Shear strength testing under constant normal load and constant normal stiffness as affected by displacement rates.

P.Meemun* and K. Fuenkajorn

Geomechanics Research Unit, Suranaree University of Technology
111 University Avenue, NakhonRatchasima 30000, Thailand
* pinid_meemun@hotmail.com

Abstract

The objective of this study is to determine shear strengths of factures under constant normal loads (CNL) and constant normal stiffness (CNS) conditions as affected by displacement rates. The rock specimens are prepared from Saraburi marble with the nominal dimensions of $100 \times 100 \times 180$ mm^3. The fracture area is about 100×90 mm^2. The fractures are artificially made in the laboratory by tension induce method. The direct shear test is performed with constant normal stresses at 0.5, 1.0, 1.5 and 2.0 MPa using thetriaxial loading frame. The applied shear displacement rates are 10^{-4} to 10^{-1} mm/s. The results indicate that the higher shear displacement rates have affected to the peak shear stresses are increaseunder CNL and CNScondition. The higher initial normal stresses have affected the shear strength and the normal displacement than the lower initial normal stresses for CNL and CNS condition. The CNS condition shows higher peak shear strength than the CNL condition. The higher initial normal stress and higher shear displacement rate give the higher peak shear strength. The CNS condition shows the effect of rock joint roughness more than the CNL condition. The conduct of CNL and CNS test conditions is shown as the effect on peak shear strength (τ_p), cohesion (c) and friction angle (ϕ).

Keywords: Rock joint, Shear test, Dilations, Cohesion.

1. Introduction

The presence of joints in the rock can affect its mechanical behavior, depending on the underground situation. When dilation of the rock joint during shearing is constrained or partially constrained, an increase in the normal stress over the shear plane occurs, which substantially increases the shear resistance. An underground excavation is potentially unstable rock blocks are constrained between two parallel dilatant rocks (Indraratna et al., 1999). The sliding of such blocks inevitably increases the normal stress, and also, dilation becomes significant if the joint surfaces are rough. The increase in normal stress on the shear plane is equal to k_n andδ_v, where k_n is normal stiffness of the surrounding rock mass, and δ_v is the dilation (Indraratna et al., 2000). The testing conducted under constant normal load (CNL) condition yield shear strengths that are too low for such practical situations. Another situation where the normal load changes during shearing is the earthquake shaking of slope, where the direction of shearing and the magnitude of normal load on any potential sliding plane are variable during shaking. In general, the CNL condition is only realistic for shearing of planar interfaces, where the normal stress applied to the shear plane remains relatively constant such as in the case of rock slope stability problems. For thesesituations development of shear resistance is a function of constant normal stiffness (CNS), and the use of CNL test results for such cases leads to underestimated shear strengths.

The objective of this study is to determine shear strengths of factures under constant normal loads (CNL) and constant normal stiffness (CNS) conditions as affected by displacement rates. The results from laboratory measurements in terms of constant normal load, constant normal stiffness, stress states and shear displacement are compared. Similarity and discrepancies are identified. Such relation is useful in the stability analysis of engineering structures on and in geologic media, such as tunnels, underground mines and dam foundations.

