The effect of weathering process to determination of residual shear strength of clay shale with triaxial multi-stage system

L'effet du processus de résistance aux intempéries sur la détermination de la résistance au cisaillement résiduel du schiste argileux avec un système triaxial à plusieurs étages

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ABSTRACT: The slope failure on clay shale with many joints under a layer of tuff breccia shortly after stress release due to cutting activity have triggered the need to investigate clay shale residual shear strength. A series of triaxial testing on undisturbed samples of clay shale have been performed to determine the residual stress for multi-stage system operation. In the first stage, residual shear strength without stress release were obtained. Then, testing continued by releasing whole-cell pressure. The triaxial test was proceed to the second multi-stage system to obtain residual shear strength parameters. Tests were conducted to investigate the effect of drying process to reduce residual shear strength up to 80 days. During the period, the maximum percentage of residual internal angle friction without stress release ($Ø_{urp}$) and residual internal angle friction with stress release ($Ø_{urf}$) were reduced by 11% and 5%, respectively. Both paremeters are compared to the peak shear strength condition.

RÉSUMÉ : La dégradation de la pente sur le schiste argileux avec de nombreux joints sous une couche de brèche de tuf peu de temps après la libération du stress due à l'activité de coupe a déclenché la nécessité d'étudier la résistance au cisaillement résiduel du schiste argileux. Une série de tests triaxiaux sur des échantillons non perturbés de schiste argileux ont été effectués pour déterminer la contrainte résiduelle pour le fonctionnement du système à plusieurs étages. Dans la première étape, on a obtenu une résistance au cisaillement résiduel sans libération de contrainte. Ensuite, les essais ont continué en libérant la pression de la cellule entière. L'essai triaxial est passé au deuxième système multi-étages pour obtenir des paramètres résiduels de résistance au cisaillement. Des essais ont été effectués pour étudier l'effet du processus de séchage pour réduire la résistance résiduelle au cisaillement jusqu'à 80 jours. Pendant la période, le pourcentage maximal de frottement d'angle interne résiduel sans libération de contrainte ($Ø_{urp}$) et le frottement d'angle interne résiduel avec libération de contrainte ($Ø_{urf}$) ont été réduits respectivement de 11% et 5%. Les deux para - mètres sont comparés à l 'état de résistance au cisaillement maximal.

KEYWORDS: Clay shale, residual shear strength, triaxial multi-stage system.

1 INTRODUCTION

The clay shale (algrillaceous rock) is sometimes called by claystone has a very high shear strength mainly in natural state prior to experience weathering process. Generally, slope on natural state clay shale is stable. However, most of sliding on clay shale deposit was reported due to overestimate shear strength parameters in design. Other causes were the unknown fracture line formed by previous slope failure in the past (Irsyam et al., 2011). The case of slope failure at STA 19+250 Toll Road Semarang-Bawen, Central of Java, Indonesia was caused by cut slope activity on clay shale deposit in order to establish roadbed, as shown on Figure 1. Prior to slope failure, it was detected many fracture line surfaces were found on the interface of tuff breccia and clay shale deposits, even on clay shale deposit alone. This condition caused clay shale weathered due to it reacts with hydrospher and atmospher (Sadisun et al., 2003). In this case, slope failure was occured by stress release due to cut slope activity and weathering on clay shale deposit.

In order to determine the residual shear strength prior to failure, it was conducted a back analysis by using both finite element method and limit equilibrium method. A series triaxial testing with multistage system was conducted by modeling the residual shear strength on slip surface with stress release and without stress release.

Figure 1. Slope failure on clay shale at STA 19+250 Semarang-Bawen tol road during construction (Himawan, 2013)

2 METHODOLOGY

The simulation of wheathered clay shale on laboratory was conducted by two methods, i.e., drying method and cycles of wetting and drying method. To obtain the effect of wheathering on degradation of shear strength of clay shale at both peak and residual stresses, it was done by triaxial test with a way such as shown in Table 1.

Table 1. Triaxial test on clay shale with variation of weathering and sample conditions (Alatas, 2017)

Weathering process	Peak strength (using 3 samples)	Residual strength using multistage		Stress condition	
		With stress release	Without stress release	Total stress	Effective stress
Drying process, until 80 days	Unsaturation	✓	✓	✓	---
	Saturation	✓	✓	✓	✓
Wetting and drying process cyles, until 24 days	Unsaturation	✓	✓	✓	---

