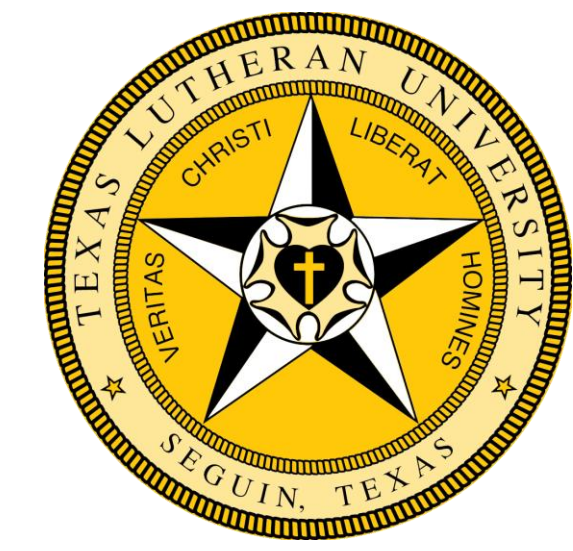


The affect of force chains on rotations in granular materials



Carly Hansen, Sinsa Mesarovic & Jagan Padbidri

Introduction to Multiscale Engineering Research Experience for Undergraduates
School of Mechanical and Materials Engineering, Pullman, Washington 99163



MOTIVATION

Granular materials have a set of complex behaviors that make them different than most conventional engineering materials. When pressure is applied to a granular material, forces are not distributed evenly throughout the sample. The force chains form networks throughout the material. Granular materials also exhibit strain localization in the form of shear bands. Strain localization occurs due to the local instability of the force networks in the region. Also, particles are observed to have higher angular velocities in the shear band.

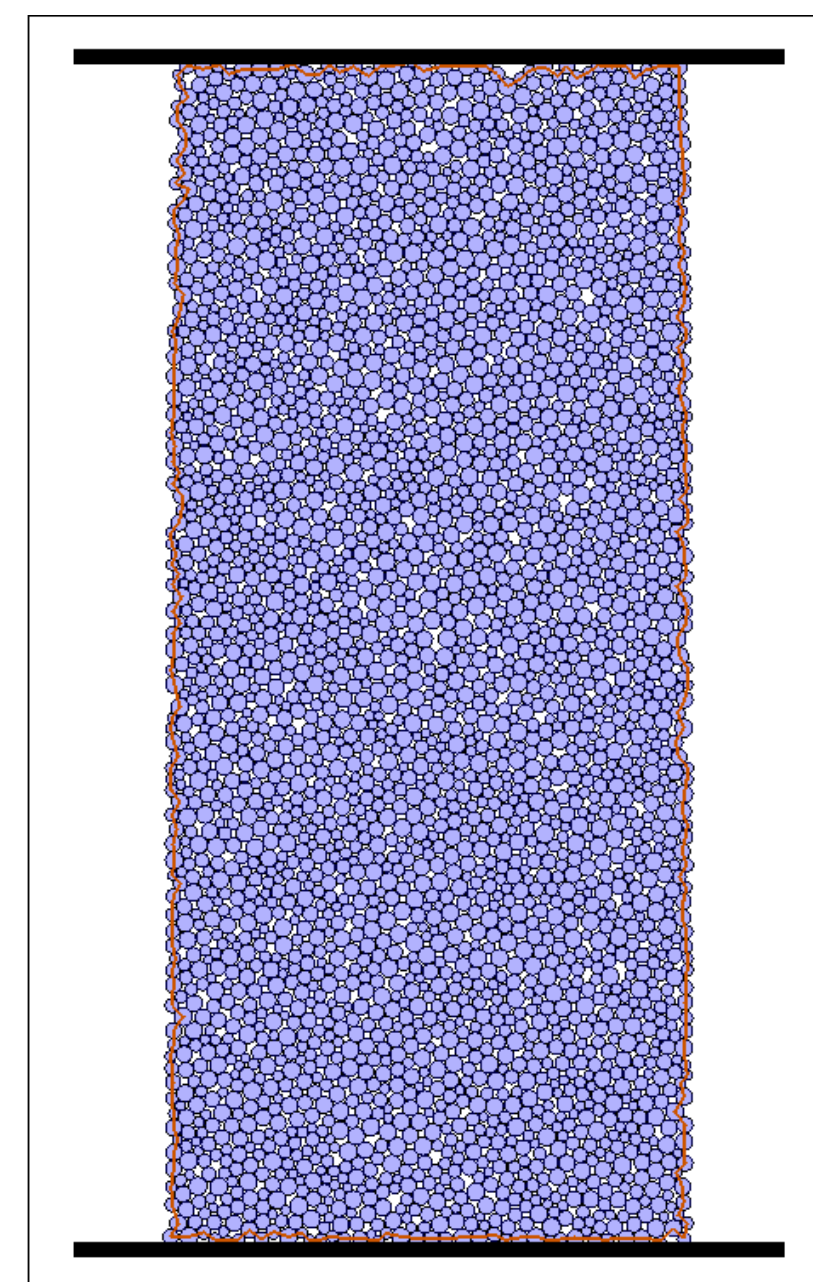


Figure 1
An assembly of disks with pressure on the lateral boundary.