2. Sample preparation

The rock specimens used in this study ares araburi marble. The rock specimens have been prepared to obtain rectangular block specimens with the nominal dimensions of $100 \times 100 \times 230$ mm^3. The fracture surfaces have an area is 100×90 mm^2 is prepared for CNL testing. The nominal dimensions are $100 \times 100 \times 180$ mm^3. The fracture surface with an area is 100×90 mm^2 for CNS testing as shown in Fig.1. The fractures are artificially made in the laboratory by tension-induced fracture method as shown in Fig. 2.
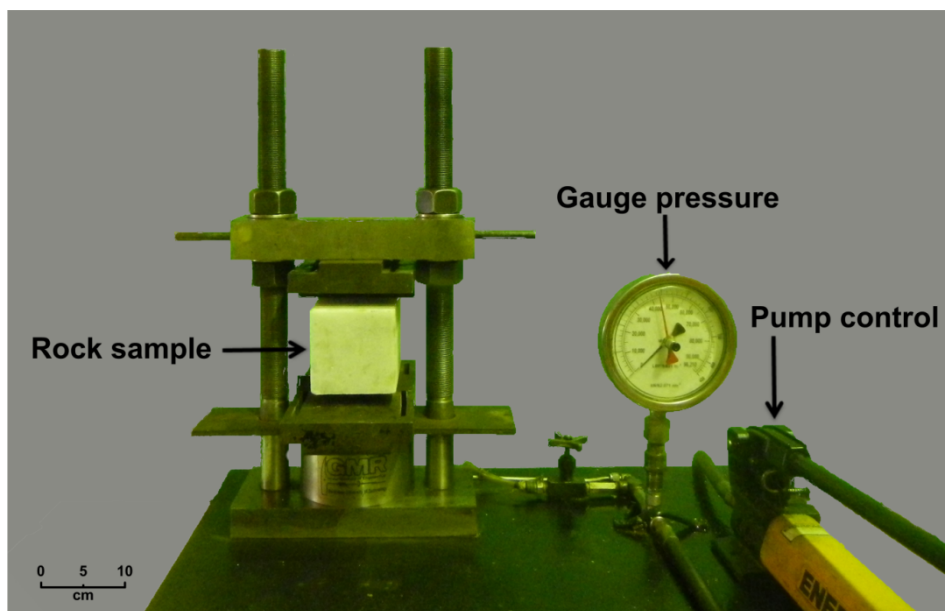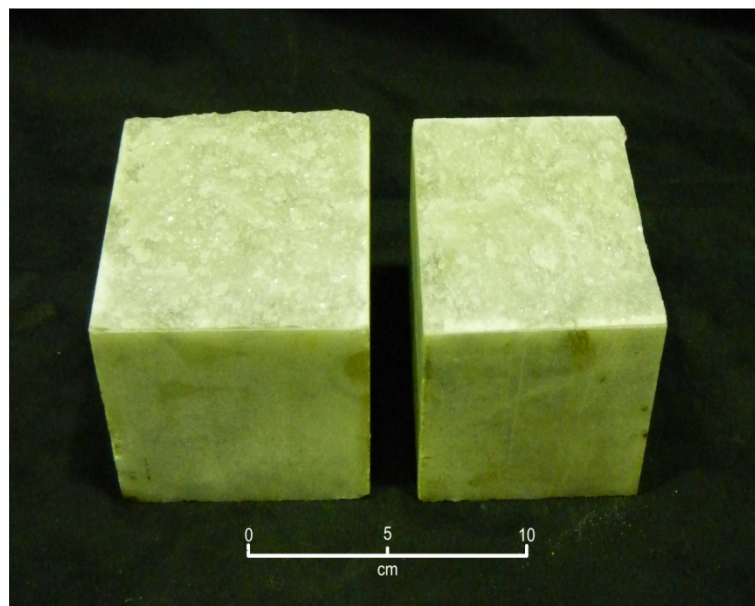

Fig. 1. Rock specimen.

Fig. 2. Tension-induced fracture by line load technique.

3. Testing Equipment and Method

The triaxial shear tests are performed to determine the shear strength and to develop sliding criterion of the fracture. Neoprene sheets are used to minimize the friction at all interfaces between the loading plate and the rock surface. A true triaxial load frame (Fuenkajornandkomenthammasopon, 2014) is used to apply true triaxial stress to the specimens (Fig. 3). The true triaxial load frame has