Three undisturbed samples of clay shale through weathering process (drying process and cycles of wetting and drying process) were tested by Unconsolidated Undrained (UU) Triaxial to determine their shear strength at peak stress condition. For each sample, after reach its peak stress, deviatoric stress decreases rapidly until a limit of certain stress as shown on Figure 2. In this figure, conditions after peak stress and a constant deviatoric stress with strain are shown as zone A. The constant deviatoric stress with strain is defined as condition of initial residual stress. Instantly, after zone A condition, the cell pressure was increased gradually by using multistage method. On this stage, it was obtained residual shear strength without stress release (c_{rp} dan ϕ_{rp}). As shown in Figure 2, for the first sample, the confining stress was increased from 39 kN/m^2 to 78 kN/m^2 until the stress condition was stable. Then, the test was continued to second sample by increasing confining pressure from 78 to 118 kN/m^2 and lasted third sample with confining pressure 118 to 157 kN/m^2. Similar procedure have been performed for the next stage to three samples, as shown in Figure 2 as zone B. After third stage, all confining pressures were then returned to zero (i.e., stress release) and the test was continued using gradually increase confining pressure to obtain residual shear strength after unloading. This condition is shown as zone C for residual stress with stress release.

3 SHEAR STRENGTH DEGRADATION OF SEMARANG-BAWEN CLAYSHALE

Peak shear strength, residual shear strength without stress release and residual shear strength with stress release degradation due to weathering process with drying process and cycles of wetting and drying processes on Semarang-Bawen clay shale as shown in Figure 3 and Figure 4. Figure 3 shows degradation of shear strength parameters, cohesion and internal friction angle. Figure 4 exhibits degradation of residual shear strength parameters. In the figure, it can be seen clearly that shear strength degradation due to wheathering caused by cycles of wetting and drying is more faster than caused by drying only.

4 BACK ANALYSIS ON SLOPE FAILURE CASE IN SEMARANG-BAWEN TOLL ROAD STA 19+250

Slope failure occured at STA 19+250 of Semarang-Bawen Toll Road during construction. The failure was triggered by cut slope activity on clay shale deposit. It was predicted that main cause of failure is fracture line formed in the past slope failure at the area.

In order to simulate the initial condition of slope, prior to failure, it was conducted a back analysis by using Finite Element Method (FEM) and Limit Equilibrium Method (LEM).

