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A Study on the Fatigue Failure Behavior of Cheon–Ho Mt. Limestone Under Cyclic Loading

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천호산 석회암의 반복하중에 의한 피로파괴거동에 관한 연구

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Abstract

In this study uniaxial cyclic loading tests were performed on Cheon–Ho Mt. Limestone specimens to investigate the fatigue failure behavior. The loading rate was kept constantly at 760kg/㎠/sec under cyclic loading. In order to reveal the fatigue behavior for each rock type, the test results were mutually compared with previous studies carried out on Indiana Limestone and Seong–Ju Sandstone. Fatigue data is presented in the form of S–N curves, which illustrate the relationship of maximum applied stress(S) to the number of cycles(N) required to produce failure. For the purpose of comparing the S–N curves for each rock type, the test data were formulated up to 10^4 cycles and the correlation coefficients(R) on Cheon–Ho Mt. Limestone and Seong–Ju Sandstone specimen are 0.886 and 0.983, respectively. All three rock specimens were found to have shorter fatigue life at higher applied stress levels. The fatigue life for each rock type was considered as no less than 81.5, 70 and 74.8%, for Cheon–Ho Mt. Limestone, Indiana Limestone and Seong–Ju Sandstone, respectively. The comparison in static strength for monotonic loaded specimens and specimens which did not fail even after 10^4 cycles indicated that the increasing rate of strength was about 6.18 and 10.96%, for Cheon–Ho Mt. Limestone and Indiana Limestone, respectively. Poisson's ratio and volumetric strain for Cheon–Ho Mt. Limestone and Seong–Ju Sandstone, tended in all the cases to rapidly increase at higher stress levels and with an increase in number of cycles. This increasing trend becomes rapid and obvious just before failure. Also Poisson's ratio and volumetric strain for each stress level were compared and analyzed at the first cycle and the cycle prior to failure.

요 약

본 연구에서는 천호산석회암에 대한 피로파괴거동을 조사하기 위해 "일축압축 반복시험"을 수행하였고, 반복 하중하에서는 하중속도를 760kg/㎠/sec로 적용하여 일정하게 유지시켰다. 또한 암종에 따른 피로거동을 규명하기 위해 Indiana석회암과 성주사암에 대한 기존의 연구결과와 비교 검토하였다. 피로현상은 파괴에 이르는데 요하는 반복횟수(N)와 최대적용응력(S)과의 관계를 S-N 곡선으로 나타낸다. 암종에 따른 S-N 곡선을 비교하기 위해 10^4 반복횟수까지 식으로 나타내었고, 이 때의 천호산석회암과 성주사암시편의 상관계수(R)는 각각 0.886, 0.983 이다. 3가지 암석시편 모두가 응력 수준이 높을수록 피로수명이 짧은 점을 알 수 있었다. 암종별 피로수명은 천호산석회암, Indiana석회암과 성주사암의 경우에 있어서 각각 응력수준 81.5% 이상, 70% 이상, 74.8% 이상에 해당한다고 볼 수 있다. 10^4회 반복에서도 파괴되지 않은 시편들에 대해 정하중강도를 측정하여 원래의 정하중강도와 비교한 결과, 강도증가율은 천호산석회암이 약 6.18%, Indiana 석회암의 경우는 10.96% 정도이다. 반복횟수에 따른 포아송비와 체적변형률의 변화를 조사하기 위해 천호산석회암과 성주사암을 비교한 결과, 두 경우 모두 응력수준이 높을수록 급증하는 경향을 나타내며, 파괴직전부터 급격한 증가추세를 보였다. 또한 각 응력수준에 대한 포아송비와 체적변형률에 있어서 1회 반복시와 파괴직전의 반복시를 비교 검토하였다.

1. Introduction

Interest in surface structures such as road foundations, bridge abutments and dams, and in substructures related to mine excavations, underground nuclear power plants, underground oil reservoirs and nuclear waste repositories in rock mass has increased recently. In view of this, the mechanical behavior of given rock masses needs to be studied to insure safety retainment and damage protection.

The underlying rocks of these structures are normally under static loading, but undergo dynamic cyclic loading caused by ground motion due to earthquakes, blasting, rock bursts and traffic, etc.. The structure and the underlying rock so affected are fatigued and likely to fail under a loading lower than their determined strength [1,2,3]. Since the current fatigue failure characteristics are determined according to time under a constant loading, to review the safety of such rocks in terms of long time, it is very important to investigate and reveal the fatigue behavior of rocks by cyclic loading.

