Simulation study on physical-mechanical parameters of argillaceous fault gouge

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Abstract: The physical−mechanical parameters of argillaceous intercalation (fault gouge, weak intercalated gouge and slip zone soil etc.) are very important for stability evaluation of rock mass. A large number of studies show that there is better relationship between the physical−mechanical properties of intercalated gouge and its natural confining pressure. Therefore, the simulation study of intercalated gouge in the laboratory, using the compression law of soil and the principle of gravity compaction of sediments is put forward and the simulation effectiveness is evaluated. The study provides a new way for evaluating and predicting the physical−mechanical parameters of intercalated gouge in weak−layer zones.

Résumé: Les paramètres physico-mécaniques des intercalations argileuses sont indispensables pur l'évaluation de la stabilité des mass de roche. Des études démontrent qu'il existe une bonne relation entre les propriétés physico-mécaniques des argiles intercalées et les pressions naturelles entourantes. En utilisant la loi de compression du sol et le principe de compaction de gravité pour des sédiments, nous avons effectué une étude simulative sur les caractéristiques physico-mécaniques des argiles intercalées. Cette étude fournira une méthode nouvelle pour évaluer et prévoir les paramétres physico-mécaniques des argiles intercalées dans des zones de couches faibles.

Keywords: mechanical properties, confining pressure, laboratory studies, compaction, shear strength, soil

INTRODUCTION

Argillaceous intercalation (fault gouge, intercalated gouge and slip zone soil) existed in rock mass is the worst part in engineering characteristics, and its physical−mechanical properties are important to evaluate the stability and engineering design of rock mass. For a long time, the applied mechanical parameters of argillaceous intercalation are relatively low because overestimation of groundwater's softening and argillization effect on argillaceous material and ignoring the role of control and protection of natural confining pressure caused by stress field in the Earth's crust.

A great deal of study indicate that the argillization of argillaceous intercalation caused by the relief of confining pressure can be avoided if adopting special sampling and testing method (Xiangong Zhang & Dexin Nie 1990, Zhuoyuan Zhang & Dexin Nie 1993, Wenxi Fu, Dexin Nie & Yuequan Shang 2002). Test results of successive samples in exploration adits and dam abutment show that intercalated gouge possess better physical−mechanical properties under natural confining pressure (Table1). Dry density and friction coefficient of argillaceous intercalation increase in company with confining pressure, but pore ratio and water content decrease, there are well relativity between these physical−mechanical parameters and natural confining pressure (Figures 1 and 2). To demonstrate the above−mentioned conclusions, disturbed samples PD37-112, PD42-90, F73, T_{66} are selected to simulate the forming process of argillaceous intercalation's physical−mechanical properties under natural condition by consolidation test in laboratory. This kind of test can be called simulation test. The simulation study results show that intercalated gouge's physical−mechanical properties basing on compression law of soil and the principle of gravity compaction are very consistent with those values under natural condition. All these proved the feasibility of simulation study.

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Table 1. Physical−mechanical indices of intercalated gouge under different confining pressure

Sample No.	Type of weak intercalation	Clay mineral composition	Physical properties						Shearing strength		Confining pressure state
			Water content *w*(%)	Density (Mg/m^3)	Dry density (Mg/m^3)	Porosity ratio *e*	Plastic limit W_p(%)	Liquid limit W_l(%)	Friction coefficient *f*	Cohesive force 100KPa	
PD37-112	weak interc-alation	glimmerton,chlorite,a little montmorillonite	15.31	1.964	1.703	0.632	16.87	29.28	0.383	56.6	exposure in adit
			9.0	2.31	2.119	0.319	14.48	27.71	0.545	62	higher confining pressure
			7.58	2.345	2.176	0.277	16.8	29.1	0.561	64.8	deep confining pressure
PD42-90	slip zone soil	glimmerton,chlorite, montmorillonite	13.73	2.212	1.945	0.429	20.42	35.8	0.423	26.7	buried depth 72.5m
S_{66}			13.04	2.102	1.86	0.489	23.0	34.0	0.416	17.5	buried depth 40.5m
S_{52}			17.5	2.10	1.79	0.575	23.3	41.1	0.363	42.8	buried depth 30.6m
f_{26}	fault	glimmerton,chlorite	30.3	1.746	1.34	0.83	16.7	34.8	0.08	5.5	0.34MPa
			5.75	2.27	2.15	0.265	16.3	33.3	0.565	9.2	5.65MPa
F_{73}	fault	montmorillonite, glimmerton,chlorite	23.6	2.06	1.66	0.64	28.8	53.1	0.398	47	buried depth 50m
			19.8	2.12	1.77	0.539	28.5	50.8	0.507	63.7	buried depth 103m
			16.9	2.13	1.82	0.495	28.5	50.8	0.61	73.4	buried depth 142m
T_{66}	intercalation	almost montmorillonite	34.8	1.47	1.09	1.569	30.8	81.3	0.152	34.0	intensely weathered zone
			24.4	1.98	1.59	0.748	32.6	62.6	0.43	23.0	higher confining pressure
			21.6	1.98	1.624	0.711	35.2	63.3	0.583	83.0	deep confining pressure

