THE STUDY ON A PRACTICAL USE OF WASTED COAL FLY ASH FOR COASTAL RECLAMATION

ETUDE D'UNE UTILISATION CONCRETE DE CENDRES VOLANTES DE CHARBON POUR GAGNER DU TERRAIN EN MER

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SYNOPSIS :

As a part of construction of the industrial complex using industrial waste matters, when coal fly ash which is residual-product of domestic coal-thermal power station is poured into static sea water, the process in constructing coastal industrial complex should be understood. And for this matter the characteristics of settling, consolidation, shear strength for coal ash in sea water should be examined. Through this study, parameters which will be the basic data for the case of using coal ash as reclamation material has been obtained.

1. INTRODUCTION

Recently, As the Requirement of new land development increases due to enlargement of land utilization, it becomes necessary to investigate the development and the usage of the construction material. Consequently, the stabilization process of construction material during reclamation and the environmental protection in the area of reclamation should be examined.

In this study, as one of the land development construction methods using waste matters, seaside development construction by means of dumping coal ash (which is by-producted from the coal power plants) into the planned static sea water is investigated. For this, the laboratory experiment was performed to observe the characteristics of settling, consolidation, and shear of coal ashes in the sea experiment was performed to observe the characteristics of settling, consolidation, and shear of coal ashes in the sea water. Six types of coal fly ashes were collected for the test, and the analysis was carried out focusing its attention on Seo-Chun fly ash. The numerical analysis with several input parameters was also conducted, and results were compared with those odserved from experiment. The amount of coal ashes for the planned reclamation area, the settlement of the coal ash layer after reclamation, and the behavior of the ground with increase of over-burden pressure are estimated from the result by parameters of experimental and numerical analysis.

2. EXPERIMENT AND ITS RESULTS

2.1 Test sample

Two types of coal ashes were used in tests : one, composed of anthracite coal (Hard coal), from SC(Seo-Chun), YD(Young-Dong), and YW(Young-Weul) coal power plants, and the other, composed of bituminous coal (Soft coal), from BL(Bo-Lyung), SP (Sam- Chun-Po) and YS(Yeo-Soo) coal power plants in Korea. There are also two types of coal ashes, bottom ash and fly ash. Since the former is less productive than the latter and does not have proper size (too big) for settling tests, experiment was performed with fly ashes only. The properties of samples are shown in Table 2.1.

Table 2.1 The material properties of fly ashes for test

Fly Ash	Specific Gravity	Classif-ication	Atterberg	D_{60} (mm)	D_{10} (mm)	C_u	Raw Material
BL	2.17	A-4 or ML	N.P	0.030	0.017	1.8	Bituminuos Coal
SP	1.99	A-4 or SM	N.P	0.130	0.024	5	
YS	2.56	A-4 or ML	N.P	0.063	0.055	1	
SC	2.33	A-4 or ML	N.P	0.049	0.004	11	Anthracite Coal
YW	2.23	A-4 or SM	N.P	0.090	0.008	11	
YD	2.40	A-4 or ML	N.P	0.060	0.008	8	

Samples for settling tests were produced by mixing coal ashes and sea water in each water content by a container for pouring settling samples, and in order to get reconstituted samples which is close to natural condition, the container for the formation of consolidation samples was used for consolidation and triaxial compression tests. Naturally - accumulated samples with the initial conditions of salinity concentration, W_{salt}=3.2%, initial water content, W_o=1000%, and initial height, H_o = 40cm were used for consolidation tests.

Samples of water content of 35% for triaxial compression test were obtained by consolidating load, p = 0.2kg/cm^2 forcedly on naturally - accumulated samples, composed of coal ashes with salinity concentration, W_{salt} = 3.2%, initial water content, W_o = 200%, and initial height, H_o = 30cm.

