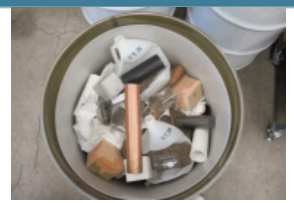
SAND2022-14749C



Sandia National Laboratories

# Waste Compaction Model



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Benjamin Reedlunn
Materials and Failure Modeling Department.

WIPP Rock Mechanics Technical Exchange

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# Outline

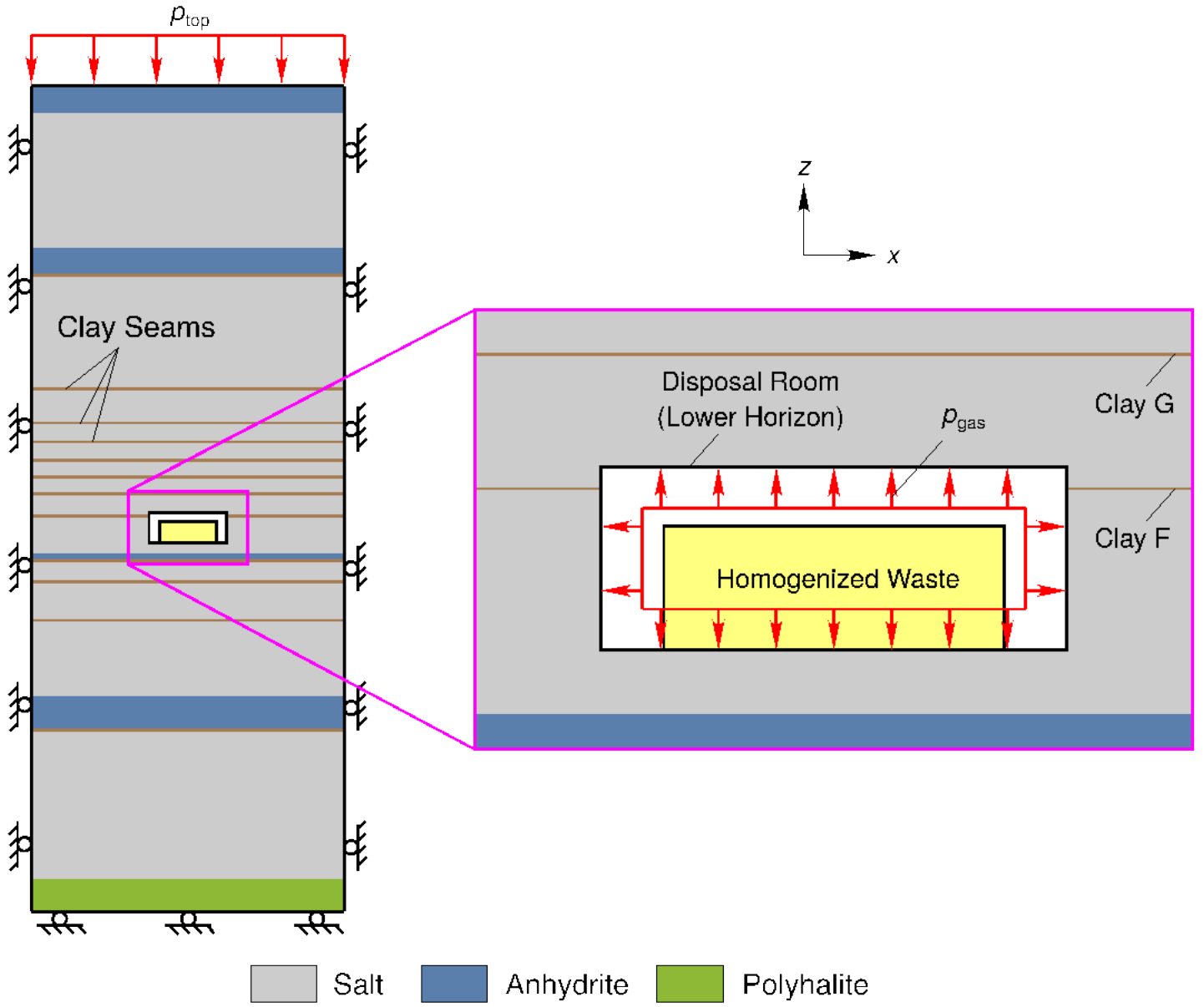
1. Motivation
2. New Waste Compaction Experiments
3. Calibration of a New Waste Compaction Model
4. Legacy vs. New Model Behavior
5. Summary

# Motivation

# Background

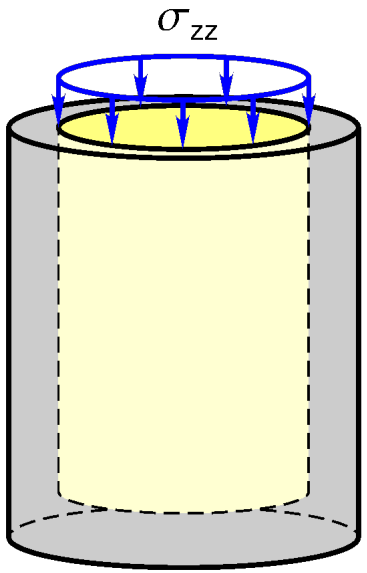
1. Room closure compacts the waste
    1. Plane strain deformation
    2. Progresses until waste plus gas can resist $p^{litho}$ = 14.7 MPa

2. Waste compaction behavior is important when gas pressure is low
    1. During the first ~300 years
    2. For low gas generation factors



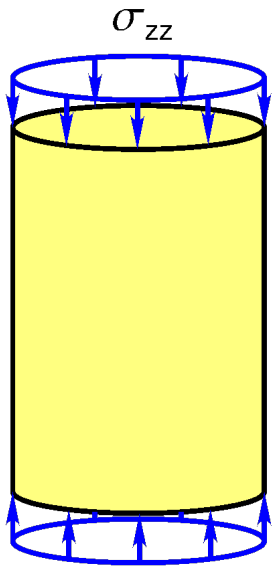
# Legacy Compaction Tests

## Uniaxial Strain (Oedometer) Tests




1. Compacted individual, non-degraded, waste components
2. Axial strain and stress measured
3. Lateral stress not measured

