Effect of Cyclic Loading on the Mechanical Properties and Fatigue Behavior of Tonalite Rocks

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Extended Abstract

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Introduction

Many civil structures (e.g. tunnel walls, bridge pillars, dam abutments and road foundations) are subjected to both static and dynamic loads. Cyclic loading leads to occurring fatigue phenomenon. Fatigue is the tendency of materials to break, or the process of damage accumulation, under cyclic loading. It was found that the dynamic fatigue strength can be reduced by 30-70 percent on average compared to uniaxial compression strength. Different materials show different response when they are subjected to cyclic loading. Some materials become stronger and more ductile, while others become weaker and more brittle. Although it is clear that the mechanical properties of rock under dynamic loads varied dramatically from those under static loads, the nature of dynamic failure in rock remains unclear, especially in cyclic loading condition. Fatigue behavior of rocks was rarely studied in respect to other materials such as steel and soil. The performed researches on fatigue behavior of rocks indicated that fatigue life will be decreased by increasing load amplitude in logarithmic and exponentially pattern. Also, strain softening is the dominated behavior of rocks against cyclic loading. Furthermore, some parameters such as maximum load level, confining pressures, amplitude, and loading frequency have considerable effects on fatigue behavior of rocks. However, available data on fatigue behavior remain insufficient for solving the practical tasks of predicting rock bursts and earthquakes. Obtained results are inconclusive and sometimes discordant. The aim of the current work was to assess tonalite rock fatigue behaviour under different loading conditions to describe the fatigue damage process of the granitic rock.

Material and methods

Several core samples were prepared to perform this research. The core samples were prepared with a L/D ratio of 2.5 with an average diameter of 54 mm. Before the fatigue tests, the physical and mechanical properties of the rocks were measured. Uniaxial compressive strength test (UCS) has been done on 5 core samples. The tests were performed in the load-control mode with a 1.6 kN/s loading rate. The tests were conducted to obtain the physico-mechanical parameters of the rocks in static loading condition, and provided a reference for subsequent dynamic tests. The cyclic tests were performed in both load and displacement control modes. To record axial and lateral strains during the fatigue tests, four strain gauges have been employed with arrangement of two axial and two laterals. Also, three acoustic emission sensors were installed on top, mean and bottom of the core samples to record cracking sound. In order to doing the tests a servocontrol Instron machine with 500 kN capacity was employed. The fatigue tests were conducted with three different maximum loads, 1 Hz frequency, and constant amplitude (0.82 of uniaxial compressive strength). The maximum stress level (the ratio of maximum cyclic stress to static strength) was varied 0.80, 0.85, and 0.90. The amplitude level (the ratio of amplitude stress to static strength) ranged from 0.50 to 0.70 and 0.90. Finally, Multi stages loading with increasing amplitude were applied for the displacement control tests. The results of fatigue tests have been evaluated by fatigue damage parameters including maximum and minimum axial strain, maximum and minimum lateral strain, tangent and secant modulus, toughness and hysteresis energy.

Results and discussion

The obtained results indicated that during fatigue process failure occurs below the maximum strength loading condition as a result of accumulative damage. Analysis of the fatigue test results showed that the fatigue failure consisted of three stages: fatigue crack formation (initiation phase I), stable crack propagation (uniform velocity phase II), and unstable crack propagation resulting in a sudden breakdown (accelerated phase III). By comparing the axial and lateral deformation, it was found that lateral deformation is more sensitive to fatigue. At higher stress levels, considerable part of fatigue life is response to crake development, whereas at lower stress levels, crack acceleration phase of fatigue life is distinguishable. Descending trend of loading and unloading tangent modulus shows a scatter pattern. This behavior may be related to the calculation method and loading condition, as well as microstructure and behavior of the rock mass. In spite of tangent modulus results, the three-stages of damage process (especially phase I and II) for secant modulus in both loading and unloading conditions are clear. The result is due to the method of calculation and increase in axial strain with increasing number of cycles. Brittle behavior of this type of rock leads acceleration phase to be hidden and unclear in most of fatigue damage parameters. A dramatic decrease of toughness and hysteresis energy in the first few cycles is due to the closing of pre-existing micro fractures. In fact, during the initial cycle, the rock behaves in a more ductile fashion than in the next few cycles. Thereafter, toughness begins to increase slowly, then steadily, and finally rapidly. A similar behavior was found for hysteresis energy as well. This fact indicated that cracks generated in parallel to loading direction. Fatigue displacement control tests show a strain softening behavior for the granitic rocks. This behavior is highlighted in variation of maximum stress during the tests. This parameter, especially in final step of loading, shows distinguishable decreasing trend.

Conclusion

The tonalite rocks were subjected to uniaxial cyclic loading in both load and displacement control mode. The following conclusions were drawn from this research.

-Accumulated fatigue damage occurs in an obvious three-stage process. This is the result of the micro-fracturing mechanism in the fatigue process.

-By comparing axial and lateral strain damages, it was found that crack propagation occurred in the loading direction and crack opening occurred in the lateral direction. So, among fatigue damage parameters, lateral strain shows the best three-stage fatigue damage behavior.

- Strain softening was found as rock response to cyclic displacement control loading.

Keywords: cyclic loading, fatigue damage, strain softening, loading amplitude

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