Experimental investigation on Toppling Failure Process of Anti-dip Rock Slopes

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Introduction

Anti-dip rock slopes, defined by bedding planes dipping opposite to the slope surface, generally have stability governed by discontinuities (Goodman and Bray, 1976. These slopes are widespread in tectonically active and high-relief areas, ranging from European Alps to Asian Himalaya. Anti-dip rock slopes typically fail through toppling, which can be classified into three main types—block toppling, flexural toppling, and block-flexural toppling (BFT)—according to Goodman and Bray (1976). Over the past decades, extensive research and models have been developed for block and flexural toppling failures. Among these, the BFT, the most complex and composite failure mode, has obtained increasing attention due to its behaviour to more accurately represent large-scale rockslides observed in anti-dip rock slopes. Although most BFTs finally possess a distinct translational sliding surface similar to bedding landslides, they have a different and prolonged developing process prior to the final catastrophically-sudden collapse. Current researches mainly focus on the visible toppling collapse stage. However, during the pre-toppling process (prior to the final toppling), a complicated cumulative damage process occurs within rock strata, with mechanisms underlying pre-toppling damage progression still inadequately understood.

To further clarify the dynamic damage processes in anti-dip rock slopes prior to final toppling failure, this study constructed a generalised geological model of anti-dip rock slopes for shaking table testing. Various analysis techniques were employed including the HHT marginal spectrum and transfer function analysis (Fan et al., 2016), to reveal the dynamic response characteristics and cumulative internal damage mechanisms in anti-dip rock slopes.

Experimental settings

In this experiment, we constructed a rock slope model with a height of 1400 mm and a width of 900 mm in a container installed on a 3 m × 3 m shaking table as shown in Fig. 1. The bedding rock layer was simulated using bonded concrete blocks, each measuring 100 mm × 100 mm × 100 mm. The bonding materials on the bedding surfaces (BS) and joint surfaces (JS) were recreated using clay-sand mixtures with a small proportion of medical glycerin. The input seismic excitation was the 2008 Wenchuan earthquake waves and Sine waves, with white noise for monitoring the variations of the natural frequency and damping ratio of the slope.

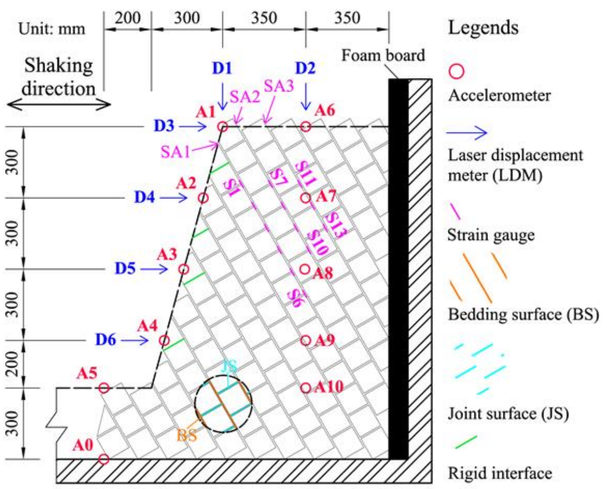

Fig. 1 Monitoring layout of the experimental model

Results and discussions

Based on the experimental results, the seismic response and toppling failure process were mainly investigated and shown in Figs. 2 to 4.

At first, the spatial distribution of acceleration amplification in time domain was revealed, involving the elevation-dependent amplification effect and free-face effect of the anti-dip rock slope model which is illustrated in Fig. 2. In addition, seismic characteristics in frequency domain were investigated as well.

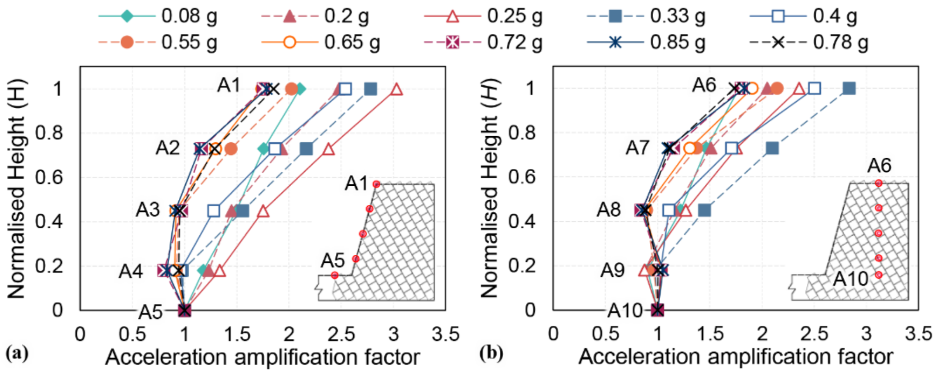

Fig. 2 Acceleration amplification (a) along slope surface and (b) within slope body under selected mainshocks

Moreover, the potential damage evolution during pre-toppling process and the final toppling failure process were both discussed based on the collaborative measurement of internal strains and external displacement monitored by laser displacement meter and the Particle Image Velocimetry (PIV) technique. According to the experimental data, the toppling process has a prolonged development process and a complex BFT failure mode as shown in Fig. 3 (Pre-toppling evolution) and Fig. 4 (final failure state).

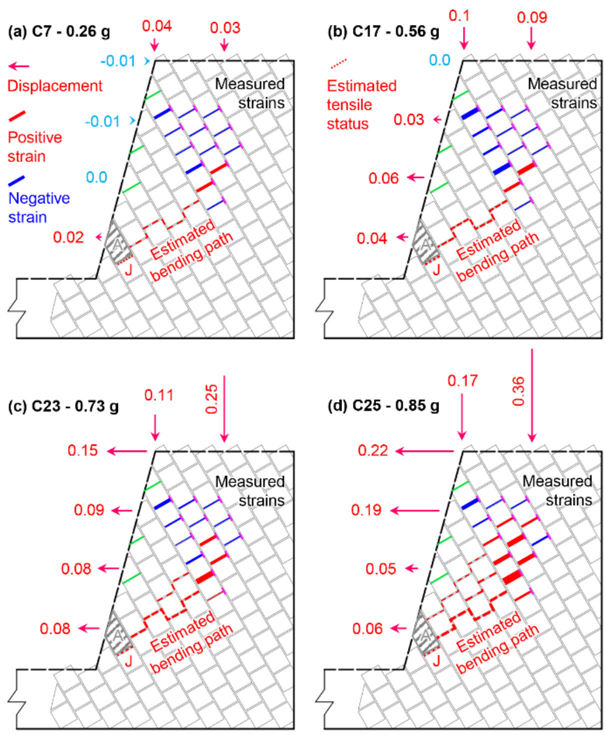

Fig. 3 Potential evolution of pre-toppling failure in anti-dip rock slope based on experimental observation.

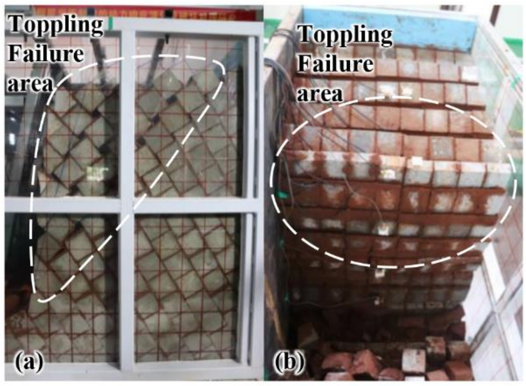

Fig. 4 Toppling failure characteristics of experimental results

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