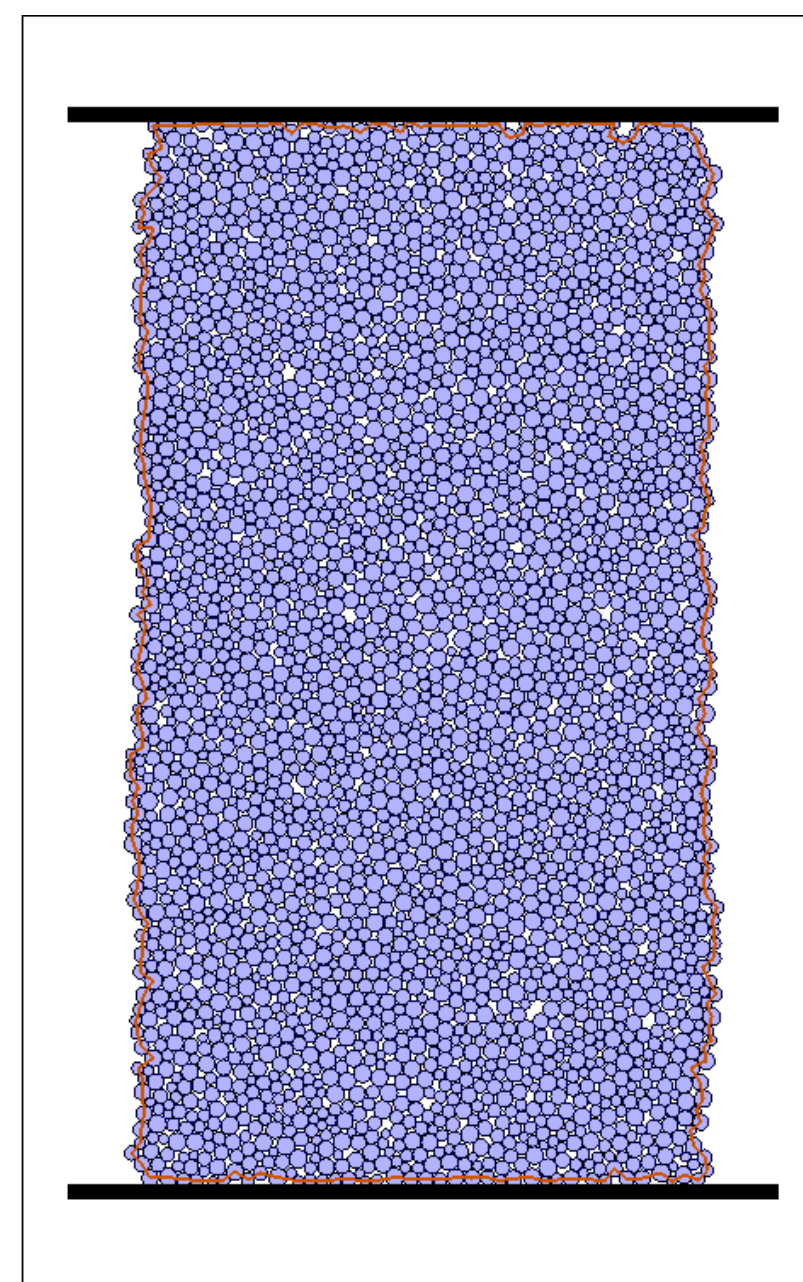


Figure 2
The same assembly of disks seen in Figure 1 with 10% axial strain applied.

