Limit analysis of masonry structures using discontinuity layout optimization

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Abstract

Limit analysis provides a simple yet effective means of verifying the safety of masonry structures, in use for at least several centuries. Although originally a hand analysis method, following pioneering research by workers such as Livesley in the 1970s, a range of numerical limit analysis models for masonry structures have been developed. Of these, rigid block idealizations have proved particularly popular. In this case geometrically expanded masonry units are used in combination with zero width joints, with rocking, sliding and/or crushing of the masonry modelled by use of suitable joint interface failure envelopes.

However, a disadvantage of rigid block idealizations is that failure can only occur at joints (or at a limited number of other pre-defined failure planes, to e.g. allow splitting of masonry units into two equally sized pieces). Also, as it will seldom be feasible to model every masonry unit in a real physical construction with a rigid block, engineering judgement must be exercised on the number of rigid blocks to be employed. If too few blocks are used there is a danger of over-estimating the safety of a given construction, particularly if a joint interface friction model obeying the associated flow rule is used.

In this contribution discontinuity layout optimization (DLO) is used as an alternative to the traditional rigid block limit analysis method. DLO involves discretizing a solid body using nodes, and then interconnecting node pairs with potential discontinuities. Optimization can then be used to identify the critical subset of discontinuities at failure which defines the geometry of the critical failure mechanism. A key feature of DLO is that potential discontinuities can cross-over one another, leading to a very wide search space. Also, singularities can be modelled without difficulty (unlike with finite element limit analysis, where time consuming adaptive mesh refinement would in this case normally be required).

Here two potential means of applying DLO to masonry structures are explored. In the first, a relatively detailed model is developed in which planes coinciding with the physical locations of masonry joints are assigned appropriately reduced mechanical properties, with units assigned stronger material properties. It is shown that this representation allows rigid block failure modes to be modelled but in addition also allows modes involving arbitrary cracking and spalling of blocks to be replicated. In the second, a homogenized masonry failure envelope is used in conjunction with DLO to enable masonry walls comprising numerous physical units to be modelled in a computationally efficient manner. In this case it is shown that the DLO results correspond closely to the results obtained using a rigid block idealization when a very large number of rigid blocks are used.

Keywords: **Limit analysis, Masonry, Discontinuity Layout Optimization, Rigid Block Analysis**