2.2 Settling

Settling test tube, Blender, salt mixing and pouring container, tubes measuring water content for each level, and pore water pressure measurement were used in the experimental work. Four Settling test tube, height of 100 cm and diameter of 5, 7.5, 10.4, or 14.5 cm were specially manufactured with perspex for tests. To measure the water content for each level, a couple of holes(diameter of 0.2 cm) were bored spaced 5 cm from the bottom of a container (height of 100 cm and diameter of 10.4 cm), and a couple of perspex tubes(diameter of 0.7 cm) were attached on each hole to drain suspension during settling tests. Water contents for each level were measured at a desired position in the middle of test by stainless steel containers measuring water content. The height variation of the pore water pressure was measured by altering values connected to the container with rubber tube. Settling tests were conduted with 6 types of fly ashes with different experimental parameters of Settling test tubes (D_o = 5, 7.5, 10.4, and 15 cm), Blending numbers(B_n = 1, 10, 20, 30, and 40 no./min.), concentration of salt (W_{salt} = 0, 1.6, 3.2, 6.4, and 10 %), initial water contents (W_o = 500, 700, 1000, 1500, and 2000 %), and initial heights (H_o = 20, 40, 60, 80, and 95 cm). The Water content for each level with the initial conditions of W_o = 700(%), H_o = 65 (cm), W_{salt} = 3.2(%), D_o = 10.4(cm), and B_n = 30(no./min.) was measured repeatedly in each layer.

In case of fresh water, generally, the settling types of the coal ashes were characterized by flocculated free settling, without formation of the zone, and in case of sea water, the zone was observed with formation of Floc. After settling started, the accumulation layer ascended, and this accumulation zone formed interface with the settling zone at a certain point. After forming the interface, settling velocity decreased rapidly and settling continued slowly. Fig 2.1 shows typical shape of zone descending at settling. From settling tests of each tube diameter, Blending number, and concentration of salt, there was little difference in settling type.

However, there appeared small difference in final settlement height in different fly ashes. The formation of the accumulation layer was observed at the bottom of the container as settling continued. At this time, the rate of H_s/H_0 (Where H_s is virtual solid height) becomes constant, and H_0 did not affect at this stage. This result will be the fundamental data in estimating the quantity of reclamation soil. Understanding of the height variations of the water content and pore water pressure according to time in

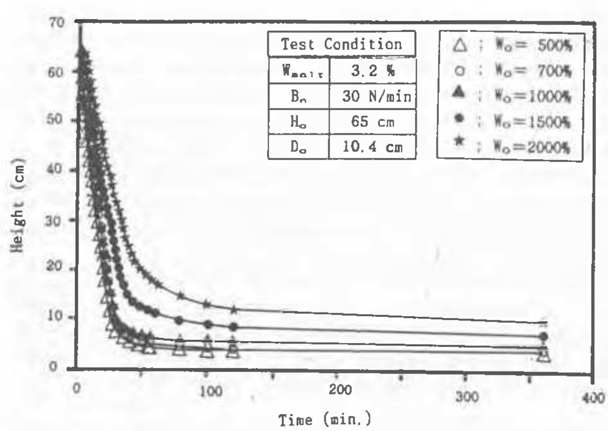

Fig 2.1 Zone settling curve of SC fly ash (for each w_o)

settling is an important factor to predict the settling type and the effective stress. Since the ideal condition to measure the height variation of the water content with time in settling test is the test should be performed with undisturbed samples. Thus the test in this study were conducted repeatedly by settling tube measuring water content for each level. According to Fig 2.2, it was observed from the height variation of water content that the water content decreased as the height reached bottom layer. This was also observed by Been(1981), who used density for each level in settling test. The application of the water content for each level instead of density for each level can be used for settling test of fly ashes. Fig 2.3 shows the height variation of the excess pore water pressure with time and has similar shape with observed by Been (1981), which means that the initial excess pore water pressure is dissipated as settling continues with time. It was also shown the rapid dissipation of the excess pore water pressure at the initial stage due to self-weight consolidation at bottom.