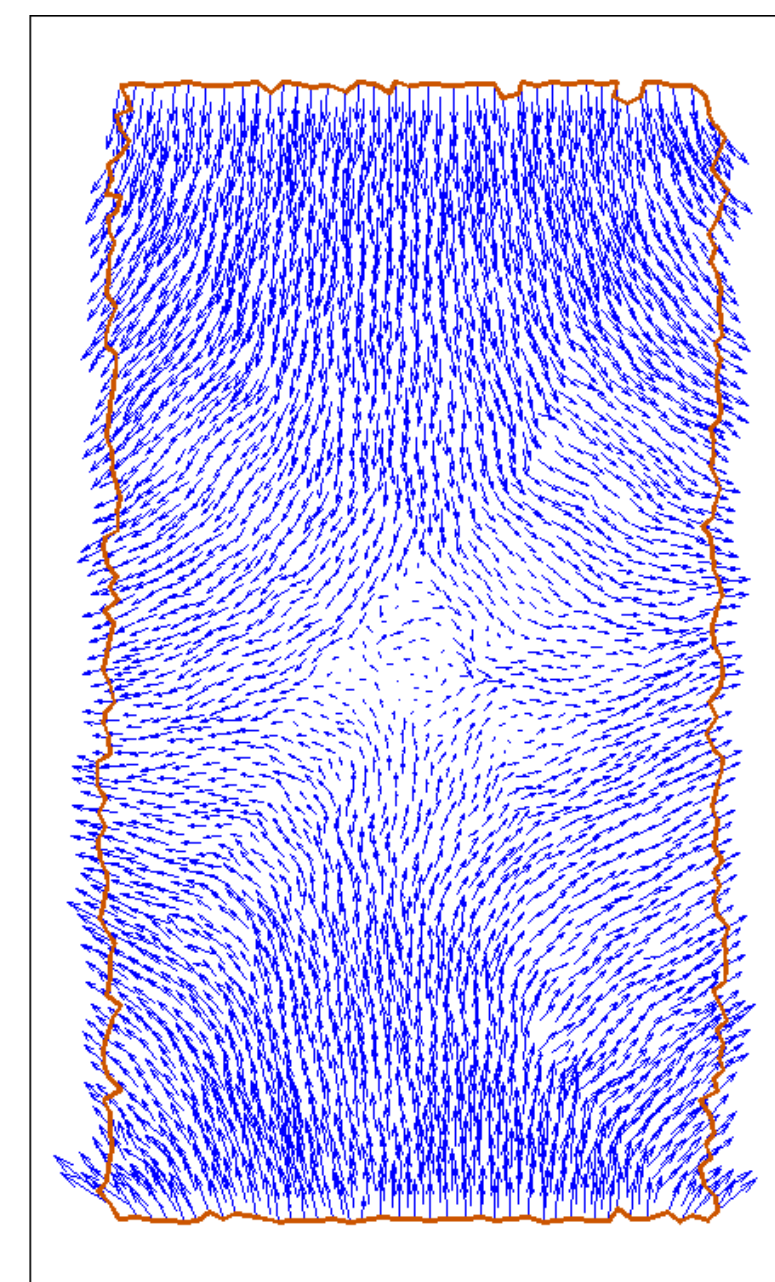


Figure 3
Displacement vectors of the particles from axial strain 7.5% - 10.0%.

