ASSESSMENT OF CYCLIC TRIAXIAL BEHAVIOR OF SHIWALIK SANDSTONE

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Abstract

The mechanical properties of rock under dynamic conditions are of great importance in which the fatigue strength of rock plays a vital role. This study represents the effect of variable frequency on dynamic properties of Shiwalik Sandstone. Shiwalik sandstone samples were collected from the powerhouse location of UJH Multipurpose Project, Jammu and Kashmir ."Prediction of fatigue life of Shiwalik Sandstone under varying frequency" was done by conducting Cyclic Load test in Uniaxial and Triaxial condition. Cyclic testing was done at three frequencies i.e. 1Hz, 2Hz and 3Hz[2] and at two confining pressures of 5 and 7 MPa[6]. The S-N curve[4] were plotted at different frequencies in uniaxial condition as well as in triaxial condition to explain the fatigue behaviour of soft rock (Shiwalik Sandstone) It has been observed that loading frequency as well as confining pressure has a significant effect on the fatigue life of the rock. As the frequency increases from 1 Hz to 3 Hz the fatigue stress increases. And in triaxial condition as the confinement increases from 5 MPa to 7MPa the number of cycles at failure increases.

Keywords: Fatigue life, Shiwalik sandstone, Cyclic load test, Amplitude, Frequency, Base load, Waveform

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1. INTRODUCTION

The mechanical behavior of rock subjected to cyclic loading is important for rock engineering design and construction like drilling and blasting, underground openings, support assessment, resource and waste deposition, working of big machineries, explosions, earthquakes pavements etc. Cyclic loading causes deterioration of rock strength which leads to fatigue failure of rocks and this type of loading causes the failure of the underground structures at a lower fatigue strength. Deterioration of rock under cyclic loading is termed as Rock Fatigue. The maximum applied stress at which rock can withstand an infinite number of cycles without destruction is termed as Fatigue Stress. The stress level at which the failure takes place is Fatigue Strength and the number of cycles is known as Fatigue life of a rock. [7]

Fatigue properties of geologic materials are highly dependent on the rock type and the parameters of the cyclic loading like loading frequency, amplitude etc. [1-2] So the designer of a dynamically loaded structure must have adequate knowledge of the cyclic loading to design a stable structure against fatigue failure. Knowledge of fatigue

characteristics could also help the designer to predict the fatigue behavior of the structure and take preventive measures. So proper attention should be focused on the dynamic properties of rocks with the goal of understanding their dynamic mechanical features under different loading conditions.

The objective of the study is to analyse the effect of frequency on dynamic properties of Shiwalik Sandstone in cyclic uniaxial loading condition and to study the effect of confining pressure on dynamic properties of Shiwalik Sandstone in cyclic triaxial condition

2. EQUIPMENT AND TEST SCHEME

2.1 Rock Samples

The present work deals with laboratory investigation of geotechnical properties and parameters of 'Shiwalik Sandstone'. The samples have been collected from the powerhouse location of UJH Multipurpose Project, Jammu and Kashmir (Fig.1)

Fig. 1: Location of samples collection (at Powerhouse, UJH Multipurpose Project, J&K)

Regionally the project area forms a part of the tertiary belt of outer Himalaya occupied by rocks belonging to Murree Group, Lower Shiwalik, Middle Shiwalik and Upper Shiwalik Groups from north to south. The present source of samples i.e., powerhouse is located in the medium to coarse grained sand stone with thin clay layers of Middle Shiwalik Group. The general strike of rock units N65^{0}W-S65^{o}E to N75^{o}W-S75^{o}E and dip varying from 30° to 45° southerly. Its age lies between Lower Pliocene to Miocene. (*Source: GSI*)

The above site is chosen for the investigation because many of our projects like Hydropower plant etc. are going on in the foothills of Himalayas. These plants require different type of heavy machines which will generate cyclic loading. The samples were cut into 2:1 length to diameter ratio with an average diameter of 51mm. Samples were prepared as per ISRM standards[8]. The UCS value for the rock sample was obtained as 46 MPa.