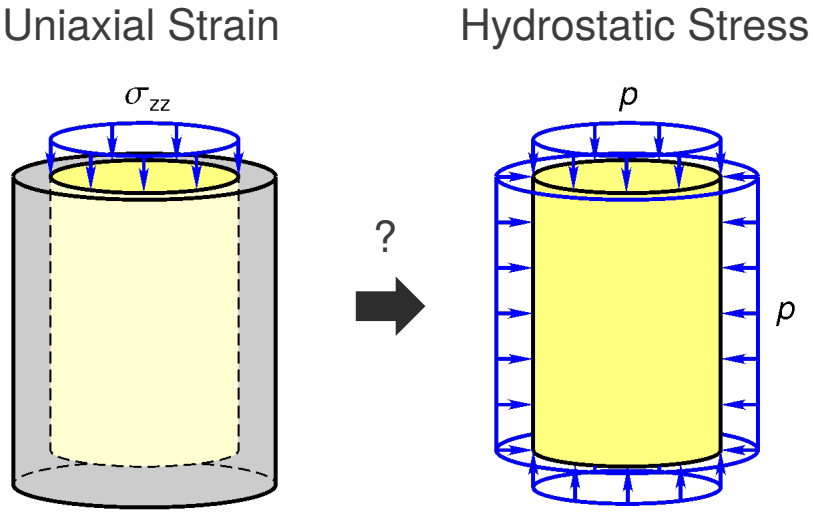
## Uniaxial Stress Tests

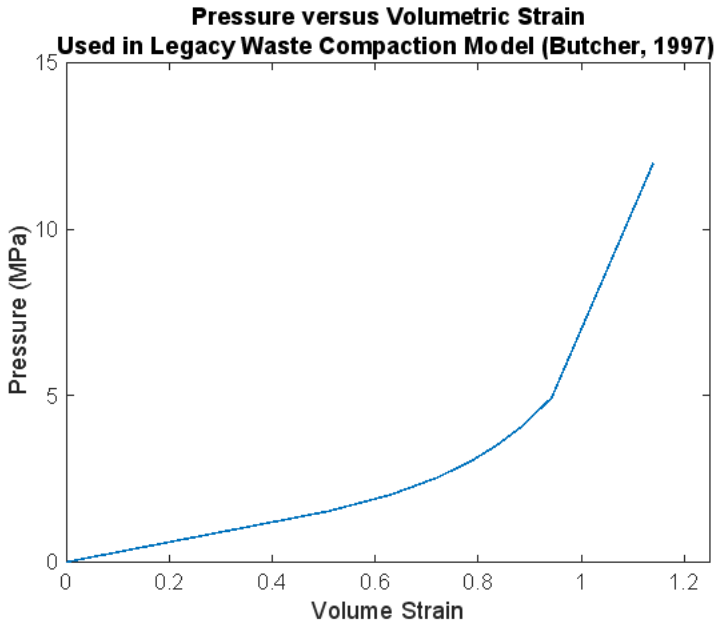



1. Compacted drums filled with mixtures of non-degraded waste components
2. Axial strain and stress measured
3. Lateral strain measured/inferred only in the first 2/3$^{rd}$ of two tests (malfunction halted lateral strain measurements after ~60% of the tests)

# Legacy Compaction Model

1. Container and waste contents homogenized into a continuous effective material
2. Utilized the Soil and Foam (SAF) constitutive model
   1. Drucker-Prager yield surface and von Mises flow potential
   2. Hydrostatic pressure cap that hardens with volume strain
3. Hydrostatic pressure vs. volume strain calibration
   1. Only used the uniaxial strain tests
   2. Mixture rule used to combine the component responses
   3. Assumed drums would be 100 % full
   4. Assumed the lateral stress was zero to compute hydrostatic pressure
   5. Extended the response from 5 MPa to 12 MPa using an assumed stiffness
   6. Last point of volume strain coincides with zero porosity

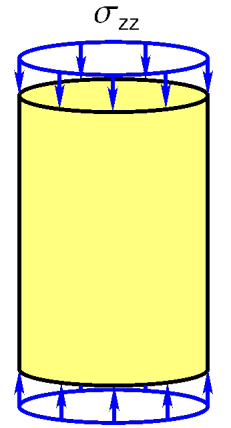


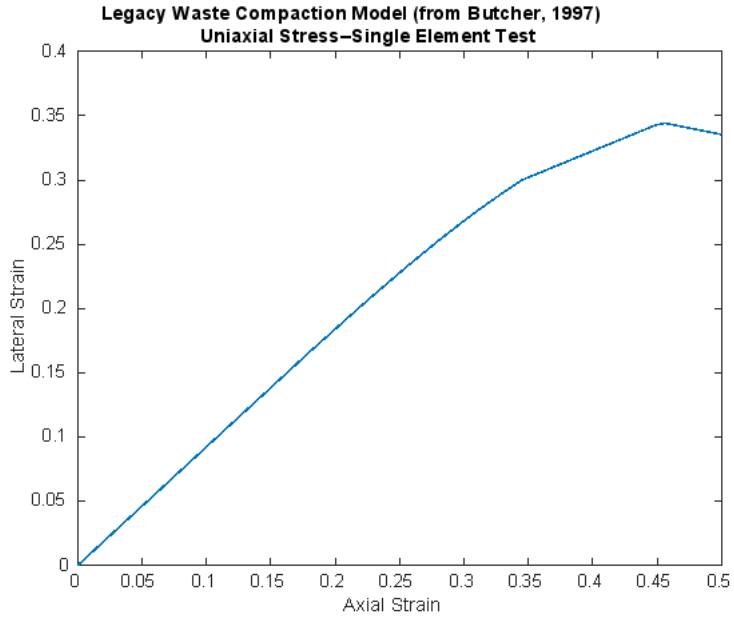



# Motivation

1. We now know the typical composition of the waste
   1. Drums are typically 66 % full.
2. Legacy model was focused on early instead of late compaction behavior
   1. Did not measure the stiffness for $p > 5$ MPa
   2. Neglected lateral expansion late in uniaxial stress tests
3. Legacy model does not produce zero lateral expansion under uniaxial stress as intended.
   1. Leads to non-physical tensile stresses along the length of the room.
4. Waste compaction could be rate dependent