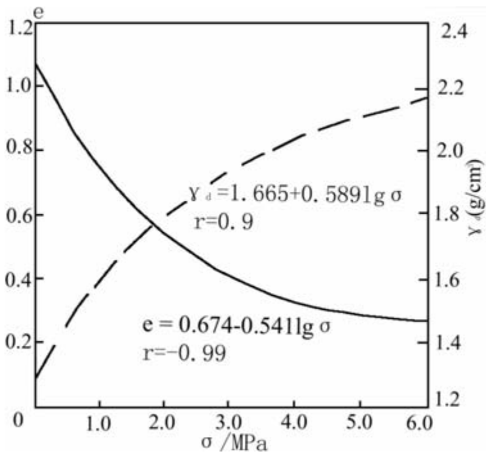

Figure 1. Relationship between the natural confining pressure (σ) and porosity ratio (*e*) or dry density(γ_d) of fault f_{26} gouge

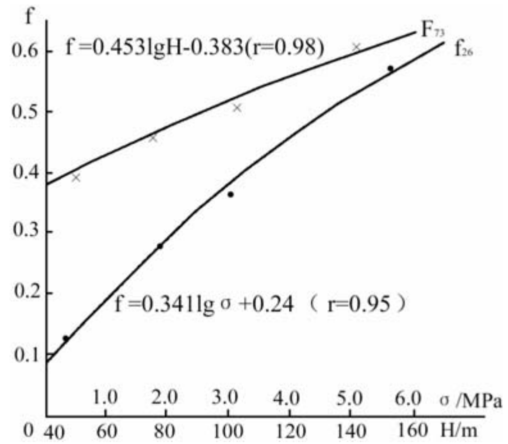

Figure 2. Relationship between the friction coefficient (f) and natural confining pressure (σ)or buried depth (H) of fault gouge

SIMULATION STUDY OF PHYSICAL-MECHANICAL PROPERTIES OF INTERCALATED GOUGE IN LAYERED WEAK ZONES

Feasibility analysis

Quantities of research results indicate that the porosity ratio (*e*) of intercalated gouge in layered weak zones is decreasing under the normal stress (*P*), just like that kind of soils, which possess condensibility. The relation between *e* and *P* is as following : $e=a-b\lg P$, Here *a* and *b* are constants(Defang Kong 1992).

The porosity ratio of soils and stress (greater than relaxation stress) follow a logarithmic relationship whatever the initial porosity ratio is. Research on compaction of argillaceous sediments carried out by Rieke & Chilingarian (1984) showed that the compaction is of great importance in the course of diagenesis. Under the action of cover load, dehydration, compression and consolidation occurred in the sediments, so the dry density increased with the increasing of depth while the porosity decreased (Rieke & Chilingarian 1982) (Figure 3), simultaneously, the state of argillaceous sediments varied from viscosity to plastic−elastic-plasticity and elasticity, and the strength, ability against deformation increased gradually (Table 2). During the course, porosity ratio, dry density and water content can be selected as quantitative index, which demonstrate the consolidation degree.

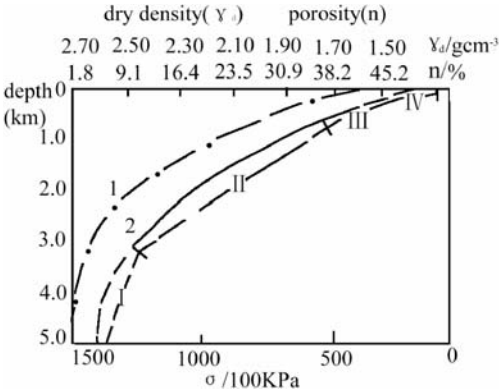

Figure 3. Variation of porosity and dry density of argillaceous sediments with depth
I. phase of most difficult to compact, II. phase of more difficult to compact, III. phase of difficult to compact, IV. phase of easy to compact.

