My model is a bead packing. I simulate each bead contact with a spring. This is what the spring network looks like overlapped with the beads packing.

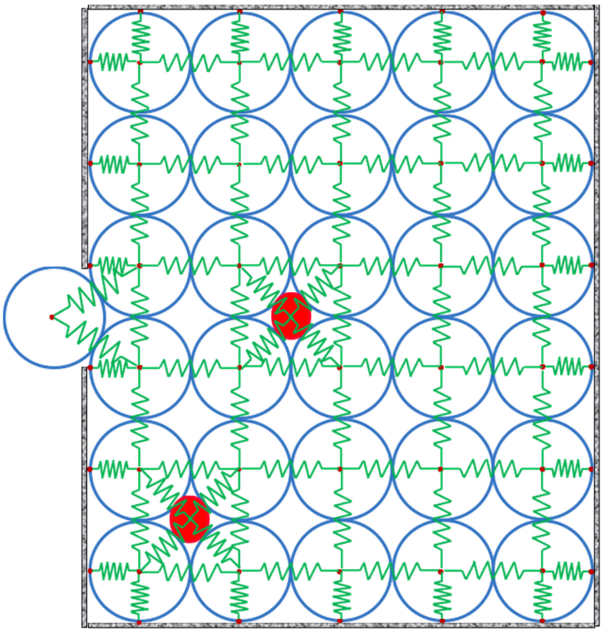

Figure 1: Discrete Element Model for the bead packing

Equilibrium equations, each node has two degrees of freedom.

$$\boldsymbol{R}^{(n)}\left(\boldsymbol{u}^{(n)}\right) = \mathbf{M}\ddot{\boldsymbol{u}}^{(n)} + \boldsymbol{K}\boldsymbol{u}^{(n)} - \boldsymbol{F}_{ext}^{(n)} = 0 \tag{1}$$

The scalar force in each spring is just

$$F_{spring} = k_{sp}\delta \tag{2}$$

where $k_{sp}$ is the spring coefficient and $\delta$ is the relative displacements between the nodes.

Each spring contributes with the following internal force vector:

$$\boldsymbol{F_{spring}} = k_{sp}\delta \cdot (\boldsymbol{t}, -\boldsymbol{t}) \tag{3}$$

The vector $\boldsymbol{t}$ is the unit vector that connects the springs' nodes.

$$\boldsymbol{t} = \frac{(\boldsymbol{X_i} - \boldsymbol{X_j})}{|\boldsymbol{X_i} - \boldsymbol{X_j}|} \tag{4}$$

Each spring contributes with the following constitutive matrix (assuming small deformations):

$$\boldsymbol{K_{spring}} = k_{sp}\delta \cdot (\boldsymbol{t}, -\boldsymbol{t}) \otimes (\boldsymbol{t}, -\boldsymbol{t}) \tag{5}$$

The mass matrix is just a diagonal matrix, one entry per degree of freedom.