Code Benchmarking Updates

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CCC-ParaSolS Project

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Science and Technology Facilities Council

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What is Benchmarking Anyway?

- Typically described as *"the process of measuring or comparing a product or service against another to identify areas of weakness or for improvement"*
  - Process benchmarking
  - Performance benchmarking
  - Strategic benchmarking
  - Common business practice

- In computer science **Benchmarking** is the process of **measuring and comparing the performance** of a computer system, its hardware (like CPUs and GPUs), or software (like databases) **using standardised tests**
  - We often do this to compare performance between DEM codes and/or HPC resources
  - The outcome of the simulation is irrelevant, the size of the problem is of concern

Silo Discharge Benchmark Problem

- Silo discharge is a very common industrial use case
- It is still very difficult to design a silo that is sufficiently strong

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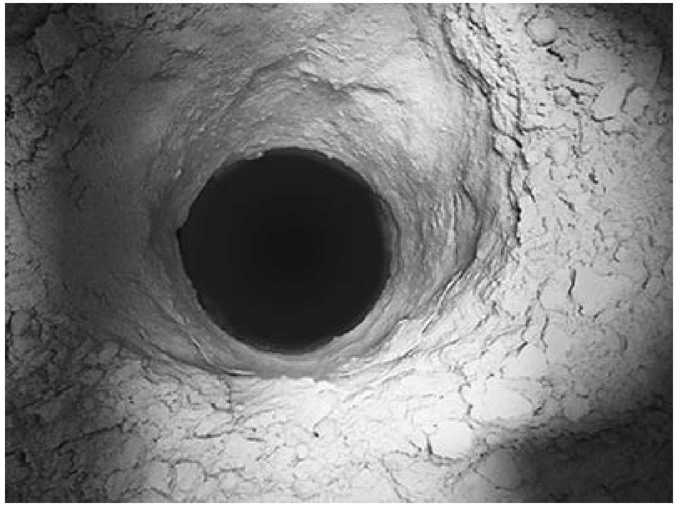
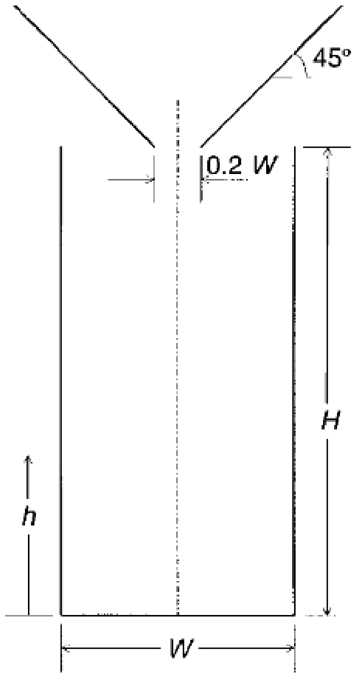
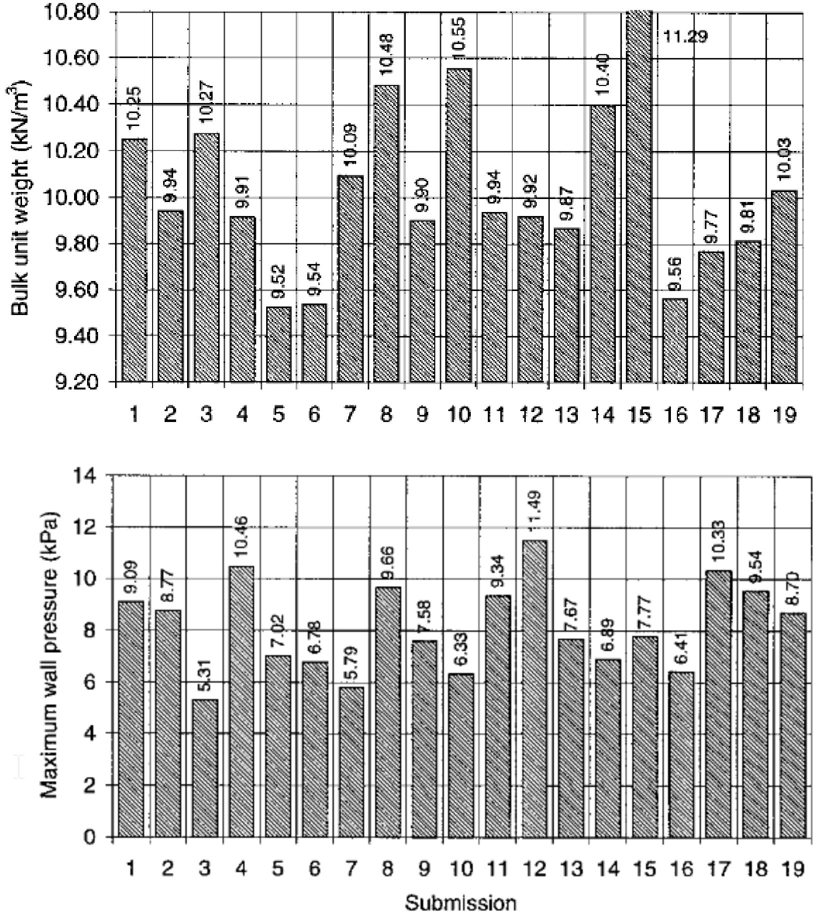


DEM Silo Benchmark Tests

- An excellent test case for DEM
  - Analytical predictions for silo wall pressures and discharge rates through an orifice
  - Eurocode EN 1991-4:2006 describes the uses of simple Janssen Theory for calculating wall pressures during the design of silos
  - Beverloo provided the prediction of discharge of discharge rate for a given opening width and particle size combination
- Not the first time tried in DEM!





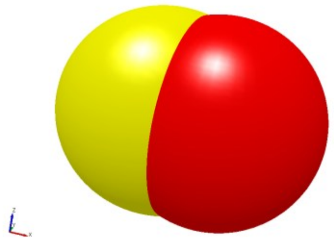
Holst, J.M.F.G., Rotter, J.M., Ooi, J.Y., Rong, G.H., 1999. Numerical Modeling of Silo Filling. II: Discrete Element Analyses. J. Engrg. Mech. 125, 104–110.

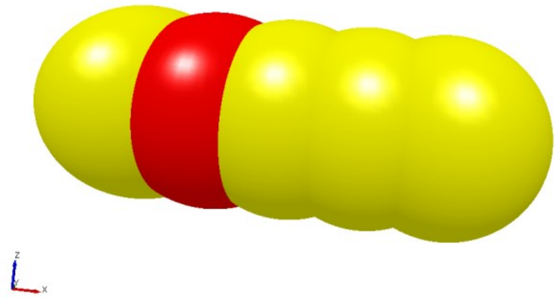
Rotter, J.M., Holst, J.M.F.G., Ooi, J.Y., Sanad, A.M., 1998. Silo pressure predictions using discrete–element and finite–element analyses. Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences 356, 2685–2712.

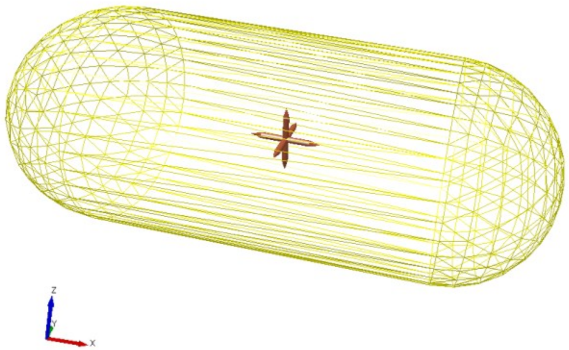
Developing a Silo DEM Benchmark

- Several items of interest:
  - Predicted fill level (and resulting bulk density)
  - Predicted wall pressure distribution (Eurocode)
  - Predicted discharge rate (Beverloo)

- Consider several particle shapes:
  - ~~Sphere~~ Sphere
  - Multi-sphere with very low aspect ratio (AR=1.25)
    - Sphere radius = 1mm
    - 80K particles
  - Multi-sphere with high aspect ratio (AR=2.5)
  - Sphero-cylinder with high aspect ratio (AR=2.5)
    - 40K particles
  - Interparticle friction = 0.5 (0.1, 0.3)
  - Wall friction = 0.4 (0.1)
  - EPSD / Type C rolling friction model (0.05)