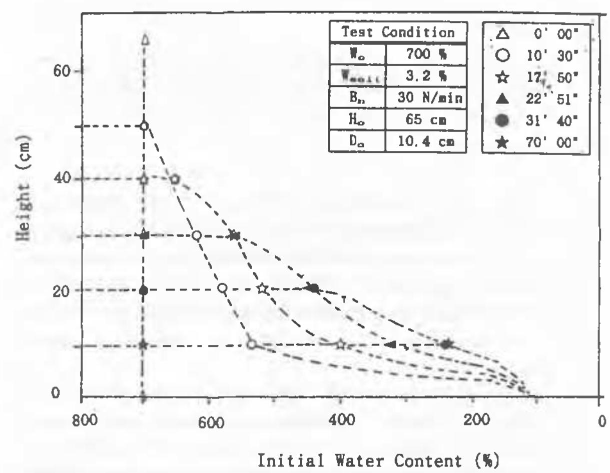

Fig 2.2 The variation of water content for each level

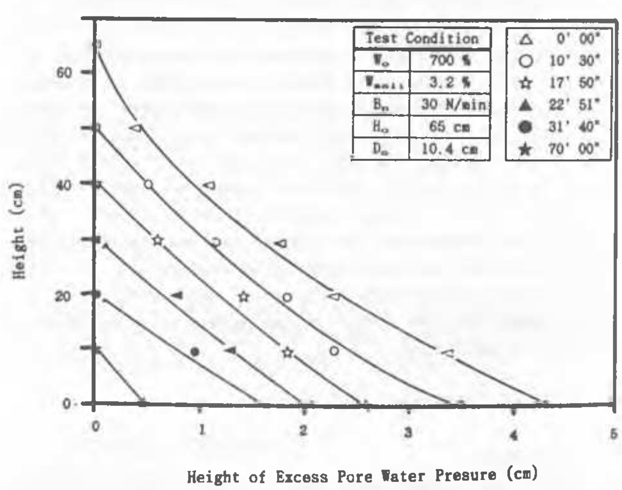

Fig 2.3 The height variation of excess pore water pressure for each level

2.3 Consolidation

Ohe dimensional consolidation and isotropic compression tests were performed to observe the characteristics of consolidation. In the one-dimensional consolidation test, samples for the Oedometer test was prepared in size of diameter of 6cm and height of 2cm, and consolidation loading between 0.1 kg/cm^2 and 12.8 kg/cm^2 was maintained during tests. Isotropic compression test was performed with the test sample of diameter of 3.5 cm and height of 8.75 cm by loading 1, 2, and 4 kg/cm^2 of consolidation pressure step generated by cell pressure. Fig 2.4 shows e-log p curve for one-dimentional consolidation test with condition of the initial void ratio of e_0 = 1.68 at BL and e_0 = 1.10 at SC of the free settling Sample.

Compression index(C_c) of 0.225 and swelling index(C_r) of 0.03 are found in case of BL, and C_c of 0.186 and C_r of 0.016 in case of SC. The maximum initial void ratio of the moldable sample for isotropic compression test are 1.23 for BL and 0.85 for Sc, and Fig 2.5 shows λ = 0.1149 and κ = 0.0134 for BL and λ = 0.0764 and κ = 0.0065 for SC.