According to previous studies, post-failure behavior of rocks under cyclic loading [4] and variations of Young's modulus and Poisson's ratio with increasing number of cycles [5] were investigated. It was demonstrated that the fatigue strength showed a decreasing trend through out the test in a maximum number of cycles of 10^4 [1]. Also, the effects on fatigue strength under uniaxial cyclic compression, uniaxial cyclic tension, and uniaxial cyclic compression-tension were mutually compared [2]. Mechanical coefficients with the stress levels and the number of cycles were observed respectively in simple cyclic loading and cyclic loading after constant loading had been applied [6].

The studies described above have seldom been attempted in terms of variations of Poisson's ratio and volumetric strain for each rock type, stress levels under cyclic loading, the correlation coefficients for S–N curves and the fatigue life, and the variation of static strengths between monotonic loading and after cyclic loading.

Therefore, in this study the fatigue failure behavior for a sample of Cheon–Ho Mt. Limestone is observed and analyzed, and is mutually compared with results of previous studies on Indiana Limestone[1] and Seong–Ju Sandstone[6]. The results obtained will be used in order to retain the safety of substructures, and will be used as basic data and applied to safety assessment and analysis [1,2,3,5,6,10].

These tests were carried out using a programmable electrohydraulic servo–controlled testing machine(INSTRON–303) of 20ton, capacity, and test procedures are as follows. Three different stress levels of 85, 82.5, and 81.5% of the dynamic compressive strength were applied respectively to investigate the fatigue failure characteristics under uniaxial cyclic loading. Also Poisson's ratio and volumetric strain according to the number of cycles were obtained for understanding the deformation characteristics during the fatigue failure process. Fatigue data is presented in the form of S–N curves, which illustrate the relationship of maximum applied stress(S) to the number of cycles(N) required to produce failure. By means of analyzing the curves, the fatigue failure characteristics are observed and mutually discussed.

2. Experimental Method

2.1. Specimen Preparation

According to the petrological characteristics on specimens used in this study, Cheon–Ho Mt. Limestone is white and medium grained, with little impure materials such as ferro–oxides and free carbon etc.. The average chemical composition of 25 samples, analyzed by Mineral Laboratory in Korea Mining Promotion Corp. in 1985, is CaO, 54.8%, MgO, 0.65%, SiO_2 , 0.37%, Al_2O_3 , 0.01% and Fe_2O_3, 0.05%, and its purity is good. Indiana Limestone obtained from Bedford in U.S.A., is off–white and fine grained, with an average size of 0.14mm. Its main composition is carbonate of 98.66% and opaques, 1.34%. It exhibits no apparent bedding planes and is highly homogeneous[1]. Also Seong–Ju Sandstone, sampled at a depth of 150~175m from Ok–Bo level in Seong–Ju Mine of Dai Han Coal Corporation is fine grained and fresh with no bedding planes[6].

In this experiment Cheon–Ho Mt. Limestone specimens were used. According to ASTM regulations, rock cores at 24mm in diameter were obtained from a rock coring machine and kept at about 50mm in length using a rock cutter. Forty specimens with a height to diameter ratio of 2 were then obtained and specimen ends were surface ground with carborundum of #100, #300 in order to be flat within ±0.02mm[7]. Six specimens for Brazilian tensile tests had a ratio of 0.5. Also Indiana Limestone specimens, 25.4mm in diameter and 63.5mm long, having a ratio of 2.5 [1]. Seong–Ju Sandstone specimens, 30mm in diameter and 60mm long, were kept at a regulated flattness[6]. The loading rates and physical properties applied to samples are shown in Table 1 and Table 2.

2.2. Experimental Equipment

The apparatus used in this experiment was an electrohydraulic servo–controlled testing machine(INSTRON–303) made at INSTRON Co. in U.S.A., which was composed of a Load Frame Assembly, a Servohydraulic Control System and a Hydraulic Power Supply. Fig.1 shows a schematic diagram of this testing system.

The Servo Controller consisted of a Function Generator Module for controlling the load, a stroke mode and cycle applied to a specimen, a Hydaulic Controller for regulating the oil pressure,

Table 1. The Loading Rates Applied to Samples

Unit:kg/㎠/sec

Rock Type	Number of Specimens	Static Loading Rate	Dynamic Loading Rate
Cheon-Ho Mt Limestone	40	5	760
Indiana Limestone [1]	10	7	260
Seong-Ju Sandstone [6]	50	7	2,795

Table 2. Physical Properties of Samples

(Data : Mean Value)

