for calculation and forecast horizontal displacement of sheetpiling construction for deep excavation of some specific projects are close to reality and can apply them in calculating actual deep excavation problem.

1.6 A calculation procedure guide on designing and constructing deep excavation pits have been proposed on the basis of forecasting results on the behavior of the ground around pits from software LadeDeep and using triaxial compression horizontal stress-reduced tests.

2. Recommendations

By the time I can continue to study the following issues:
- Study of factors affecting the calculation model such as the influence of seepage, consolidation, three-dimensional elements and initial stress state in the ground.
- Extend the problem to the case that considers of construction time.