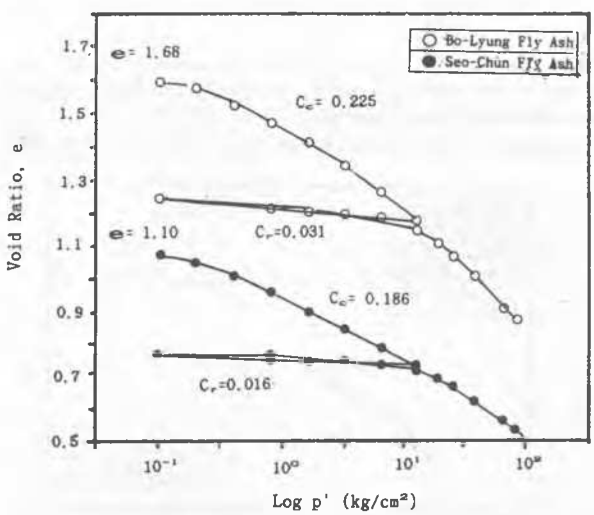

Fig 2.4 e - log p curve of fly ash

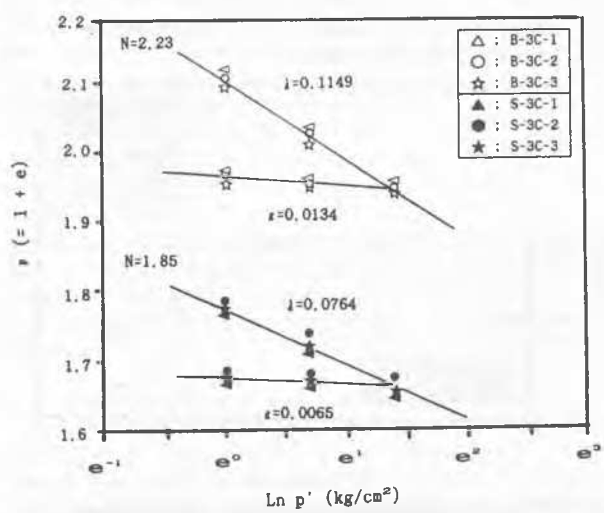

Fig 2.5 ν - ln p curve of fly ash

2.4 Shear

Undrained consolidation (CU) test was performed with the sample of diameter of 3.5cm and height of 8.75cm. Destruction of normally-consolidated or over-consolidated samples was induced by Shear velocity of 0.4 %/min, loading the axial load of strain control. Normally consolidation was conducted with consolidation pressure of 0.4, 0.8, and 1.6kg/cm^2, and over consolidation was conducted with the range of preconsolidation pressure between 0.4 and 4kg/cm^2 to obtain 10, 5 and 2 of over consolidation ratio (O.C.R). Table 2.2 shows a test conditions of triaxial compression test.

Table 2.2 Test conditions of triaxial compressure test.

Test Code	Pre-Consolidation Pressure	OCR
BNT-0.4, SNT-0.4	0.4 kg/cm^2(1day)	1
BNT-0.8, SNT-0.8	0.4 kg/cm^2(1day)	1
BNT-1.6, SNT-1.6	0.4 kg/cm^2(1day)	1
BOT-10, SOT-10	0.4 kg/cm^2(1day)→0.4 kg/cm^2(1day)	10
BOT-A-5, SOT-A-5	0.4 kg/cm^2(1day)→0.4 kg/cm^2(1day)	5
BOT-B-5, SOT-B-5	0.4 kg/cm^2(1day)→0.4 kg/cm^2(1day)	5
BOT-A-2, SOT-A-2	0.4 kg/cm^2(1day)→0.4 kg/cm^2(1day)	2
BOT-B-2, SOT-B-2	0.4 kg/cm^2(1day)→0.4 kg/cm^2(1day)	2

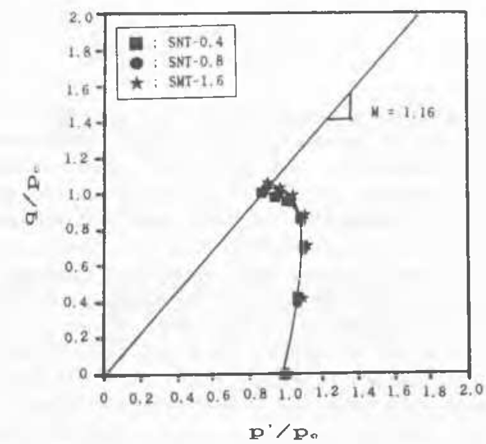

Fig 2.6 State path of normally consolidated fly ash (SC)

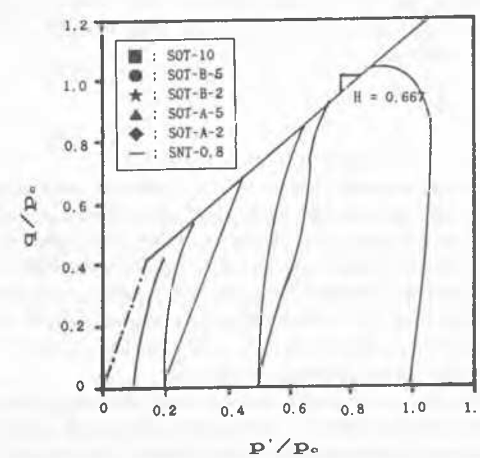

Fig 2.7 State path of over consolidated fly ash (SC)

In normally-consolidating Tests of fly ashes, effective stress path and critical state line during shear were obtained from (p',q) coordinates which resulted from the relationships between vertical shear strain and deviator stress and between vertical shear strain and pore water pressure to the variation of consolidation pressure. According to Fig 2.6, the slope of critical state line for BL and SC shows M = 1.13 and M = 1.16 repectively, which means yield-surface does not related to consolidation pressure before shear.