Physical properties	Rock type		
	C.H-LS	I.D-LS	S.J-SS
Apparent specific gravity	2.707	–	2.69
Apparent porosity(%)	0.274	17.2	0.54
Water content(%)	0.016	0.02	–
Static compressive strength(kg/㎠)	742.30	515.09	2,560
Dynamic compressive strength(kg/㎠)	872.98	576.04	2,790
Tensile strength(kg/㎠)	69.03	54.49	235
Static average Young's modulus($\times 10^5$ kg/㎠)	6.10	3.66	6.76
Dynamic average Young's modulus($\times 10^5$ kg/㎠)	6.70	–	7.21
Static average Poission's ratio	0.278	0.30	0.26
Dynamic average Poisson's ratio	0.307	–	0.36

* C.H-LS : Cheon-Ho Mt. Limestone I.D-LS : Indiana Limestone
S.J-SS : Seong-Ju Sandstone

* Data on Indiana Limestone and Seong-Ju Sandstone were obtained from Hardy et al. [1] and Kim [6], respectively.

a Cyclic Counter for giving the number of cycles per test, a Readout Module for selecting the signal voltage, a Controller for commanding the Hydaulic Controller and controlling the feedback and error signal, and an Interlocked Limit Module for protecting the testing system.

In this experiment, axial and lateral strains on a specimen were measured through the cross type of an electrical resistance strain gauge directly mounted in its central portion with an adhisive of CC-15A, and the strains, through a dynamic strain amplifier, were automatically plotted using an X-Y_1, Y_2 recorder.

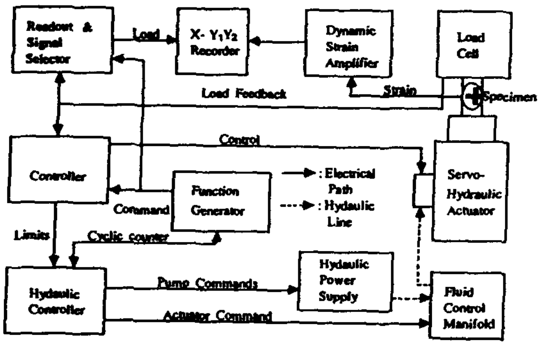

Fig. 1. Schematic Diagram of Servohydraulic Testing System.

2.3. Experimental Method

In this experiment, the loading rate was constantly kept as 760kg/㎠/sec to investigate the fatigue failure behavior of the Cheon–Ho Mt. Limestone specimens under cyclic loading. The static and dynamic compressive strength were defined as the failure strength at loading rates of 5 and 760 kg/㎠/sec, respectively. In order to verify the variations of mechanical coefficients, the failure process and the failure characteristics by uniaxial cyclic loading, the specimens were cyclic loaded up to stress levels of 85, 82.5 and 81.5% of the dynamic compressive strength, respectively, with a cyclic waveform shown in Fig.2. Also the stress levels are the same as the levels of 99.9, 97, 95.8% of the static compressive strength, respectively.

Since the fatigue behavior should be also considered the time dependence in long term, equipment simulating conditions as close as possible to in situ conditions must be carried out in a laboratory.

Hence this experiment, based on revealing the fatigue behavior under cyclic compression in a maximum number of cycles of 10^4 by Hardy et.al. [1] and Singh[8], applied the same number of cycles, and the data used in considering the test results were selected as the data corresponding to

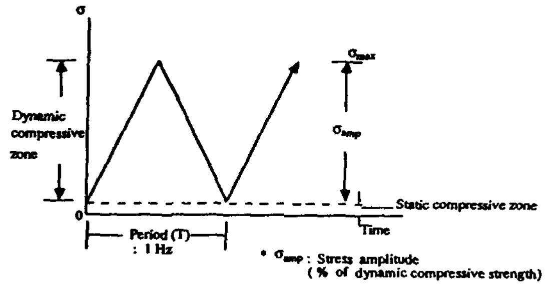

Fig. 2. Cyclic Waveform in the Case of a Cyclic Loading Test.

the mean value of fatigue life in each of the test results.

