Assessing the Stability of Precariously Balanced Rocks and their Geomorphic Settings

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ABSTRACT

Precariously balanced rocks (PBRs) are balanced boulders that serve as *in situ* negative indicators for earthquake-generated strong ground motions and can physically validate seismic hazard analyses over multiple earthquake cycles. Understanding what controls the formation of PBRs, when they were formed, and how long they remained balanced is critical to their utility in seismic hazard assessment. The geologic and geomorphic settings of PBRs were investigated using PBR surveys, slenderness analysis from digital photographs, joint density analysis, and landscape morphometry. An efficient field methodology for documenting PBRs was designed and applied to 261 precarious rocks in central Arizona. An interactive computer program that estimates 2-dimensional (2D) PBR slenderness (α_{min}) from digital photographs was developed and tested against 3-dimensional (3D) photogrammetrically generated PBR models. 2D slenderness estimates are accurate compared to their 3D equivalents, attaining <8.8% error in the heights of the estimated PBR centers of mass. Mean height, diameter, and aspect ratio (diameter/height) values for the surveyed PBRs are 1.16 m, 1.32 m, and 1.25 with coefficients of variation 47%, 48%, and 40%, respectively. Mean α_{min} values for all PBRs estimated using the software is 29° with a coefficient of variation of 38%. The joint density analysis reveals a mean PBR joint density of 0.39 m^{-1} with few PBRs formed in joint densities <0.22 m^{-1} and >0.55 m^{-1}. Landscape morphometry shows that PBRs are situated in upper reaches of drainage basins near divides and hillslope crests. Surveyed PBRs are preserved on local hillslope gradients between 10° and 45°, and contributing areas (per unit contour length) between 1 m^2/m and 30 m^2/m. The close comparison between the 2D and 3D PBR stability estimates indicates that our software may be used to estimate PBR slenderness from digital photographs taken in the field within reasonable accuracy. The streamlined workflow of the software allows for an efficient estimation of slenderness values for large PBR populations. The software may also potentially be used directly in the field to assess the precariousness of an entire precarious rock zone. The joint density results indicate that structural control on the bedrock from which PBRs are produced is critical to their formation and preservation; high joint densities create small corestones that completely decompose prior to exhumation while low joint densities create relatively larger corestones that are not precarious. Landscape morphometry results indicate that the location of a PBR in a drainage basin controls its formation and preservation potential. Therefore, this may help predict expected locations of PBRs in landscapes. More

importantly, the morphometric analyses caution that the construction of PBR exhumation rates from surface exposure ages needs to account for their geomorphic location in a drainage basin given that soil production and PBR emergence rates may be strongly controlled by the geomorphic state of the landscape; PBRs that emerged from landscapes in dynamic denudational equilibrium will have steady-state (uniform) exhumation rates, whereas PBRs produced in non-steady state conditions will contain multiple exhumation rates in their surface exposure record.

URL: http://activetectonics.la.asu.edu/Precarious_Rocks/