In tests of Over-consolidated fly ashes with conditions of 10, 5 and 2 of O.C.R, the slope of Hvorslov of H = 0.172 for BL and H = 0.607 for SC in Fig 2.7 also shows no relationship between yield-surface and consolidation pressure before shear.

3. NUMERICAL ANALYSIS

To predict the variation of void ratio during settling and consolidation, a numerical program was developed by substituting $\beta = 0$ or $\beta = 1$ into the linear finite strain equation in following way :

$$g(e)\frac{\partial^2 e}{\partial z^2} + f(e)\frac{\partial e}{\partial z} = \frac{\partial e}{\partial t} \quad \cdots\cdots\cdots\cdots \quad (3\text{-}1)$$

where, $g_{(e)} = \dfrac{k_{\varepsilon(e)}}{\rho_w(1+e)} \dfrac{d\sigma'}{de}$

$$f_{(e)} = -\left(\frac{\rho_s}{\rho_w} - 1\right)\frac{d}{de}\left[\frac{k_{\varepsilon(e)}}{(1+e)}\right]$$

Linear and non-linear are characterized from g(e) and f(e), and g(e) and f(e) are defined by relationship of void ratio, permeability coefficient, and effective stress. Linear finite strain program, SCP(settling consolidation program) in the present investigation, was developed from equation (3-1) by finite-difference, and the numerical results were compared with those from experiment. Height(cm), time(sec.), initial void ratio and void ratio at the boundary were used for input: Coefficients of first and second partial differential term of the equation on Z were substituted by experimentally-calculated values from the relationship either between void ratio and permeability coefficient or between void ratio and effective stress. Critical state program (CRISP) was used to predict stress path, and stress path at undrained shear was analyzed by substituting parameters of fly ash into program and then compared with experimental results.

4. DISCUSSION

4.1 Characteristics of settling and Sedimentation

According to experimental results, The hindered settlement was kept with the self-weight consolidation at water content , W_0=1000%. And in case of at W_0>1000%, after the flocculated free settling had occurred, the self-weight consolidation phenomenon could be checked(found by Imai,1980). Therefore from this knowledge, it is desirable that the estimation of time and quantity completed settling for reclamation is followed by initial water content of fly ash.

Fig 4.1 shows the relationship between zone settling velocity and initial water content, it is shown that as W_0 increases, V increases. Since settling type differs from the variation of initial water content on the basis of W_0 = 1000%, the values of V and W_0 for each sample are following :

at $W_o \geq 1000\%$,	at $W_o \leq 1000\%$,
BL ; $V = 0.0018 \cdot W_o + 6.1282$	BL ; $V = 0.0095 \cdot W_o - 1.6437$
SC ; $V = 0.0022 \cdot W_o + 5.0799$	SC ; $V = 0.0066 \cdot W_o + 0.7574$

In the free settling of samples containing large initial water content, however, settling velocity is constant and is not related to initial water content, therefore, Stokes' equation of settling velocity should be used in the settling analysis using above equations.

To define a final accumulation layer and an initial point of self-weight consolidation, it is necessary to find a settling point. Time completed settling was decided from a cross point by drawing tangents on the fore part and the later part of settling curve. Fig 4.2 shows the relationship between log (H_a/H_0), where H_a is final settlement height and log (W_0), and H_a in each fly ash is estimated in following way

$$H_a = H_0 \cdot \exp(\, a \log(w_0) + b \,)$$

where, a = -0.8228 and b = 1.5980 for BL fly ash
a = -0.6966 and b = 1.0455 for SC fly ash

so that once initial water content and initial height in settling of fly ashes are known, the final settlment height is calculated by above equation.