3. Results and Discussion

3.1. Fatigue Failure Characteristics with Stress Levels

In this study uniaxial cyclic compression tests of the Cheon–Ho Mt. Limestone were performed to investigate the fatigue failure characteristics with three stages of stress levels applied as a percentage of the dynamic strength. Namely, the air dried specimens were cyclic loaded up to stress levels of 85, 82.5, and 81.5% of the dynamic

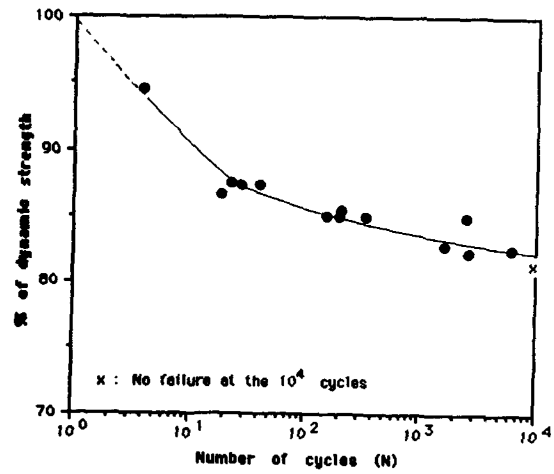

Fig. 3. S–N Curve for Cheon–Ho Mt. Limestone Specimens Cyclic Loaded to Different Maximum Stress Values.

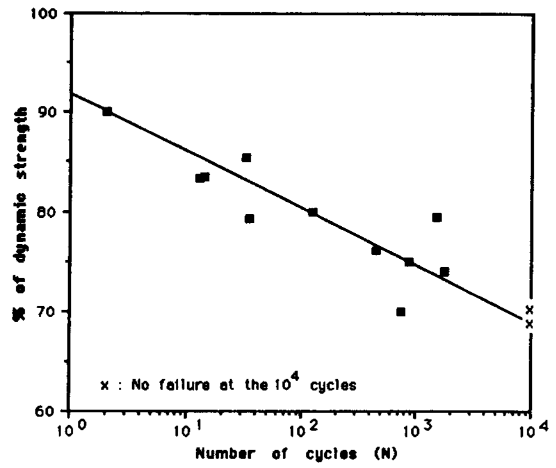

Fig. 4. S–N Curve for Indiana Limestone Specimens Cyclic Loaded to Different Maximum Stress Values [1].

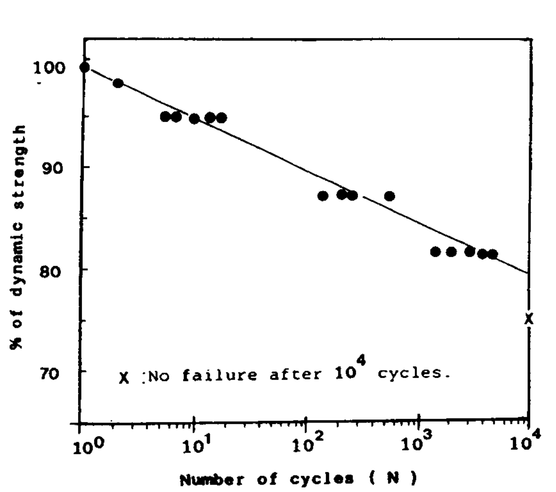

Fig. 5. S–N Curve for Seong–Ju Specimens Cyclic Loaded to Different Maximum Stress Values [6].

strength. Also, in order to reveal the fatigue characteristics for each rock type, Indiana Limestone and Seong–Ju Sandstone specimens were applied as the stress levels of 85, 80, 75, and 70%, and of 94.8, 87.4, and 74.8% of the dynamic strength, respectively [1,6].

Fatigue phenomenon can usually be presented in the form of an S–N curve, which illustrates the relationship of the applied stress level(S) to the number of cycles(N) required to bring about failure. Hence, the S–N curves for considering the fatigue process for each rock type are shown in Fig.3, Fig.4, and Fig.5, respectively.

Also, this relationship can be formulated within a range of 10^4 cycles, in the case of Cheon–Ho Mt. Limestone and Seong–Ju Sandstone, the formulae are, respectively, presented in the form of S(%)=92.84(%)–2.878 Log N and S(%)=99.82(%)–5.17 Log N [6], and their correlation coefficients(R) are 0.886 and 0.983 [6], respectively. However, in the form of S–N curves Cheon–Ho Mt. Limestone shows a curvilinear feature, which is different from a linear one in the case of Indiana Limestone or Seong–Ju Sandstone.

As shown in Fig.3, Fig.4 and Fig.5, Cheon–Ho Mt. Limestone specimens at stress levels of 85 and 82.5% failed at 205 and 6,230 cycles, respectively. But they did not fail even after 10^4 cycles at the level of 81.5%. Also Indiana Limestone and Seong–Ju Sandstone did not fail at the same cycles for the level of 70 and 74.8%, respectively [1,6]. Therefore, the fatigue lifes of Cheon–Ho Mt. Limestone, Indiana Limestone and Seong–Ju Sandstone are estimated to be no less than 81.5, 70 and 74.8% at each stress level. Thus, Cheon–Ho Mt. Limestone has much shorter fatigue life, the reason being that it is medium grained. On the other hand, the other two types are fine grained, with an average size in rock specimen. According to this, it is assumed that the frictional sliding at intergranular boundaries causes the specimen to easily fail due to the weighted cyclic loading. Also in the case of Indiana Limestone, the reason for its fatigue life being the longest of the three rock types (in spite of having the largest porosity) seems to be that strain hardening appears to accumulate in the specimen with the deformation which occurs in every cycle.