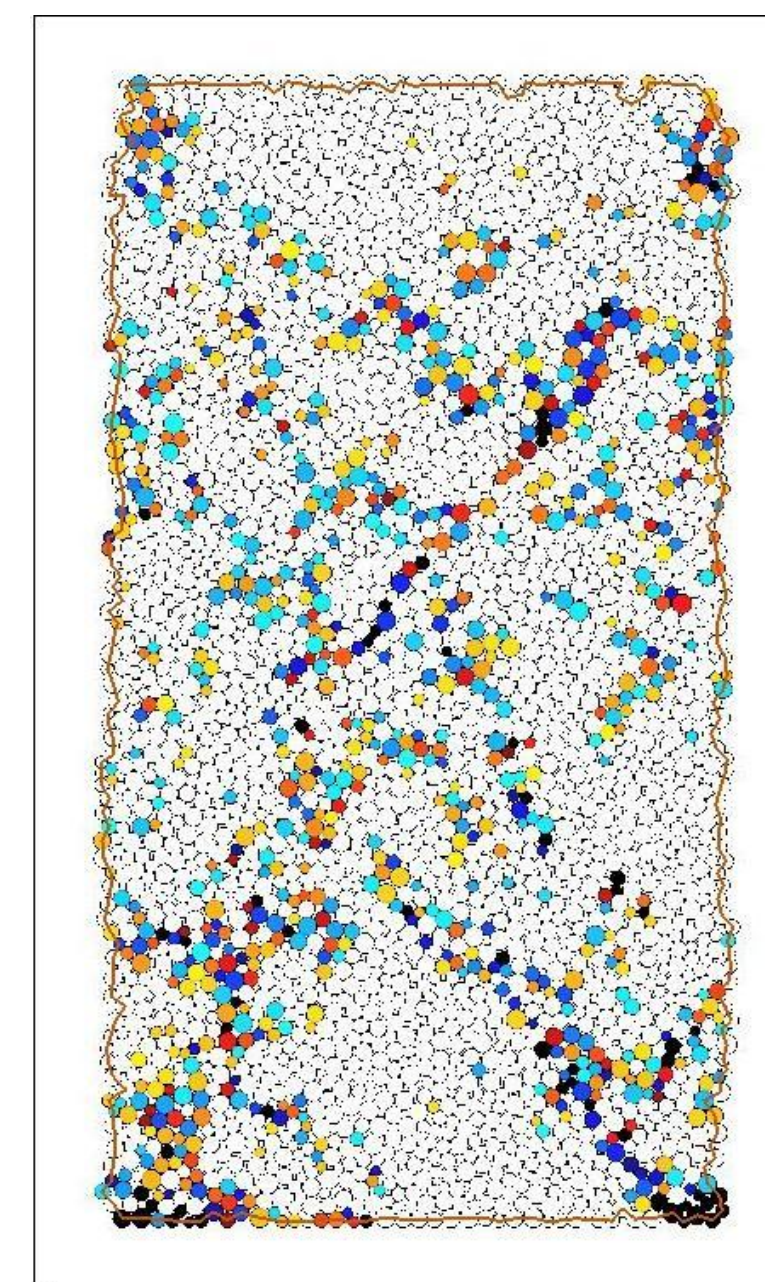


Figure 4
Rotation of disks in the same strain window. Angular velocities are higher in the shear band.

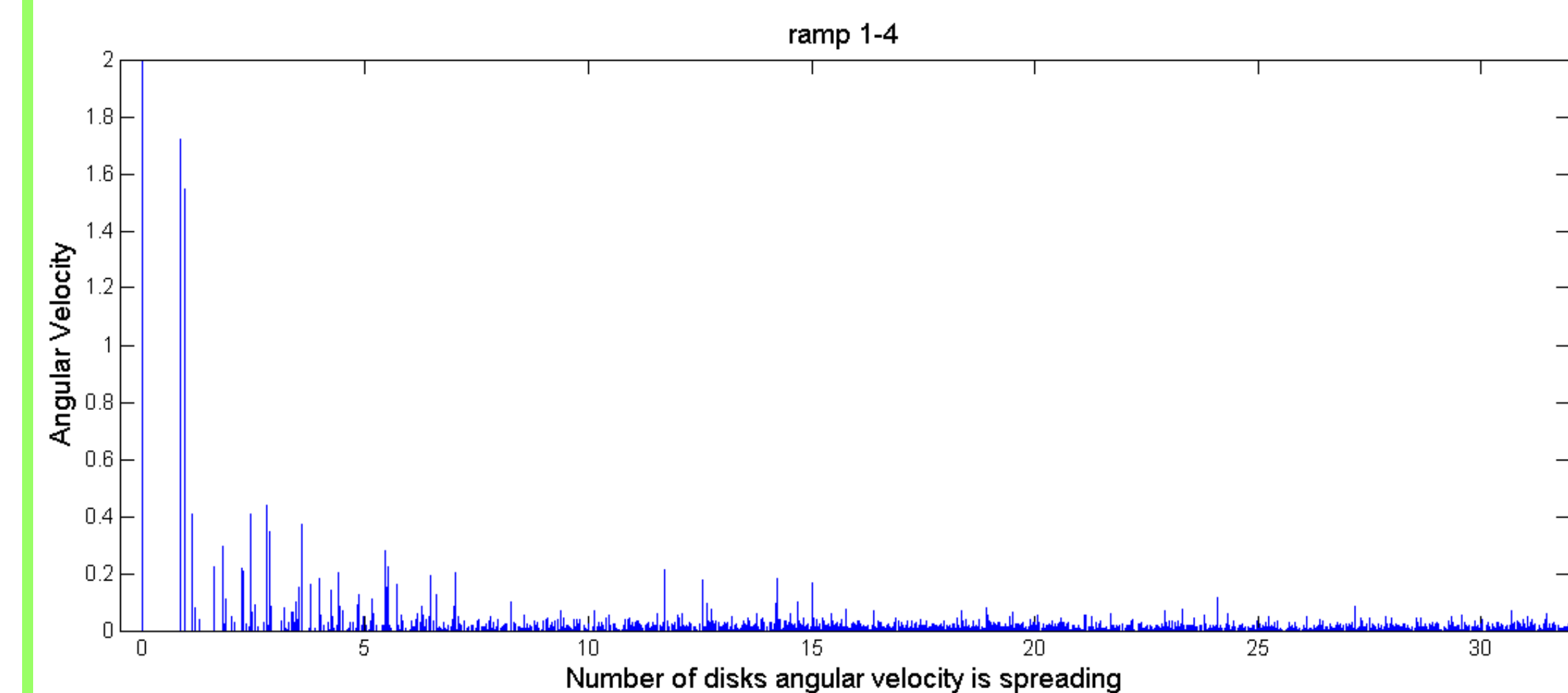


Figure 9

Plot of the disk arrangement seen Figure 8. Showing the number of disks angular velocity spreads.

