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MODELLING OF SHEAR TESTS WITH DIFFERENT BOUNDARY CONDITIONS

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ABSTRACT

The behaviour of masonry under shear loading is not well understood. Researchers have used different test configurations to determine the strength of masonry panels, the majority being with an aspect ratio close to one. Numerous equations have been proposed for estimating the shear strength of masonry. For a set of recent tests on stone masonry, the maximum principal tensile stress at the centre of the wall was shown to be the best predictor of wall strength. This criterion was proposed in 1970 following tests on brickwork. We show why this particular measure would be a good predictor of the strength of plain masonry panels. We also show why different compressive strut widths should be considered for predicting the stiffness of a masonry panel subject to shear and for predicting the strength of that panel. The effect of axial compression on the strength of the panel is also clarified.

KEYWORDS: *finite element modelling, shear tests, compressive strut width, tensile splitting*

INTRODUCTION

Masonry buildings are vulnerable to horizontal wind loading and seismic excitation due to the low tensile and shear strength of unreinforced masonry. The behaviour of masonry subject to in-plane shear is not yet fully understood, but is commonly believed to be determined by the compressive strength of the masonry, the level of axial compression load, and for reinforced masonry, the amount of reinforcement. We have used finite element models of plain masonry subject to in-plane shear, to try to begin to understand the effects of the following factors:

Axial Load

Axial compression load is agreed amongst researchers as a major factor affecting the shear strength of masonry walls. The main reason is that the axial load suppresses tensile stresses in the wall, which consequently increases the wall's shear-resistance.

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Aspect Ratio

Wall aspect ratio is known to affect the behavior of masonry shear walls. Increasing the aspect ratio typically decreases the shear strength of reinforced masonry [1]. Janaraj and Dhanasekar [2] suggested that the aspect ratio of the unreinforced masonry panel in partially grouted masonry shear walls needs to be incorporated into the design expression. Most experimental studies have been carried out on walls and panels with aspect ratios close to one. More data are needed to define the effect of aspect ratio more precisely.

Boundary Conditions

Boundary conditions play an important role on the behaviour of masonry walls under in-plane shear. For example, Xi and Liu [3] found that for masonry infills in steel frames, a distributed load on the frame beam benefited the shear strength of the infilled frame, whereas point loads on the columns reduced the strength of the combination. Haach et al. [4] found boundary conditions also influenced the effect of pre-compression and the reinforcement on the wall's strength.

FINITE ELEMENT MODEL

To begin to understand the effects of the factors above on an unreinforced masonry panel, various 2-D finite element models were created with the same geometric width (but different heights when aspect ratio was considered). Abaqus v.6.14 was used. Linear elastic material properties were applied as we sought basic understanding of the effects of these three parameters on the stress distribution in the panels and the possible consequences of any changes. The masonry was defined simply with a Young's modulus of 10,000 MPa and Poisson's ratio of 0.25.

First, four models of square panels were analyzed to investigate the effect of the method of load application on the panel. The panels were subject to the same magnitude of a distance-controlled shear load, either applied on the top surface (from left to right) or over the top 1/10 of the left side. The bottom of each panel was fixed, while the top was either free or constrained in the vertical direction. Large tensile principal stresses developed at the top right and bottom left corners under this configuration. To represent what happens in actual tests more realistically, bond beams were added to the top and the bottom of the panel, as shown in Figure 1. The interactions between the bond beams and the panel were defined as a surface-to-surface contact with cohesive behaviour. This meant that the panel could separate from the beam at a set tensile stress. The bottom beam was fixed in the x- and y-directions, while the top beam was constrained only in the y-direction. Shear (lateral) load was applied to the panel by applying load distributed evenly over the whole of the top beam (Model A), just on the central vertical line of the beam (Model B), or on a square area at the centre of the beam (Model C).

To investigate the effect of axial load, Model A was also subject to displacement-controlled axial stresses of 1, 2, 5 and 10 MPa. Similarly, Model A was adjusted to have aspect ratios of 0.5, 0.75, 1, 1.5 and 2. Axial stresses of 0, 5 and 10 MPa were applied to each of these panels to examine the interaction of axial load and aspect ratio on the resulting stress distribution.

