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CAPACITY INTERACTION CURVES FOR MASONRY WALLS UNDER BIDIRECTIONAL SEISMIC LOADING

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During an earthquake a wall is subjected to a three dimensional acceleration field and undergoes simultaneous in-plane and out-of-plane loading. The presence of one type of loading on a structural element affects the strength of that element against another type of loading. A considerable number of numerical and experimental studies, carried out to-date to investigate the behaviour of masonry walls under seismic loading, have considered the in-plane or the out-of-plane response of the wall separately without due consideration for any possible interaction between the two responses.

Very litttle work is reported in the liturature on the combined effects of in-plane and out-of-plane load/capacity of brick walls. Shapiro et al. (1994) studied the interaction in brick infills confined in concrete frames. Their test results showed that the in-plane cracks may reduce the out-of-plane strength of infills up to 100%. Recently, Hashemi and Mosalam (2007) conducted an in-plane shake table test on a concrete infilled frame, subsequently used to calibrate a numerical model that was further developed to include out-of-plane loading. In a recent experimental study, Maheri et al. (2011) highlighted the orthotropic nature of the out-of-plane response of brick walls. Another recent experimental work carried out in 2014 by Najafgholipour et al. (2014) examined the in-plane, out-of-plane interaction in brick masonry panels. The authors found that the interaction follows a general circular pattern.

In the proposed paper, results of a series of tests on brick panels with different combinations of in-plane and out-of-plane loads are first presented. In each test, the wall panel was first subjected to a certain value of out-of-plane load. Then, while the out-of-plane load was kept constant, the in-plane diagonal compressive load was monotonically increased until failure. In total, five load combinations were tested, corresponding to out-of-plane loads of 33%, 50%, 67%, 83% and 90% of the ultimate flexural strength of the panels. As expected, the in-plane shear capacity of the panel reduces with an out-of-plane load increase. The shear stiffness of the brick panels is also reduced with increasing out-of-plane load.

Following the experimental studies, the results of a numerical study aimed at evaluating the in-plane and out-of-plane interaction curves for full scale brick walls are presented. For this propose, results obtained from the experiments discussed in the previous section are first utilised to validate the numerical models adopted. The interaction curves are then evaluated numerically for full scale brick walls having three different aspect ratios (Height/Length) of 0.5, 1 and 2 and with different material properties. Due to the complex in-plane and out-of-plane loading, for numerical modelling of the test panels, suitable continuum macro model based on anisotropic plasticity is adopted for the three dimensional analysis of brick walls (Lourenço, 2000). This material model is implemented in software Diana V9.4 via a user supplied subroutine.

To investigate the influences of material and geometrical properties of the walls on the in-plane and out of plane loads in full scale unreinforced masonry walls, a series of parametric numerical studies are carried out. The investigated parameters included the aspect ratio of the wall and material properties of the masonry. The effects of wall aspect ratio are shown in Figure 1. The material properties investigated include; elastic properties such as moduli of elasticity of masonry in x (along bedjoints) and y (normal to bedjoints) directions (E_x and E_y) and shear modulus of masonry (G), inelastic material properties in tension such as tensile strengths of masonry in x and y directions (F_{tx} and F_{ty}), tensile fracture energies in tension along x and y directions (G_{tx} and G_{ty}) and parameter α and the inelastic material properties in compression, including; compressive strengths in x and y directions (F_{cx} and F_{cy}), compressive fracture energies in compression along x and y directions (G_{cx} and G_{cy}) and parameters β and γ.

Based on the extensive numerical investigations summarized above, in-plane, out-of-plane capacity interaction relations for full-scale masonry walls are derived and presented and the effects of different parameters are incorporated by introducing correction factors given in diagrams and relations.

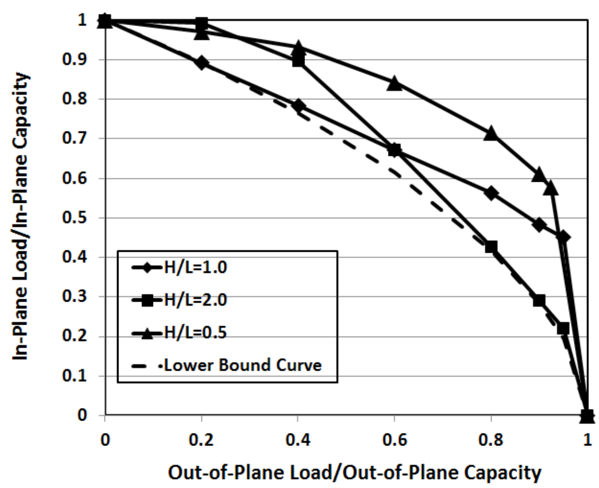

Figure 1. In-plane/Out-of-plane interaction curves for walls with different aspect ratios

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