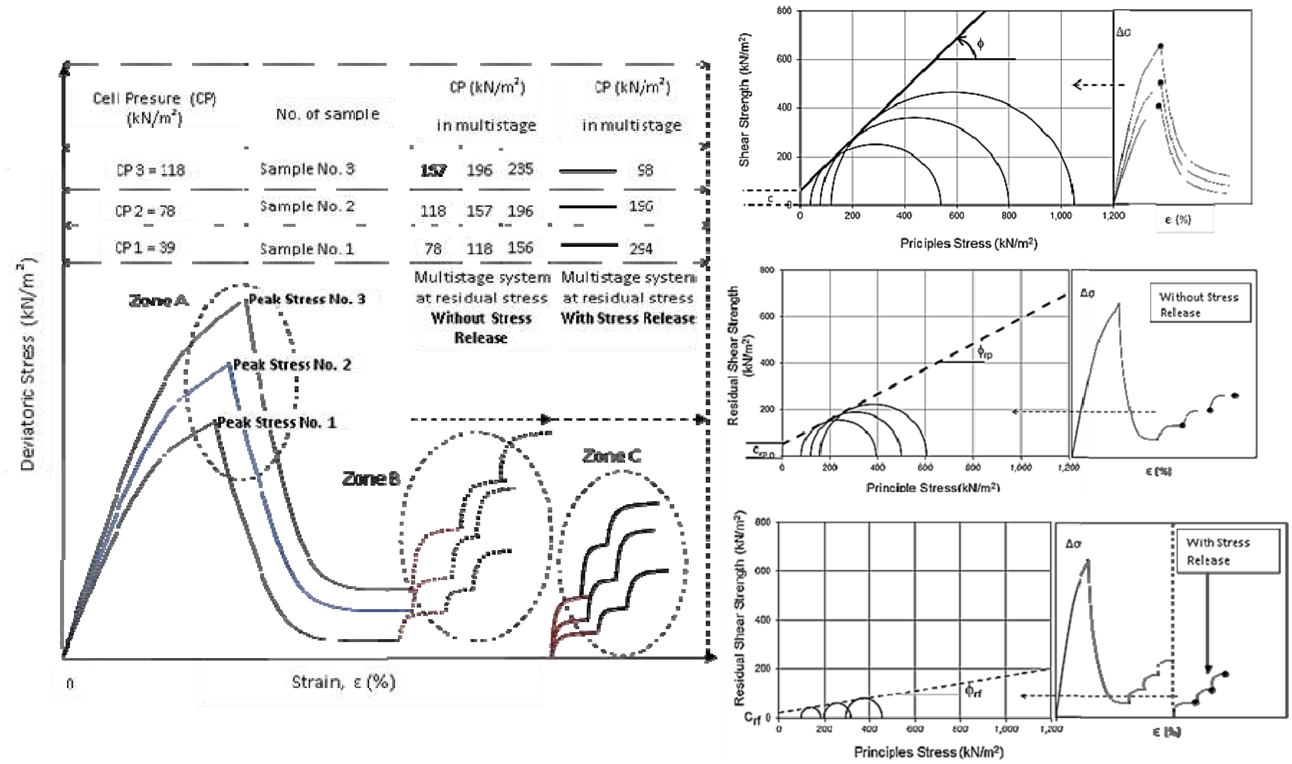

Figure 2. Stress strain at peak stress and residual stress wihout stress release and residual stress without stress release (Alatas et al., 2017)

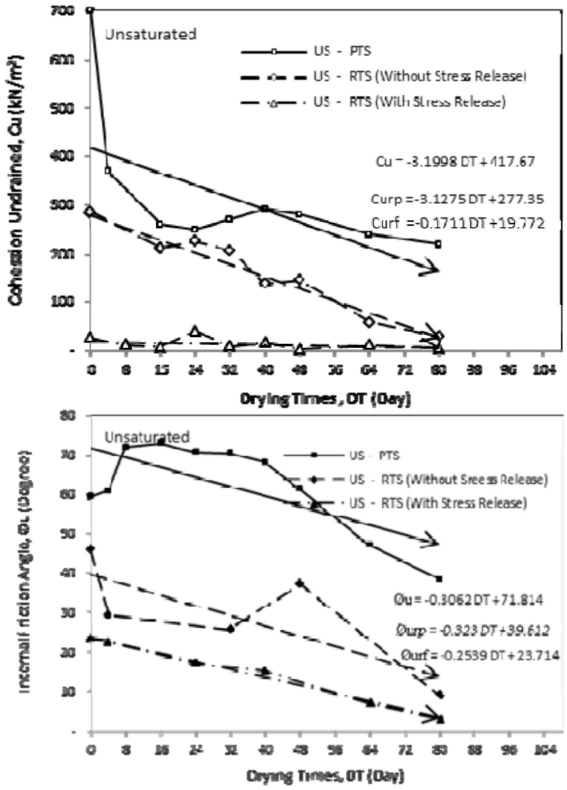

Figure 3. Shear strength degradation Semarang-Bawen clay shale due to drying process (Alatas, 2015 b)

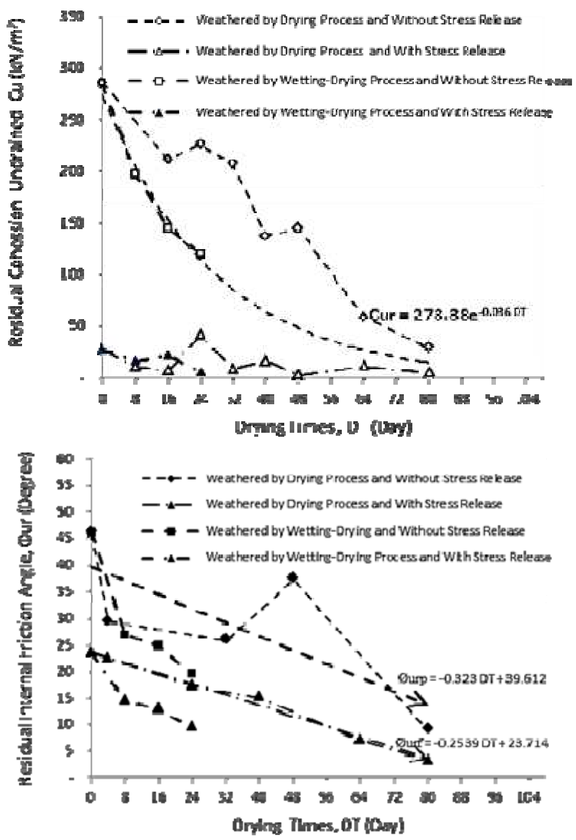

Figure 4. Degradation of residual shear strength between drying process and cycles of wetting and drying process Semarang-Bawen clay shale (Alatas, 2015 a)

Residual shear strength was obtained from laboratory test both without stress release and with stress release are plotted in the same figure with the result from FEM and LEM. The effect of weathering both drying process and cycles wetting and drying process is also included in the same figure, as shown in Figure 5.

