3D Effects of permeability and strength anisotropy on the stability of weakly cemented rock slopes subjected to rainfall infiltration

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Abstract

This study investigates the impact of permeability and strength anisotropy on the stability of weakly cemented sedimentary rock slopes under rainfall infiltration. Using three-dimensional finite element modeling, the research simulates changes in groundwater levels and pore water pressure in slopes with varying bedding plane orientations before and after rainfall events. Findings indicate that slopes with steeply dipping bedding planes experience a faster and greater rise in groundwater levels and pore pressure compared to those with gentle dips, leading to a more significant reduction in slope stability.

Additionally, four critical unfavorable conditions for slope stability are identified, where bedding planes and the slope face are nearly parallel: (1) daylight bedding planes, (2) coincident bedding planes and slope faces, (3) steep bedding planes dipping outwards, and (4) steep bedding planes dipping inwards. These results suggest that slope design in mountainous regions should carefully consider the orientation of bedding planes to ensure stability, particularly under heavy rainfall conditions.

Keywords: Permeability anisotropy, Strength anisotropy, Slope stability, Rainfall, Three-dimensional analysis, Numerical modeling.

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ABSTRACT

Weakly cemented sedimentary rocks with pronounced stratification exhibit permeability and strength anisotropy. The influence of permeability and strength anisotropy on the groundwater flow and slope stability depends on the orientation of the bedding planes. The stability of slopes with different orientations of bedding planes under rainfall infiltration was evaluated in this study using three-dimensional finite element modeling. The groundwater table and pore water pressure in slopes before and after rainfall were simulated, and the calculated pore pressure corresponding to the initial and highest groundwater tables was used for slope stability analyses. The results showed that in comparison with gently dipping bedding planes, a slope with steeply dipping bedding planes exhibits a greater rise of the groundwater table and a greater increase of pore pressure, leading to a larger reduction in the factor of safety. Also, a shorter time is required to reach the highest groundwater table and the maximum pore pressure at a certain position. In consideration of the anisotropic behavior and the groundwater table rise during rainfall, unfavorable conditions were identified for the slope stability. The four unfavorable conditions, where the bedding planes and the slope face approximately strike in the same direction are: (1) the daylight condition of the bedding planes, (2) the coincidence of the bedding planes and the slope face, and (3) steep bedding planes dipping out or (4) into the slope. Slopes with the unfavorable orientations of bedding planes need additional attention in order to ensure a safe land development in the mountainous areas.

以三維分析弱膠結岩坡在降雨滲透下之透水性與強度異向性對邊坡穩定之影響

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摘要

本研究探討透水性與強度各異向性在降雨滲透條件下對弱膠結沉積岩邊坡穩定性的影響。利用三維有限元素模型，模擬不同層理傾角下邊坡在降雨前後的地下水位及孔隙水壓變化。結果顯示，相較於和緩傾角層理，較陡傾角層理的邊坡在地下水位及孔隙水壓上升速度與幅度上要明顯更大，進而導致邊坡穩定性顯著降低。

此外，研究辨識出四種不利的層理與坡面相對方位，包括：(1) 邊坡層理面有出露狀態時、(2) 層理面與坡面重合既接近順向坡時、(3) 陡峭層理面順坡向向外傾斜、以及 (4) 層理面逆坡向向內傾斜。提出建議山區邊坡設計時應審慎考量層理方向，特別是在高降雨情況下對以上具有不利層理方向的邊坡，在山區土地開發中需特別加以注意其邊坡穩定分析之合理性以確保安全的結論。

關鍵字: 透水性異向性、強度異向性、邊坡穩定性、降雨、三維分析、數值模擬。

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