Failure features of Cheon–Ho Mt. Limestone specimens under cyclic loading are shown in

Photo.1. The first type of failure is a common feature consisting of double conical end segments, free from cracks, and the fragments with long silvers of rock from around the periphery[9]. (which seems to be due to triaxial compression effect by the difference of elastic moduli at the specimen ends in contact with the upper and lower platens.) Also, the second type shows shearing failure produced by either platen rotation or concentration of lateral stress. However, Haimson and Kim [10] verified that extensive structural damage was observed in specimens that had reached the last stage prior to failure under the photomicrographic condition, revealing that the reason is due primarily to vertical cracking. In the case of Seong–Ju Sandstone, the failure feature of the specimen is mainly characterized by columns, as shown in Photo.2, and the development of one or more major cracks almost parallel to the direction of loading is observed, particularly when the end constraint is eliminated.

Photo. 1. Feature of Fatigue Failed Cheon–Ho Mt. Limestone Specimens by Cyclic Loading.

Photo. 2. Feature of Fatigue Failed Seong–Ju Sandstone Specimens by Cyclic Loading[6].

3.2. Variation of Mechanical Coefficients by Cyclic Loading

When a rock specimen is cyclic loaded up to the constant stress level, Poisson s ratio(ν) and volumetric strain(ϵv) at n cycles with the level, which is calculated from the total axial and lateral strain(ϵas and ϵls) detected at the cycle of N=n, are obtained by using the Eq.(1) and Eq.(2), respectively.

$$\nu = -(\epsilon as/\epsilon ls) \quad (1)$$

$$\epsilon_v = \epsilon as/2\epsilon ls \quad (2)$$

Table 3 and Table 4 show Poisson's ratio and volumetric strain on Cheon–Ho Mt. Limestone and Seong–Ju Sandstone specimens at the number of N=n cycles, in case of the cycle of N=1 and of the cycle at failure, calculated from the above equations, respectively. The graphs present the variation of Poisson's ratio and volumetric strain with each stress level in the range $1 \leq N \leq 10^4$ cycles for each rock type as shown in Fig.6, Fig.7 and Fig.8, Fig.9, respectively.

As shown in Fig.6 and Fig.7, Poisson's ratio with each stress level for both Cheon–Ho Mt. Limestone and Seong–Ju Sandstone specimens shows a trend of increase with increasing number of n cycles. Also, in comparison with the variation of Poisson's ratio with each stress level under cyclic loading, at all the stress levels except 81.5% of the level the ratios of Cheon–Ho Mt. Limestone show relatively smooth increase at the initial stage when subjected to cyclic loading, but tend to increase rapidly just before fatigue failure. However, Poisson's ratio at the stress level of 81.5% shows

Table 3. The Results of the Cyclic Loading Tests on Cheon–Ho Mt. Limestone.

Measuring cycles	The first cycle			The cycle at failure		
Stress levels (%)	85	82.5	81.5	85	82.5	*81.5
ν	0.254	0.231	0.210	0.691	0.543	0.408
ϵ_V	1.180	0.635	0.400	4.896	3.200	1.987

Table 4. The Results of the Cyclic Loading Tests on Seong–Ju Sandstone [6]

Measuring cycles	The first cycle			The cycle prior to failure		
Stress levels (%)	94.8	87.4	74.8	94.8	87.4	*74.8
ν	0.305	0.266	0.207	0.406	0.364	0.229
ϵ_V	−1.47	−1.55	−1.74	−0.74	−1.10	−1.70

ν : Poisson's ratio
ϵ_V : Volumetric strain($\times 10^{-3}$)
* : No failure at the 10^4 cycles