mutually perpendicular 3 pairs of steel plates. Four pillars secure each pair. Each pair has spacing about 61 cm^2. The steel plates have dimension of 43×43×4 cm^3 and other two are 30×30×6 cm^2. Six hydraulic load cells have capacity of 10,000 psi. Diameter of hydraulic load cell is 9 cm^2. One of the lateral(horizontal) stresses is set perpendicular to the fractures plane, which is designated as normal stress (σ_n). The shear stress (τ) is applied by top hydraulic load cell. The bottom hydraulic pump is fixed. Two dial gages are used for monitoring the normal and shear displacement. Fig. 4 shows the cross-section of the true triaxial load frame.
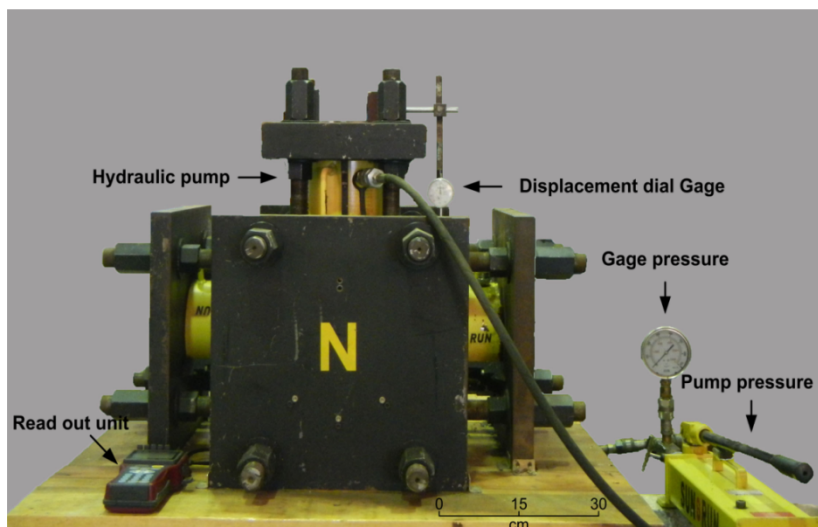

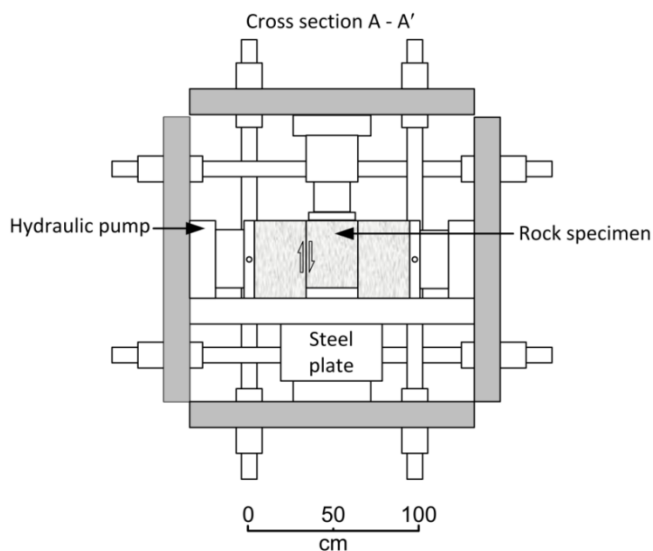Fig.3. True triaxial load frame used in this study (Fuenkajornandkomenthammasopon, 2014).

Fig.4. Cross-section of truetriaxial load frame for tested (Fuenkajornandkomenthammasopon, 2014).

4. Test Results

The shear behavior of rock joints based on test results has been performed in geomechanics research unit laboratory, and used the true triaxial load frame. The created fractures on rock specimens are made by tension-induced method. The rock specimens have been subjected to CNL test and CNS test. The test results for the CNL and CNS conditionsare presented as a function of shear displacement rates.