Uniaxial Stress




Compressive Strains are positive

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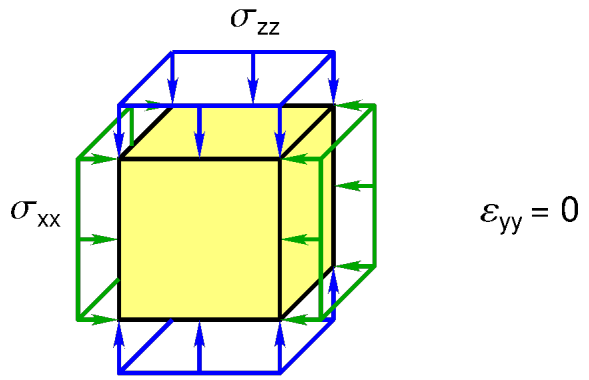
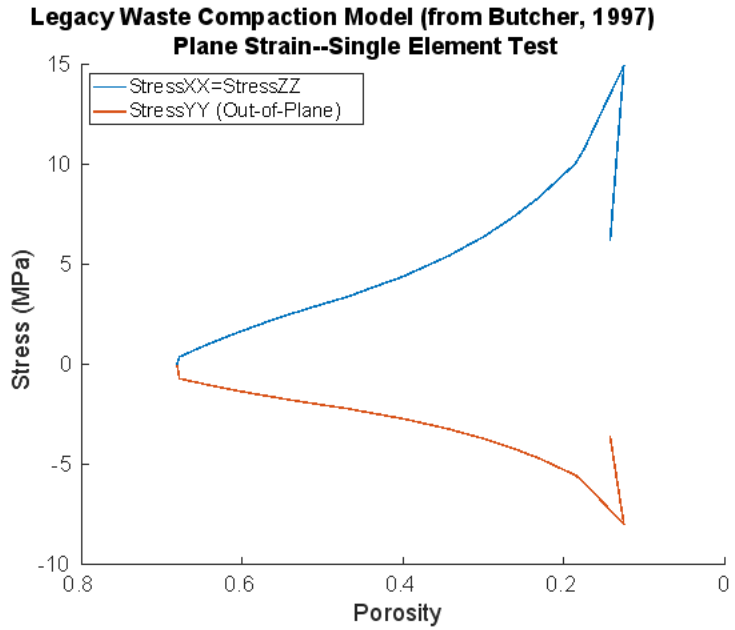
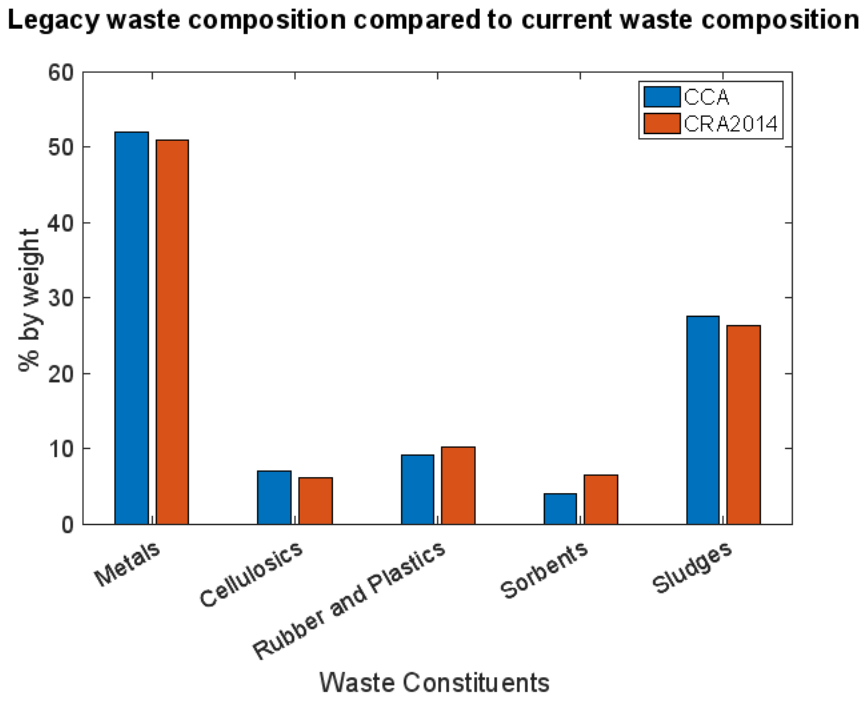



Compressive Stresses are positive

# New Waste Compaction Experiments

# Surrogate, Non-Degraded, Waste and Waste Containers




55 Gallon Drum
(with surrogate waste)

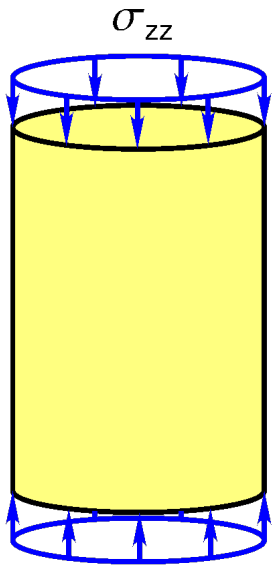
¼-Scale Drum
(with surrogate waste)

Waste containers only 66 % filled.