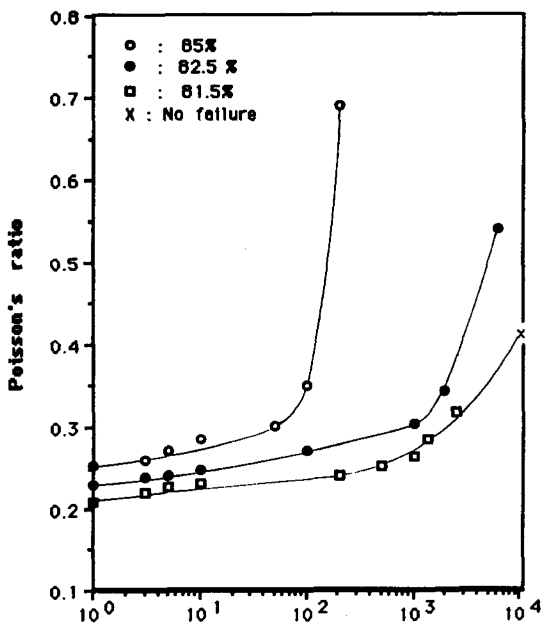

Fig. 6. Variation of Poisson's ratio with the Number of Cycles and the Stress Levels in the Case of a Cyclic Loading(Cheon–Ho Mt. Limestone).

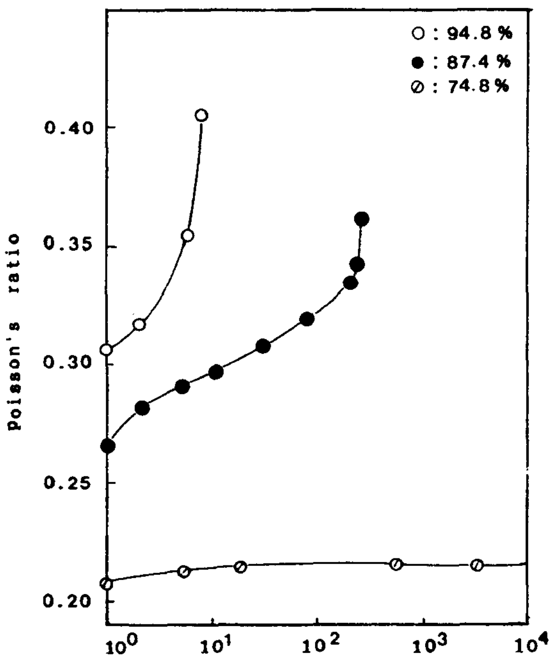

Fig. 7. Variation of Poisson's ratio with the Number of Cycles and the Stress Levels in the Case of a Cyclic Loading(Seong–Ju Sandstone) [6].

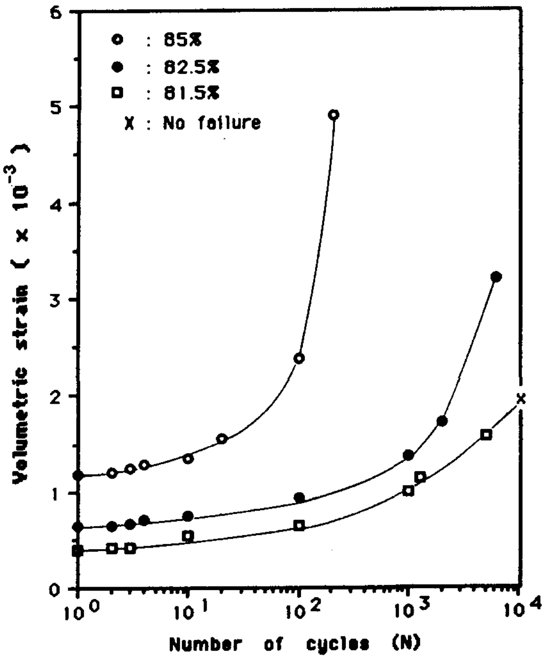

Fig. 8. Variation of Volumetric Strain with the Number of Cycles and the Stress Levels in the Case of a Cyclic Loading(Cheon-Ho Mt. Limestone).

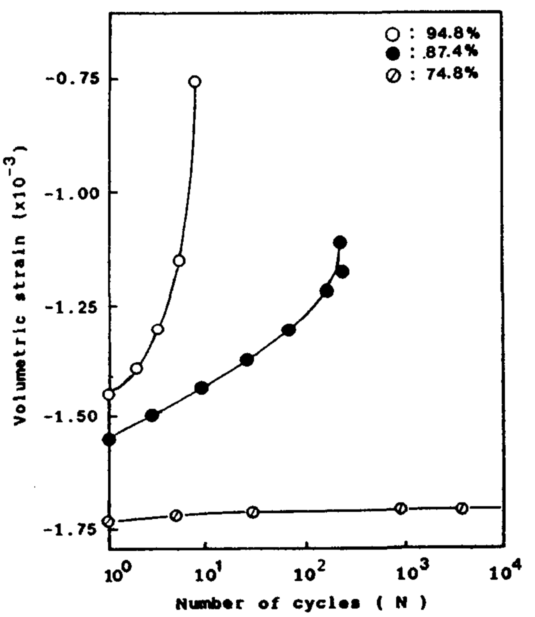

Fig. 9. Variation of Volumetric Strain with the Number of Cycles and the Stress Levels in the Case of a Cyclic Loading(Seong-Ju Sandstone) [6].

