The not-so-simple effects of boundary conditions on models of simple shear

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Analogue modeling of geological structures, such as the behavior of inclusions in a matrix or folding instabilities commonly employs a linear simple shear or general shear rig. In theory, a homogeneous plane strain flow is prescribed at the boundaries of such deformation rigs, but, in practice, the resulting internal deformation of the analogue material (commonly paraffin wax or silicone putties) often strongly deviates from the intended homogeneous strain field. This can easily lead to misinterpretation of such analogue experiments. We present a numerical finite element approach to quantify the influence of imperfect simple shear boundary conditions on the internal deformation of a homogeneous viscous analogue material. The results (Fig. 1) demonstrate that imperfect circumferential boundary conditions in the simple shear plane (x-y-plane) lead to the heterogeneous strain observed in some analogue experiments, depending on their design. However, in other experiments, the analogue material lies on top of a weak lubricating material (e.g. Vaseline) or is sandwiched between two such materials. These layers lead to a viscous drag force acting on the surface of the analogue material that represents imperfect simple shear boundary conditions in the third dimension (z-direction). For this experimental configuration, the numerical results (Fig. 2) show that the lubricating layers are responsible for the heterogeneous strain observed in analogue models. The resulting errors in internal strain can be as high as 100% and these important boundary effects, which are difficult to avoid, must be considered when interpreting analogue simple shear experiments.

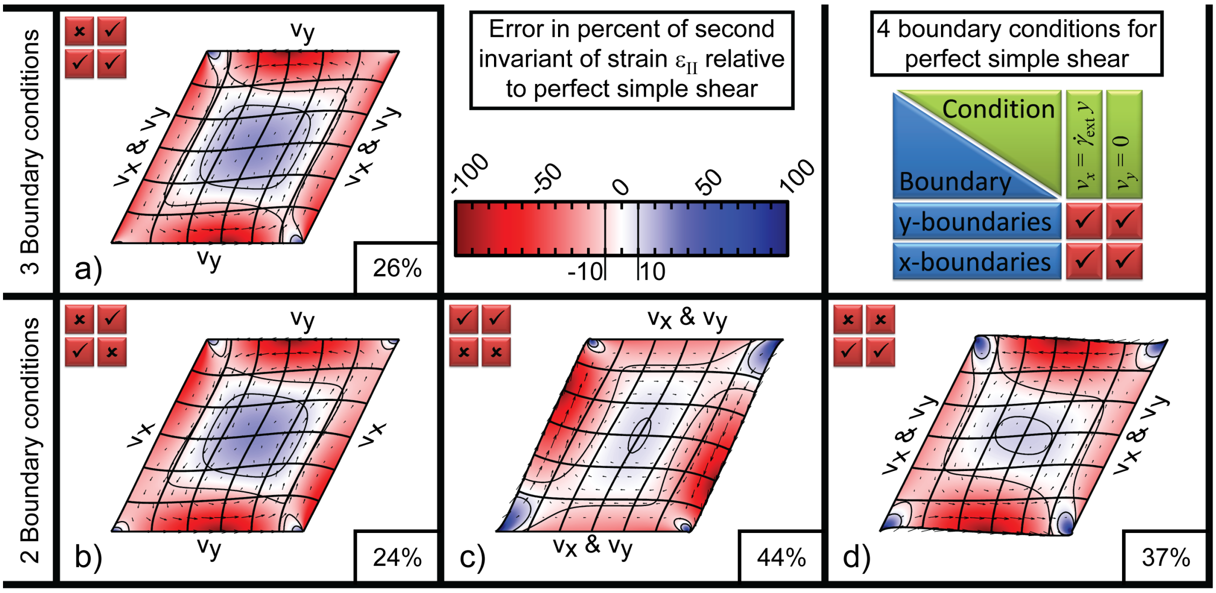

Fig. 1: Numerically deformed homogeneous square in simple shear with an applied shear strain of 0.5. For perfect simple shear (not shown here), four boundary conditions need to be applied, which are listed in the table in the upper right corner of the figure. In a), only three and in b) to d), only two boundary conditions are applied (indicated in each upper left corner in the same way as in the table and noted at each boundary). Thick black lines are passive marker lines. The color represents the second invariant of finite strain, plotted as the error in percent relative to perfect simple shear. Thin black lines are the ±10% contour lines. Numbers in the lower right corner of each subfigure represents the area of the model with an absolute error smaller than 10%. Arrows represent the scaled finite perturbation displacement, i.e., the difference between the actual displacement and perfect simple shear.

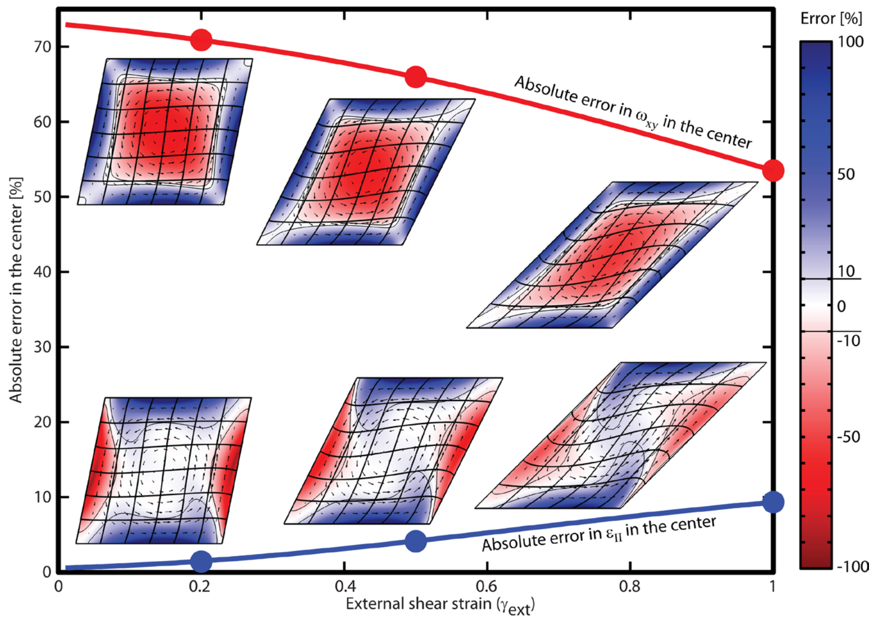

Fig. 2: Numerically deformed homogeneous square in simple shear with increasing applied shear strain and perfect simple shear boundary conditions in the *x*-*y*-plane, but viscous drag boundary conditions in the *z*-direction. In the inset figures, the color represents the second invariant of finite strain (lower inset figures) and the finite spin (upper inset figures), respectively, both plotted as the error in percent relative to perfect simple shear. Thin black lines are the ±10% contour lines. Thick black lines are passive marker lines. Arrows represent the scaled finite perturbation displacement, i.e., the difference between the actual displacement and perfect simple shear. The bold blue and red line represent the second invariant of finite strain and the finite spin at the very center of the model, respectively, with big dots indicating the external shear strain for which the inset figures are plotted.