Postprint: Mechanical Strength Deterioration Mechanism of Qinghai Ashigong Sandstone and Mudstone under Freeze-Thaw Cycles

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Abstract

The Guide Basin in Qinghai features extensive red bed distribution, with distinct summer-winter alternation and prolonged low temperatures. The red bed rocks in this region generally exhibit poor frost resistance, high water sensitivity, and loose structure, leading to frequent occurrences of landslides, collapses, and slope deformation-instability disasters induced by freeze-thaw action. This study selects red bed sandstone and mudstone from Ashigong in the Guide National Geopark as research objects, conducting physical-mechanical, microstructural, and phase analysis tests as well as numerical simulations based on freeze-thaw cycle experiments. The main research findings are as follows: (1) The freeze-thaw deterioration patterns of sandstone and mudstone under different water content states were investigated. Freeze-thaw cycle tests were conducted on red bed sandstone and mudstone under three water content states (dry, natural, and saturated). The results demonstrate that with increasing freeze-thaw cycles, rock diameter, height, mass loss rate, wave velocity loss rate, and porosity all increase, and their rates of change exhibit an upward trend with increasing water content. (2) The mechanical response of rocks to freeze-thaw-confining pressure coupling was explored. Through triaxial mechanical tests on freeze-thaw-treated red bed sandstone and mudstone, it was found that increasing freeze-thaw cycles and water content lead to reductions in peak strength and elastic modulus, while confining pressure enhances rock frost resistance. (3) The microstructural damage mechanisms of rocks were analyzed. Sandstone and mudstone are composed of minerals such as quartz, illite, and kaolinite. After freeze-thaw cycles, clay mineral content decreases, pore and particle contents increase, and fracture number and width increase and interconnect to form networks. (4) The microcrack propagation and mechanical deterioration process of sandstone were revealed using a particle flow model. With the aid of PFC2D software, it was discovered that as freeze-thaw cycles and axial load increase, damage diffuses from both ends of the specimen toward the middle, peak strength decreases, the stress-strain curve exhibits plastic characteristics, and the failure mode transitions from shear failure to tensile failure. This study reveals the mechanical damage mechanisms of red beds under freeze-thaw cycles, provides mechanical data references for stability assessment and disaster prevention of rock-soil masses in alpine red bed regions, offers scientific support for in-depth research on red bed landscape evolution mechanisms, and holds certain engineering application value for implementing red bed disaster remediation.

Full Text

Study on the Mechanism of Mechanical Strength Deterioration of Sandstone and Mudstone under Freeze-Thaw Cycles in Ashigong, Qinghai Province

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Abstract

The red beds of the Guide Basin in Qinghai Province are widely distributed. Characterized by distinct seasonal transitions and prolonged low temperatures, these red bed rocks generally exhibit poor frost resistance, high water sensitivity, and loose structure, resulting in frequent landslides, collapses, and slope deformation and instability induced by freeze-thaw action. This study selected red bed sandstone and mudstone from Ashigong in the Guide National Geopark as research subjects. Based on freeze-thaw cycle tests, physical and mechanical property tests, microstructural analysis, mineral phase analysis, and numerical simulations were conducted. The main research findings are as follows:

(1) Investigation of freeze-thaw deterioration patterns under varying moisture conditions. Freeze-thaw cycle tests were conducted on red bed sandstone and mudstone under three moisture states—dry, natural, and saturated. Results demonstrated that with increasing freeze-thaw cycles, loss rates in rock diameter, height, mass, wave velocity, and porosity all increased, with their rates of change accelerating as moisture content rose.

(2) Examination of mechanical response to coupled freeze-thaw and confining pressure effects. Triaxial mechanical tests on post-freeze-thaw red bed sandstone and mudstone revealed that increasing freeze-thaw cycles and moisture content led to reductions in peak strength and elastic modulus, while confining pressure enhanced the rocks' resistance to freeze-thaw damage.

(3) Analysis of microstructural damage mechanisms. Sandstone and mudstone were found to be composed of quartz, illite, kaolinite, and other

minerals. Following freeze-thaw cycles, clay mineral content decreased while pore and particle contents increased, with fracture numbers and widths growing and interconnecting to form networks.

(4) Revelation of microcrack propagation and mechanical deterioration processes in sandstone via particle flow modeling. Using PFC2D software, it was observed that as freeze-thaw cycles and axial loading increased, damage diffused from both sample ends toward the middle, peak strength decreased, stress-strain curves exhibited plastic characteristics, and failure modes transitioned from shear to tensile failure.

This study elucidates the mechanical damage mechanisms of red beds under freeze-thaw cycles, providing mechanical data references for stability assessment and disaster prevention of rock-soil masses in cold red bed regions, offering scientific support for investigating red bed landscape evolution mechanisms, and possessing engineering application value for red bed disaster mitigation.

Keywords: red bed sandstone and mudstone; freeze-thaw cycles; strength deterioration; microstructure; chemical composition; numerical simulation

Note: Figure translations are in progress. See original paper for figures.