Broome, S.T., Ingraham, M.D., Flint, G.M., Hileman, M.B., Barrow, P.C., and Herrick, C.G., "Laboratory Testing of Surrogate Non-degraded Waste Isolation Pilot Plant Materials", 2016, American Rock Mechanics Assoc., ARMA 16-120

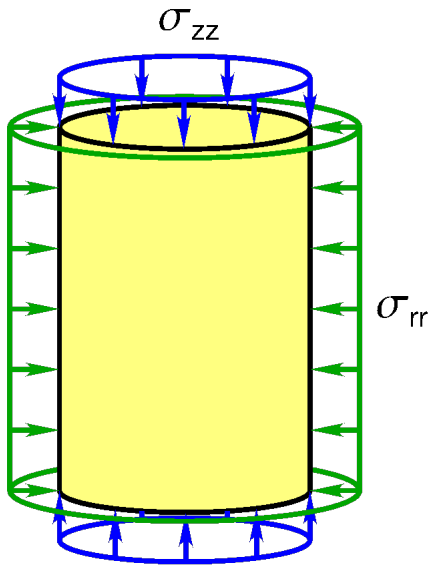
# Experiment Types

## Uniaxial Stress



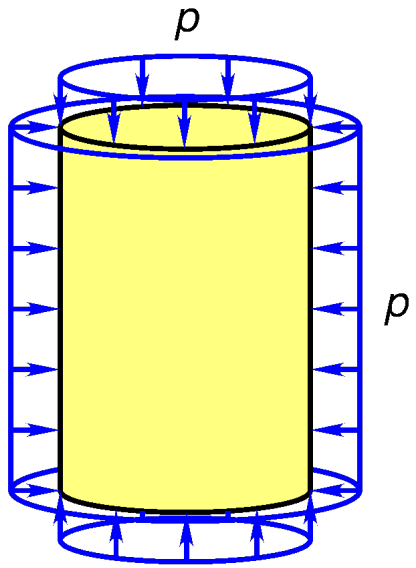

1. Full and ¼ size drums
2. Lateral strain inferred from axial and volume strain
3. Strain rates ranged from $10^{-7}$ to $10^{-4}$ 1/s