OBJECTIVE

Correlate the angular velocity and the strength of the force networks in a shear band.

EXPERIMENTAL APPROACH

Distinct Element Method

- Each disk is treated as a separate entity.
- Integrate Newton's second law of motion in time.

$$\mathbf{F}^i = \sum_{j=1}^{\text{contacts}} (\mathbf{F}_{n,\text{Hertz}}^{ij} + \mathbf{F}_{n,\text{damping}}^{ij} + \mathbf{F}_t^{ij})$$

$$\mathbf{F}_{n,\text{Hertz}}^{ij} = \frac{2E}{3(1-\nu^2)} \sqrt{\frac{R_i R_j}{R_i + R_j}} \xi^{3/2} \hat{\mathbf{n}}$$

$$\mathbf{F}_{n,\text{damping}}^{ij} = -\alpha K_{\text{eff}} (\mathbf{v}^{ij} \cdot \hat{\mathbf{n}}) \xi^{1/2} \hat{\mathbf{n}}$$

$$\mathbf{F}_t^{ij} = -\mu |\mathbf{F}_n| \left(\frac{\eta^{ij}}{\eta_0} \right)^{1/m} \hat{\mathbf{n}}^{ij} \quad \mathbf{M}^i = \sum_{j=1}^{\text{contacts}} \mathbf{F}_t^{ij} \times R^i \hat{\mathbf{n}}$$

- Verlet time integration is used to update positions.

Procedure

2-D DEM simulations on a circular assembly of disks. Hydrostatic pressure was applied as a boundary condition and rigid body rotation was prevented. A single disk was rotated to observe the transmission of rotations based on the force chains surrounding it.