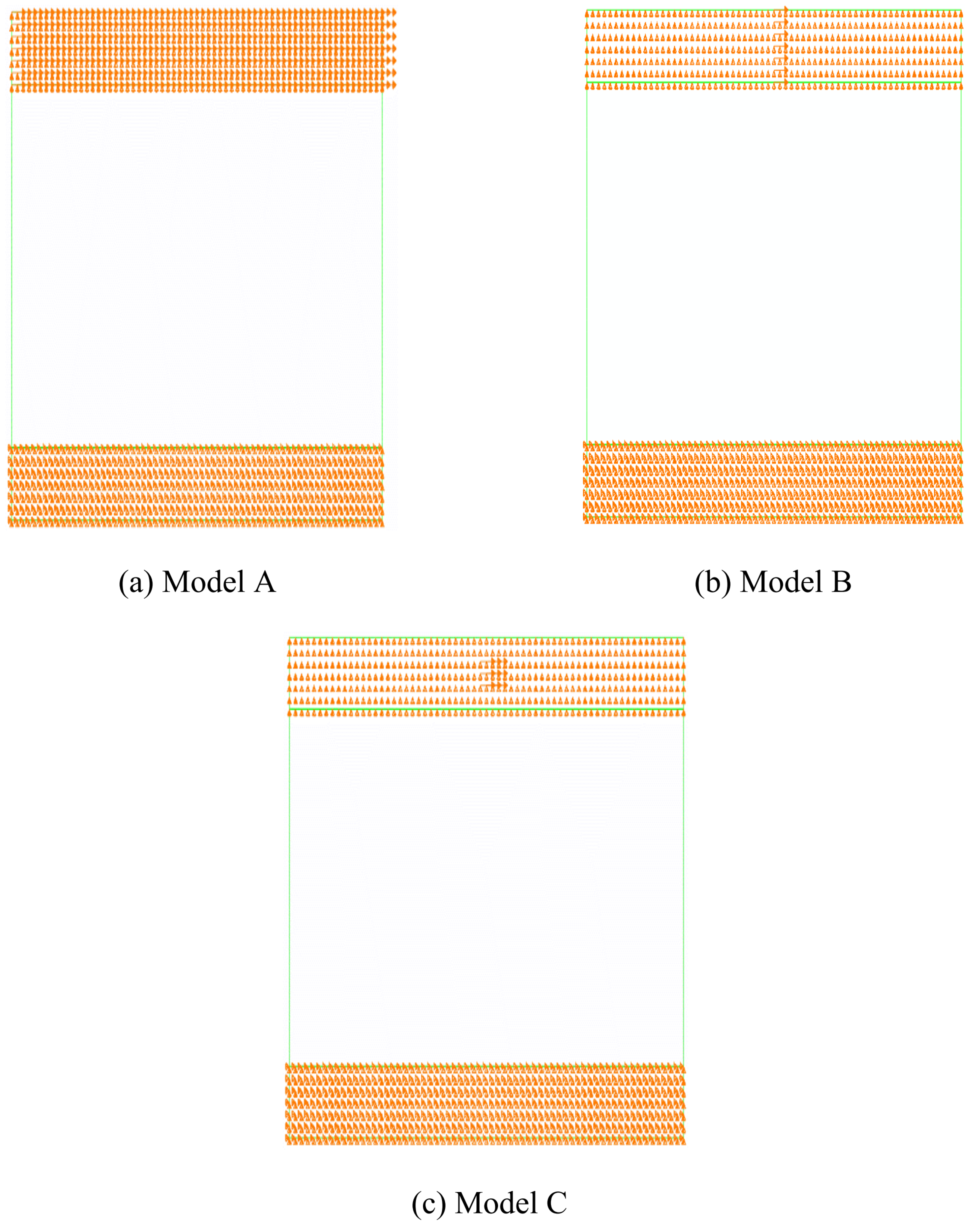
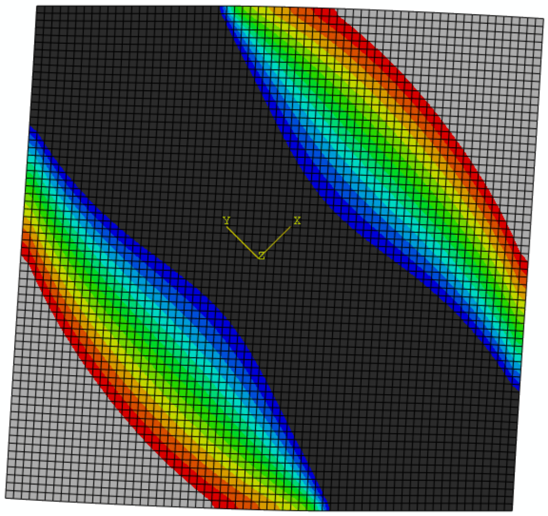


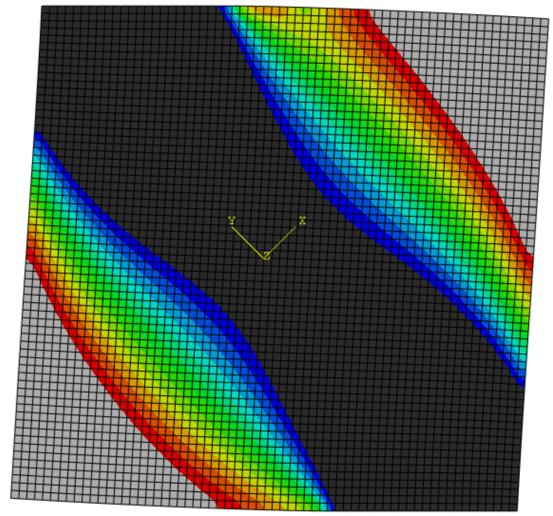
Figure 1: Models built to investigate the effect of loading conditions