## Triaxial (Axisymmetric) Stress




1. Only ¼ size drums
2. Lateral strain inferred from axial and volume strain
3. Strain rate = $10^{-4}$ 1/s

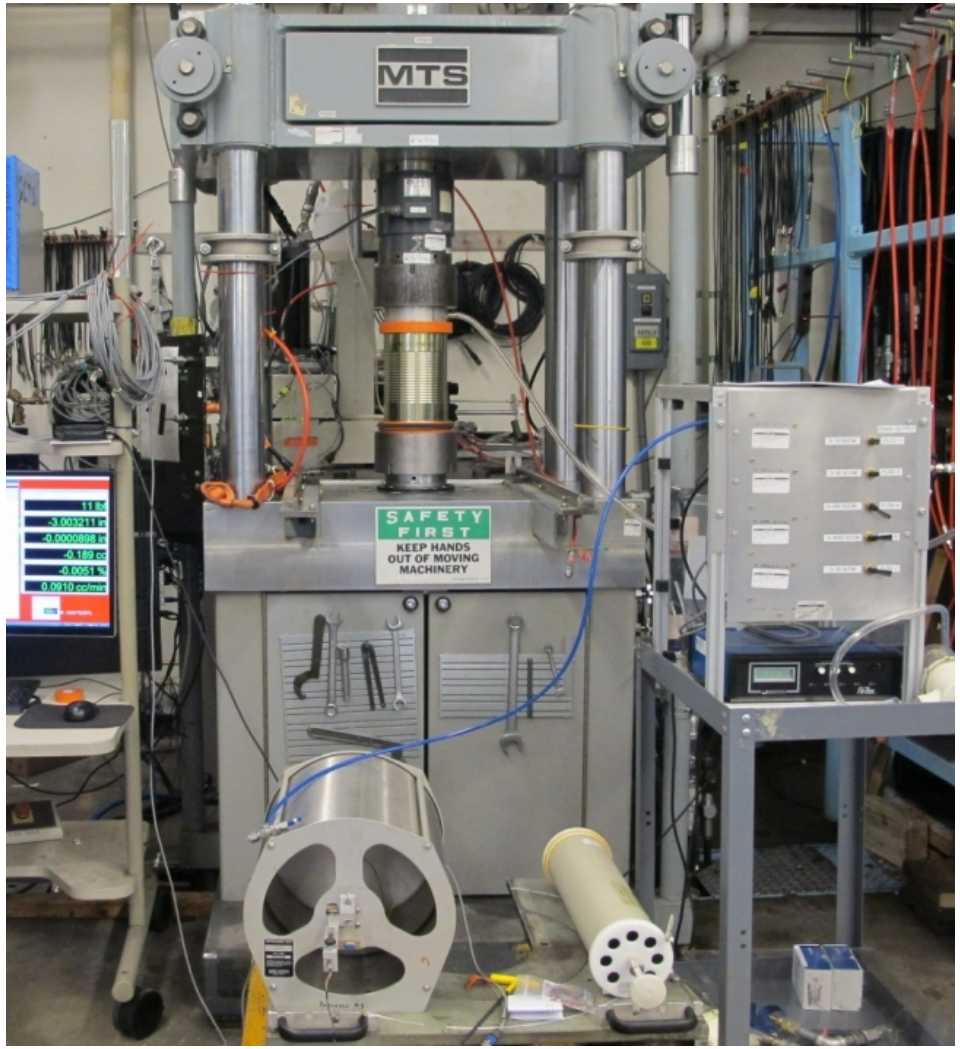
## Hydrostatic Stress



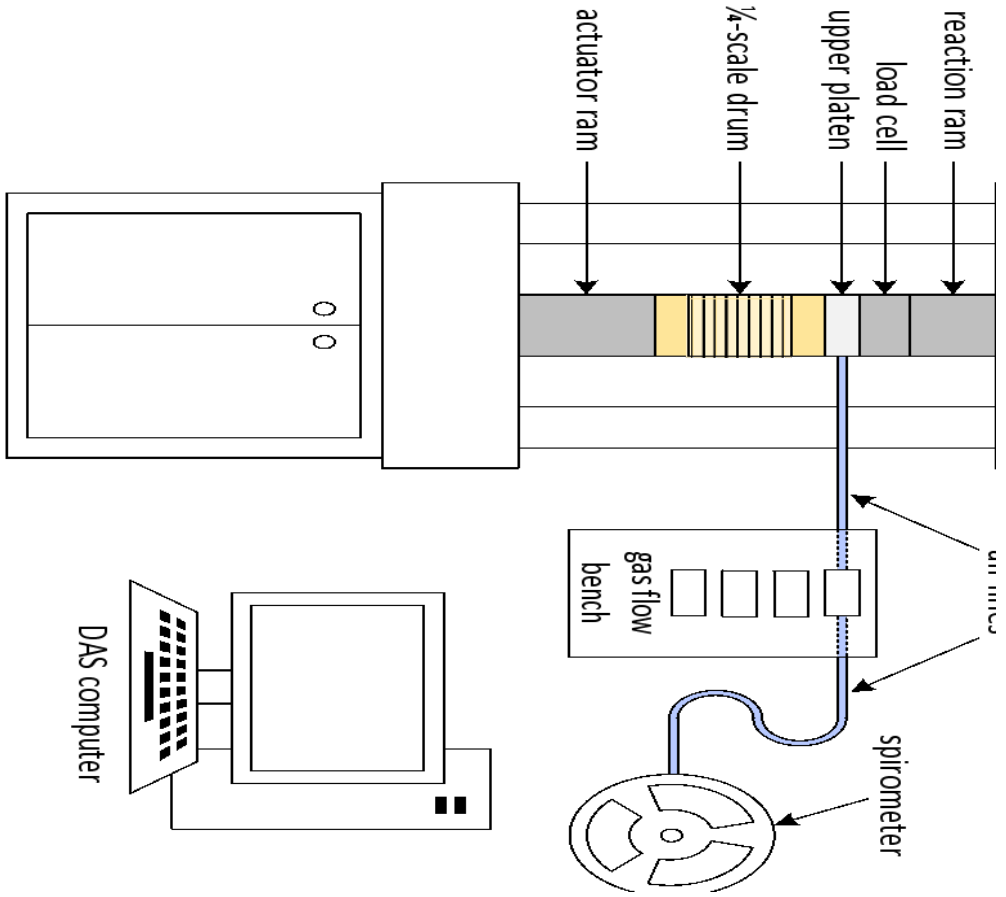

1. Full and ¼ size drums
2. Measured only volume strain
3. Strain rate = $10^{-4}$ 1/s

# ¼ Scale Uniaxial Stress Test Setup

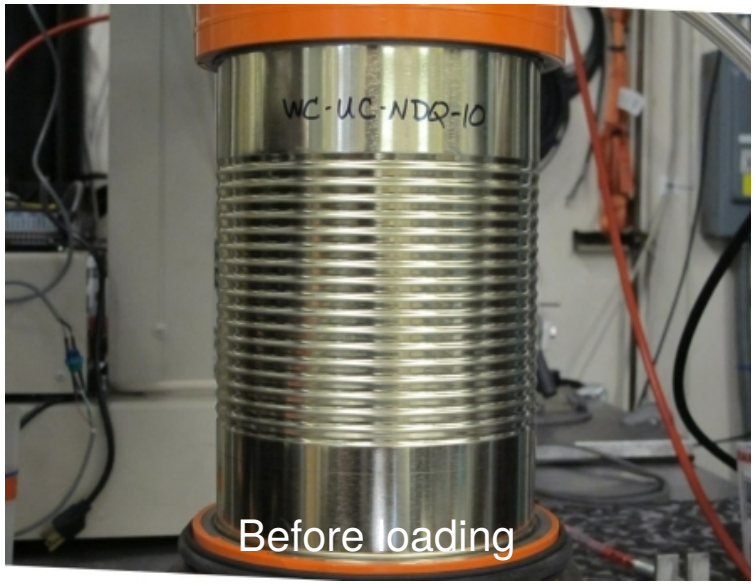
Photograph




Schematic



# ¼-Scale Uniaxial Stress Compaction Images

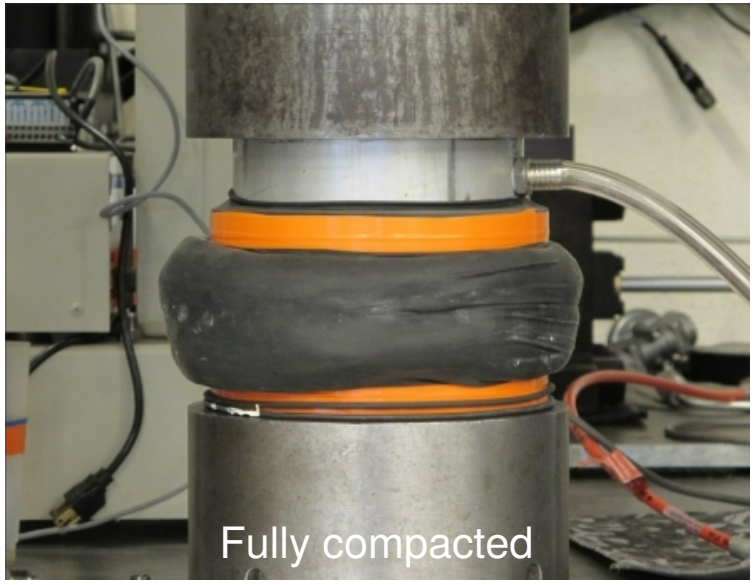


Before loading


