A numerical study on bulging deformation of castle stone walls using MPM-DDA

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There have been many cases of collapse of castle stone walls caused by large earthquakes. To conserve the heritage structures, understanding the failure mechanisms is important in determining effective restoration methods. Most common form of deformation seen is ‘bulging’, that is the local swelling of the wall surface. It is known that a bulged stone wall has a high risk of collapse during heavy rain or earthquakes. Therefore, clarifying the conditions under which bulging occurs is crucial. Since a stone wall has a structure in which cobble stones and a backfill ground exist inside the surface stones, investigating the collapse behaviors requires a numerical analysis that considers the collapse of stones, the large deformation of the backfills, and the interaction between them.

In this study, numerical experiments were conducted using MPM-DDA, which can analyze the interactive behavior between a continuum (ground) and discontinuum (stones). The MPM-DDA is a coupled method of the implicit Material Point Method (MPM) and Discontinuous Deformation Analysis (DDA), an implicit type of numerical method for jointed rock mass. MPM models cobble stones and a backfill ground, and DDA models stones, and the contact between the two methods is treated using the penalty method to represent the mechanical behavior of a stone wall. First, a simulation of a previous model experiment on the overturning collapse of a stone wall was conducted for validation. Then, a parametric study on seismic behavior of stone walls was conducted by varying the height and slope angle of the wall model. The results showed that when a stone wall is high or gentle, bulging occurs. On the other hand, when a stone wall is high and steep, it collapsed in an overturning form. The difference in collapse behavior was explained by the amount of subsidence of the backfill ground during shaking.