Proceedings of the 4th World Congress on Civil, Structural, and Environmental Engineering (CSEE'19)
Rome, Italy – April, 2019
Paper No. ICGRE 192
DOI: 10.11159/icgre19.192

Deformation Characteristics of Cement Treated Pasak Clay and Bangkok Clay with Different Stress Path

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Abstract **-** This study presents the result of triaxial tests of cement admixed Bangkok Clay and Pasak Clay. Loading conditions were loading and unloading compression. From test results, the state parameter can be employed to characterized cement admixed clay behaviors. Strength and stiffness of cement admixed clay were increased with decreasing state parameter. Undrained shear strength of cement admixed clay can be predicted by a proposed empirical equation based on a level of a state parameter. Stress response envelops of certain strain level is presented. Base on stress response envelops, the stiffness of cement admixed clay was affected by different stress path and initial stress state.

Keywords**:** Cement Admixed Clay, State Parameter, Triaxial

1. Introduction

Failure and excessive deformation of soft clay are the most challenging problems in a geotechnical engineering project. Many methods of soil stabilization have been chosen to encounter these problems. Deep Cement Mixing (DCM) is an effective ground improvement in deep soil level without removing topsoil. It was first applied in Japan in 1970 [5] by using cement slurry injecting from the nozzles at the end of drilling rig through to the soil. Currently, deep cement mixing method is used in different type of project such as a foundation of road embankment, tunneling, excavation and retaining structure. Deformation and strength characteristics of cement treated clay with different stress state, as well as mixing ratio, need to be estimated during the design and construction period.

There are many researches attempted to investigate and predict the strength and stiffness of cement treated clay. Cement content and curing time were used to predict mechanical properties of cement treated soil [4]. Due to the variation of water in untreated soil, unconfined compressive strengths of soil cement mixed in the field were varied in each project. Water and cement content in the soil cement before curing was employed to predict its strength [6, 10, 11]. However, the total clay water content (C_w), void ratio and specific gravity varied during the construction period. A ratio between after curing void ratio and cement contents, e_{ot}/A_w, was presented to characterize cement treated clay behaviors [2]. Currently, with considering stress state, a state parameter was presented based on stress state, cement and water content for Bangkok Clay [1, 7, 9]. The objective of this paper is to present deformation characteristics of cement treated clay at compression and loading and unloading stress state with different location of mixed clay. A state parameter was evaluated based on the results of a triaxial test.

2. Background

Since, water content, unit weight, and specific gravity of soil cement were not constant while curing [2], after curing void ratio (e_{ot}) was a strong parameter that point to soil cement structure. The after curing void ratio (e_{ot}) can be easily determined from the laboratory as shown in Eq. (1) below. [2]

$$e_{ot} = \frac{(1 + w_t)G_{st}\gamma_w}{\gamma_t} - 1 \tag{1}$$

Whereas e_{ot} is after-curing void ratio, w_t is after-curing water content, G_{st} is after-curing specific gravity, γ_w is unit weight of water, and γ_t is after-curing unit weight.

The prime parameter proposed by Lorenzo [2] was considered together with soil cement structure and cement content as the ratio of after curing void ratio and cement content (e_{ot}/A_w). Jongpradist et al. [7] concluded that strength and stiffness of cement admixed clay based on water content for the hydration process and total water content. After curing void ratio, cement content and total water contest (C_w) were used to combine together to propose as an effective void ratio (est) [7] as shown in Eq. (2) below.

$$e_{st} = C_w \ln\left(\frac{e_{ot}}{A_w}\right) \tag{2}$$

Whereas e_{st} is effective void ratio, e_{ot} is after-curing void ratio, C_w is total clay water content (in remolded soil and cement slurry), and A_w is cement content (by weight of dry soil).