RESULTS & DISCUSSION

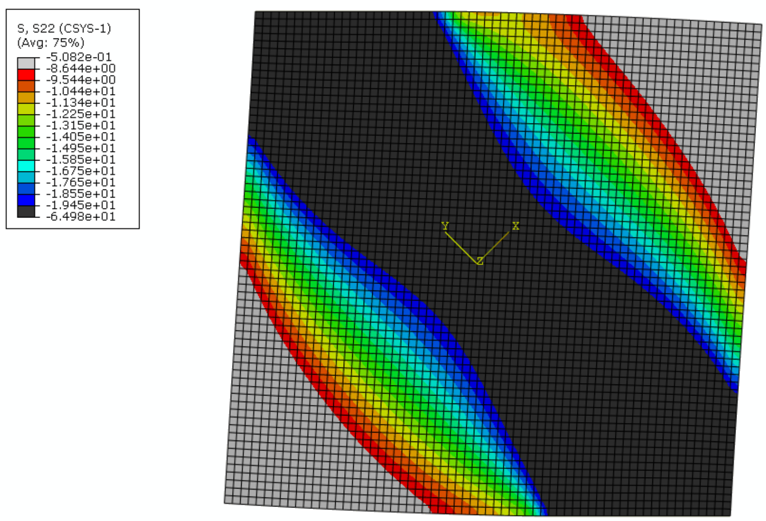
The different loading conditions produced very similar stress distributions in the panels as may be seen in Figure 2. In this figure we have plotted the stress in the direction parallel to the compressive diagonal from top left to bottom right in order to show the compressive "strut" that develops across the panel. It is clear that the zone of high compression, where failure might initiate is much narrower than the width of material that is compressed. Thus for the purpose of stiffness, the width of the strut is wider than that for failure.



(a) Model A



(b) Model B

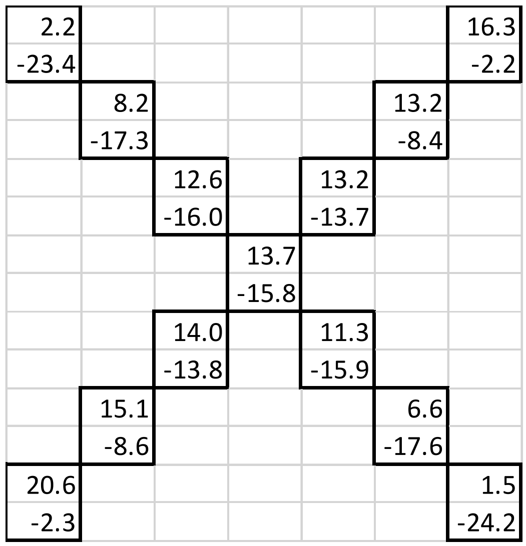


(c) Model C

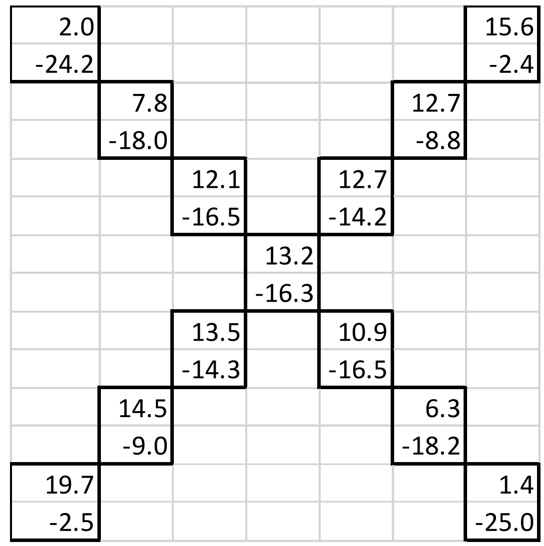
Figure 2: Compressive stress parallel to the diagonal

Axial Load

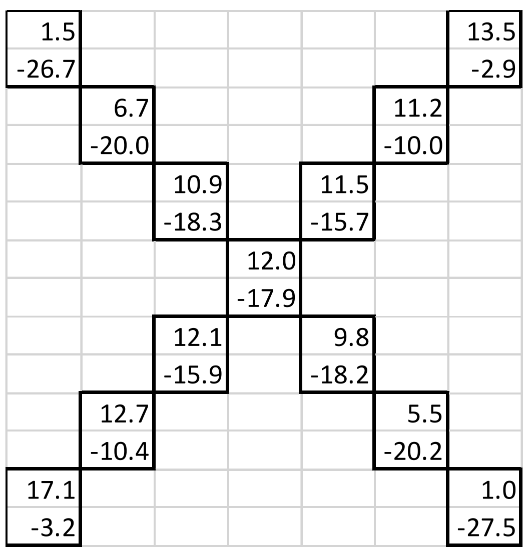
For Model A, the stress distribution is symmetric when there is no axial load applied to the panel. The plots presented in Figure 3 show the maximum and minimum (principal) stresses at locations along the diagonals of a square panel as the axial stress is increased. The principal tension on the diagonals decreases with increasing axial stress, which suggests that the wall should bear more shear load with increasing axial load.