The existence of effective stress was estimated from the

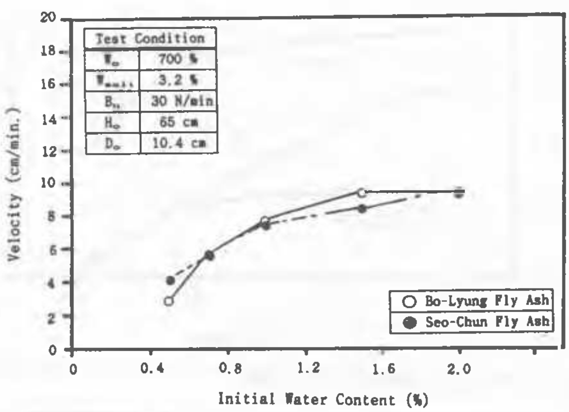

Fig 4.1 The relationship between initial water content and zone settling velocity

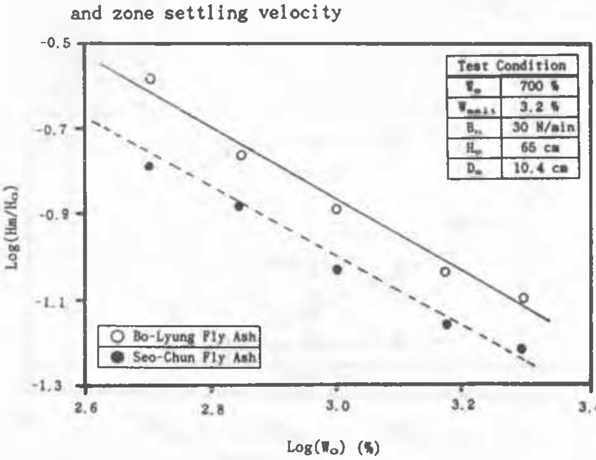

Fig 4.2 The rerationship between initial water content and settling height ratio

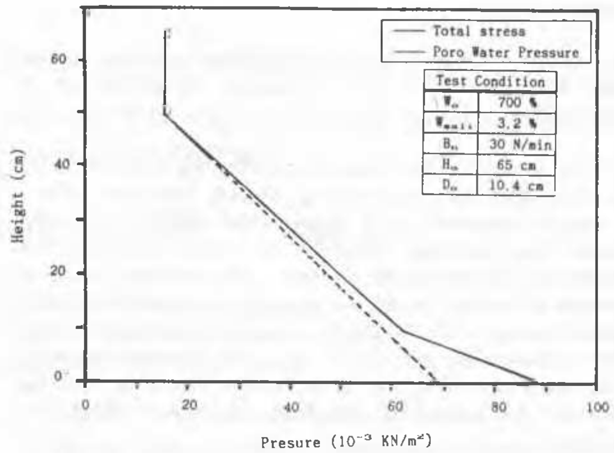

Fig 4.3 The variation of effective stress at 10 min. 30 sec.

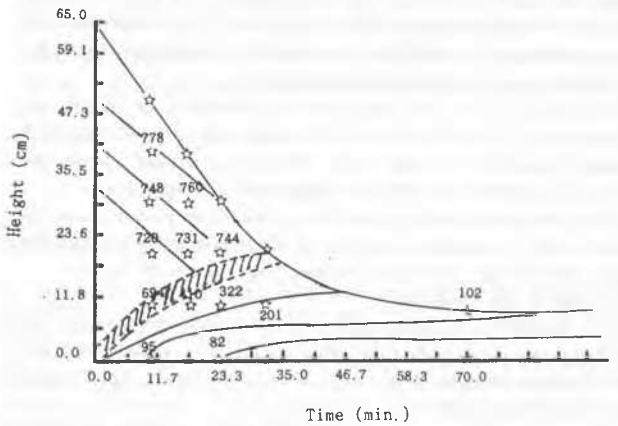

Fig 4.4 The distribution of constant water content at the zone settling

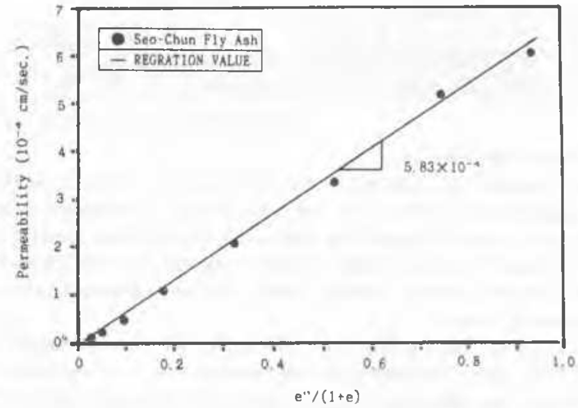

Fig 4.5 The relationship between $e^n/(1+e)$ and k during the consolidation of SC fly ash