2.2 Equipment

The testing facility was based on the principle of "Closed Loop Servo Control".The system can be operated in load or displacement control mode.It Consists of three parts i.e. Compression Loading Frame (1000 KN), Power Pack Unit ,Control system and Control Software
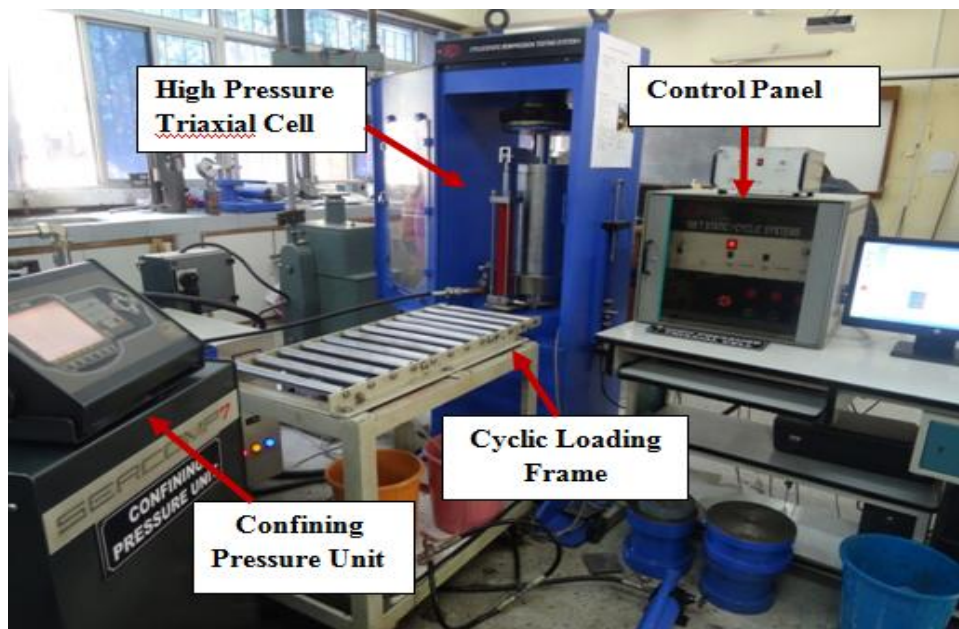

Fig-2: Cyclic Triaxial Testing Facility

Fig-3: High Pressure Triaxial Cell

The HPT cell can withstand confining pressure upto 140MPa.It is basically designed for N_X size sample. There is a hydraulic jack for the lifting of the cell so that samples can be easily placed and a valve which is released for the lowering of the cell.

The tests were conducted under strain controlled mode. In order to "Predict the Fatigue Life of Shiwalik Sandstone under Variable Frequency" cyclic test were carried out in Uniaxial [3] as well as in Triaxial State. The waveform used in cyclic compression test was sinusoidal.
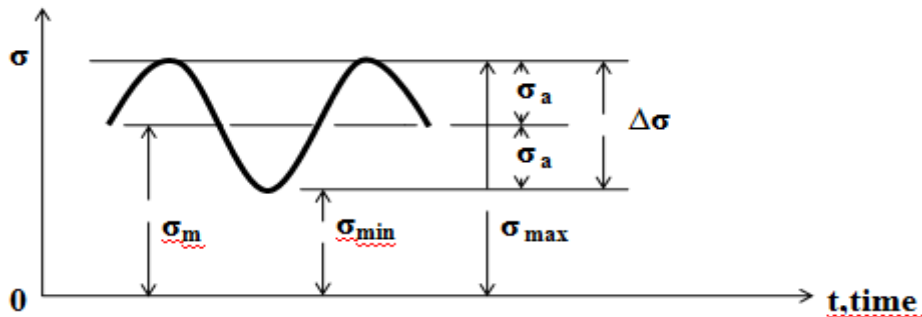
2.3 Test Scheme

Fig-4: Sinusoidal waveform showing variation of stress with time (σ_m is base load and σ_a is the amplitude)

3. CYCLIC LOAD TEST

3.1 Uniaxial Cyclic Load Test at Varying Frequency

In the first set of experiment test were conducted to study the effect of frequency on fatigue strength of rock.So testing was done at frequency of 1Hz ,2Hz and 3Hz. The waveform used was sinusoidal.The valley stress was taken as 50% of UCS and peak stress varied from 90% to 60% of UCS. Four samples of N_X size were tested at different values of peak stress at each frequency

Table-1: Observation of the Cyclic Load Test in Uniaxial codition at Varying Frequency

f=1 Hz			
N	S (%UCS)	Base (kN)	Amp (kN)
77	90	45.15	36.12
146	80	45.15	27.09
1400	70	45.15	18.06
10000	60	45.15	9.03

f=2 Hz			
N	S (%UCS)	Base (kN)	Amp (kN)
113	90	45.15	36.12
465	80	45.15	27.09
913	75	45.15	22.57
10000	70	45.15	18.06

f=3 Hz			
N	S (%UCS)	Base (kN)	Amp (kN)
146	90	45.15	36.12
327	85	45.15	31.60
10000	80	45.15	27.09

3.2 Cyclic Triaxial Strength Test Under Varying Confining Pressure

Cyclic triaxial test was performed on Shiwalik Sandstone samples under two confining pressure of 5 MPa and 7 MPa.