To characterized triaxial test behaviors [8] [9] [3], stress level was combined with effective void ratio as a state parameter (ψ_i). The state parameter can be determined as shown in Eq. (3) below.

$$\psi_i = e_{st} - e_{ssl} \tag{3}$$

Whereas ψ_i is an initial state parameter, e_{st} is an effective void ratio, and e_{ssl} is an effective void ratio at steady state [8]. The initial state parameter was significant relationship with the behavior of shear stress, stress path, and pore water pressure of cement admixed clay and cement – fly ash admixed clay [9]. In this research, the relationship of initial state parameter and physical properties of cement treated clay, Pasak Clay, is studied with isotropic consolidated undrained triaxial compression test (CIU test) with loading and unloading stress condition.

3. Project description and properties of base clay

Pasak River is a river in central Thailand and is important for the canal for transportation of cargo ships as shown a location in Fig. 1. Because of shallow of stream channel in drought season, dredging and river bank and slope protection are needed to solve the problem. Pasak River wall was a combination of a sheet pile and cement column that overlaid with a pavement structure. The typical section of the project is shown in Fig. 2.

The general soil conditions are divided into 3 layers, soft clay, stiff clay and sand layer respectively. Soft clay layer is a problem in this construction project. it was treated by Portland cement with 200 kg/m^3 of untreated soil via jet grouting and deep mixing method depending on a contractor. Due to a different mixing method, initial water content and soil profile along a project (15 km. long), a prediction strength and stiffness of cement admixed clay are strongly needed. The properties of Pasak Clay and Bangkok Clay are shown in Table 1. A plasticity index and natural water content of Pasak Clay was significantly lower than Bangkok Clay.

Fig. 1: Location of the project.

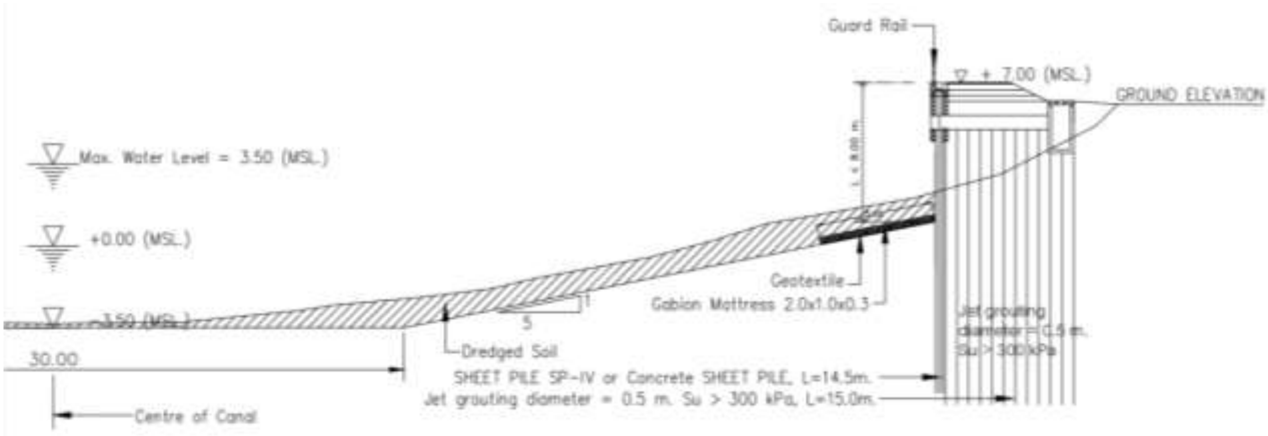

Fig. 2: Typical section of Pasak River bank protection project.

Table 1: Basic properties of Pasak Clay and Bangkok Clay.