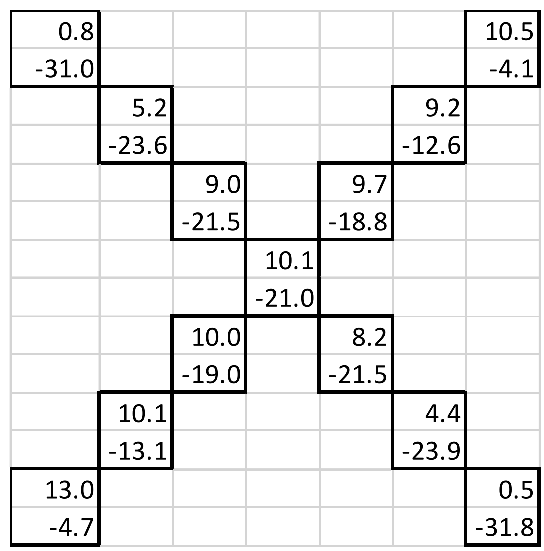
(a) axial stress = 1MPa



(b) axial stress = 2MPa



(c) axial stress = 5MPa

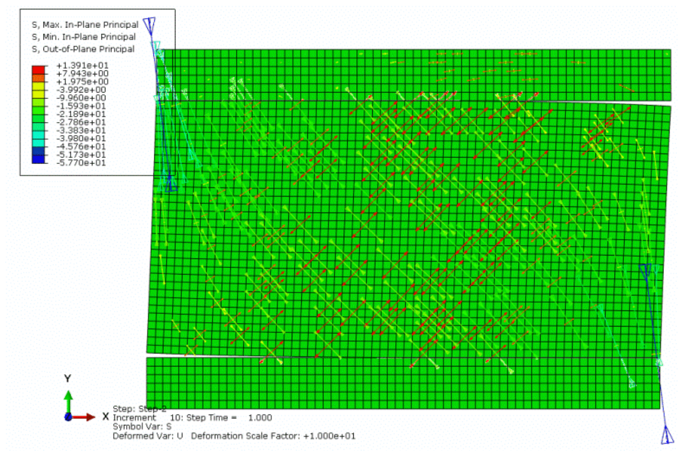


(d) axial stress = 10MPa

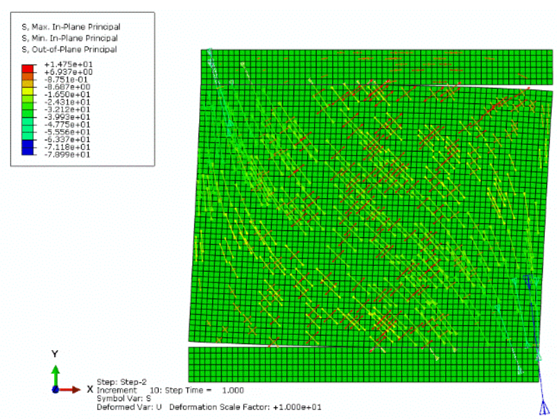
Figure 3: Compressive (-ve) and tensile (+ve) principal stresses on the diagonals (axial load)

Aspect Ratio

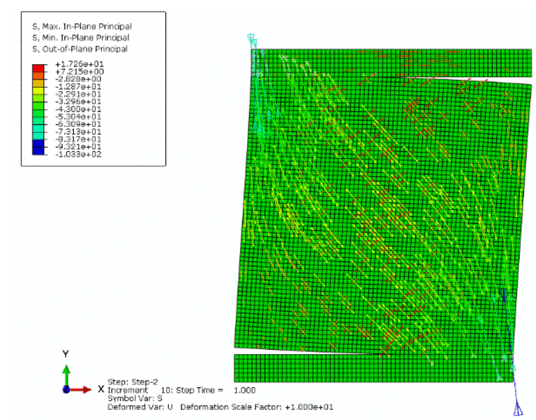
Model A was adjusted to assess the effect of aspect ratio. The minimum and maximum principal stress distributions are shown in Figure 4 for a shear force of 1000N and zero axial load. As the aspect ratio increases, the distribution of principal compression changes from a widely-spread pattern to a more concentrated pattern aligned with the central diagonal. Of interest here is the maximum principal tensile stress in the middle of the wall, as this was used by Turnsek and Cacovic [5] to develop an equation for predicting the shear strength of masonry walls. When compared to other methods, this equation was found to be the most effective for predicting the strength of stone masonry walls [6].