RESULTS

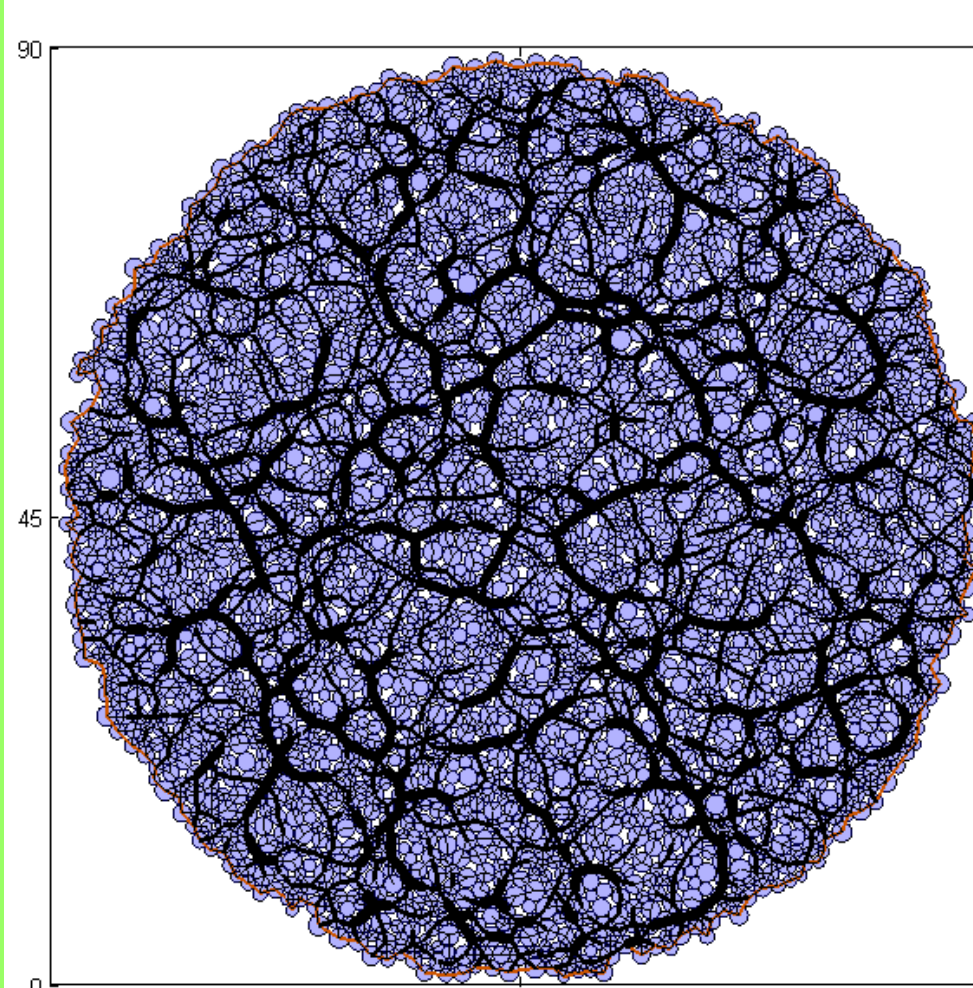


Figure 5
Circular assembly of disks under 0.1 MPa pressure with a coefficient of friction of 0.5.

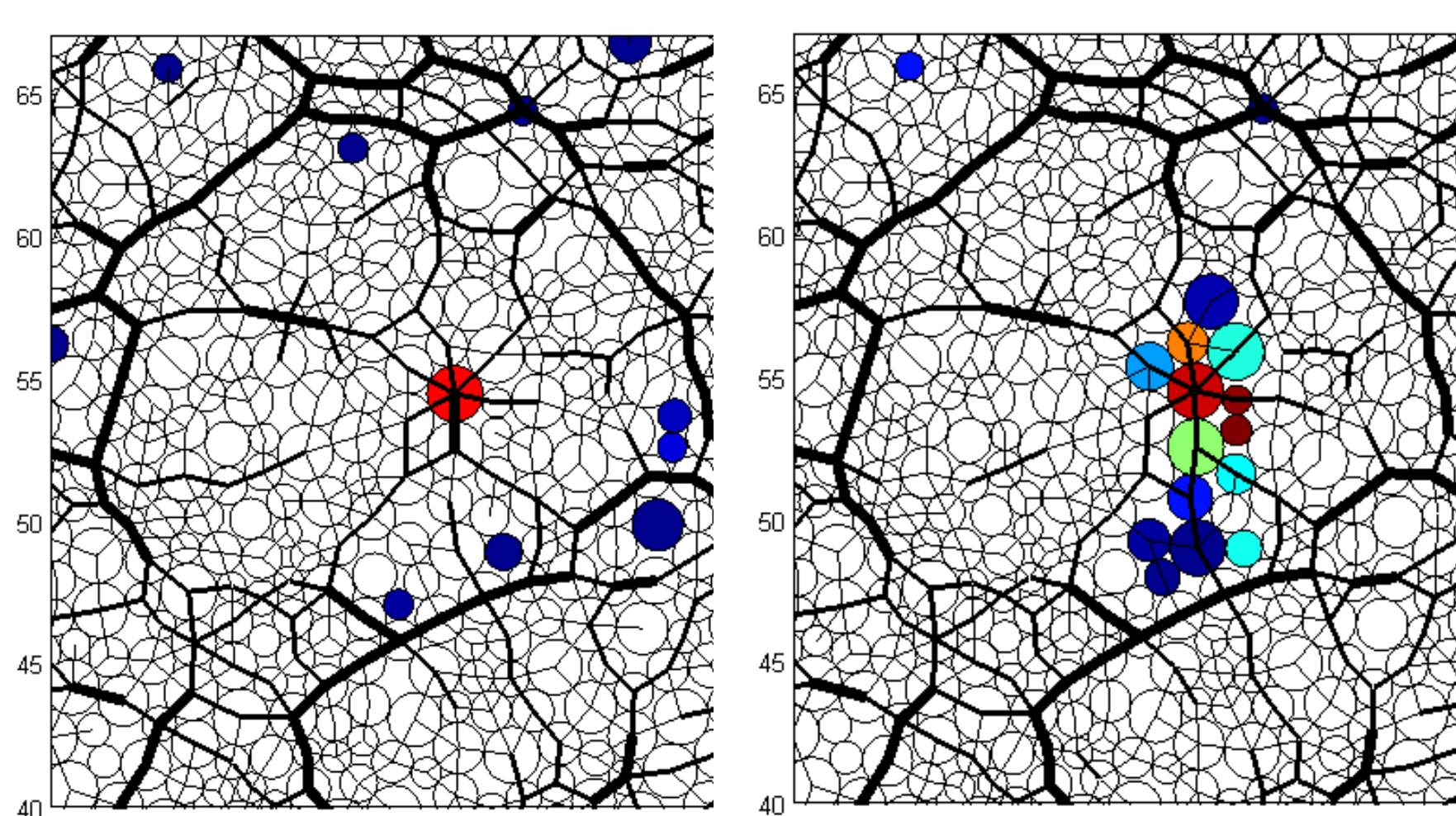


Figure 7
These images show the beginning and first step of a disk being rotated. The disk is surrounded by strong force chains, so it is difficult for the angular velocity to move past them.