Properties	Pasak Clay (This study)	Bangkok Clay – KMUTT [7]	Bangkok Clay – AIT [2]
Liquid limit, LL (%)	83	117	103
Plastic limit, PL (%)	31	39	43
Plastic index, PI (%)	52	78	60
Water content, w (%)	42	84	76 – 84
Specific gravity, G_s	2.71	2.65	2.61
Total unit weight, γ_t (kN/m^3)	15.0	14.6	14.3
Dry unit weight, γ_d (kN/m^3)	8.20	7.92	7.73
Initial void ratio, e_i	2.24	2.28	2.31
Soil classification (USCS)	CH	CH	CH

4. Laboratory test

Base clay was collected at a construction site at Pasak project and mixed cement in the laboratory as cemented clay. The undisturbed soil was be tested for basic properties. The base clay was collected at the site from 2 to 5 meter deep. The water content of the base clay was remolded to 125% (w* = 125%) to simulate the mixing method with a slurry of cement and jet mixing. The quantity of added water is shown in Eq. (4) below [7].

$$\Delta W_W = \frac{W_T}{1 + w_0}\left(w^* - w_0\right) \tag{4}$$

Whereas ΔW_W is weight of added water to the soil for remolding, W_T is total weight of base clay, w* is required remolding clay water content, and w_0 is natural water content of base clay.

In this research, the ratio of total clay water content to cement content (C_w/A_w) was 2.92, 6.92, and 10.92. A cement content can be calculated from Eq. (5). Water cement ratio of cement slurry (w/c) was 1.0. Cement content in this tests were 65.1%, 21.1%, and 12.6%.

$$A_w = \frac{w^*}{\left(C_w/A_w\right) - \left(w/c\right)} \tag{5}$$

Whereas A_W is the cement content (by weight of dry soil), C_w/A_w is the ratio of total clay water content and cement content, and w/c is water - cement ratio of cement slurry.

Soil-cement samples were made by pushing the soil cement paste into PVC mold that was 70 mm. in diameter and 150 mm. in high. Pushing was done to remove air bubbles as shown in Fig. 3. The molded paste was allowed to protrude out from the other end of the mold for checking the occurrence of "honeycomb" structure. Pushing will be continued until the surface of the protruding specimen is uniform and smooth. The mold together with the specimen was waxed to prevent moisture loss. It was cured in a humidity room having a maintained ambient temperature of 25°C for 28 days.

In the saturation period, cell pressure was increased up to 300 kPa with being constantly higher than back pressure at 10 kPa. Consolidation state would start when pore pressure parameter B was more than 0.90. Isotropic consolidation pressures in this test were set as 50, 100, and 200 kPa. If excess pore water pressure reduced more than 95% of the initial value, the shearing stage could be started. Undrained shearing with loading and unloading condition was tested in this research.

(a) a curing sample

(b) testing machine

Fig. 3: Testing sample and testing machine.

5. Testing results

5.1. Stress - strain behavior and initial state parameter

Strength and stiffness of cement admixed clay can be characterized by a state parameter [9]. For the triaxial loading test, the relationship of undrained shear stress, distortional strain with different state parameters are shown in Fig. 4 and Fig. 5. Initial state parameter depends on mixing ratio, untreated soil property, and consolidation stress before shearing. Normalized undrained shear stress significantly increased according to strain with decreasing state parameter as shown in Fig. 4. The sample with the low value of the initial state parameter had a higher stiffness than the one with a higher value of a state parameter as shown in Fig. 5. The strength of cement admixed clay also increased with decreasing state parameter value as shown in Fig. 6. The equation to predict maximum undrained shear strength can be proposed as Eq. (6) below.

$$q_{max}/p'_0 = 1.7407e^{-0.354\psi_i} \quad (6)$$

Whereas q_{max} is maximum undrained shear strength, p'_0 is consolidation pressure before shearing (confining pressure), and ψ_i is initial state parameter.

For unloading compression test, state parameter can be employed to characterize behavior of cement admixed clay as shown in Fig. 7 and Fig. 8. The test condition did not reach a failure state because initial consolidation pressure (p'_0) was reduced until zero at the end of test. The stiffness of cement admixed clay in compression unloading state increased with decreasing its state parameter.