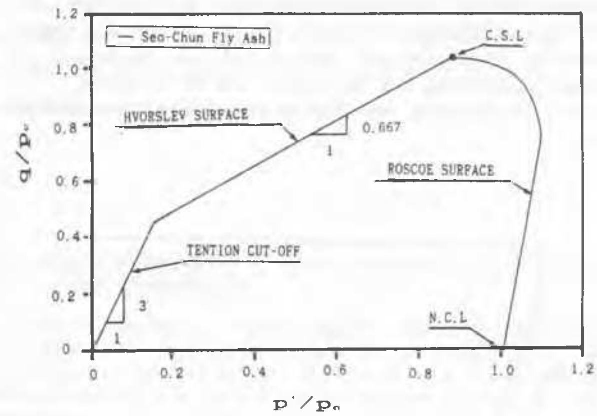

Fig 4.6 complete state boundary surface of SC fly ash

difference of water content and pore water pressure for each level. Fig 4.3 shows effective stress from difference between total stress and pore water pressure after 10 min 30 sec, and there exists 0.02 kN/m^2 of effective stress at the bottom. There also appears effective stress at the upper part with very small magnitude. Therefore, it is inferred that there exists effective stress during settling of fly ashes. Fig 4.4 shows distribution of constant water content at zone settling, obtained by connecting each point of water content for each level on height-Time plane.

At a large water content due to rapid settling of large particles after injection, the water content of suspension at upper part tends to be larger than that at the time of injection.

The shadow section corresponds to initial water content and there appears consolidaton by self-weight from the initial stage of settling. The water content decreased as time passes and the variation of water content becomes small in 100 min.

4.2 Characteristics of shear and Consolidation

To analyze the variation of permeability coefficient during consolidation void ratio(e), $e^n/(1+e)$, coefficient of volume change (M_v), coefficient of consolidation (C_v), and permeability coefficient(k) in each loads for Fly ashes were obtained. When the relationship between $e^n/(1+e)$ and k which are suggested by Samarasighe(1982), is applied in Coal ashes, the slope, n, shows 9.78 for BL and 11.8 for SC. Fig4.5 shows relationship btween $e^n/(1+e)$ and k. When k is considered as a function of e, $k=(0.101 + 0.287\ e^n/(1+e))\times10^{-4}$ at n=9.78 for BL, and $k=(0.16 + 5.83\ e^n/(1+e))\times10^{-4}$ at n=11.8 for SC. A range of void ratio in 1.1~1.6 for BL and 0.7~1.1 for SC. From experimental results of isotropic compression, the equations of specific volume and effective stress is as following :

In case of BL, $\nu_\lambda = 2.23 + 0.1149 \ln P'$
$\nu_\kappa = 1.98 + 0.0134 \ln P'$
In case of SC, $\nu_\lambda = 1.85 + 0.0764 \ln P'$
$\nu_\kappa = 1.68 + 0.0065 \ln P'$

The relationship between C_c and λ for fly ashes (generally, $C_c/\lambda=2.03$ for clay), is as following :

$C_c = 2.091\ \lambda$ for BL
$C_c = 2.368\ \lambda$ for SC

Table 4.1 shows the parameters of fly ashes from the experiment and Fig 4.6 shows the complete state boundary surface combined Roscoe surface from normally consolidation with Hvorslev surface from over consolidation of reconstituted fly ashes.

Table 4.1 The parameters of fly ashes from experiment

Ash	e_0	C_c	C_r	G_s	PI	λ	κ	M	H	Class.
B.L	1.68	0.225	0.031	2.17	N.P	0.1149	0.0134	1.13	0.712	ML
S.C	1.10	0.186	0.016	2.33	N.P	0.0764	0.0065	1.16	0.667	ML

4.3 Numerical Results

Fig 4.7 shows the comparison of the numerical result with the experimental result in the variation of average void ratio with time. Although the numerical anaysis was conducted by linear finite strain theory instead of non-linear finite strain theory, result shows a good agreement with experimental result.