4.1.CNL conditions

Fig. 5 showsthe shear stresses as a function of shear displacement for various shear displacement rates ($\delta d_s/\delta t$). Fig. 6shows the normal displacementasa function of shear displacement for various shear displacement rates ($\delta d_s/\delta t$). Table 1 summarizes the peak shear stresses for all displacement rates. The higher shear displacement rates applied the higher the peak shear stresses are obtained. The higher initial normal stresses affected on shear stresses and normal displacement more than the lower initial normal stresses.
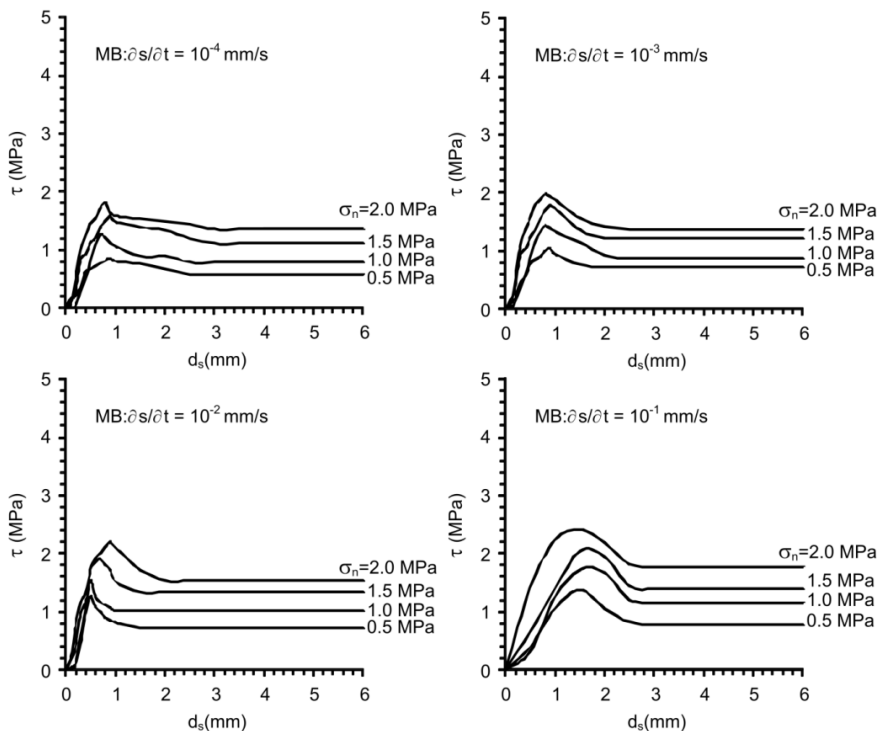

Fig.5. Shear stresses as a function of shear displacement for CNL tests.
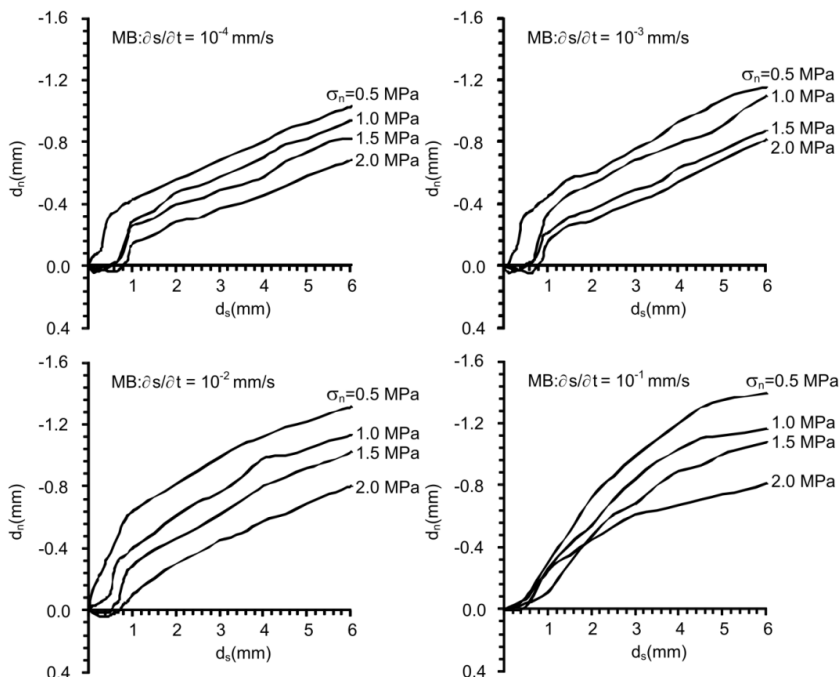

Fig.6. Normal displacements as a function of shear displacement for CNL tests.