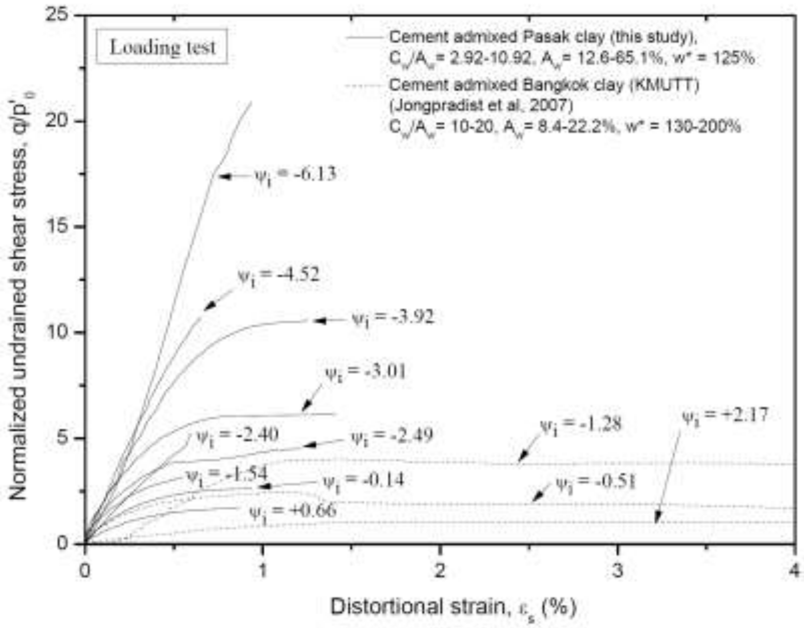

Fig. 4: Relationships between normalized undrained shear stress and strain with the different initial state parameter for triaxial loading compression test.

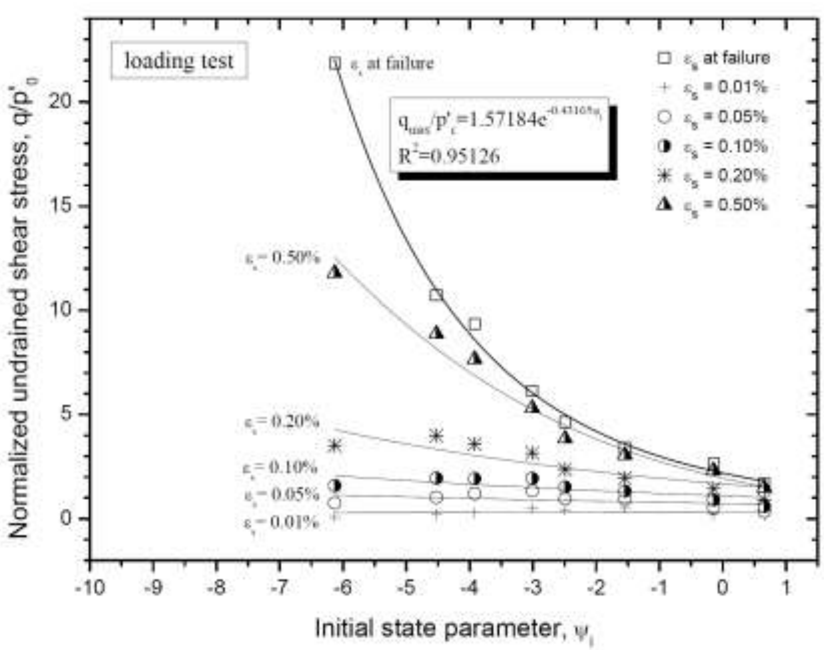

Fig. 5: Relationships between normalized undrained shear stress and initial state parameter with different distortional strain level.