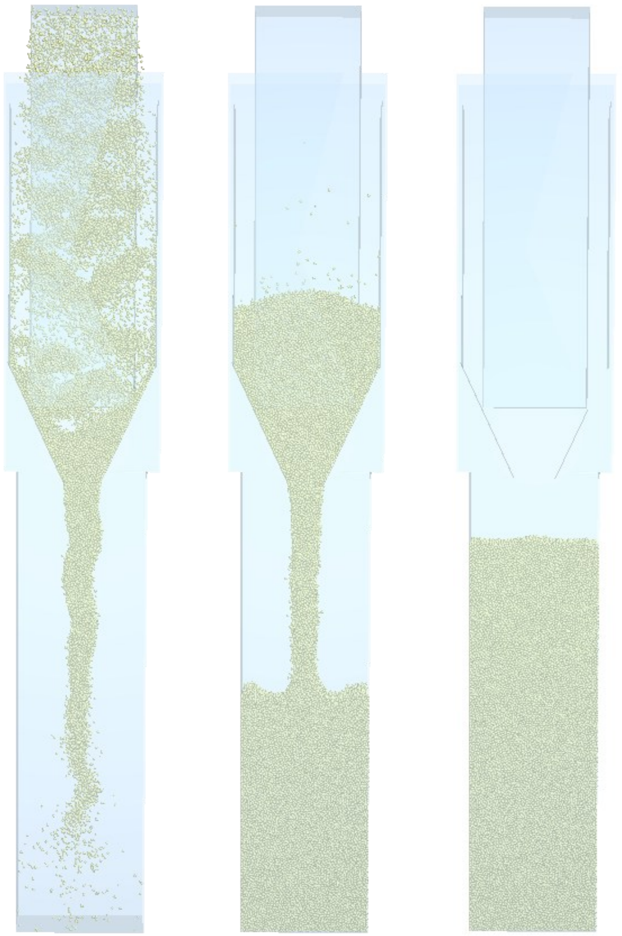






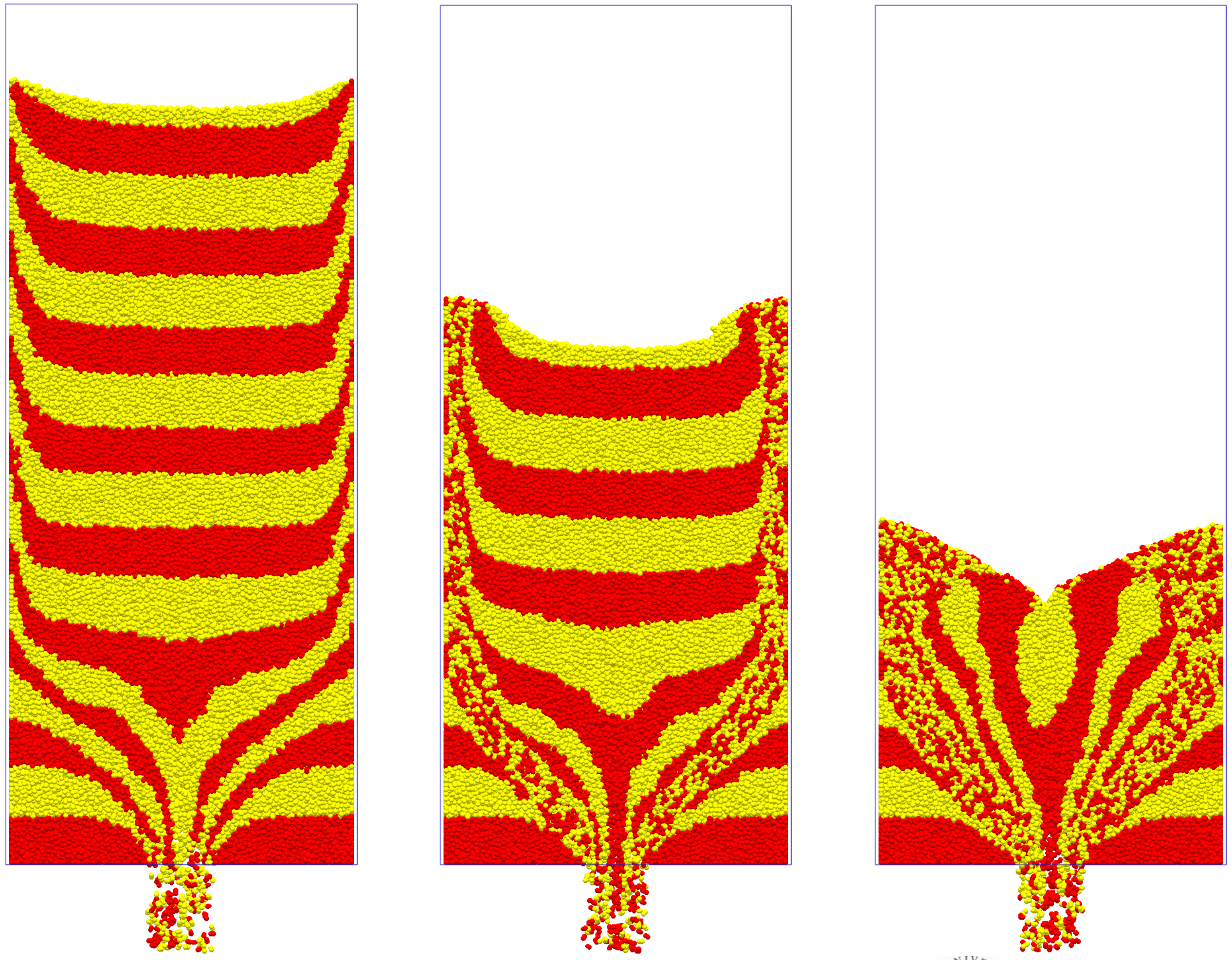
Silo Geometry Definition

- Geometry
  - Width = 0.1m (40-50 particles of low AR)
  - Height = 0.4m
  - Depth = 0.025m
  - Non-periodic
    - Frictionless walls front and rear
    - Frictional walls elsewhere
  - 2 wall friction values: 0.1, 0.4
- Relatively tall silo
  - Aspect ratio when filled > 3
- 7~~4~~ opening widths (new discharge cases added)
  - 5, 10, 15, 20, 25, 30, 40 (mm)



DEM Analysis Criterion

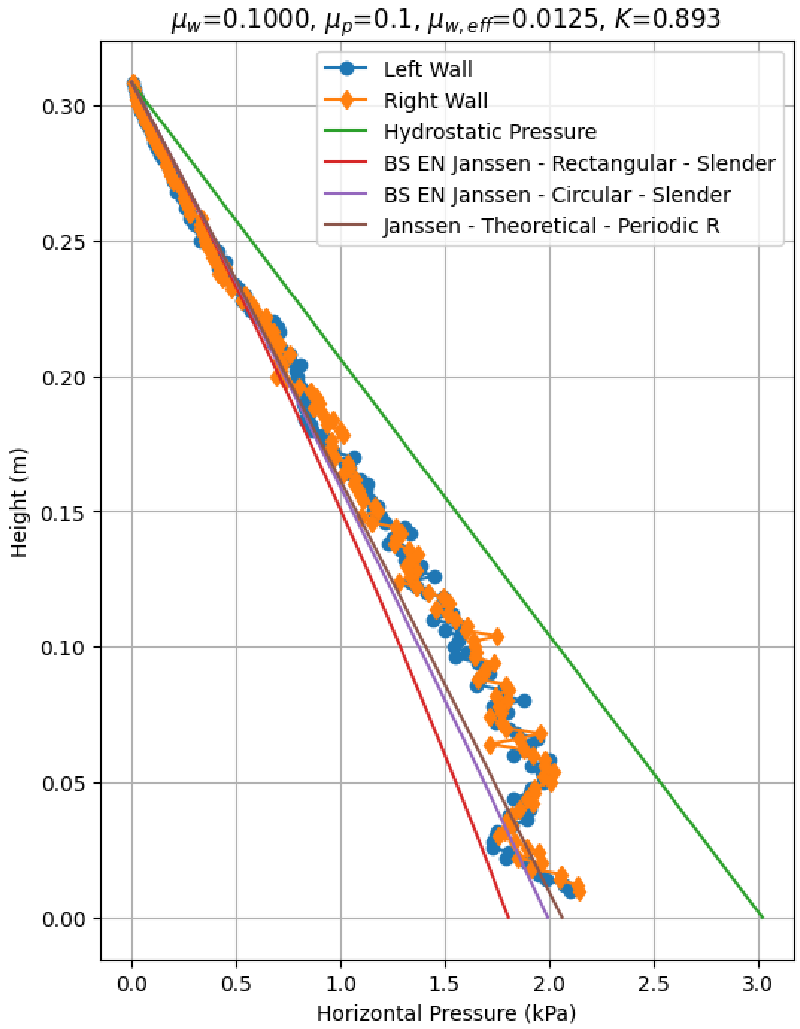
- Expected behaviour:
  - Mass flow above transition
  - Transition height
  - Shear layer at wall
  - Asymptotic wall pressure distribution
  - Asymmetric wall pressures
  - Mass flow rate variation
    - Per particle shape
    - Per opening width
    - Per wall friction value?