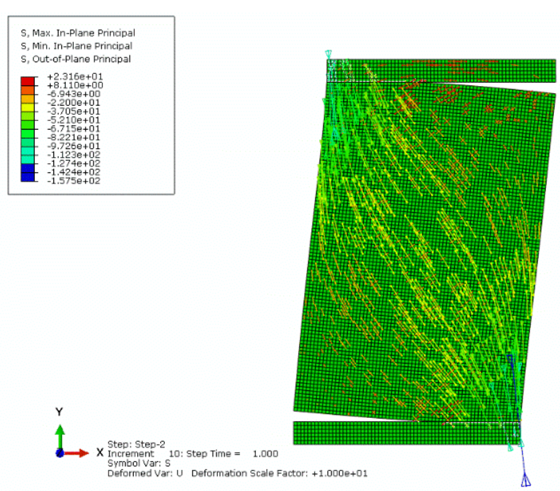
(a) aspect ratio = 0.5



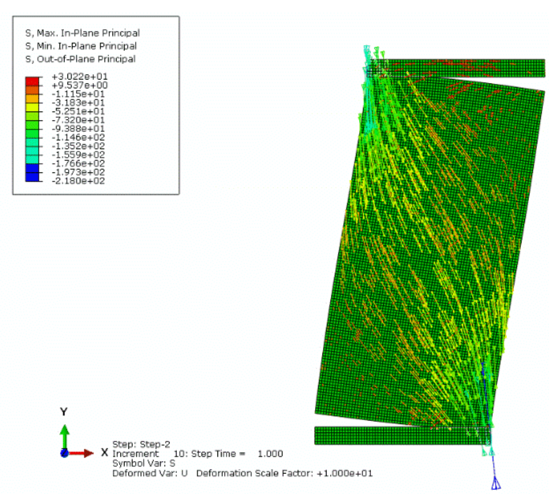
(b) aspect ratio = 0.75



(c) aspect ratio = 1



(d) aspect ratio = 1.5

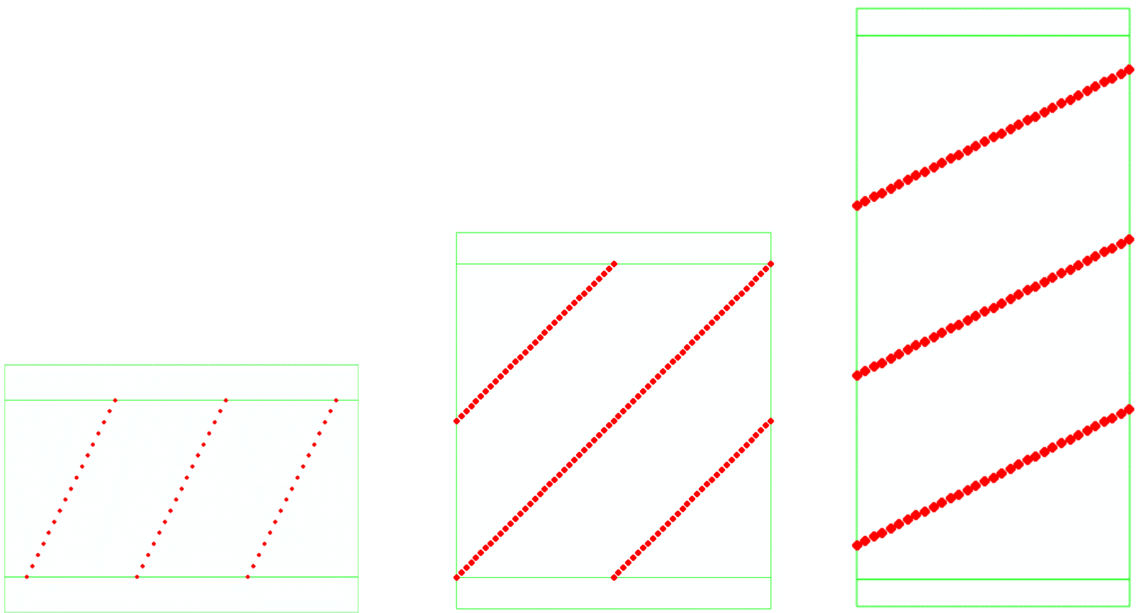


(e) aspect ratio = 2

Figure 4: Minimum and maximum principal stress patterns for different aspect ratios

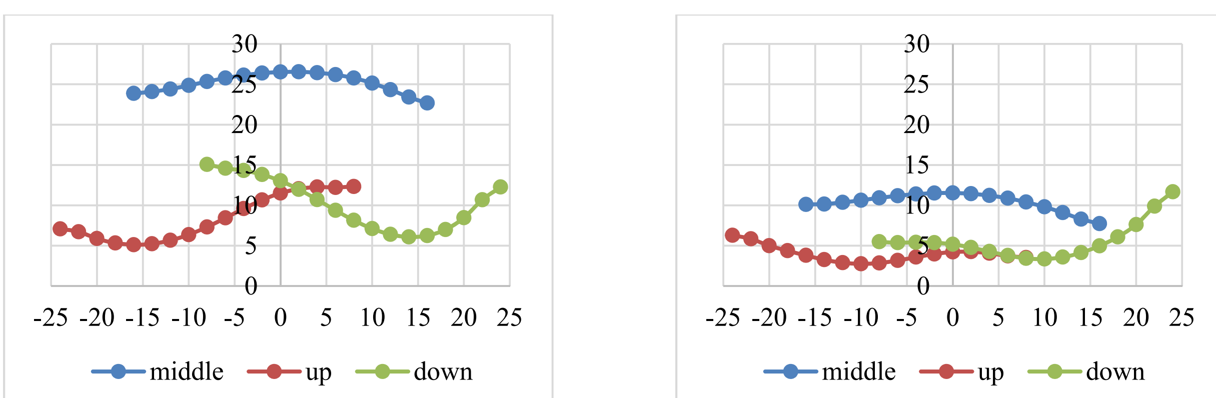
Failure: spherical void model

The tensile stress that develops at the surface of a spherical void [7] was calculated from the principal stresses at specific locations, rather than using just the maximum principal stress. Three quadrant lines perpendicular to the diagonal in different aspect ratio walls are shown in Figure 5. The tensile stress that would develop at a spherical void on these lines are shown in Figure 6 for different aspect ratio walls and two levels of axial stress. In Figure 6 "up" refers to the quarter point of the diagonal in the top left area, while down refers to the quarter point in the bottom right area. As may be seen, the maximum tensile stress – which would initiate a crack parallel to the compressive strut – is often near the middle of the wall. The effect of axial stress appears to be much less in the higher aspect ratio walls.