Drum breech


Wrapped in modeling clay

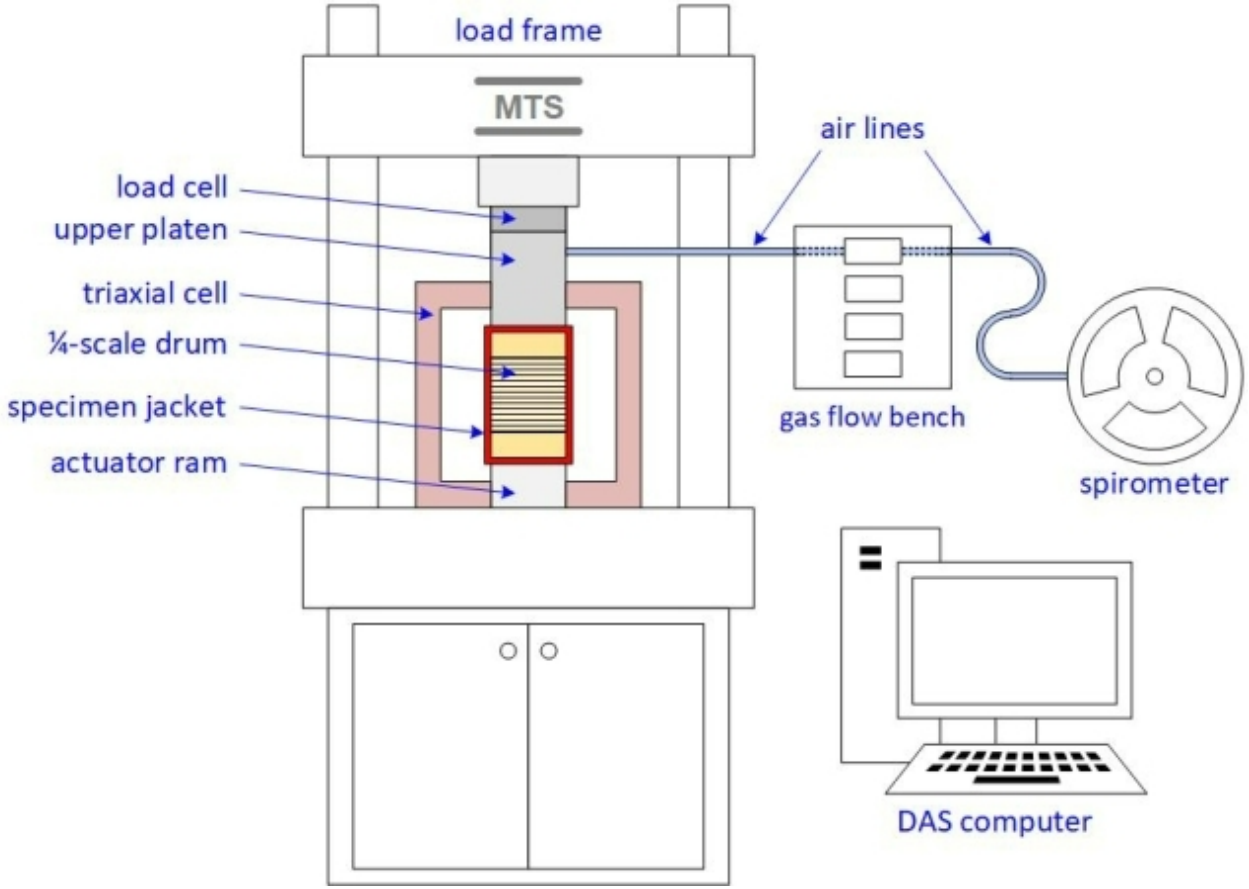

Secondary balloon seal


Fully compacted

Final state of drum

# Triaxial and Hydrostatic Test Setups

## Triaxial Test Setup




## Full Size Hydrostatic Pressure Vessel

# Triaxial and Hydrostatic Stress Test, Post-Test Images

## Triaxial Stress

### ¼-Size Drums


## Hydrostatic Stress

### ¼-Size Drums

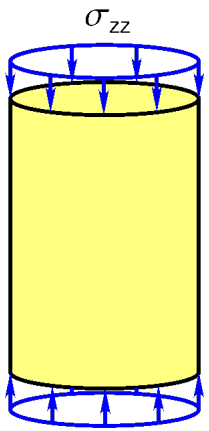

### Full Size Drums

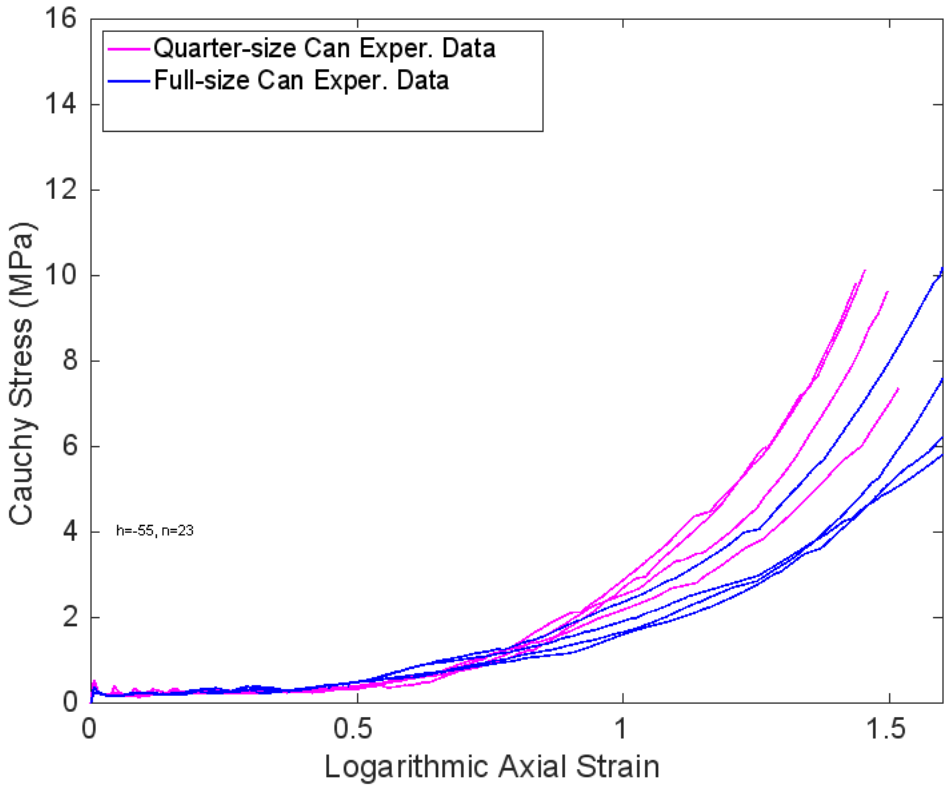
# Calibration of a New Waste Compaction Model