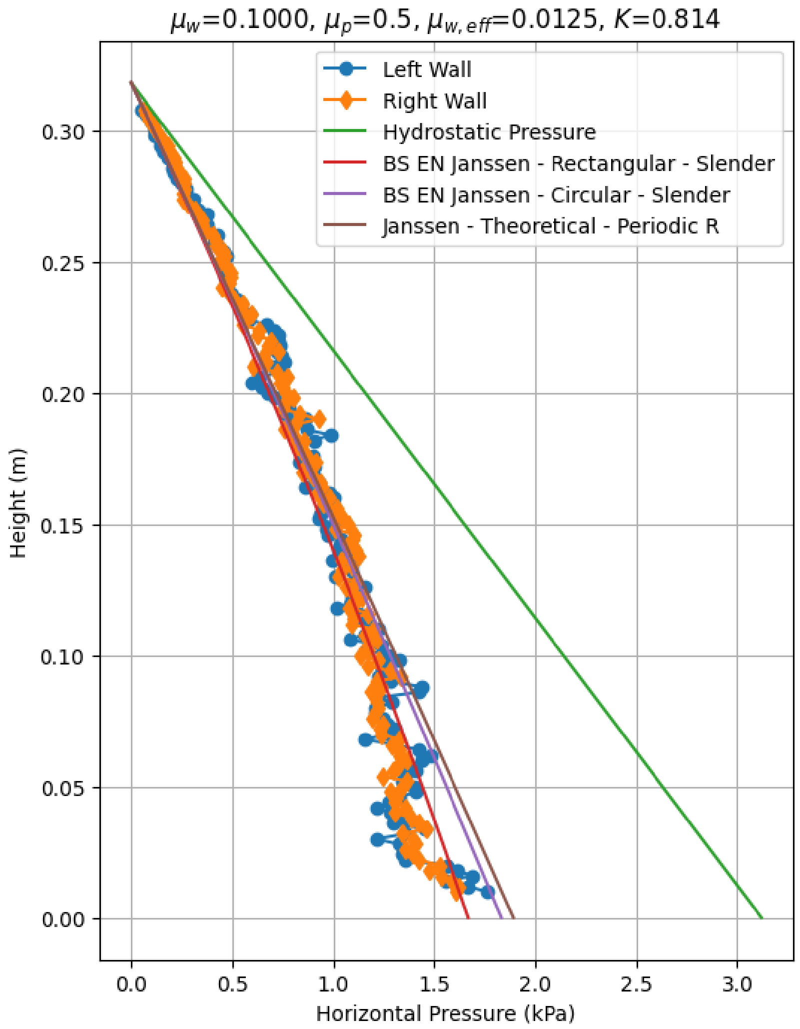


Initial Reference Results

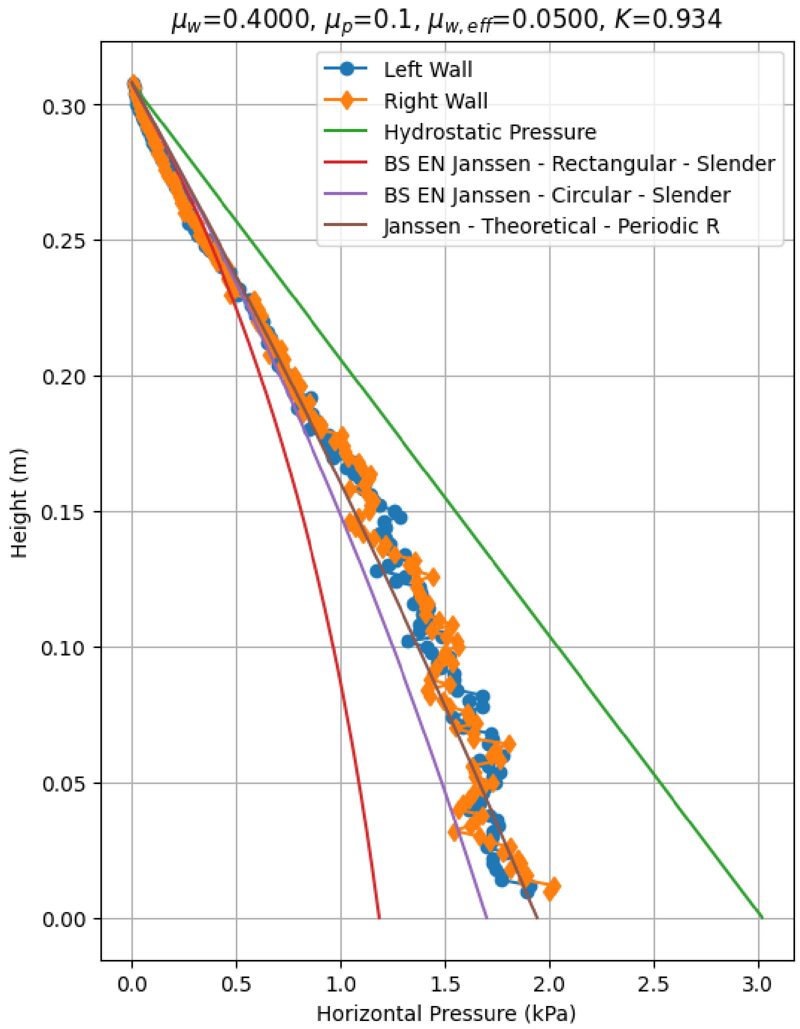
Sphere Filling

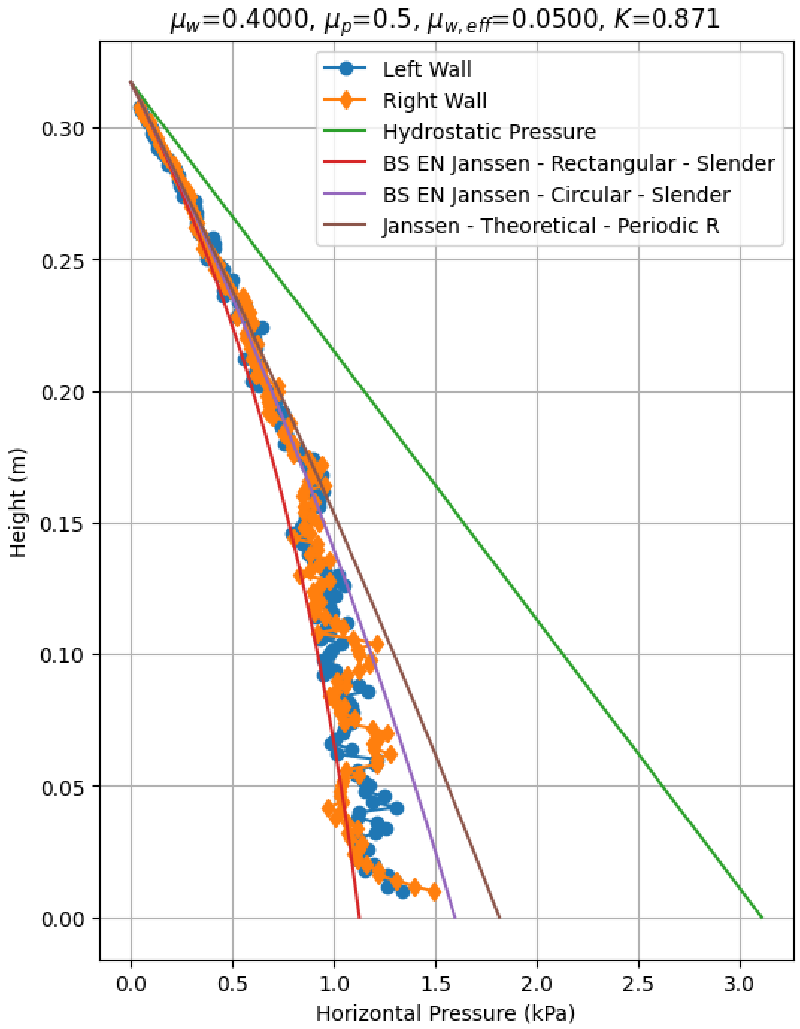
Sphere Filling – Low Wall Friction





