Strain localization within nonlinear shells

Nonlinear shells may exhibit **strain localization** when materials or components lose strength. This phenomenon is well-described in engineering literature, readily observed in reality, and implemented within CSI Software. It may be challenging to create a model such that localization occurs as it will in a real structure, though mathematical simulation does capture the mechanical attributes, and correlate with the underlying principles.

Strain localization in slabs

To demonstrate strain localization, we will observe the following case study:

Analytical model

Take a reinforced-concrete panel which is modeled using nonlinear layered shell objects. The slab has an orthogonal grid of rebar, is fixed along its base, and is subjected to a vertical displacement along its top surface.

Linear behavior

Given linear response, these conditions will generate nearly uniform tensile membrane forces in the vertical direction. Distribution is not perfectly uniform because of mathematical round-off. Linear shell objects will report linear behavior beyond the cracking stress of concrete, and beyond the yield point of steel. Over-stressing is reported though deformation and stress distribution remain uniform. Given nonlinear shells, however, this is not the case.

Nonlinear behavior

When the model uses nonlinear layered shells, stresses are nearly uniform until the concrete reaches its cracking strength, at which point nonuniform distributions may be observed, as shown in Figure 1:

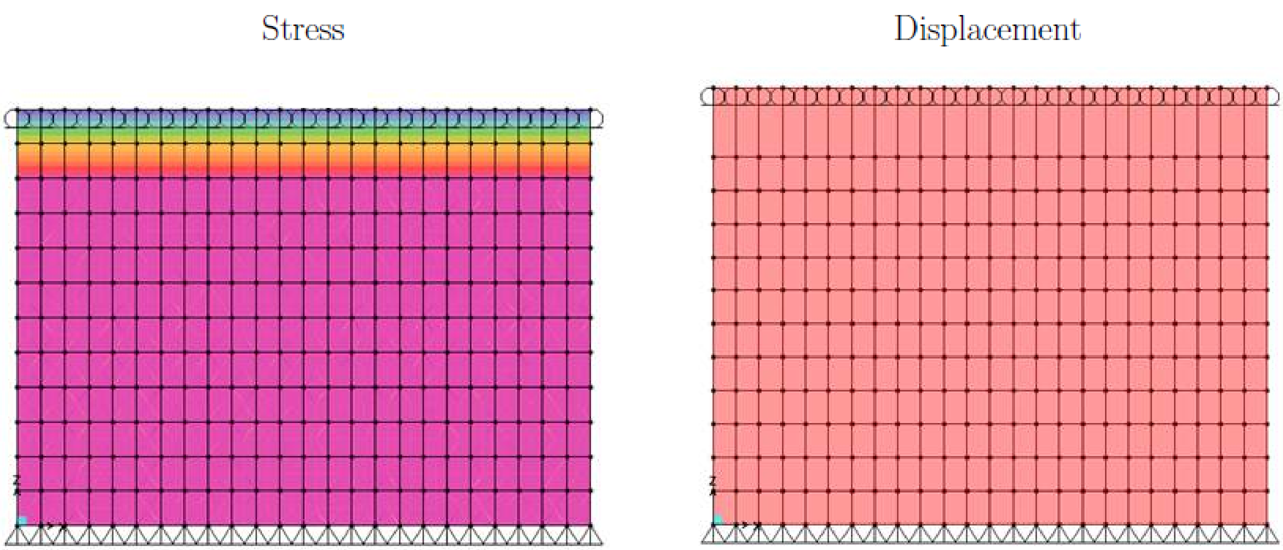

Figure 1 - Localization of material nonlinearity

As expected, this behavior is the result of localization. In both the analytical model and the real structure, localized cracks will form in distinct locations. Reinforced concrete will not lose strength uniformly, and the entire slab will not simultaneously crumble under tension. Instead, steel will carry the entire load across crack openings, and where cracking has not occurred, concrete will share the load with steel reinforcement. The example shown in Figure 1 is consistent with this explanation. Cracking is found to occur across the upper row of elements, vertical steel is found to carry all tension, and displacement is more pronounced in the region of cracking. Once this region begins to crack, stresses are relieved within the rest of the domain, which does not crack.

In reality, cracking is the result of stress concentrations which occur in locations of structural imperfection. Mathematically, cracking occurs because of round-off, and according to the geometry of the finite-element mesh.

For the cracking problem, calculated crack size will be equal to the mesh size, which should be decided upon beforehand. If detailed stress modeling is your objective, physical behavior will need to be considered when deciding upon the mesh size. If practical design information is your objective, such as with performance-based design, detailed modeling is not warranted, and may even be misleading. In this case, use the largest elements possible. Strain demand will be averaged over the larger element, and results will be more useful.

Strain localization in steel

Another physical example of strain localization is the necking of a steel tensile specimen. During loading, strain is uniform over the central region of the specimen. Once strength loss occurs, most strain occurs in a local region, or the *neck*. The length of this region is controlled by specimen geometry, and is typically on the order of specimen width. A finite-element model of this behavior will also demonstrate localization, though mesh size will control the length of the necking region. This is not physically realistic, so the choice of an appropriate mesh size merits consideration.