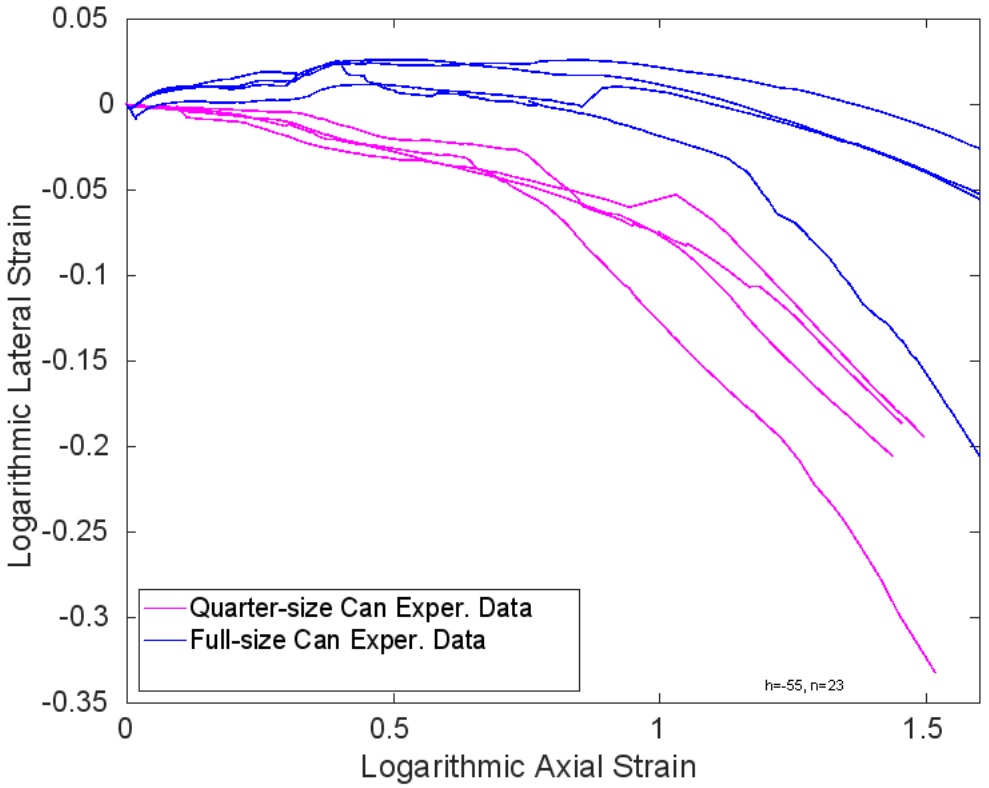
# New Waste Compaction Model

1. Container and waste contents again homogenized into a continuous effective material
2. Utilized the Foam Damage (FD) constitutive model
    1. Ellipsoidal yield surface
    2. Independent ellipsoidal flow potential
    3. Ellipsoid axes evolve with porosity
        1. Stiffness can increase as porosity reduces
        2. Lateral strain can evolve faster as porosity reduces
    4. Can incorporate strain rate sensitivity
3. Calibration
    1. Elected to focus on triaxial and hydrostatic behaviors
    2. Calibrated against ¼-scale container behavior, then adjusted to match full size container behavior