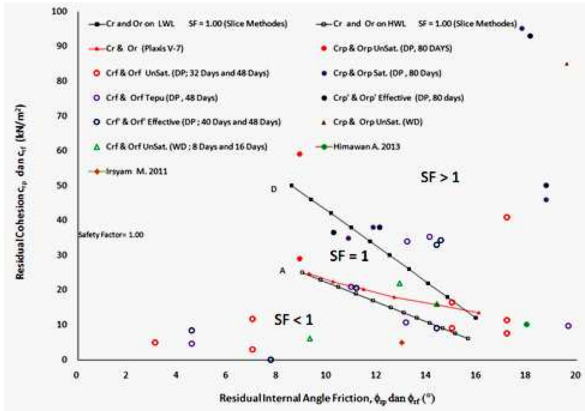

Figure 5 Back analysis methods compared with laboratory residual shear strength parameter (Alatas, 2017)

Weathering simulation on laboratory by drying and cycles wetting and drying for Semarang-Bawen clay shale exhibits the effectiveness for determine residual shear strength on laboratory. It is indicated by a good agreement with results from back analysis. Table 2 shows the weathering simulation method with variation on weathering time necessary to obtain the same residual shear strength which resulted by back analysis during slope failure occured at STA 19+250 Semarang-Bawen toll road.

Table 2. Type of weatherting process and sample condition to make safety factor, SF =1.00 (Alatas, 2017)

Weathering Time (days)	Weathering Process		Condition Triaxial Sample	Residual Shear Strength	
	DP	WD		Wihout Stress Release	With Stress Release
80	✓		Unsaturated	✓	---
80	✓		Saturated	✓	---
80	✓		Saturated	✓(effective)	---
48	✓		Unsaturated	---	✓
48	✓		Saturated	---	✓(effective)
40	✓		Saturated	---	✓
32	✓		Unsaturated	---	✓
8		✓	Unsaturated	---	✓
16		✓	Unsaturated	---	✓

Remarks : DP is Drying Process and WD is Wetting Drying process

5 CONCLUSIONS

From this study, it can be drawn the following conclusions.

1. A proper simulation of weathering process in laboratory is very important to estimate the residual shear strength of clay shale. A proper shear strength parameters which used in slope stability calculation for clay shale deposit to be key in repairing cut slope after failure.
2. Cycles of wetting and drying processes until 16 days with 2 times soaked every 8 days within 5 minutes will be reccomended to prepare triaxial testing samples. However,

drying process needs a longer time within range of 32 to 80 days.

3. During the drying period, the maximum percentage of residual internal angle friction without stress release ($Ø_{urp}$) and residual internal angle friction with stress release ($Ø_{urf}$) were reduced by 11% and 5%, respectively. Both paremeters are compared to the peak shear strength condition.
4. Determination of residual shear strength with stress release is supposed as a proper method to use in slope stability calculation for clay shale deposit in case of fracture line was formed in the past failure of slope.

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7 REFERENCES

Alatas I. M. 2017. Kesan Luluhawa Terhadap Kekuatan Ricih Syal Lempung Dalam Penentuan Parameter Kestabilan Cerun. Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia. (in Malaysian)

Alatas I.M., Samira A. K., Ramli N. and Irsyam M. 2015 a. Effect Of The Weathering on Disintegration and Shear Strength Reduction of Clay Shale. Paper presented at The Manuscript Paper For : "Geotropika 2016".

Alatas I.M., Samira, A. K., Ramli, N., Irsyam, M. and Himawan, A. 2015 b. Shear Strength Degradation of Semarang-Bawen Clayshale Due to Weathering Process. *Jurnal Teknologi (Sciences and Engineering) Special Edition , acceptance September 2015*.

Himawan A. 2013. Alternatif Mitigasi Kelongsoran dan Perkuatan Lereng Galian Tower SUTT STA 19+255 Pembangunan Jalan Tol Semarang - Solo Tahap I Ruas Ungaran - Bawen Paket V Tinalun - Lemah Ireng STA 18+000 - 21+825 In *Technical Report* LAPI ITB PT. (in Indonesian)

Irsyam M., Jayaputra.A.A., Himawan A. and Kartawiria A. 2011. Kasus-Kasus Kelongsoran Pada Tanah Clay Shale dan Alternatif Penanggulangannya. *Proceeding of the 9th Indonesian Society for Geotechnical Engineers Conference and 15th Yearly Scientific Meeting, Jakarta*. (in Indonesian)

Sadisun I.A, Hideki.S., Masatomo I. and Kikuo M. 2003. Experimental Insights on the Characteristics of Rock Slaking with Particular Reference to the Sedimentary Argillaceous Rocks. *Department of Geology, Institut Teknologi Bandung, INDONESIA*.