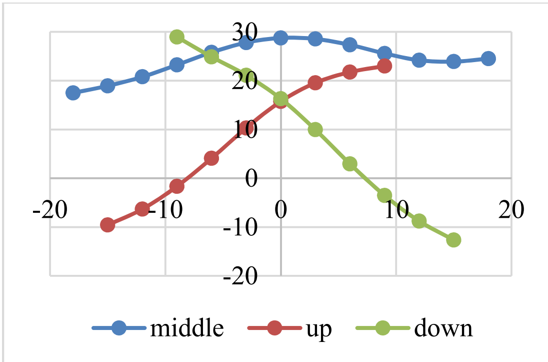


(a) aspect ratio=0.5 (b) aspect ratio=1 (c) aspect ratio=2

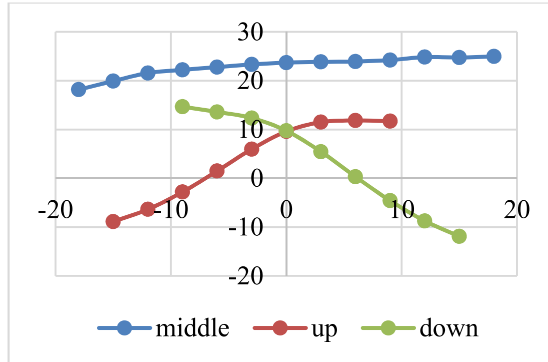
Figure 5: Three quadrant lines perpendicular to the compressive diagonal in walls of different aspect ratio



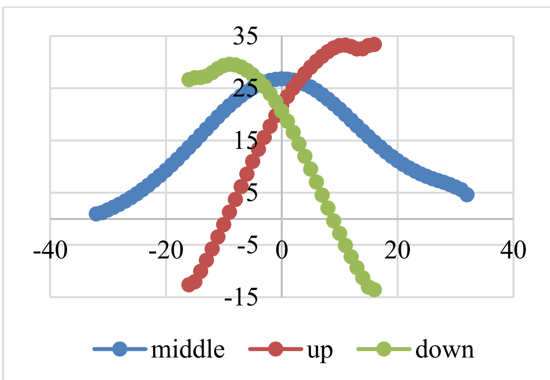
(a) aspect ratio=0.5, axial load=0 (b) aspect ratio=0.5, axial load=10MPa



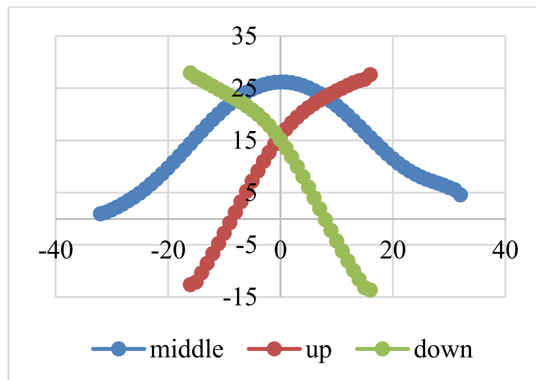
(c) aspect ratio=0.75, axial load=0



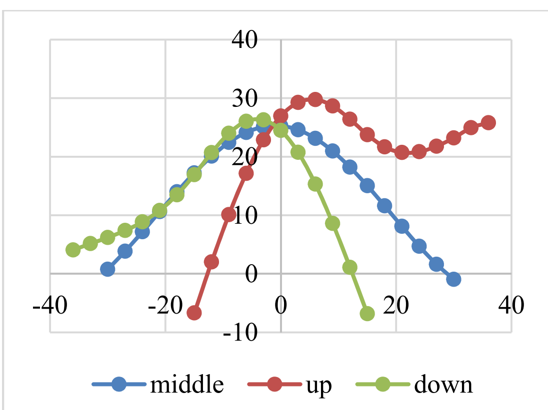
(d) aspect ratio=0.75, axial load=10 MPa