[6] The parameters of cyclic loading were same as that of cyclic uniaxial state.

Table-2: Observation of the Cyclic Load Test in Triaxial codition at Varying Confining Pressure

0 MPa σ$_c$ = 46 MPa				
Sample Id	**N**	**S (%UCS)**	**Base (kN)**	**Amp (kN)**
A12	77	90	45	36
A21	146	80	45	27
A31	1400	70	45	18
A32	10000	60	45	9
5MPa σ$_1$=97.96MPa				
Sample Id	**N**	**S (%UCS)**	**Base (kN)**	**Amp (kN)**
S1	690	90	96	77
S2	999	80	96	58
S3	1580	75	96	48
S4	10000	70	96	39
7MPa σ$_1$=166.56MPa				
Sample Id	**N**	**S (%UCS)**	**Base (kN)**	**Amp (kN)**
S5	1124	90	163	131
S6	2567	85	163	115
S7	3464	80	163	99
S8	10000	75	163	82

4. EXPERIMENTAL RESULTS AND DISCUSSION

In the first set of experiments test were conducted to study the effect of frequency on the cyclic fatigue behavior of Shiwalik Sandstone.The S-N [4] curve below shows the variation of number of cycles with fatigue strength at different frequencies.
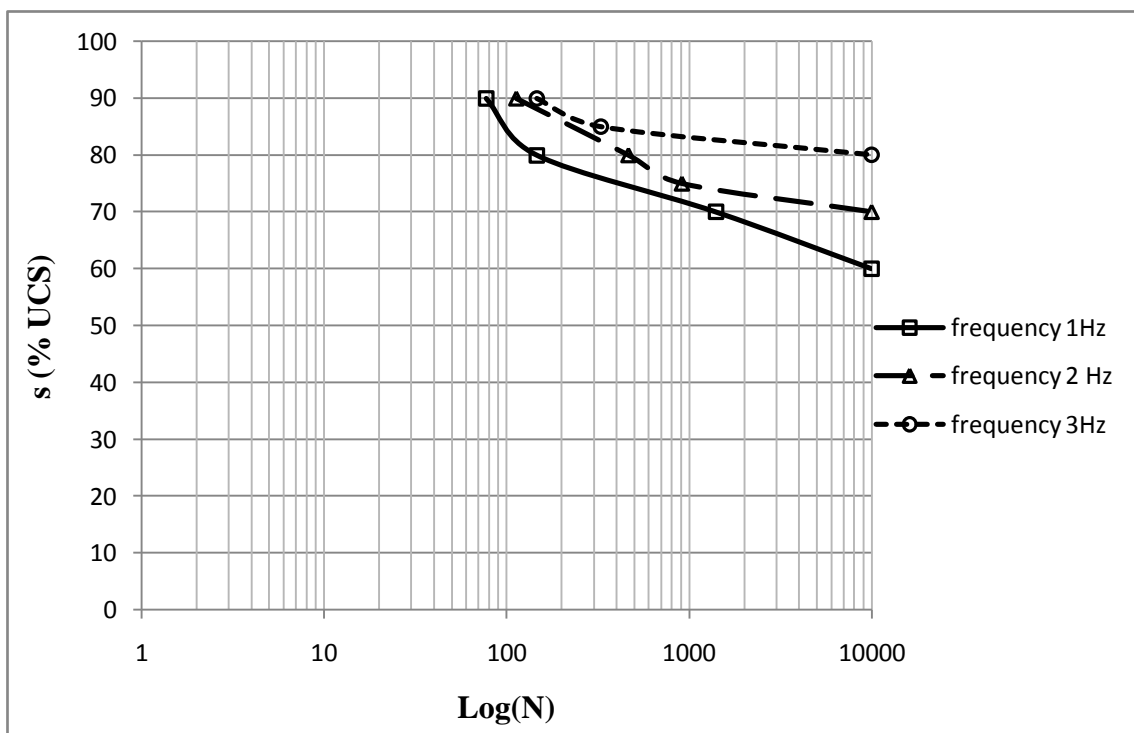

Fig-4: Comparison between S-N curve for Shiwalik Sandstone under varying frequency

From the S-N curve it is clear that as the frequency increases the number of cycles at failure also increases.Fatigue strength of Shiwalik Sandstone goes on increasing as the frequency increases. Fatigue strength of Shiwalik Sandstone at 1Hz frequency is 60% of UCS at 2Hz it is 70% of UCS and at 3 Hz frequency it is 80% of UCS.This shows that as the frequency increases rock fatigue occurs at a higher stress and so the fatigue life of the rock increases.