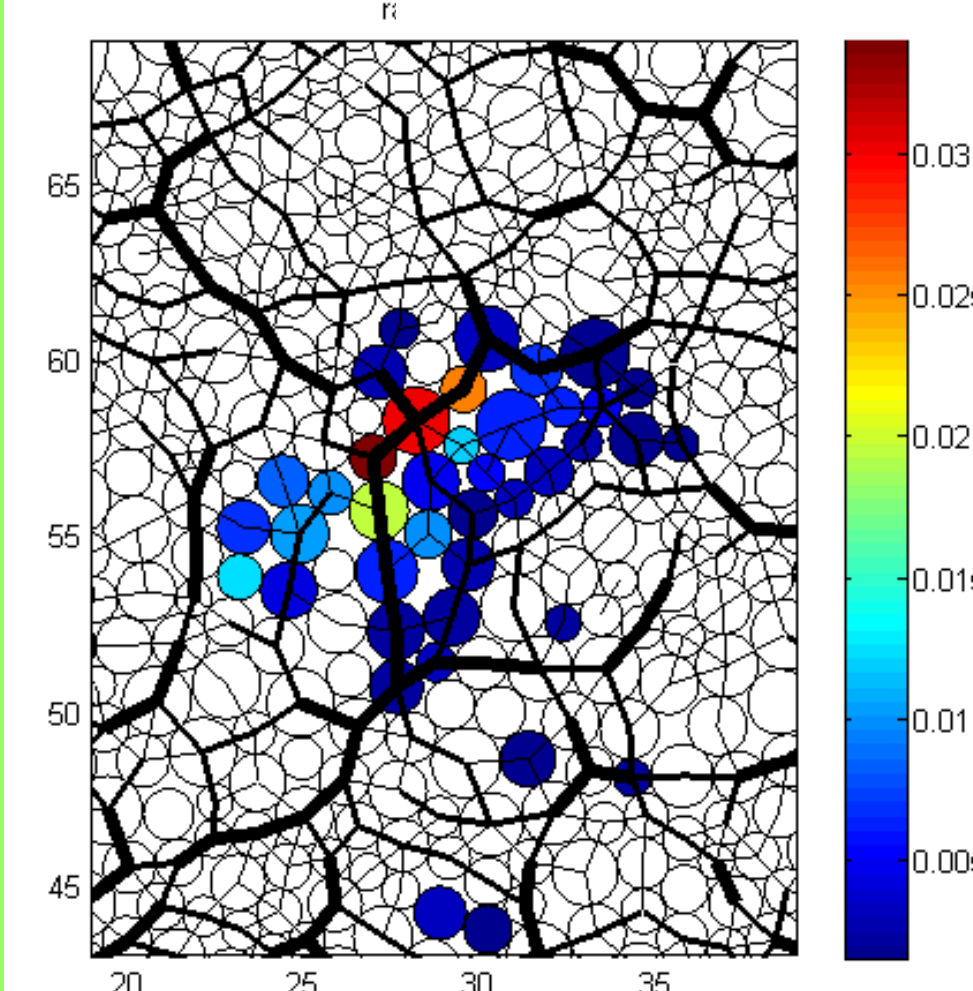


Figure 6
Angular velocity moving in directions lacking strong force chains.