However, referring to Fig 4.8, due to material characteristics of fly ash, the numerical estimation and the theorectical estimation obtained from the Cam-Clay Model and Modified Cam-Clay Model show some differences from experimental result. The numerical estimation of stress path does not correspond well to the experiment's results. Therefore, for the correct estimation of stress path of fly ash, it should be done by developing and appling the new parameters of material, considering the characteristics of fly ashes.

This will be possible from further experiments and studies later on.

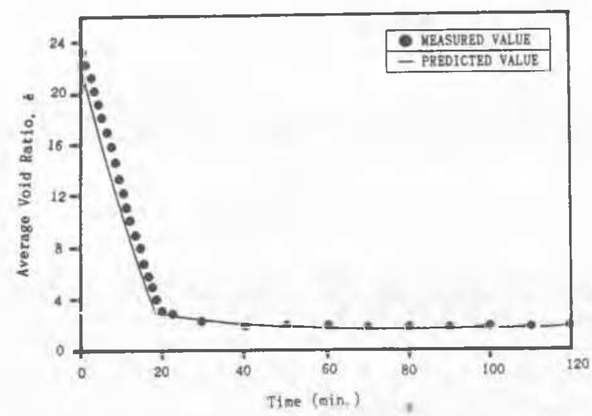

Fig 4.7 The comparison of the numerical result by SCP with experimental result

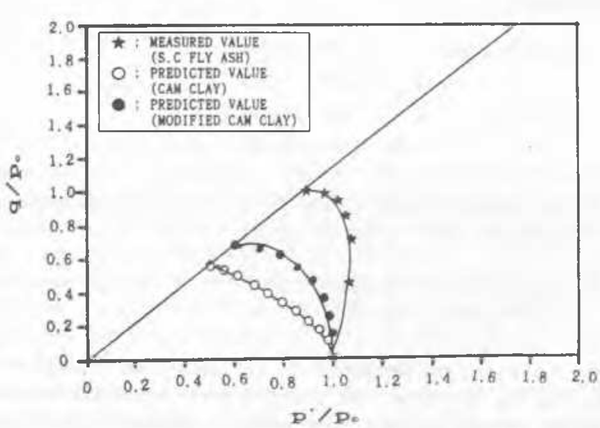

Fig 4.8 The comparison of the numerical result by CRISP with experimental result

5. CONCLUSION

The summary of experimental and numerical results on the usage of the Coal fly ash for seaside reclamation is as following :

1) It is observed that hindered settling is dominant at w_0 less than 1000% and free settling, showing indistinct settling zone is dominant at W_0 larger than 1000%. It is also observed that settling types of fly ashes are primarily affected by initial water content, and settling velocity increases as initial water content was increased. The relationship between V and W_0 for Fly ashes on the basis of W_0 = 1000% is shown from experiment. The final accumulation height decreases as the initial water content increases, and the equations for estimation of final settlement height is suggested.

2) Effective stress is generated during settling of fly ashes and confirmed from the distribution of water content and pore water pressure for each level. The variation of water content in settling container is obtained from the distribution of constant water content.

3) The equation for the variation of permeability coefficient according to void ratio of fly ashes and the relationship between specific volume and effective stress from the isotropic compression test are suggested in equation.

4) From the experimental results of one-dimensional consolidation test, isotropic compression test and Triaxial compression test on BL and SC fly ashes the values of C_0, C_r, λ, κ, M and H are obtained.

5) The numerical program, SCP, is developed to analyze the settling and consolidation behaviour of fly ashes, and the variation of average void ratio with time shows a good agreement with experiment result.

6) Stress path of fly ashes observed in the experiment shows some differences from the theorectical and numerical estimations. This disagreement resulted mainly from problems in deciding elastic limit and plastic limit artificially when dividing volume strain and shear strain in strain process. Fig 4.6 shows complete state boundary surface of fly ashes in the concept of critical state. Stress path always has a direction to critical state line (CSL) and a new state surface equation can be induced from this phenomenon.

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