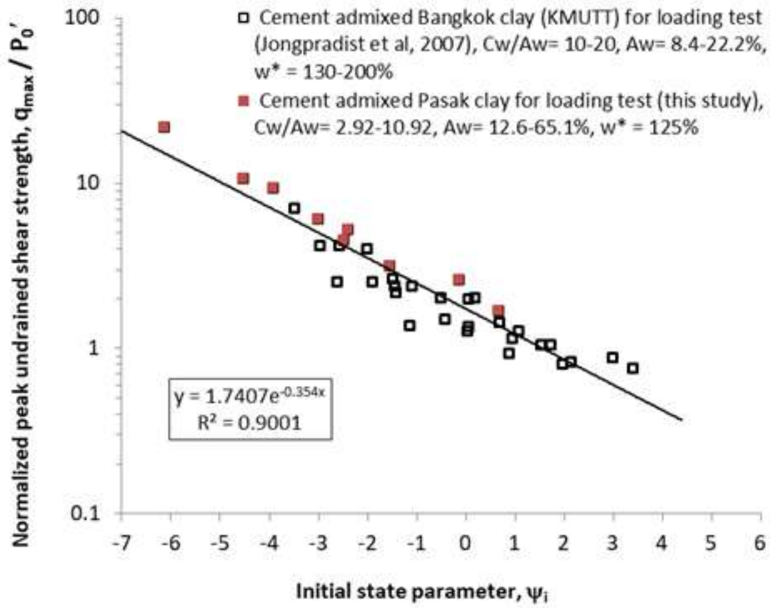

Fig. 6: Relationships between normalized undrained shear strength and initial state parameter for cement admixed Bangkok Clay and Pasak Clay.

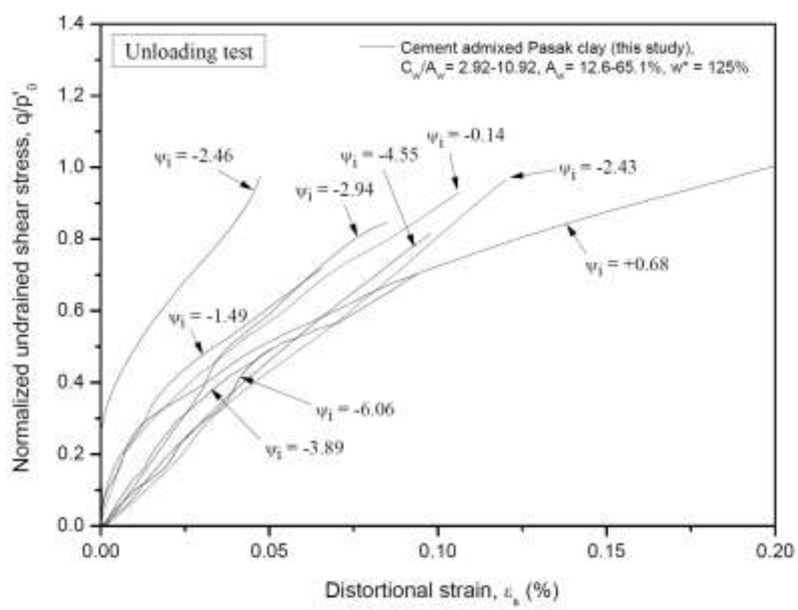

Fig. 7: Relationships of normalized undrained shear stress and strain with the difference value state parameter for compression unloading test.

