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Influence of confining pressure on the mechanical behavior of Phu Kradung sandstone

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1. Introduction

Understanding mechanical behavior of rock masses which was subjected to cyclic loading with confining pressure is essential for design and construction of roads, railways, tunnels, rock fill dams, and the likes. These structures are not only subjected to cyclic loading such as vehicle passing, water wave and surge actions but also confined under overburden pressure whether being road surface pavements, soil and rock masses, and reservoir water. The behavior of rock in fatigue loading (cyclic loading) under uniaxial and triaxial loading has been focused on geotechnical and rock engineering design. The two studies of rock behavior under cyclic loading have been a special interest since the diverse cyclic load significantly influences rock properties. It is known that different materials show different responses under cyclic loading conditions. Some of these materials become stronger and more ductile, while others may become weaker and more brittle.[1,2] The mechanical behavior of rock subjected to cyclic loading has been extensively investigated. Many researchers have carried out studies on different rock types to examine the loading effects and loading strain rates on their strength and deformation characteristics.[3–8] In addition, the effects of frequency on dynamic properties of rocks under confining pressure conditions were assessed by the laboratory tests.[9,10] Furthermore, extensive work was conducted to determine whether rock is weakening due to fatigue from cyclic loading.[11–14] Anisotropy of construction materials can dictate their mechanical properties which is also crucial in design of engineering structures.[15] Rock masses are not an exception and their anisotropic behaviors can affect their mechanical properties tremendously[16].

The above studies tend to mainly focus on mechanical properties of rock samples under influences of loading rate and cyclic loading mostly in uniaxial condition. However, rock masses applied in engineering prospective are usually in a stress state under confined pressure, and very few studies considered the effects of fatigue, it is evident that rock mechanics science needs future works in this area, especially in three axial conditions. Therefore, this research aims to investigate the influence of cyclic loading on specimens under confining pressure as to provide more understanding on the rock mechanical behavior.

The rock specimens in this investigation were taken from Phu Kradung Formation which is part of the Khorat Group that consists of continental red-beds which form most of the Khorat Plateau, Northeast Thailand. This Group is subdivided into 9 Formations, namely from older to younger sequences as, Haui Hin Lat, Nam Phong, Phu Kradung, Phra Wihan, Sao Khua, Phu Phan, Khok Kruat, Mahasarakarm and Phu Thok Formations. These formations unconformably overlie Triassic and Permian rocks and underlie Tertiary and Quaternary deposits. The Khorat Group was dated as Upper Triassic to Cretaceous-Lower Tertiary as determined by fossil assemblage of vertebrates, bivalves and palynomorphs.[17] Rocks in the Khorat Group generally are sandstone, siltstone, and

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Table 1
Mineral composition of the rock.

Optical microscope method Minerals (%)			X-ray diffraction method Minerals (%)		
Quartz	Plagioclase	Weathered feldspar	Quartz	Albite	Dickite
70–73	19–23	7–11	60.63	19.70	19.67

mudstone in each Formation and exposed by folding structures as anticline and syncline on the Khorat plateau and its vicinity except in the southwestern part of the plateau, with overlying thick soil. The Phu Kradung Formation was generally formed through coarsening upwards succession in alluvial and fluvial floodplain environments, with most of the river systems appearing to be meandering of which its outcrops spread all over the borders of Khorat-Sakon Nakorn Basin.[18] This Formation is subdivided into 2 units; the lower of which is dominated by alluvial floodplain deposit consisting of red-brown to grey-brown claystones and siltstones with thin bedded, fine-grained sandstone, while the upper was deposited in fluvial floodplains of meandering rivers. This unit is typically thicker bedded, medium-grained sandstone (5–10 m. thick) and generally changes from reddish-brown to grey and white.[19] The upper Phu Kradung sandstone was investigated in this research, because it is evidently weakened by lamination or bedding. Moreover, it has been involved in construction of several kinds of engineering projects such as the turbine tunnel of Lam Ta Khong Pumped Storage Project.[20,21] As mentioned above, the rock mechanical and physical properties would also be observed and correlated to their fabric arrangements.

2. Tested rock material and experimental procedure

The sandstone specimens were core drilled from the in situ rock blocks at Nong Bualumphu Province, Northeast Thailand, from the Phu Kradung sandstone Formation outcrop located at the transition contact to the younger Phra Wihan sandstone Formation. The core specimens were drilled in two orthogonal directions, normal and parallel (0° and 90°) to lamination. The specimens were cut and lapped as specified by the ASTM D 4543-08 standard practice.[22] The basic and mechanical properties were obtained from twenty cylindrical specimens with the aspect ratio (length/diameter) of 2–2.25. All specimens were systematically labeled as to their rock Formation (PK), orientation (D0 or D90), type of test (M, monotonic or C, cyclic), and their applied confining stress (0, 6, 12, 20, 30 MPa). The representative thin sections of the samples were also prepared for petrographic examination.

Table 3
Basic properties of specimens for cyclic loading.

Sample no.	Density (g/cm^3)	Porosity (%)	Confining pressure (MPa)
PK-D0-0C	2.36	7.48	0
PK-D0-6C	2.38	9.77	6
PK-D0-12C	2.39	9.39	12
PK-D0-20C	2.36	9.34	20
PK-D0-30C	2.35	7.74	30
PK-D90-0C	2.40	8.19	0
PK-D90-6C	2.42	7.56	6
PK-D90-12C	2.41	6.79	12
PK-D90-20C	2.38	8.15	20
PK-D90-30C	2.44	8.68	30

2.1. Basic properties

The mineral compositions of the rock samples were evaluated by two methods i.e. polarized microscope and X-ray diffraction. The results of the mineral composition are shown in Table 1 which indicates high percentage of quartz and feldspar. Thus the rock can be classified as Arkosic sandstone.

Physical properties and mineral composition of the samples were also determined in this study. Two physical properties, density and porosity were evaluated for the specimens to be used for loading examinations. These properties were conducted by water replacement method following the testing standard of ISRM 1981[23] and their values are shown in Tables 2 and 3 for monotonic and cyclic tested specimens respectively. The ranges of density and porosity of tested specimens are 2.33–2.50 g/cm^3 and 6.79–10.77%, respectively.

2.2. Experimental procedure

The specimens were oven dried before the mechanical test. Specimens were separated into two sets; the first set of core specimens was monotonically tested of which the maximum strength of the rock was determined at the confining pressures of 0, 6, 12, 20 and 30 MPa. The other set was tested under cyclic loading at 70–80% of maximum stress level with the same confining pressure as the first. Specimens were tested in two directions; parallel and normal to laminations, in order to investigate the significant effect on the mechanical properties of the rock. A summary of the specimens and their mechanical testing results are listed in Table 4. Details of testing procedures are as follows.

An ELE Compact 1500 Rock and Concrete Motorized Compression Test Machine was used for both monotonic and cyclic

Table 2
Basic properties and the stress state at failure.

Sample no.	Density (g/cm^3)	Porosity (%)	Maximum strength (MPa)	Confining pressure (MPa)
PK-D0-0M	2.35	10.35	36.07	0
PK-D0-6M	2.34	9.82	87.33	6
PK-D0-12M	2.35	10.56	104.79	12
PK-D0-20M	2.36	9.37	170.68	20
PK-D0-30M	2.36	10.77	184.75	30
PK-D90-0M	2.44	7.17	31.39	0
PK-D90-6M	2.50	8.35	105.18	6
PK-D90-12M	2.50	7.73	129.71	12
PK-D90-20M	2.37	9.01	184.75	20
PK-D90-30M	2.33	7.99	218.32	30