Table 2. Variation of physical−mechanical properties of argillaceous sediments under gravity compaction

porosity	water content(%)	state	deformation modulus/MPa	internal friction angle/(°)	cohesive force/MPa
70-90	$W >> W_L$	viscosity-flow	0.3-1.0	0-5	<0.01
55-70	$W > W_L$	viscosity	1-3	5-12	0.01-0.03
40-55	$W_P < W < W_L$	plasticity	3-10	10-20	0.03-0.08
30-40	$W \le W_P$	elastic-plasticity	10-30	14-26	0.08-0.2
25-30	$W << W_P$	elasticity	30-100	22-28	0.2-1.0

After the intercalated gouge formed, the normal stress acted on its plane resumed. Under the impact of this normal stress, compaction and consolidation would happen in intercalated gouge, and made its physical-mechanical properties suitable to the stress state, this mechanism is similar with the compaction of sediments under the action of gravity. Therefore, it is feasible for us to carry out experiment like this. Firstly, modulate the water content of intercalated gouge disturbed samples approximating to its liquid limit, then high pressure consolidation tests are prosecuted in high pressure consolidation apparatus in order to simulate the process of water discharging, porosity ratio decreasing, density increasing. Physical-mechanical properties of intercalated gouge (such as water content, dry density and porosity ratio) under different pressure levels can be obtained.

Simulation study on physical properties of intercalated gouge

Experiment methods

Put the intercalated gouge disturbed samples with water content approximating to its liquid limit into pressure vessel, inject water outside the vessel to keep the samples in saturated state, then apply loads gradually, observing their compression deformation. According to the geotechnical test regulations of the Ministry of Hydroelectricity, apply the load of next level when the compression deformation levels off, and measure their physical−mechanical properties after reaching the scheduled load level.

Table 3. The relationship between the porosity ratio or dry density and compression stress for intercalated gouge under simulation condition

Sample No.	Relation between porosity ratio (e) and compression stress (σ)		Relation between dry density (γ_d) and compression stress (σ)	
	Correlated equation	Correlation coefficient	Correlated equation	Correlation coefficient
PD37-112	e=0.666-0.3094lg	-0.997	γ_d=1.571+0.4767lg	0.998
PD42-90	e=0. 7377-0.2937lg	-0.994	γ_d=1.6444+0.3079lg	0.996
F_{73}	e=0.8766-0.2394lg	-0.994	γ_d=1.4524+0.22375lg	0.987
T_{66}	e=1.212-0.2566lg	-0.99	γ_d=1.265+0.1667lg	0.998

Making use of correlated equations in Table 3 and confining pressure of sites for in–situ sampling based on crustal stress inversion results by FEM, the porosity ratio and dry density of intercalated gouge under simulation condition are calculated in Table 4. The field testing values under natural conditions are also listed in this table.

Table 4. Comparison between physical indices under natural condition and in simulation test

Sample No.	Confining pressure/100kPa		Porosity ratio (e)			Dry density γ_d (Mg/m^{-3})		
	Self-weight stress field	Tectonic stress field	Natural condition	Simulation test	Diversity	Natural condition	Simulation test	Diversity
PD37-112	22.52		0.277	0.248	0.029	2.176	2.216	0.040
PD42-90	11.2		0.4290	0.4295	0.0005	1.945	1.968	0.023
F_{73}	22.74		0.554	0.552	0.002	1.783	1.822	0.039
		44.82	0.554	0.481	0.073	1.783	1.822	0.039
T_{66}	145.0		0.664	0.857	0.193	1.680	1.495	0.1846
		24.10	0.664	0.657	0.0066	1.680	1.625	0.0547

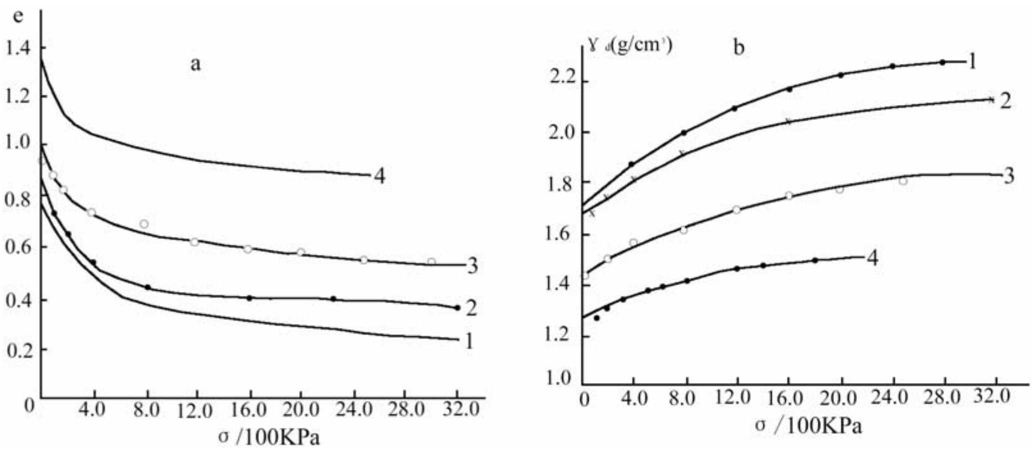

Figure 4. The curves between the porosity ratio or dry density and compression stress for intercalated gouge under simulation condition
(a) e−σ (b) γ_d −σ 1.PD37−112 2.PD42−90 3.F_{73} 4.T_{66}

Experiment results analysis

Based on the above−mentioned experiment results, curves between porosity ratio, dry density and compression stress are shown in Figure 4. It is easily to be seen that the porosity ratio decreased with the growth of stress, while the dry density increased at the same time. Yet, whether the simulation testing results can reflect the field condition is the key to judge the reliability of tests. Table 3 shows the correlation analysis results between simulation compression stress and corresponding porosity ratio, dry density.