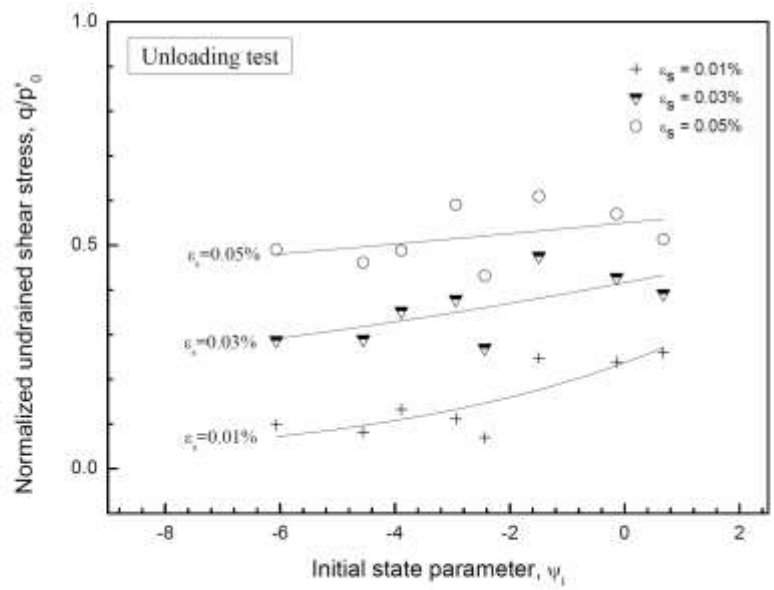

Fig. 8: Relationship of normalized undrained shear stress and state parameter relationship with the different level of distortional strain for compression unloading test.

The stiffness of cement admixed clay was significantly affected by a stress path and initial stress state as shown in Figs. 9 to Fig. 11. Stress response envelopes at a certain level of strain of cement admixed Pasak Clay are shown in Fig. 9 to Fig. 11. For 50 kPa of consolidation pressure, the deviator stress for unloading condition was lower than loading condition at similar strain level (0.01 – 0.1% strain). However, for a higher level of confining stress (100 and 200 kPa), deviator stress level for loading and unloading condition was similar.

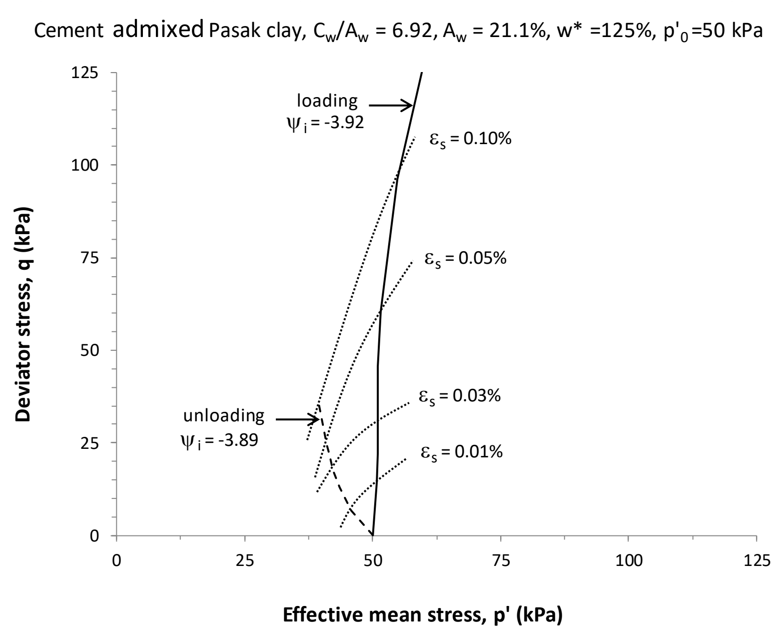

Fig. 9: Stress response envelope of Pasak clay admixed cement for the samples of C_w/A_w = 6.92, w* = 125% and p_0' = 50 kPa.