Table 1. Peak shear stresses for all displacement rates under CNL conditions.

$\delta d_s/\delta t$(mm/s)	Peak Shear Stresses (MPa)			
	σ_n=0.5	1.0	1.5	2.0
0.0001	0.861	1.267	1.580	1.819
0.001	1.048	1.431	1.781	1.975
0.01	1.267	1.538	1.909	2.251
0.1	1.377	1.718	2.039	2.408

4.2.CNS conditions

Fig. 7 showsthe shear stresses as a function of shear displacement for various shear displacement rates ($\delta d_s/\delta t$). Fig. 8 showsthe normal displacement as a function of shear displacement for various shear displacement rates ($\delta d_s/\delta t$). Table 2 summarizes the peak shear stresses for all displacement rates. The higher shear displacement rates have affected to the peak shear stresses are increase. The higher initial normal stresses have affected on shear stresses and normal displacement than lower initial normal stresses.
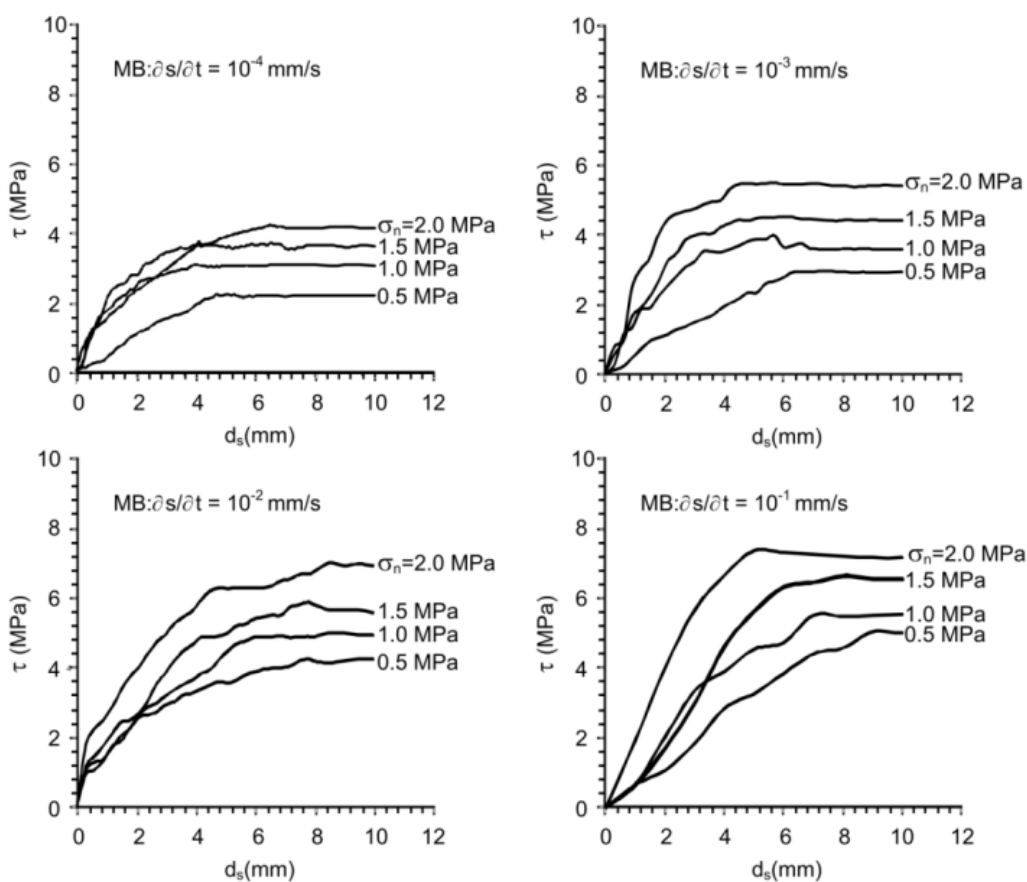