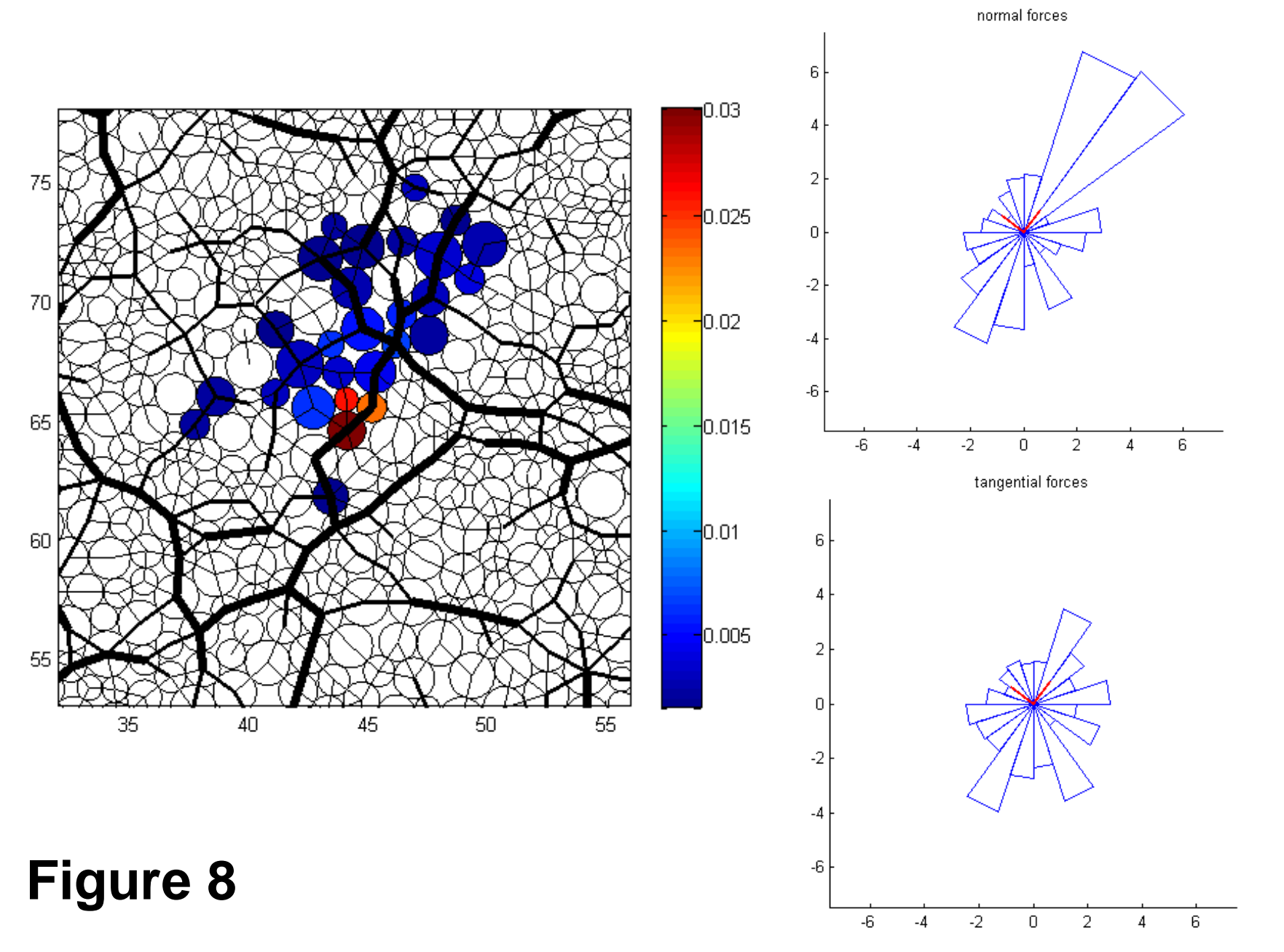


Figure 8
The first image shows angular velocity moving along strong force chains. The second image shows the strength of forces in the direction of propagation of angular velocity. The third image shows the strength of forces perpendicular to the propagation of angular velocity.

CONCLUSIONS

- The strength and direction of force chains contained by the disk initially rotated greatly affected the way rotations propagated through the sample.
- Rotations propagated further if they were moving along a strong force chain compared to moving along a weak force chain. However, it was difficult for rotations to move across a strong force chain.
- Not only did the force chains going through the disk being rotated affect how far rotations propagated, but also the force chains surrounding the rotated disk.
- If the disk was surrounded by strong force chains several disks out, it was still be hard for rotations to propagate because the disk was experiencing a high tangential force.
- If a disk was not surrounded by strong force chains, rotations propagated much further than disks that were surrounded by strong force chains.

FUTURE RESEARCH

- Perform simulations using arrangements of disks other than a circular arrangement.
- When using the magnitude of a force in a force chain to make calculations, we also need to take into account the force chains surrounding the force.

REFERENCES

Cundall P.A.; Strack O.D.L.; *Geotechnique* **1979**, 29, 47-65
Mesarovic S.Dj.; Padbidri J.; *Phil. Mag.* 2005, 85(1), 65-78

ACKNOWLEDGEMENTS

Special thanks to Jagan Padbidri for all of his help. This work was supported by the National Science Foundation's Research Experience for Undergraduates program under grant number EEC-0754370.