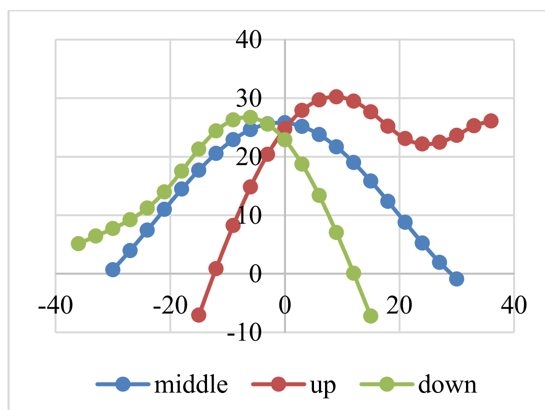
(e) aspect ratio=1, axial load=0



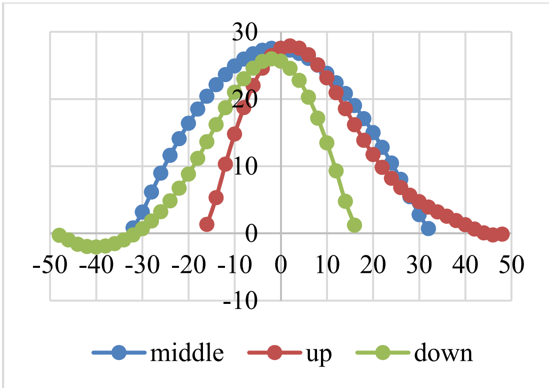
(f) aspect ratio=1, axial load=10 MPa



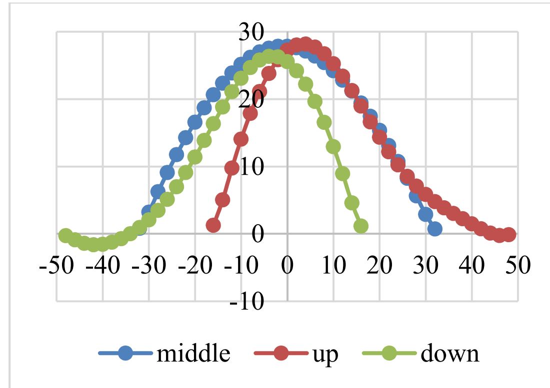
(g) aspect ratio=1.5, axial load=0



(h) aspect ratio=1.5, axial load=10 MPa



(i) aspect ratio=2, axial load=0

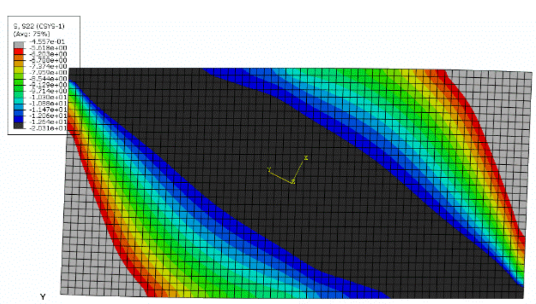


(j) aspect ratio=2, axial load=10 MPa

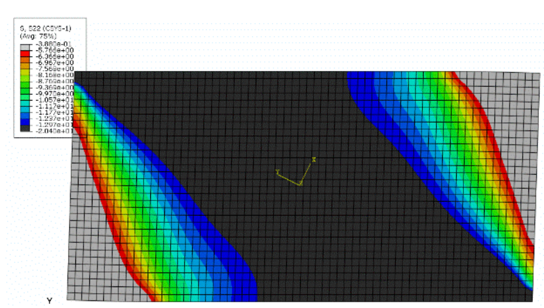
Figure 6: Tensile stress on the three quadrant lines

Compression strut width with aspect ratio and compressive stress

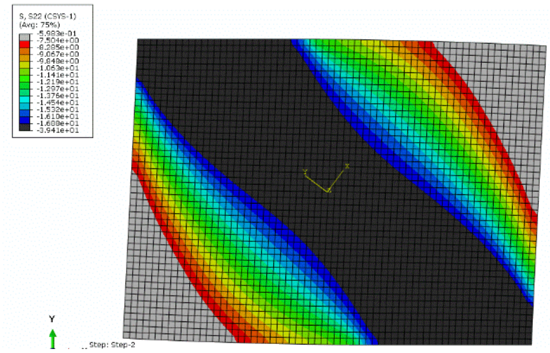
The combined effect of aspect ratio and axial load on the compressive strut is shown in Figure 7. Here the compressive stress parallel to the diagonal is plotted. The black area shows the zone with compressive stress 90% or more of the peak compressive stress at the centre of the bisector line, and therefore this upper bound represents the zone of the panel where cracking parallel to the strut is most likely to occur (we omit tensile cracking at the heel). The zone contained within the red limits shows the width of the strut which contains compressive stresses of 40% or higher of the peak stress: this lower bound is used to represent the section of the panel that bears compression and therefore contributes to the stiffness of the panel. It may be seen that as the aspect ratio increases from 0.5 to 2, the direction of the 90%-peak strut changes gradually from being on the left (under) side of the panel diagonal to being on the right (upper) side. In addition, when the axial load is increased from 0 to 10 MPa, the width of the 90%-peak strut widens in the low aspect ratio walls. This widening is coupled with an increase in the slope of the strut. As the aspect ratio is increased a larger fraction of the wall length is released from contact with the loading beam. The compression is subsequently applied through a smaller portion of the wall. When the aspect ratio is higher the slope of the compressive strut is already steep, so the addition of axial compression does not significantly change the strut geometry.