Data from Table 4 indicate that there is little difference between physical index under natural and simulation conditions, besides, dry density is larger under simulation condition, but porosity ratio the other way around. It can be easily understood. Although strict measures are taken when sampling in field to protect the physical state of argillaceous gouge, the relaxation is unavoidable once the overlying rock mass are deprived. So porosity ratio increases and dry density decreases. On the other hand, in the simulation test, porosity ratio is calculated based on compression deformation, which is reflexed in measuring gauge, that is to say, the rebound is removed. All this show that confining pressure controlled the physical state of intercalated gouge, likewise, the physical state also reflexed the confining pressure. Thereby, the simulation testing results is believable.

Simulation study on strength parameters of intercalated gouge

Intercalated gouge No. PD37-112 is selected to study the strength characteristic under simulation condition. 4~5 samples are made at each stress level and direct quick shear tests can be carried out. Shear strength and corresponding compression pressure of intercalated gouge under simulation condition are shown in Figure 5.

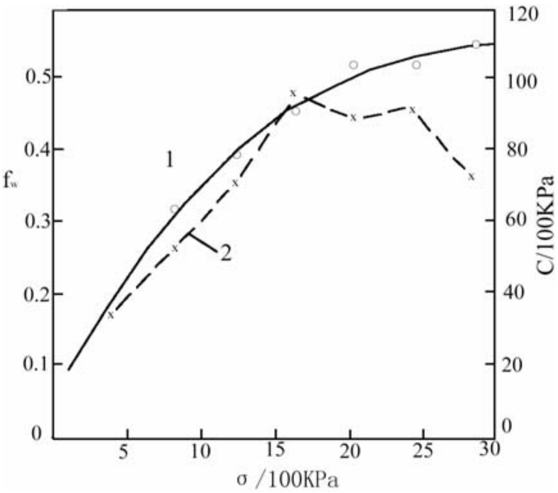

Figure 5. Curves of relation between friction coefficient (f_w) or cohesive force(C) and compressive stress (σ) for intercalated gouge in simulation test
1. f_w–σ curve 2. C–σ curve

Curves in Figure 5 shows that the friction coefficient increases with stress, so does cohesive force in general (few value are preclusive). Since cohesive force(C) always act as safety reserve in dam stability analysis, here only the relation between friction coefficient and corresponding compressive stress is analyzed. The correlated equation is:

$$f_w=0.426\lg - 0.062 \quad r=0.995$$

where f_w is the friction coefficient , σ is the compressive stress in 100KPa,r is the Correlation coefficient.

The saturation of shearing sample reaching 100% after unloading, so the above equation not only represent the relation between friction coefficient and compressive stress under simulation condition, but also reflex the strength character of saturated intercalated gouge. f_w can be easily gained basing on confining pressure of field sampling sites and this equation. Comparing f_w with f which is friction coefficient of intercalated gouge under field unsaturated condition (Table 5), the value of f_w/f ranges from 91.7%~94.3%. That is to say, the friction coefficient of intercalated gouge in saturated state decreased to 90% of that under confining pressure in deep part. All the above mentioned test results indicate that shear strength parameters of simulation test can be applied to predict shear strength values under natural saturated condition.

Table 5. Comparison between friction coefficients of intercalated gouge under simulation condition and in−site test

Confining pressure 100KPa	Simulation condition			In−site test					f_w/f (%)
	γ_d Mg/m^3	e	f_w	Sample No.	γ_d Mg/m^3	e	f	C 100 kPa	
22.52	2.216	0.248	0.514	PD37-112	2.176	0.277	0.561	64.8	91.7
					2.119	0.319	0.545	62.0	94.3

CONCLUSIONS

The following recognition and conclusions can be drawn basing on the above study:

- Intercalated gouge possess better physical−mechanical properties under natural confining pressure, besides, there are well relativity between these parameters and confining pressure.
- The simulation study results of intercalated gouge's physical−mechanical properties basing on compression law of soil and the principle of gravity compaction are very consistent with those values under natural condition. All these proved the feasibility of simulation study.

  The equations between porosity (e),dry density (γ_d), friction coefficient (f_w) and stress (σ) basing on simulation tests not only possess substantial practical value, for example, to evaluate the physical−mechanical properties of intercalated gouge located in those places where field test are difficult to carried out, but also possess significant theoretical value to the prediction of intercalated gouge's strength parameters.

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