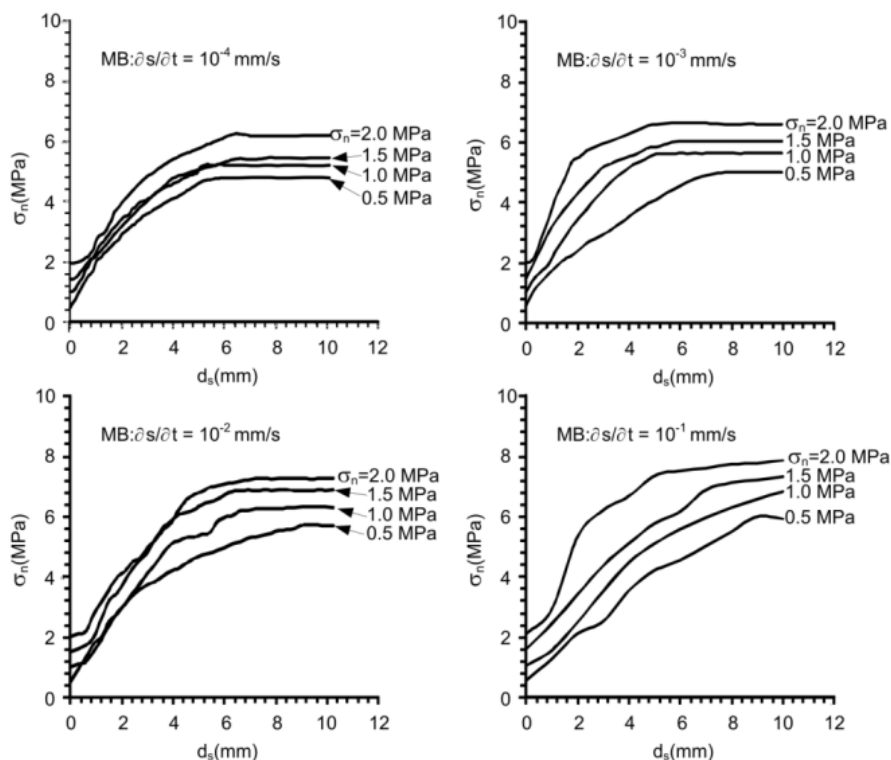Fig.7. Shear stresses as a function of shear displacement for CNS tests.

Fig.8. Normal stresses as a function of shear displacement for CNS tests.

Table 2. Peak shear stresses for all displacement rates under CNS conditions.

$\delta d_s/\delta t$(mm/s)	Peak Shear Stresses (MPa)			
	σ_n=0.5	1.0	1.5	2.0
0.0001	2.550	3.182	3.837	4.733
0.001	2.958	3.980	4.570	5.413
0.01	4.128	4.980	5.857	6.680
0.1	5.038	5.532	6.647	7.370

4.3.Conductunder CNL and CNS conditions.

