

Postprint: Influence of Randomness of Bidirectional Seismic Ground Motion on Fuzzy Reliability of Toppling Rock Masses

Authors: Zhang Jixu, Fu Xiaodong, Wang Linfeng

Date: 2025-08-20T00:00:00+00:00

Abstract

Unstable rock masses are highly susceptible to collapse disasters under seismic action. To calculate the stability of toppling-type unstable rocks under bidirectional seismic action and investigate the influence of ground motion randomness on their dynamic fuzzy reliability, the dynamic response of toppling-type unstable rocks is analyzed through structural dynamics and random process theory. First, based on structural dynamics theory, a mechanical model for seismic dynamic response of toppling-type unstable rocks and its motion equations on two main controlling surfaces are established. The Wilson- method and pseudo-excitation method are respectively employed to solve these motion equations, thereby establishing calculation methods for dynamic response of toppling-type unstable rocks under deterministic seismic waves and random seismic excitation. Then, based on limit equilibrium theory, the calculation formula for dynamic stability coefficient of toppling-type unstable rocks under deterministic seismic action is derived. Random earthquakes are regarded as stationary random processes, and based on the first-passage failure criterion, the mean and variance of peak seismic force response of toppling-type unstable rocks under random seismic excitation are derived, thereby establishing a calculation method for random dynamic stability of unstable rocks. Finally, the instability event of toppling-type unstable rocks is regarded as a fuzzy event. A fuzzy failure criterion is introduced and an improved Monte-Carlo method is adopted to calculate the fuzzy reliability of unstable rock masses, establishing a rapid calculation method for dynamic fuzzy reliability and analyzing the influence of ground motion randomness on fuzzy reliability. The proposed method is applied to an engineering example. The results show that after considering ground motion randomness, the dynamic stability coefficient and fuzzy reliability of toppling-type unstable rocks increase by 6.34% and 22.83% respectively, reducing the failure probability of unstable rock masses. Moreover, the fuzzy reliability calculated using the fuzzy failure criterion is more favorable to engineering safety. Considering

the bidirectional nature and randomness of ground motion provides a better assessment of the dynamic stability of toppling-type unstable rocks, offering a reference for the evaluation of random seismic dynamic stability of unstable rocks.

Full Text

Effects of Randomness of Bidirectional Ground Motion on the Fuzzy Reliability of Toppling Perilous Rock Mass

Jiang-Xu Zhang^{1,2,3}, Xiao-Dong Fu^{1,2}, Lin-Feng Wang^{3,*}

¹ State Key Laboratory of Geomechanics and Geotechnical Engineering Safety, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan, Hubei 430071, China

² University of Chinese Academy of Sciences, Beijing 100049, China

³ Key Laboratory of Geological Hazards Mitigation for Mountainous Highway and Waterway, Chongqing Jiaotong University, Chongqing 400074, China

Abstract

Perilous rock masses are highly susceptible to collapse under seismic action. To evaluate the stability of toppling perilous rock under bidirectional seismic loading and investigate how ground motion randomness affects its dynamic fuzzy reliability, this study analyzes the dynamic response using structural dynamics and stochastic process theory. First, a mechanical model for seismic dynamic response is established based on structural dynamics theory, along with equations of motion on two dominant control planes. These equations are solved using the Wilson- method and pseudo-excitation method to develop computational approaches for dynamic response under both deterministic seismic waves and random excitation. Subsequently, based on limit equilibrium theory, the dynamic stability coefficient formula under deterministic seismic action is derived. Random earthquakes are modeled as stationary random processes, and the mean and variance of peak seismic force response under random excitation are obtained using the first-passage failure criterion, thereby establishing a method for calculating random dynamic stability. Finally, the instability event is treated as a fuzzy event, fuzzy failure criteria are introduced, and an improved Monte-Carlo method is employed to compute the fuzzy reliability of the perilous rock mass. This establishes a rapid computational method for dynamic fuzzy reliability and enables analysis of how ground motion randomness influences this reliability.

The proposed method is applied to an engineering case study, revealing that considering ground motion randomness increases the dynamic stability coefficient and fuzzy reliability of toppling perilous rock by 6.34% and 22.83%, respectively, thus reducing the failure probability of the perilous rock mass. Moreover, fuzzy reliability calculated using fuzzy failure criteria proves more conservative and

thus safer for engineering practice. By accounting for both the bidirectionality and randomness of ground motion, this approach provides a more accurate assessment of dynamic stability for toppling perilous rock and offers a valuable reference for random seismic dynamic stability evaluation of perilous rock masses.

Keywords: toppling perilous rock; bidirectional random earthquake; Wilson-method; pseudo-excitation method; fuzzy reliability

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

Source: ChinaXiv –Machine translation. Verify with original.