When subjected to dynamic or cyclic loads, different materials respond in different ways.Some of these materials become stronger and more ductile, while others become weaker and more brittle In this case as the frequency is increasing the material is gaining strength. And so the S-N curve shifts up at higher frequency.

(a) f= 1 Hz   **(b) f= 2 Hz**   **(c) f= 3 Hz**

Fig-5: Failed samples of Shiwalik Sandstone under Varying Frequency

In the second set of experiments test was conducted to study the effect of varying confining pressure on the fatigue strength of rock. The results are based on the S-N curve shown below.
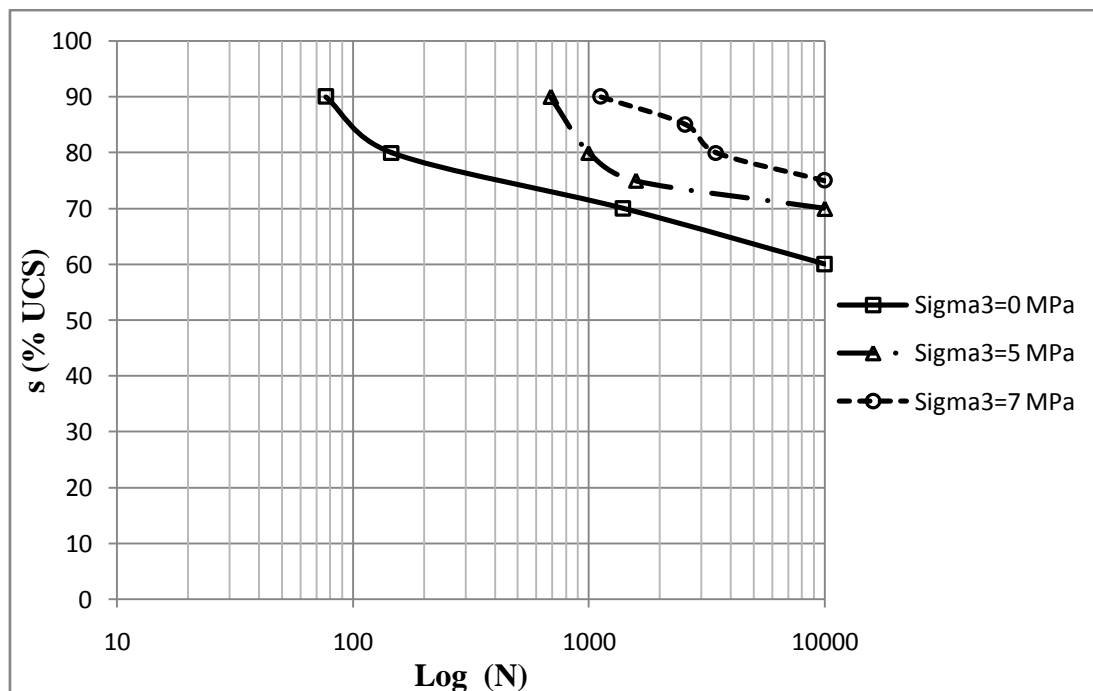

Fig-6: Comparison between S-N curve for Shiwalik Sandstone under varying Confining Pressure

From the S-N curve it is clear that the fatigue life of the rock increases as the confinement increases.As the confinement increases the stiffness of the rock increases and so the strength also increases. Failure pattern for Shiwalik Sandstone clearly shows that at same frequency the failure plane extends to the bottom in unconfined state and in confined state it is not so.

Fig-7: Failed samples in Cyclic Triaxial test at f=1Hz and $\sigma_3 = 0$

Fig-8: Failed samples in Cyclic Triaxial test at f=1Hz and $\sigma_3 = 5MPa$

Fig-9: Failed samples in Cyclic Triaxial test at f=1Hz and $\sigma_3 = 7MPa$

5. CONCLUSION

- Cyclic Uniaxial behaviour of Shiwalik Sandstone was studied and fatigue limit was obtained under varying frequency.S-N curve was plotted. [4]
- As the frequency of loading increases the number of cycles at failure increases which can be clearly observed from the S-N curve at 1Hz, 2Hz and 3Hz frequencies
- This study can also be useful for the performance of machine foundations which produce vibrations generally at a frequency of 1-5 Hz.
- The failure pattern shows that larger the frequency wider is the localised failure band which is very much in agreement with the study done in 2012 [5]
- It has been found that as the confinement increases the voids reduce and material gains stiffness and strength and so the fatigue life of the rock increases.This is clearly visible by the S-N curve

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