Sphere Filling – High Wall Friction





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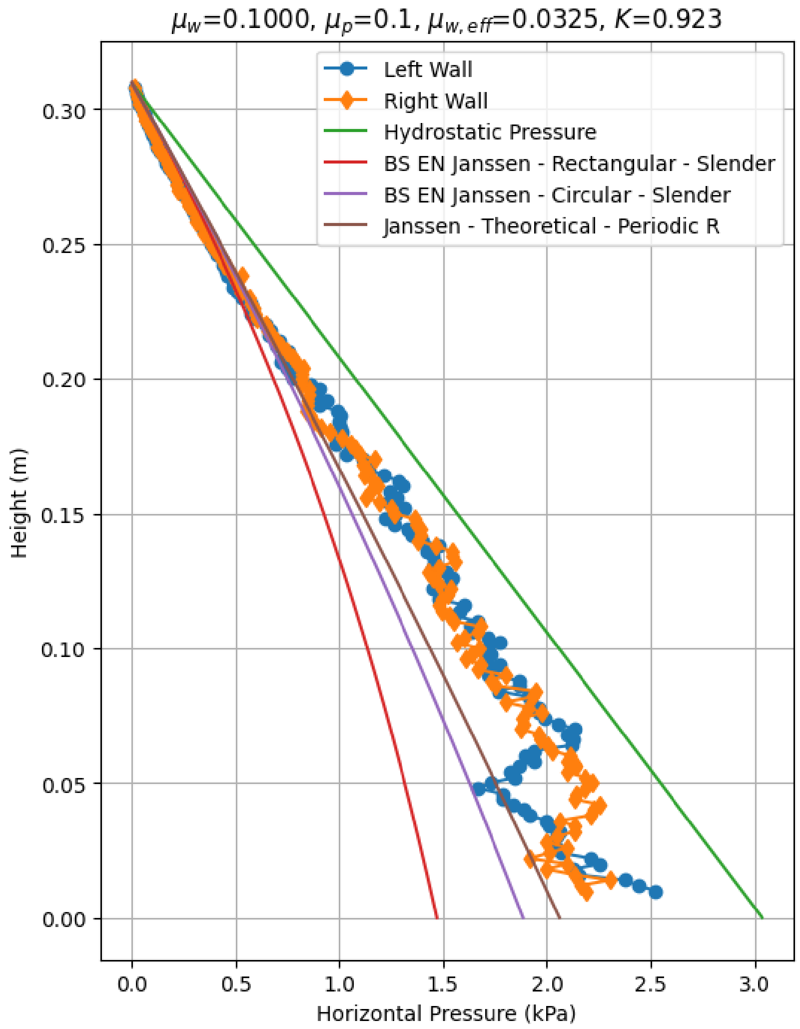
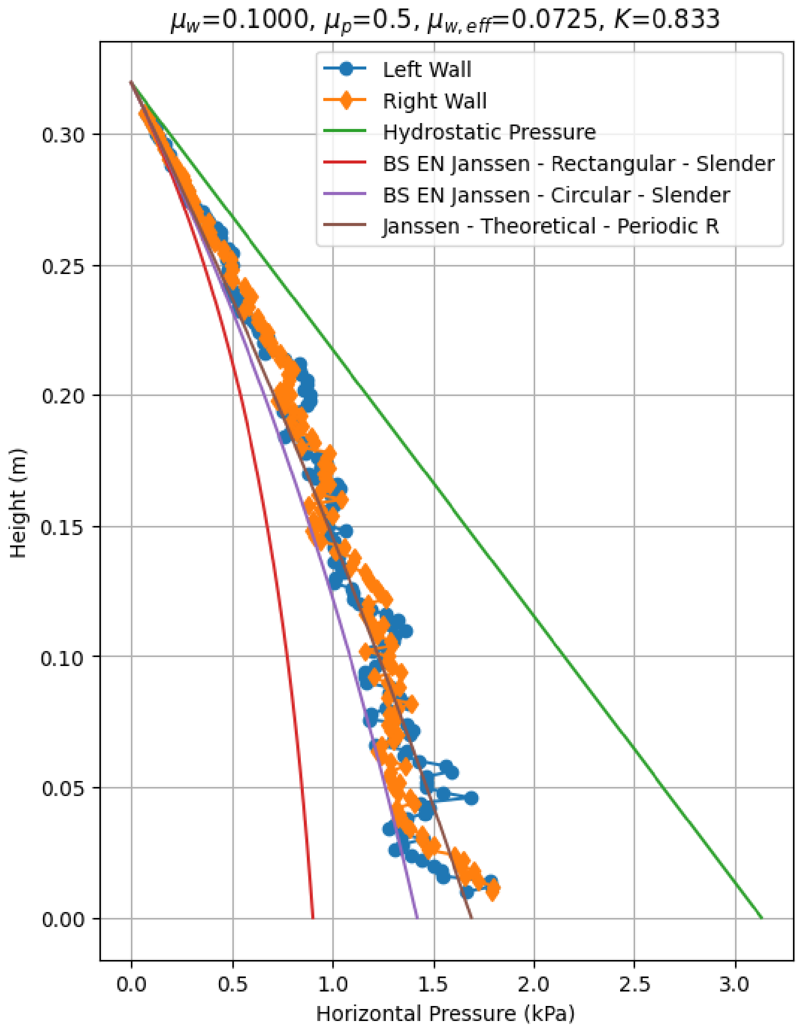