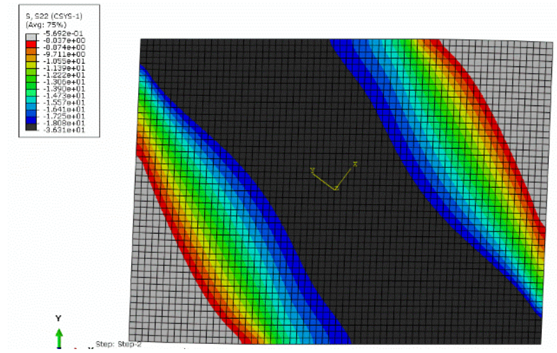
(a) aspect ratio=0.5, axial load=0



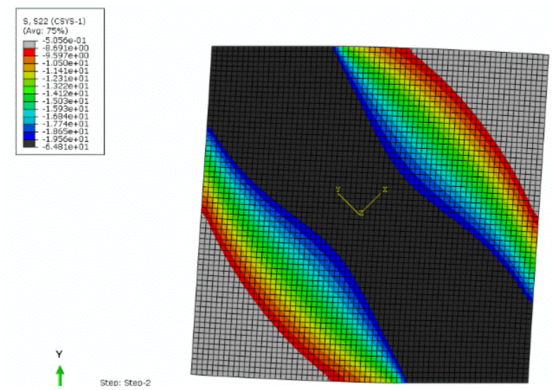
(b) aspect ratio=0.5, axial load=10MPa



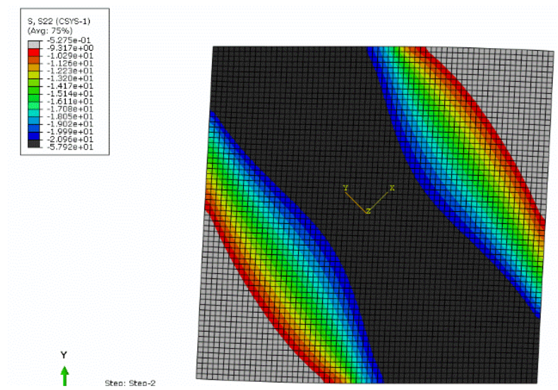
(c) aspect ratio=0.75, axial load=0



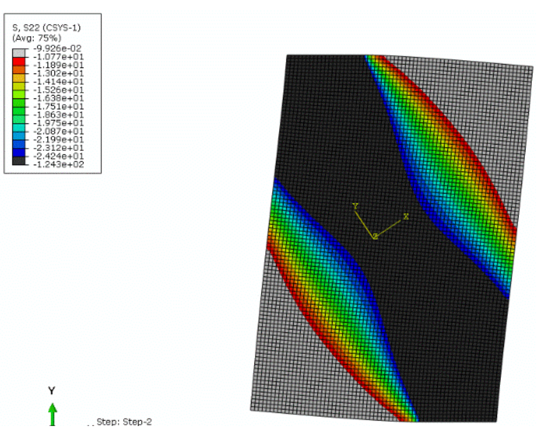
(d) aspect ratio=0.75, axial load=10MPa



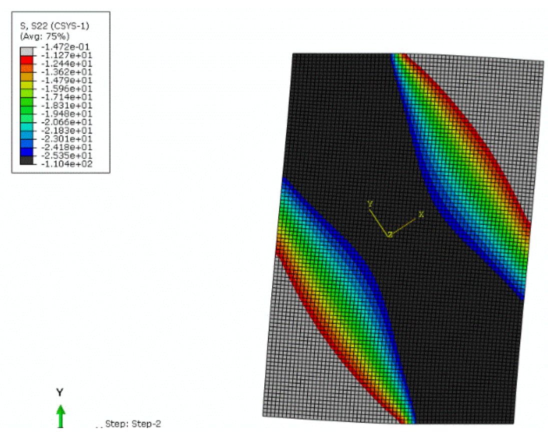
(e) aspect ratio=1, axial load=0



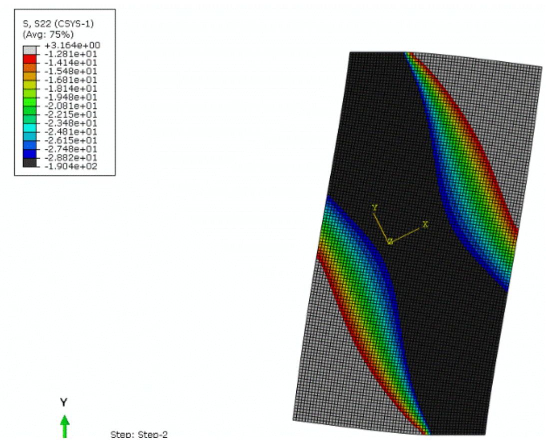
(f) aspect ratio=1, axial load=10MPa



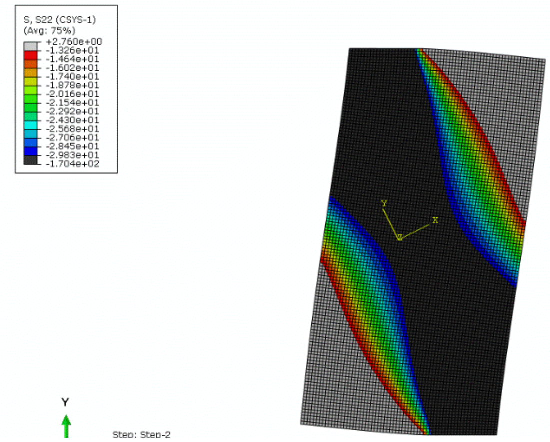
(g) aspect ratio=1.5, axial load=0



(h) aspect ratio=1.5, axial load=10MPa



(i) aspect ratio=2, axial load=0



(j) aspect ratio=2, axial load=10MPa

Figure 9: Compression strut width for changing aspect ratio and axial stress

CONCLUSIONS

There appears not to be a clear understanding of the behaviour of masonry under shear loading, what test methods produce in terms of stress state and how that might relate to a wall in practice. The modelling here is a first step to provide such basic knowledge.

ACKNOWLEDGEMENTS

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