a relatively smooth increase, and the specimen did not fail even after 10^4 cycles. The variations of Poisson's ratio on Cheon-Ho Mt. Limstone and Seong-Ju Sandstone, as shown in Table 3 and Table 4, show that Seong-Ju Sandstone, at the first cycle, has a higher value than Cheon-Ho Mt. Limestone at all the stress levels except 74.8% of the level, and that Cheon-Ho Mt. Limestone, near the failure, conversely has a higher value than Seong-Ju Sandstone at all the stress levels. The reason seems that Cheon-Ho Mt. Limestone specimen, in the mineralogical grain size, consists of medium grains(average size of 2 mm) larger than the fine grains of which Seong-Ju Sandstone specimen is composed, and that Poisson's ratio of Cheon-Ho Mt. Limestone specimen with much lower failure strength, while increasing smoothly at the initial stage of cycles, appears to be extremely brittle due to the rapid increase in the lateral strain just before failure.

Fig.8 and Fig.9 also show that the volumetric strain for each of the two rock types tends to increase with an increase in the number of N cycles at each stress level, and in the variation of volumetric strain, as similar to that of Poisson's ratio described above. Seong-Ju Sandstone, on the other hand, has the higher value of the two rock types at the initial stage of cycles at all the stress levels. Near the failure Cheon-Ho Mt. Limestone has all the higher values conversely. It is considered that these trends, at the initial stage of cycles, are due to the phenomenon of more extreme closure of the pores or cracks by the accumulated loading for Seong-Ju Sandstone which shows a higher value than Cheon-Ho Mt. Limestone in porosity. The converse trends near the failure are due to the fact that lateral strain increases more rapidly than axial strain under cyclic loading for Cheon-Ho Mt. Limestone. Cheon-Ho Mt. Limestone and Seong-ju Sandstone specimens exhibit similar trends and tend to mildly increase up to 10^4 cycles at 81.5 and

74.8% stress levels, respectively.

When the above results are analyzed according to the variations of Poisson's ratio and volumetric strain with the number of cycles at each stress level, at the initial cycles, Seong-Ju Sandstone has the higher values of the two rock types at all the stress levels except 74.8% of the level, and from the last cycle prior to failure, it finally suffers fatigue failure with the values rapidly increased. Especially, in the variations of Poisson's ratio and volumetric strain for the higher stress levels, all specimens of the two rock types tend to rapidly increase, therefore, their fatigue life is very short.

Also Poisson's ratio and volumetric strain at the same cyclic number have higher values for the higher stress levels, and their increasing rates tend to rapidly increase. Corresponding to these values, the specimens of the two rock types show lower cyclic numbers, required to reach the fatigue limit for the higher stress levels, and then they fail easily.

3.3. Variation of Static Strength in Post-Cyclic Loading

As described above, surface structures and subsurface structures built in rock mass are normally under static loading. However, the rock structures and the surrounding rock mass are not in a state of stress equilibrium due to the outside impact loading such as blasting, drilling, etc. or frequent earthquake loading and, consequently, undergo dynamic or static cyclic loading. It seems to be significant, therefore, in analyzing the stability of subsurface structure, that the variation of strengths for rock specimens is revealed by the laboratory test carried out under a simple static loading and static loading in post-cyclic loading.

In this experiment, the basic cycle under cyclic loading was selected a frequency of 1 Hz (equivalent to the frequency of large events in earthquakes and blasting)[2]. Under this condition, Cheon-Ho Mt. Limestone and Indiana Limestone were mutually analyzed in order to investigate the variation of strengths for each rock type. Table 5 shows the difference in the static strength before cyclic loading is applied and the failure strength when monotonic loading, with a constant rate, is subjected to the specimen not failed even after 10^4 cycles.

In analyzing the results described above, all of the two rock types show that static strength measured after 10^4 cycles is higher than a predetermined static strength, and the increasing rate of strength for Cheon-Ho Mt. Limestone and Indiana Limestone, is approximately 6.18 and 10.96%, respectively.