Sphere Filling - Periodic – Low Wall Friction





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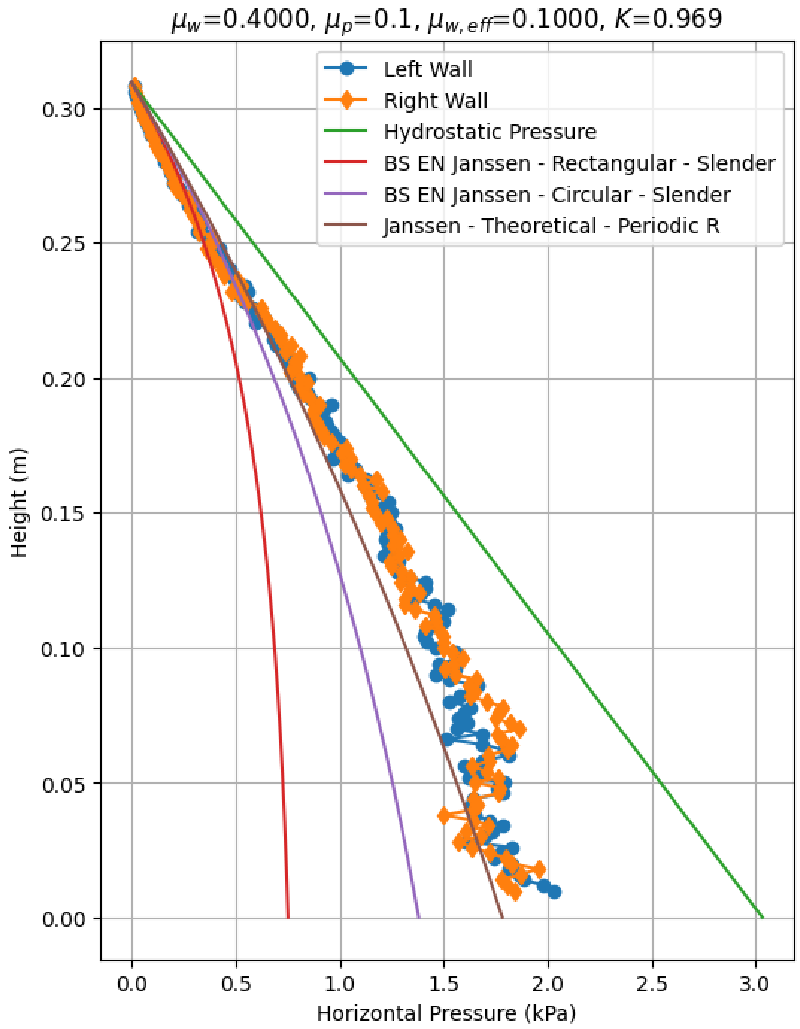
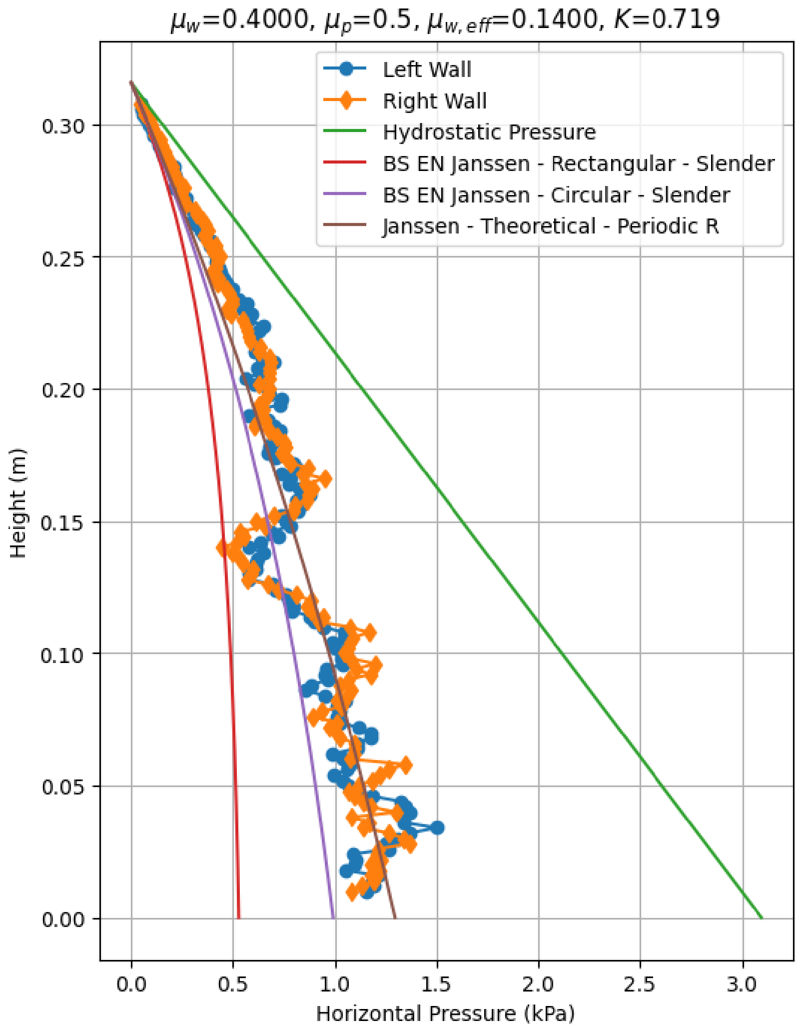
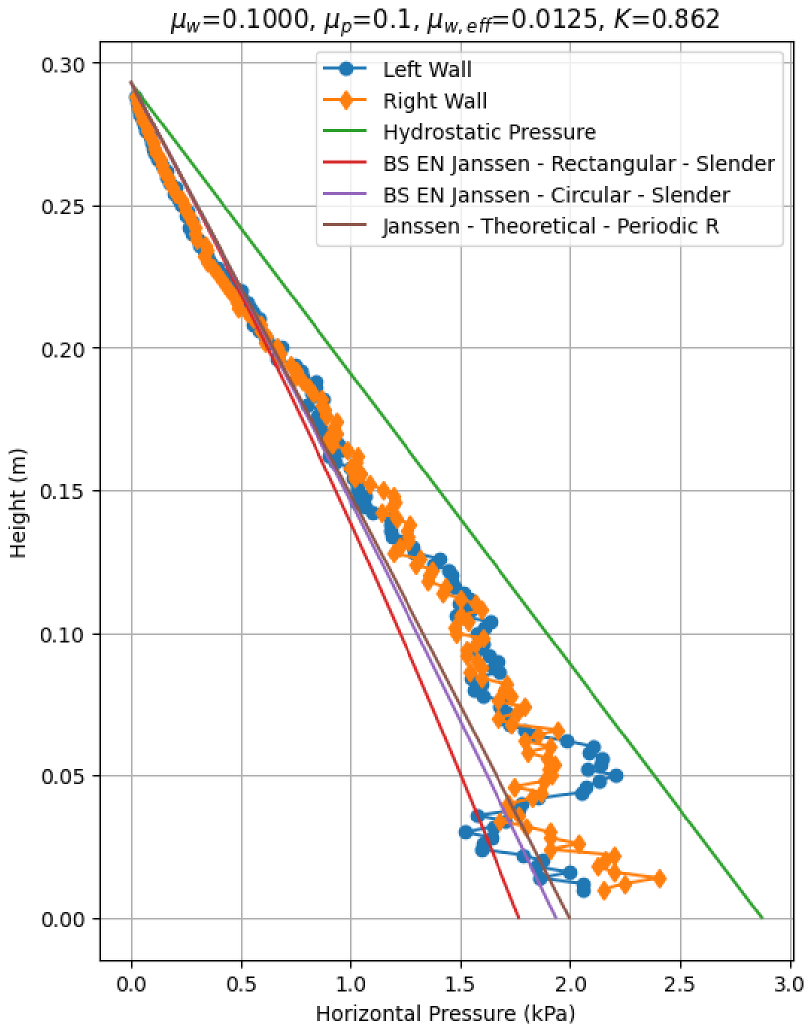