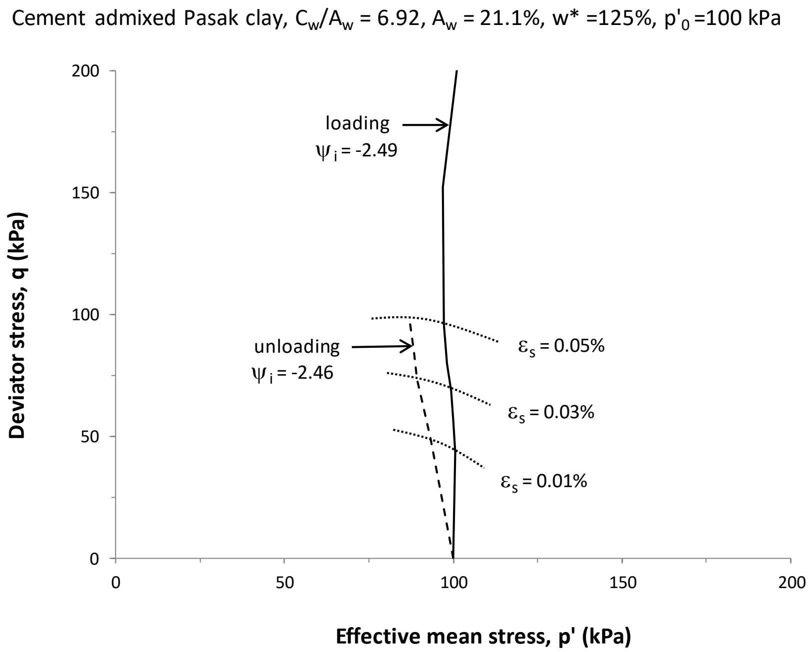

Fig. 10: Stress response envelope of Pasak Clay admixed cement for the samples of C_w/A_w = 6.92, w* = 125% and p_0' = 100 kPa.

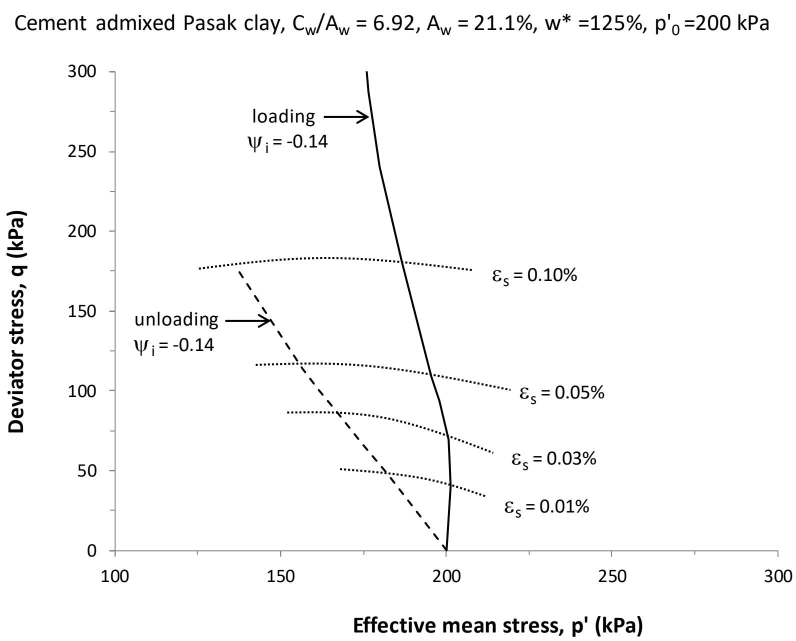

Fig. 11: Stress response envelope of Pasak Clay admixed cement for the samples of C_w/A_w = 6.92, w* = 125% and p_0' = 200 kPa.

6. Conclusions

This study presented deformation characteristics, of cement treated Pasak Clay and Bangkok Clay at the differing mixed ratio and stress path. State parameter can be employed to characterized cement admixed clay behaviors. Strength and stiffness of cement admixed clay were significantly increased with decreasing state parameter. Undrained shear strength of cement admixed clay can be predicted by a proposed empirical equation based on the level of initial state parameter (ψ_i) and confining stress ($q_{max}/p'_0 = 1.7407e^{-0.354\psi_i}$). Based on stress response envelop, the stiffness of cement admixed clay significantly affected by a stress path and initial stress state.

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