Thus, an increasing trend in static strength is demonstrated for both rock types that the phenomenon of fatigue has almost no effect on the

Table 5. Comparison of Static Strengths before Cyclic Loading and after 10^4 Cycles

Rock Type	Static Strength(A)	Static Strength(B)	Increasing Ratio(%)
Cheon-Ho Mt Limestone	742.30(12)	788.20(3)	6.18
Indiana Limestone	515.09(10)	571.54(2)	10.96

* Static Strength(A) and (B) : Failure strengths under a constant loading before cyclic loading and After 10^4 cycles (Unit : kg/㎠)
* Numbers in parenthesis indicate the number of specimens tested.

specimen under cyclic loading for 10^4 cycles. Fatigue limit can be verified by considering the fact that applied stress levels at this time, for Cheon–Ho Mt. Limestone and Indiana Limestone, are 81.5 and 70% of dynamic strength, respectively. Regarding this, Hardy and Chugh[1] revealed that this factor of increase in static strength was related to the effect of some form of inelastic behavior, i.e., axial strain is increased with the number of cycles up to 10^2 cycles, and remains constant regardless of the number of additional cycles, and finally appears to be further evidence of inelastic behavior.

Also Indiana Limestone specimen showed an increase of more than 4% in static strength as compared with Cheon–Ho Mt. Limestone specimens ; Porosity for Cheon–Ho Mt. Limestone is approximately 0.274%, but Indiana Limestone, 17.2%. The reason seems to be that porosity reduction in the specimen is remarkable for Indiana Limestone under cyclic loading, but that its increase for Cheon–Ho Mt. Limestone results in brittle failure due to the increase of internal microfracturing.

4. Conclusions

In this study uniaxial cyclic loading tests of the Cheon–Ho Mt. Limestone specimens were performed to investigate the fatigue failure behavior. The loading rate was constantly kept at 760kg/cm² /sec under cyclic loading. In order to reveal the fatigue behavior for each rock type, the test results were also mutually compared with each other and with previous studies carried out on Indiana Limestone and Seong–Ju Sandstone.

Conclusions which may be derived from the test data obtained under these condition and the results of previous study are as follows ;

1. S–N curves are compared for each rock type, and the relationship of test results can be formulated within a range of 10^4 cycles, in the case of Cheon–Ho Limestone and Seong–Ju Sandstone. The formulae are presented in the form of S(%)=92.84(%)–2.878 LogN and S(%)= 99.82(%)–5.17 LogN, respectively. Also their correlation coefficients(R) are 0.886 and 0.983, respectively.

2. All three rock specimens were found to have shorter fatigue life with the higher applied stress levels. Also since Cheon–Ho Mt. Limestone, Indiana Limestone and Seong–Ju Sandstone did not fail even after 10^4 cycles at the stress level of 81.5, 70 and 74.8%, respectively, the fatigue life for each rock type is estimated to be no less than 81.5, 70 and 74.8% at each stress level for Cheon–Ho Mt. Limestone, Indiana Limestone and Seong–Ju Sandstone, respectively. And also the fatigue strength of Cheon–Ho Mt. Limestone is verified to be 95.8% of the static strength.

3. The comparison in static strengths on the monotonic loaded specimens and the specimens which did not fail even after 10^4 cycles indicated that all of the latter had increasing values, and the increasing rate of strength was about 6.18 and 10.96%, respectively, for Cheon–Ho Mt. Limestone and Indiana Limestone.

4. In all the cases, Poisson's ratio and volumetric strain for Cheon–Ho Mt. Limestone and Seong–Ju Sandstone tended to rapidly increase for the higher stress levels with increasing number of cycles. This increasing trend becomes rapid and obvious just before failure. The variation of two values on Cheon–Ho Mt. Limestone shows that with a mild increasing trend, they did not fail even after 10^4 cycles at a stress level of 81.5%, and the values for the level of 82.5 and 85% increased relatively smoothly during the initial cycles, but tended to increase rapidly just before fatigue failure.

5. Poisson's ratio and volumetric strain for each stress level were analyzed at both the first cycle and the cycle prior to failure. The result is as follows ; while Seong–Ju Sandstone, at all the

stress levels except the level of 74.8%, has the higher value of two rock types at the initial stage of cycles, near the failure Cheon–Ho Mt. Limestone has all the higher values conversely.

The effect of cyclic loading on the safety of construction and the stability of rock can not be neglected by mining engineers and earthquake researchers. Therefore, fatigue characteristics are believed to also be indicative of jointed and faulted rock behavior under cyclic loading. The results of this study are expected that in surface and underground design the fatigue limit or fatigue strength be used instead of the commonly employed compressive strength value. If studies on the effects of cyclic waveform, cyclic frequency, loading rate, size effect and moisture condition of specimen are continuously progressed in future, the results seem to be more applicable to the field than those of current study.

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