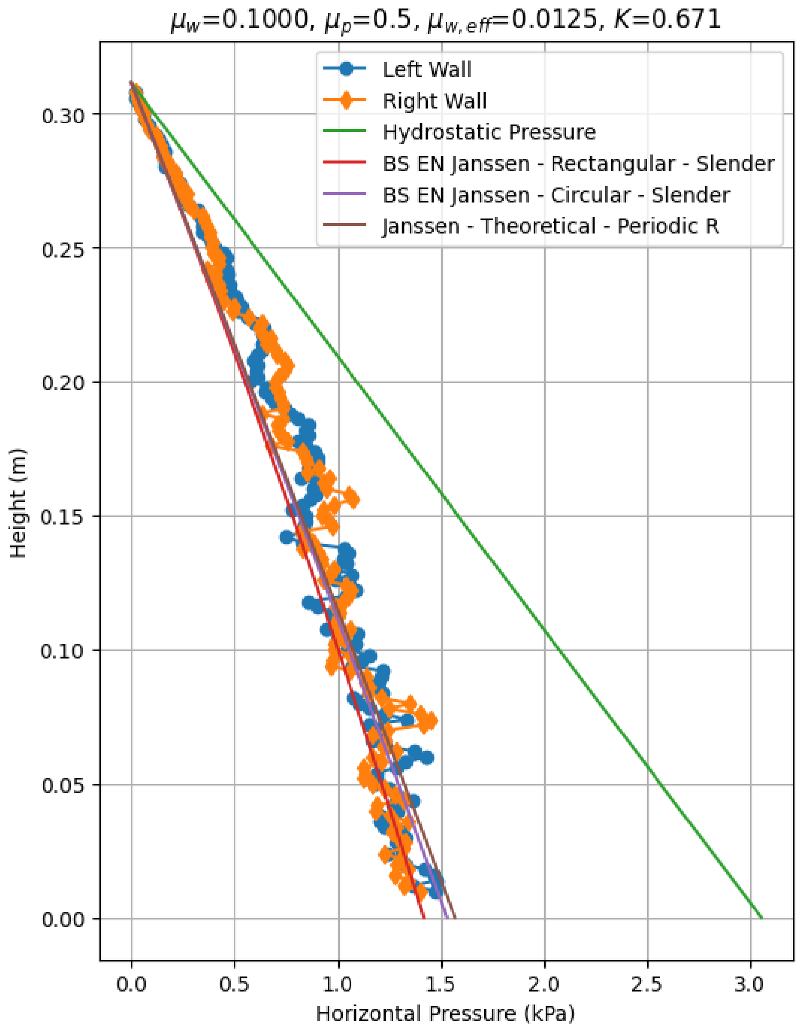


Initial Reference Results

Multi-Sphere Filling – Aspect Ratio = 1.25

Multisphere – AR=1.25 - Low Wall Friction





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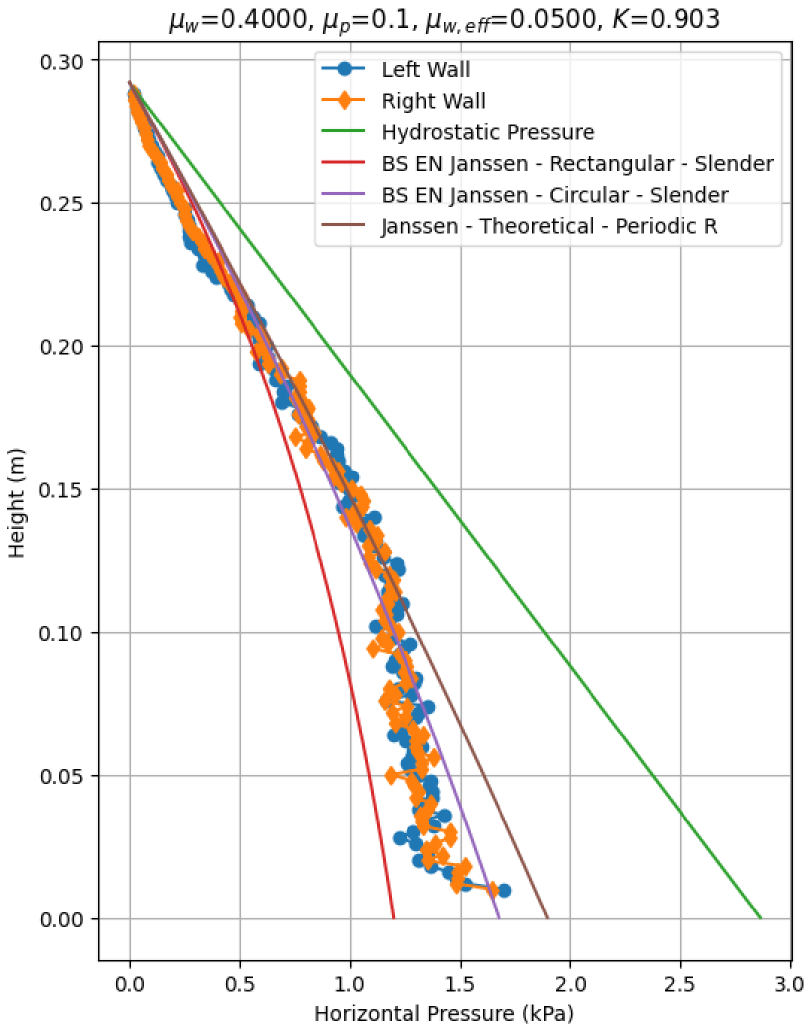
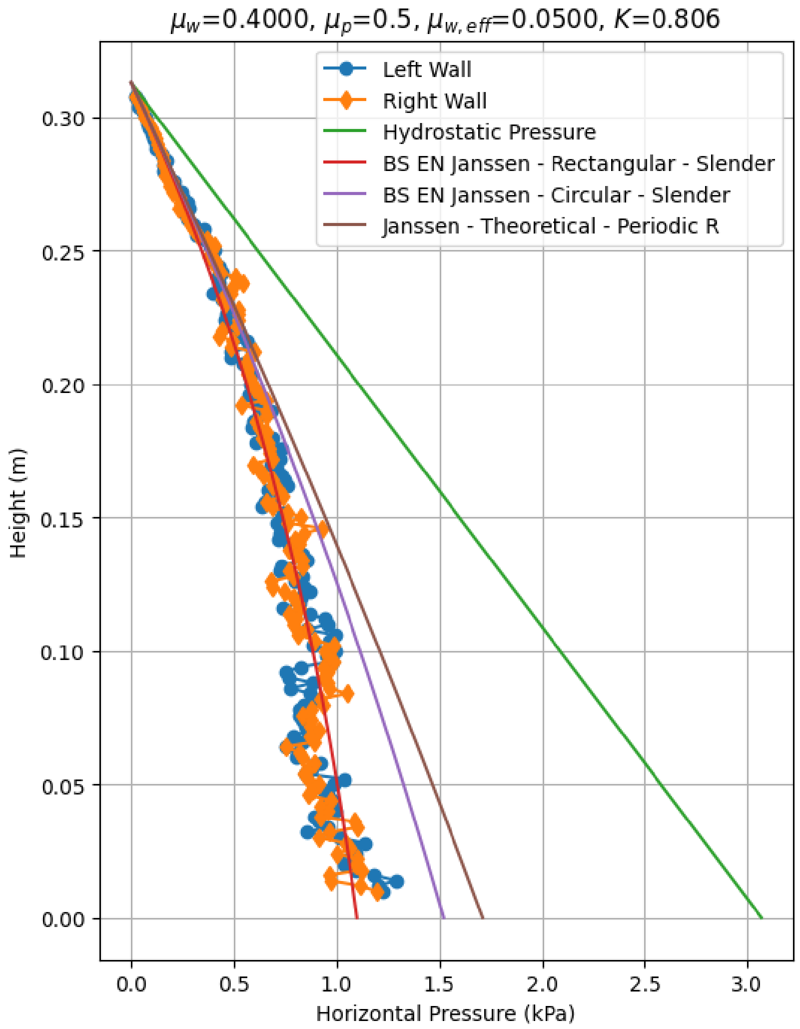
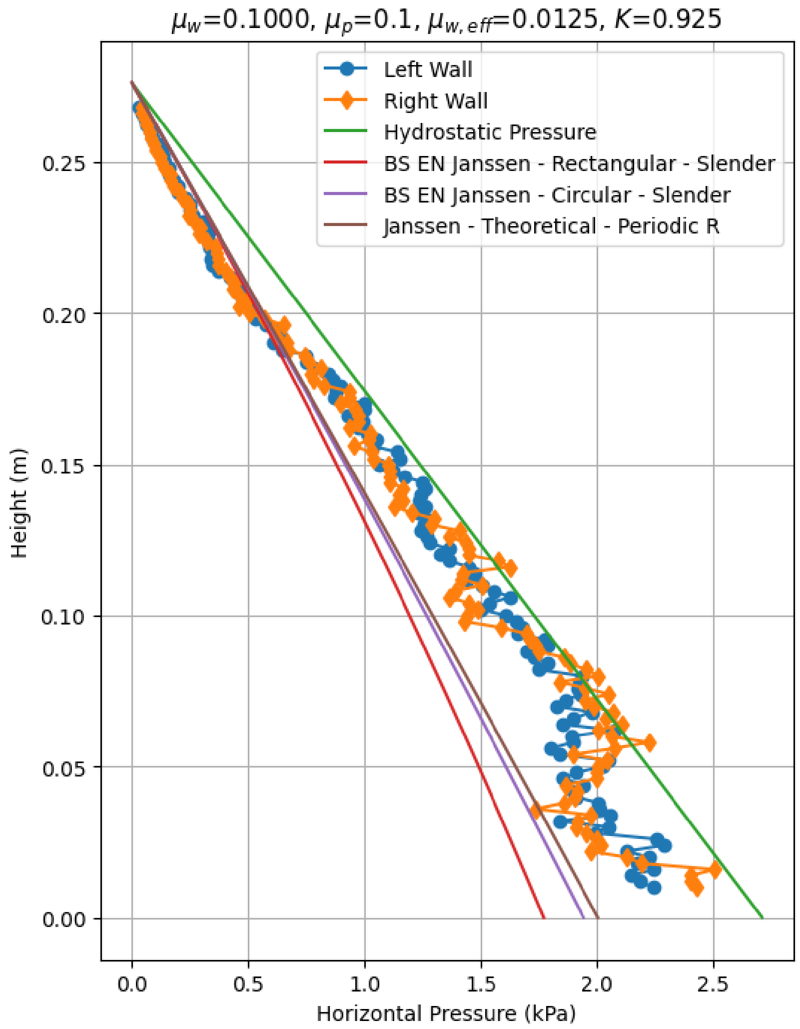


