**Discrete Element Method model of brain for NPH simulation**

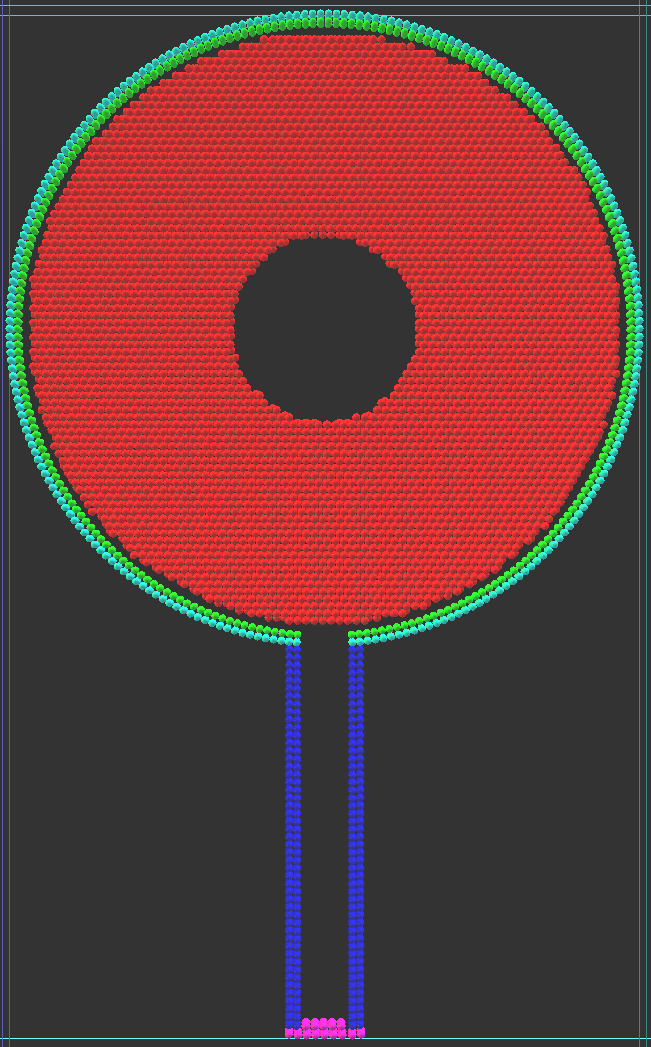
1. Geometry and properties of the initial model

We use a quasi 2D simplified geometry to model the brain parenchyma, subarachnoid space, skull and spinal canal. In Figure 1 a screenshot of the DEM model is shown. The characteristic dimensions of the model are reported in Table 1.

|  |  |
| --- | --- |
| Parenchyma | |
| Inner Radius | 3.0 cm |
| External Radius | 10.0 cm |
| Spina canal | |
| Width | 1.4 cm |
| Length | 13.26 cm |
| Skull | |
| Inner Radius | 10.28 cm |
| External Radius | 10.56 cm |

Table 1: Characteristic dimensions of the model

We used a regular hexagonal packing for the red particles that represents the parenchyma, the other particles have been added one by one in a for loop. The DEM model has been implemented using the software Yade.

  
Illustration 1: DEM model: red is parenchyma, green, light blue, blue and purple are skull and spine.

In Table 2 radius and mass of the particles are reported. In Table 3 density, Young modulus and Poisson ratio are reported.

|  |  |  |
| --- | --- | --- |
| Color | Radius | Mass |
| Red | 1.4 mm | 1.15e-5 kg |
| Green | 1.27 mm | 1.72e.5 kg |
| Light Blue | 1.30 mm | 1.87e-5kg |
| Blue | 1.30 mm | 1.87e-5 kg |
| Purple | 1.49 mm | 2.75e-5 kg |

Table 2: Radius and mass of the DEM particles

|  |  |  |
| --- | --- | --- |
| Color | 𝛒 | E, 𝛎 |
| Red | 1000 kg/m³ | 500 Pa, 0.35 |
| Green and Light Blue | 2000 kg/m³ | 10 GPa, 0.35 |
| Blue and Purple | 2000 kg/m³ | 10 GPa, 0.35 |

Table 3: Material properties of DEM particles

In the literature, there is not much agreement on the material properties of brain tissue. The Young’s modulus can vary between 500 to 10000 Pa. As concerns the Poisson ratio, this varies between 0.35 and 0.48 .⁠ (Li, von Holst, & Kleiven, 2012; Vardakis et al., 2016)⁠.

At the moment, we have have considered an elastic material with contact friction (FrictMat in Yade). The material properties for each of the spheres are listed in Table 1. All the spheres have the same properties. It is also possible to assign different properties to each sphere.

To be corrected. What is written in the manual is not true.

1. Contact model and its properties

We use a law for linear compression, and Mohr-Coulomb plasticity surface without cohesion. This law implements the classical linear elastic-plastic law from (Cundall & Strack, 1979.)⁠.

We use an elastic-plastic relation between the force and the relative displacement between two interacting particles to describe the contact interaction. The normal component of the force is defined as , where is the normal stiffness and is the normal component of the displacement . The tangential component of the force is defined as , where is the shear stiffness and is the tangential component of the displacement .

The compliance of the contact itself will be the sum of compliances from each sphere . The normal stiffness is defined as:

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and the shear stiffness is defined as:

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The values are reported in Table 3.

The normal force is defined as *F*, . The shear force is and the plasticity condition defines the maximum value of the shear force: , with φ the friction angle.

Table 3. Contact model properties

|  |  |  |
| --- | --- | --- |
| Property | Unit | Value |
| Normal stiffness, | N/m | 2.5 |
| Shear stiffness, | N/m | 0.875 |

Bibliography

Cundall, P. A., & Strack, O. D. L. (1979). A discrete numerical model for granular assemblies. *Géotechnique*, *29*(1), 47–65. https://doi.org/10.1680/geot.1979.29.1.47

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