The test results have the difference between the CNL and CNS conditions. Fig. 9 shows the peak shear strengths between CNL and CNS conditions as a function of shear displacement rates.The CNS condition shows higher peak strength, friction angle and cohesionthan the CNL conditions. The CNS has higher peak shear strength than CNL conditions. Fig. 10 and 11 show the cohesions and frictions angle between CNL and CNS conditions as a function of shear displacement rates. Table 3summarizes the cohesions and frictions angles for all displacement rates.
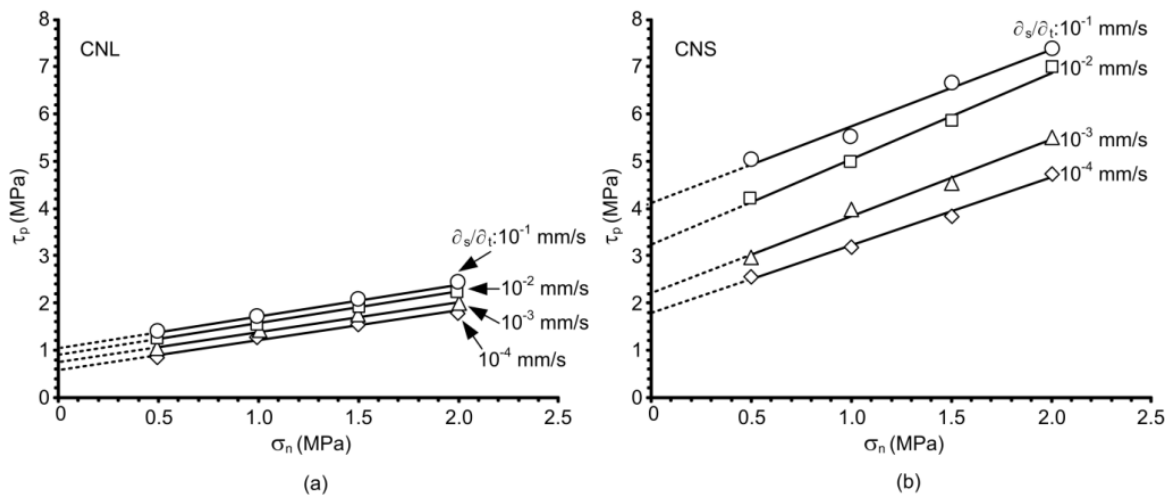
Fig.9. Shear strengths as a function of shear displacement rate, (a) CNL conditions, (b) CNS conditions.
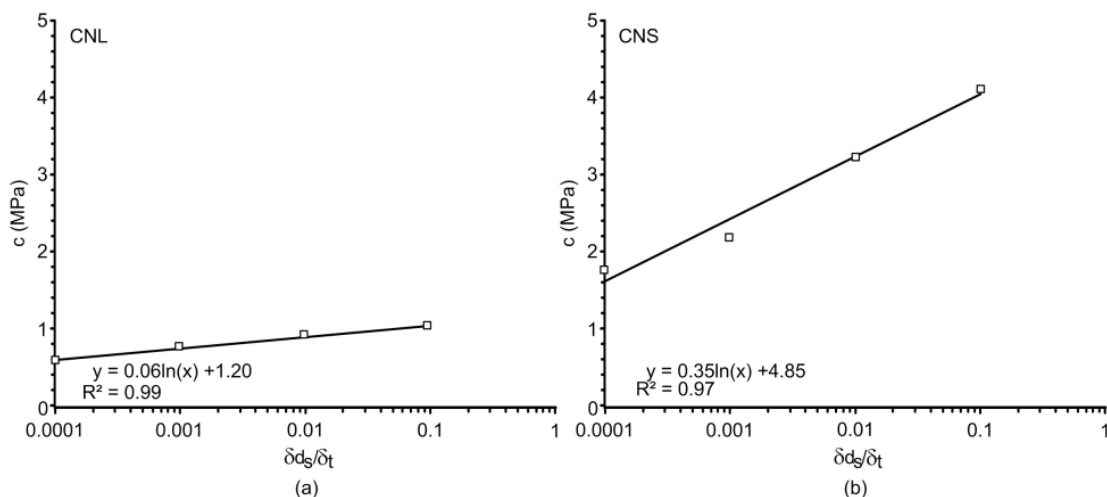