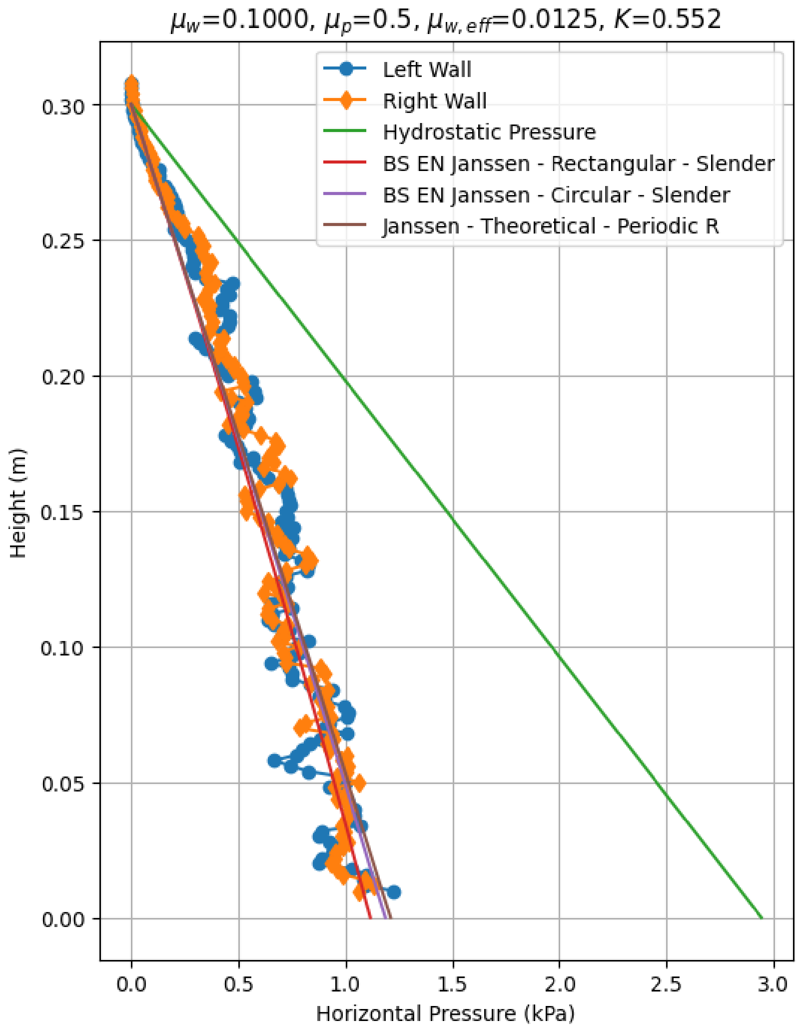


Initial Reference Results

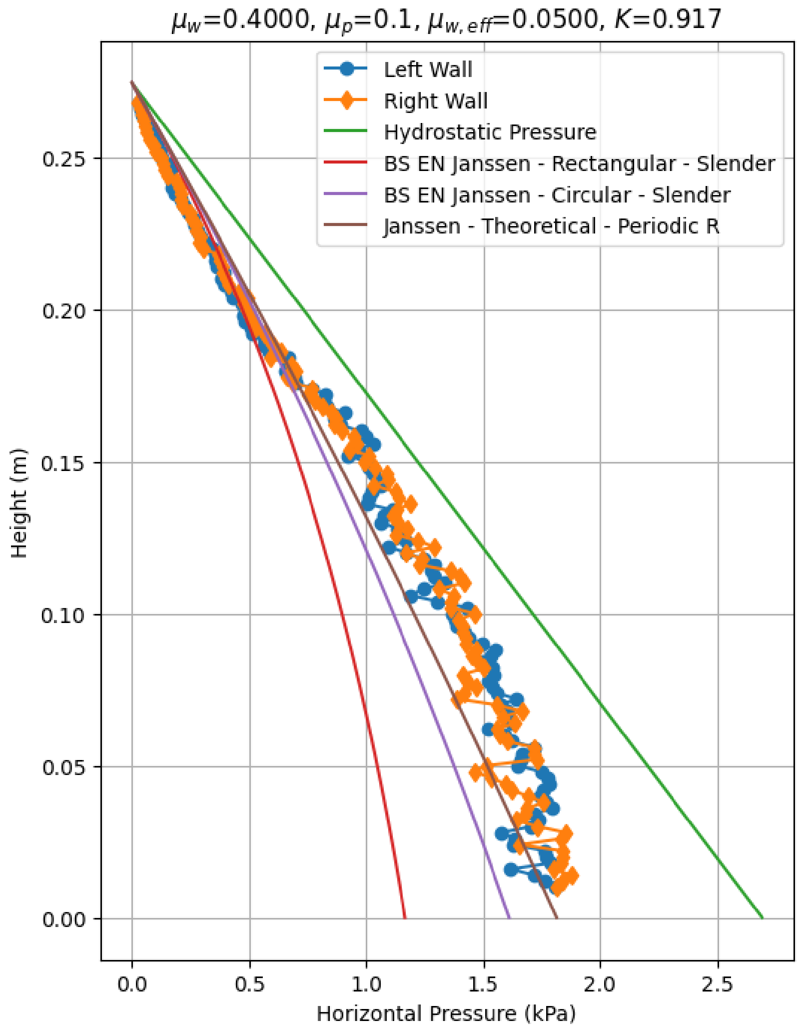
Spherocylinder Filling – Aspect Ratio = 2.5

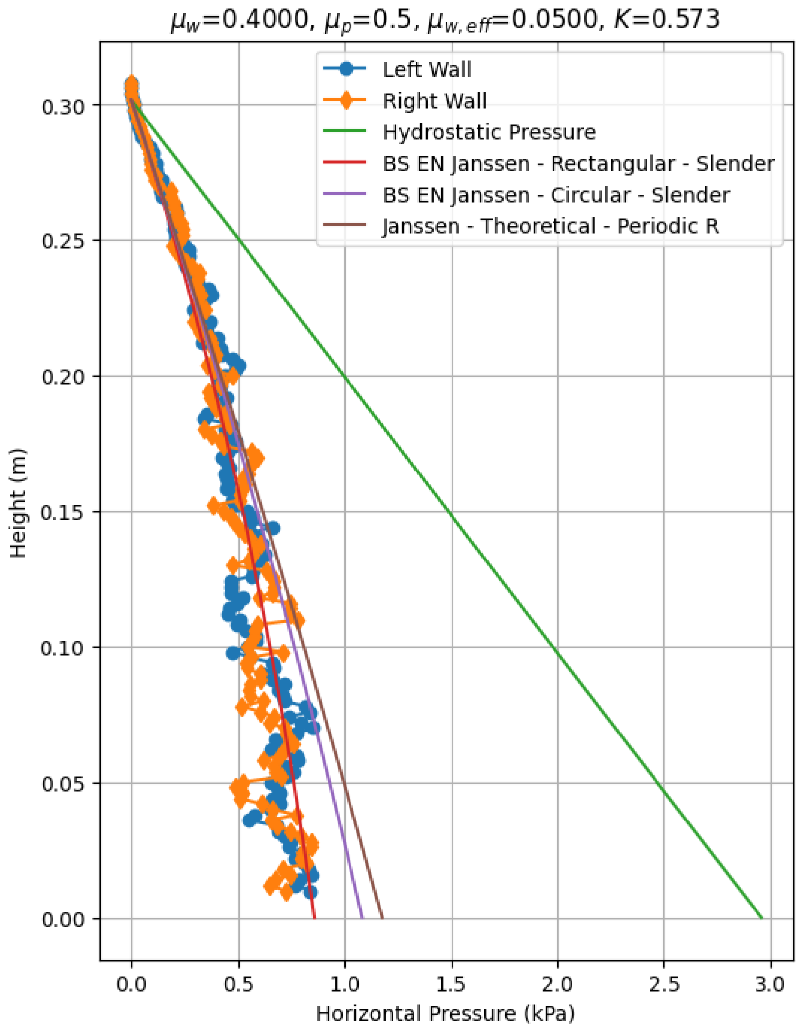
Multisphere – AR=2.5 - Low Wall Friction





Multisphere – AR=2.5 - High Wall Friction





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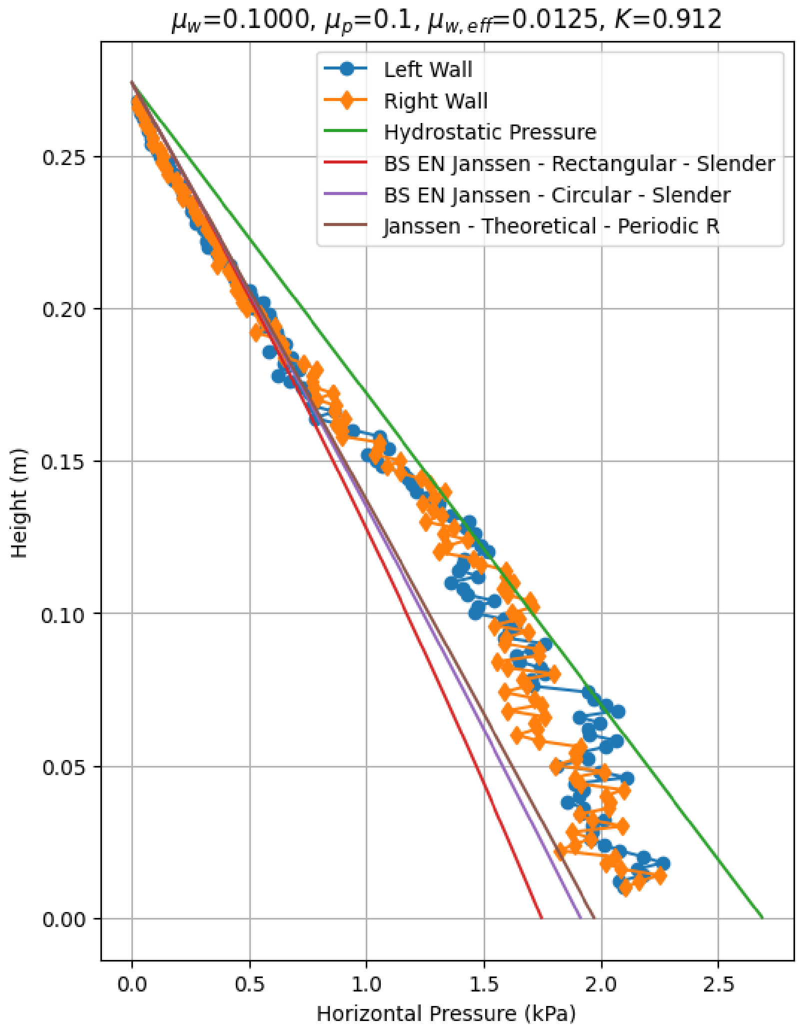
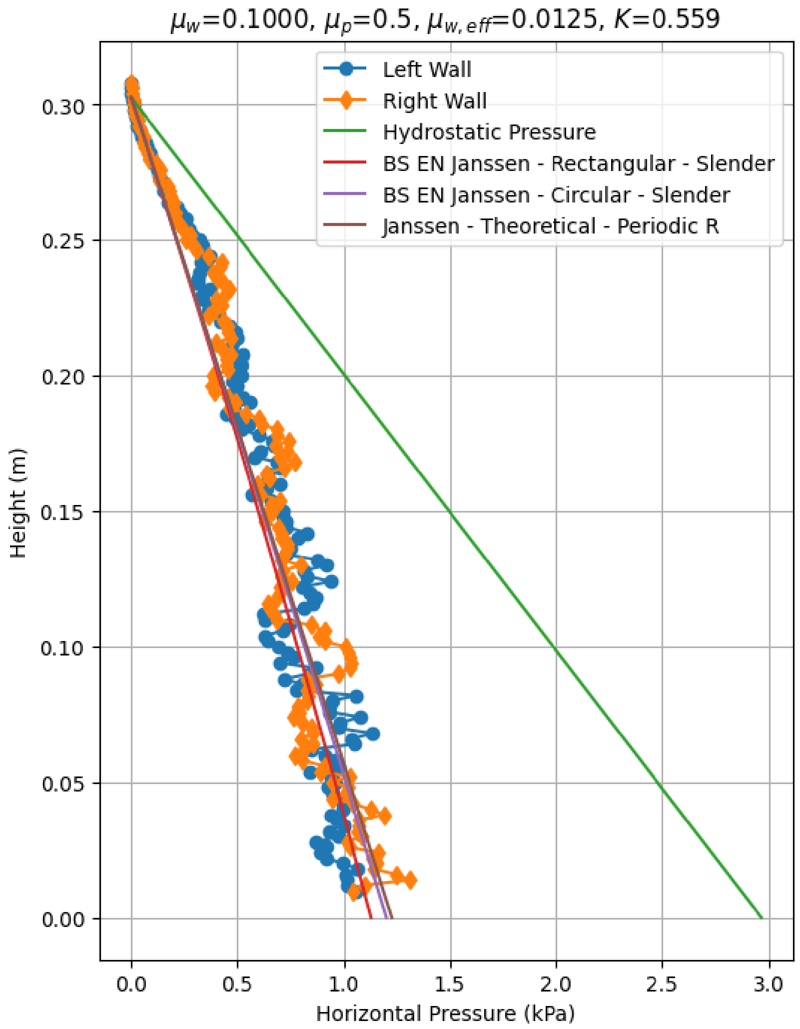
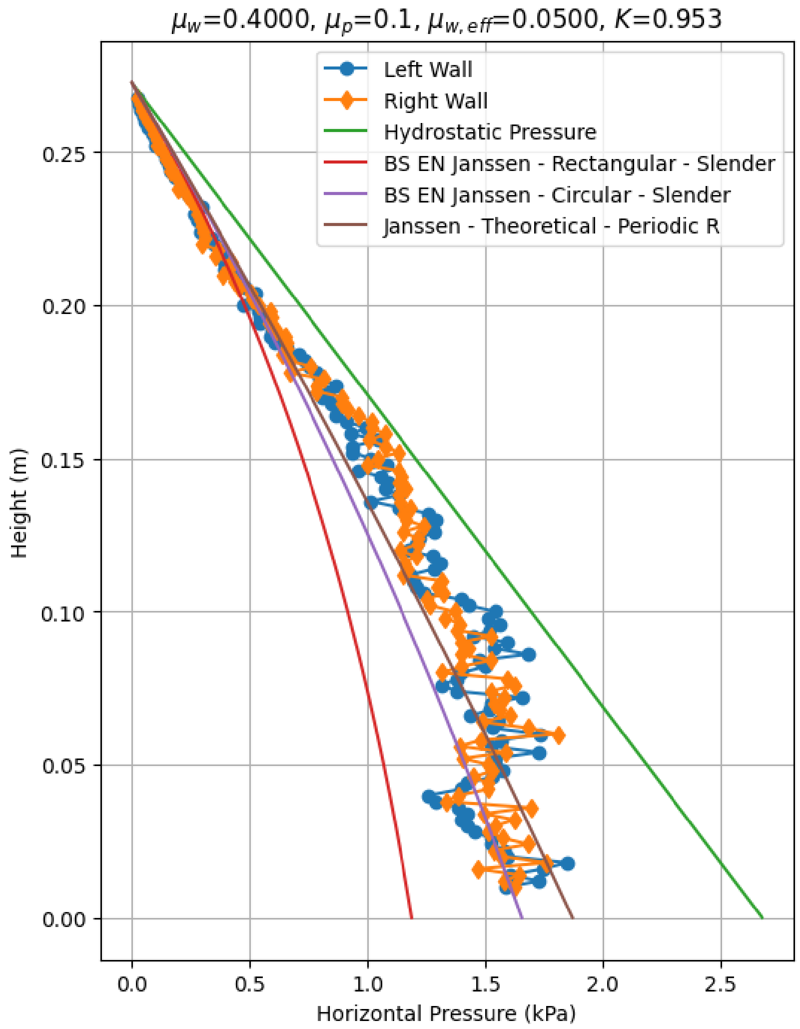
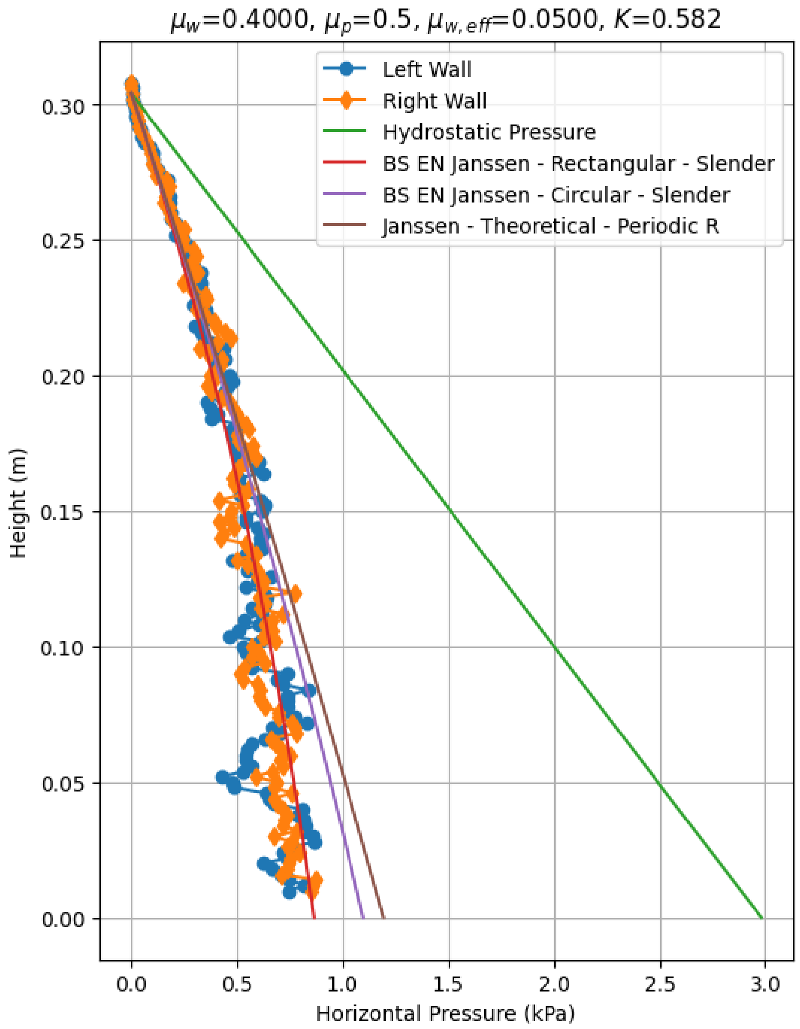
Spherocylinder – AR=2.5 - Low Wall Friction





Spherocylinder – AR=2.5 - High Wall Friction





Discussion

Effect of Wall Friction

- Effect of wall friction is very important
  - Low wall friction tends towards hydrostatic behaviour – more liquid like
  - Frictional granular solids end up with an asymptotic wall pressure distribution as the wall friction gets activated during filling

- Failure to capture to filling process could lead to incorrect predictions

- However, restarting from a filled assembly to run in other codes could lead to errors
  - Tangential history is lost, sample would compress leading to different pressure predictions
  - To be investigated – how to do this fairly – packing import vs different filling?

Model Implementation

- Infinite planar walls can be used for sides
- Finite planar walls are required for the various bases segments that create the various opening diameters
  - All codes provide some implementation of finite walls
- Not progressed much further due to other activities
  - See later…

Extended Dataset Generation

- Dataset has been expanded to re-included spherical particles

- Additional opening widths included discharge cases to provide more resolution around the flow / no-flow transition for non-spherical particles
  - Spheres are free flowing in all cases
  - May include very small opening to intentionally block flow

- Why?
  - See GRaiNNs talk….

Summary

- Initial analysis complete
  - Silo slice dimensions make it difficult to apply Janssen directly to get exact predicted pressure
  - Need to describe a better estimation procedure for effective wall friction
    - Comparison of wall pressure best fit parameters across DEM codes
- Considered use of periodic silo
  - Similar results in sphere case, but some out-of-plane interactions
  - Not suitable for very large aspect ratio particles in narrow slice as would require at least double current thickness
    - No longer considered
- Extended dataset generation for GRaiNNs

Questions?

ParaSolS

Particulate Solids Simulations

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Discourse https://parasols.discourse.group/

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