Fig.10. Cohesions as a function of shear displacement rates,(a) CNL conditions, (b) CNS conditions.
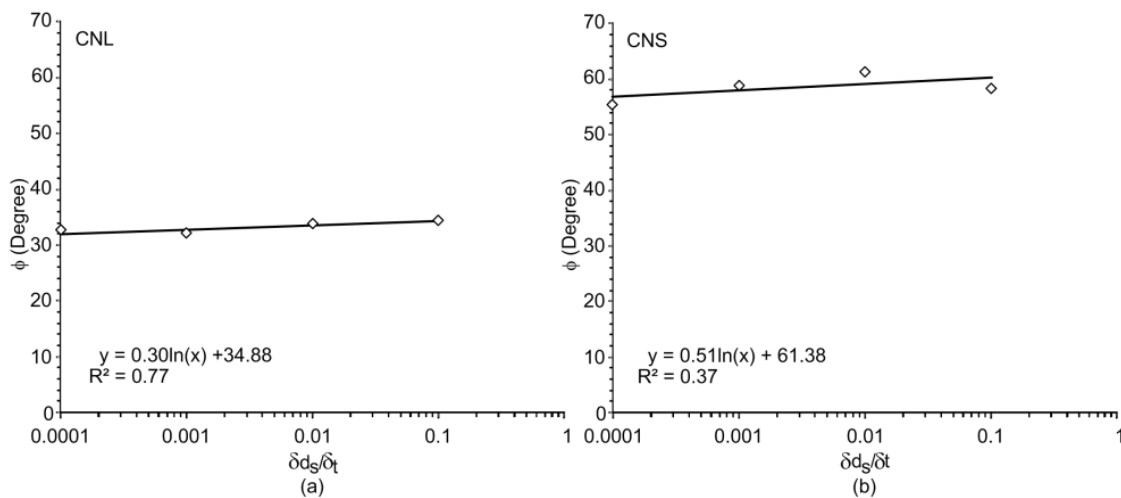

Fig.11. Friction angle as a function of shear displacement rates,(a) CNL conditions, (b) CNS conditions.

Table 3. The cohesions and frictions angle for all displacement rates and all conditions.

$\delta d_s/\delta t$(mm/s)	CNL conditions		CNS conditions	
	ϕ (Degree)	c (MPa)	ϕ (Degree)	c (MPa)
0.0001	32.51	0.585	58.31	4.12
0.001	32.05	0.776	59.68	3.28
0.01	33.61	0.911	58.78	2.19
0.1	34.32	1.032	55.22	1.77

5. Discussions and Conclusions

The shear displacement rates can affect the shear strengths of the tension-induced fractures. The Coulomb criterion can well describe the joint shear strengths of the rocks under the shear displacement rates ranging from 10^{-4} to 10^{-1} mm/s with the initial normal stresses from 0.5, 1.0, 1.5 and 2.0 MPa. As a result the cohesion and friction angle obtained from the coulomb criterion can be correlated among different shear displacement rates. The higher initial normal stress and higher shear displacement rateare applied the peak shear strength is increase. Fracture shear strength under CNS conditions is higher than under the CNL conditions. This implies that the sliding resistant under confined conditions such as aroundthe deepunderground opening greater than under the unconfined condition (e.g. on slope, embankment)

Acknowledgements

References

ASTM D5607-08., Standard test method for performing laboratory direct shear strength tests of rock specimens under constant normal force, *Annual Book of ASTM Standards.*, Vol. 04.08.West Conshohocken, PA.

Komenthammasopon, S., Fuenkajorn, K., 2014, Effect of stress path on biaxial strengths of three Thai sandstones, *International conference on advances in civil engineering for sustainable development., 249-253.*

Indraratna, B., haque A.,1999, Experiment study of shear behavior of rock joints under constant normal stiffness conditions. , *Int. J. Rock Mech. Min. Sci.*, 34 (3-4): 141.e1-141.e15.

Indraratna, B., haque A.,2000, Shear behavior of clean rock joint. *Shear behavior of rock joints*, pp.17-51.