# Uniaxial Stress Mechanical Responses



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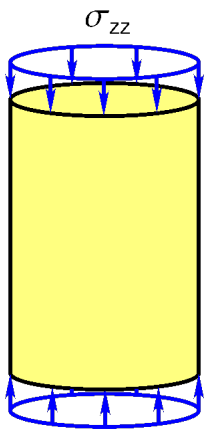
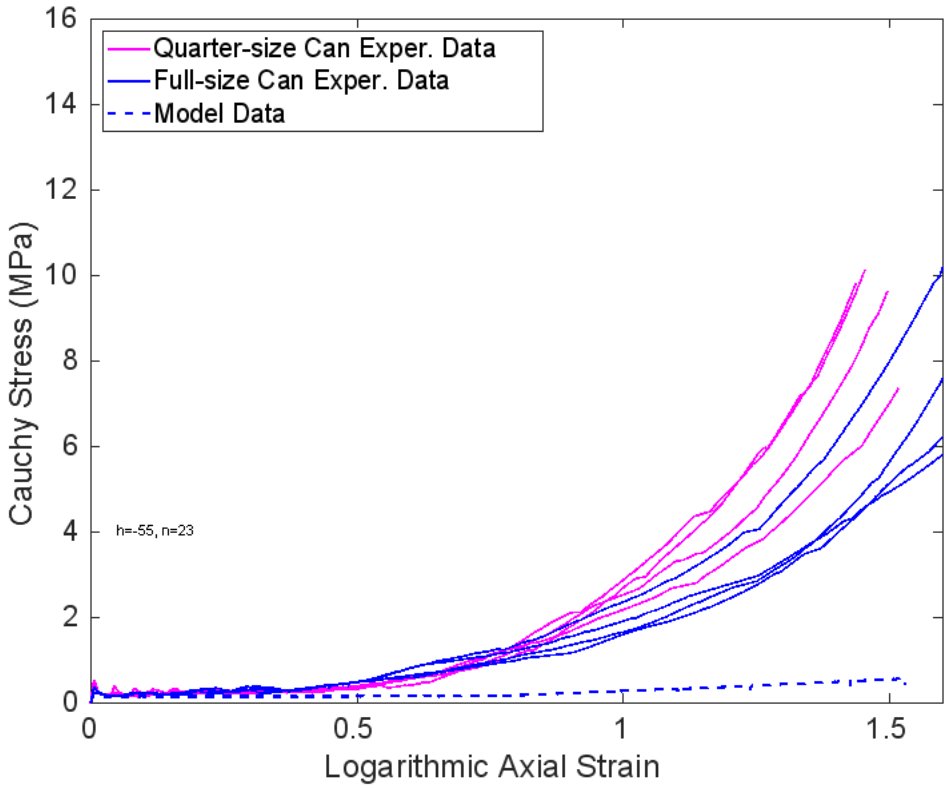
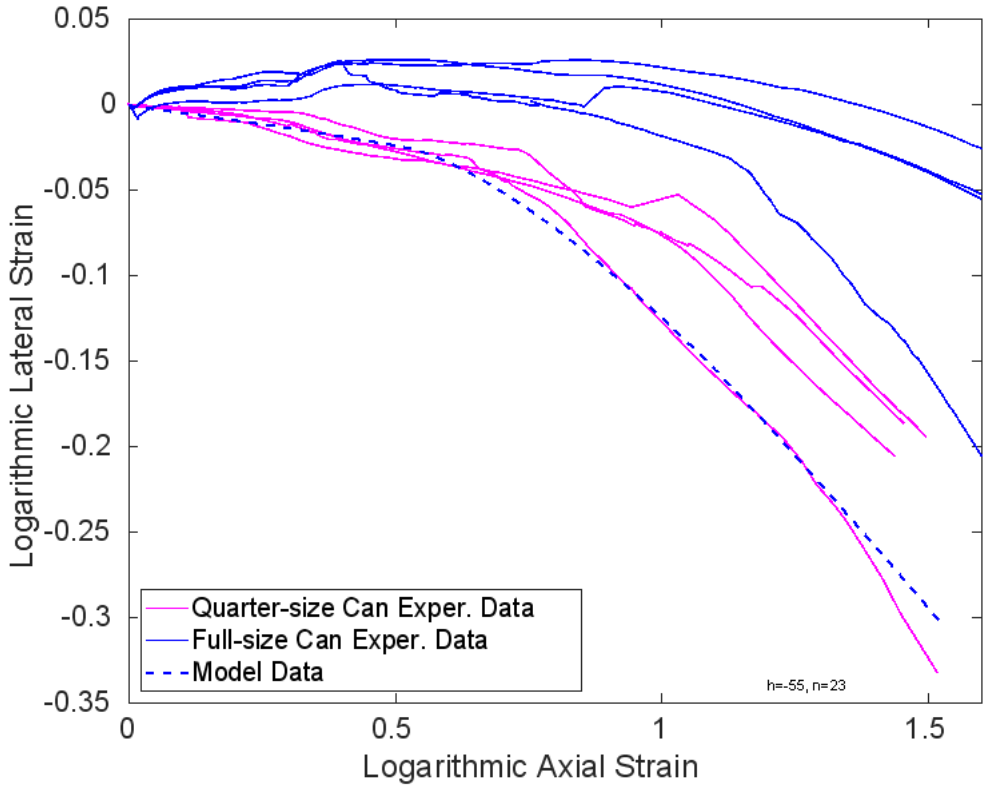
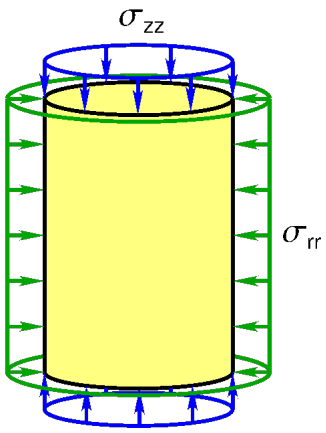
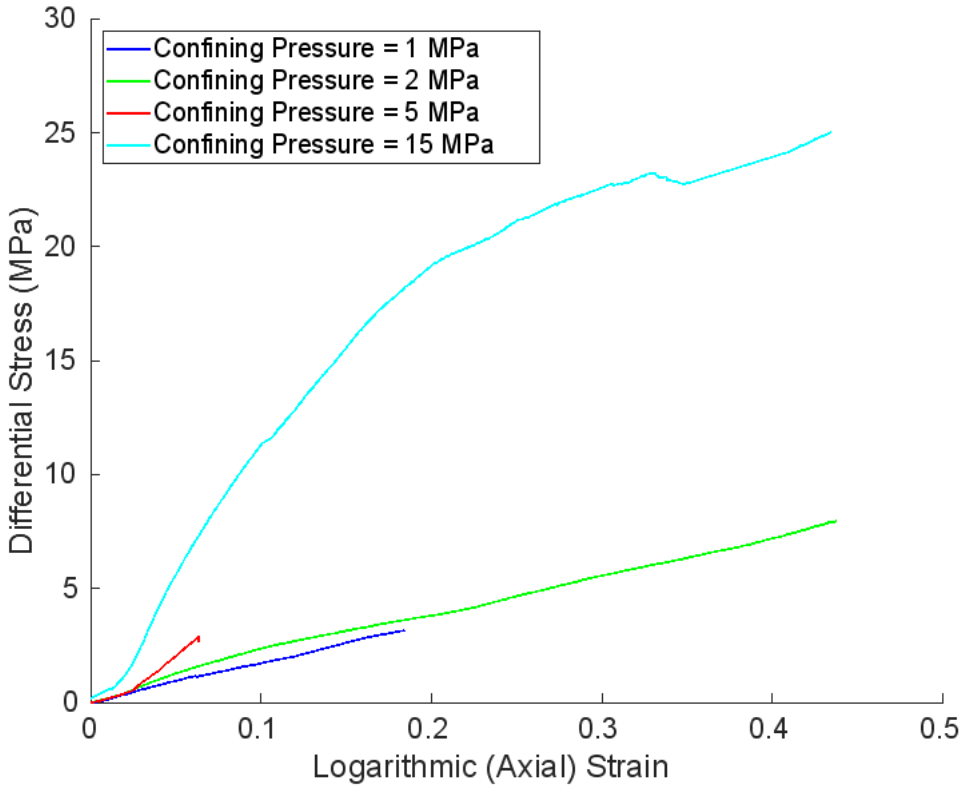


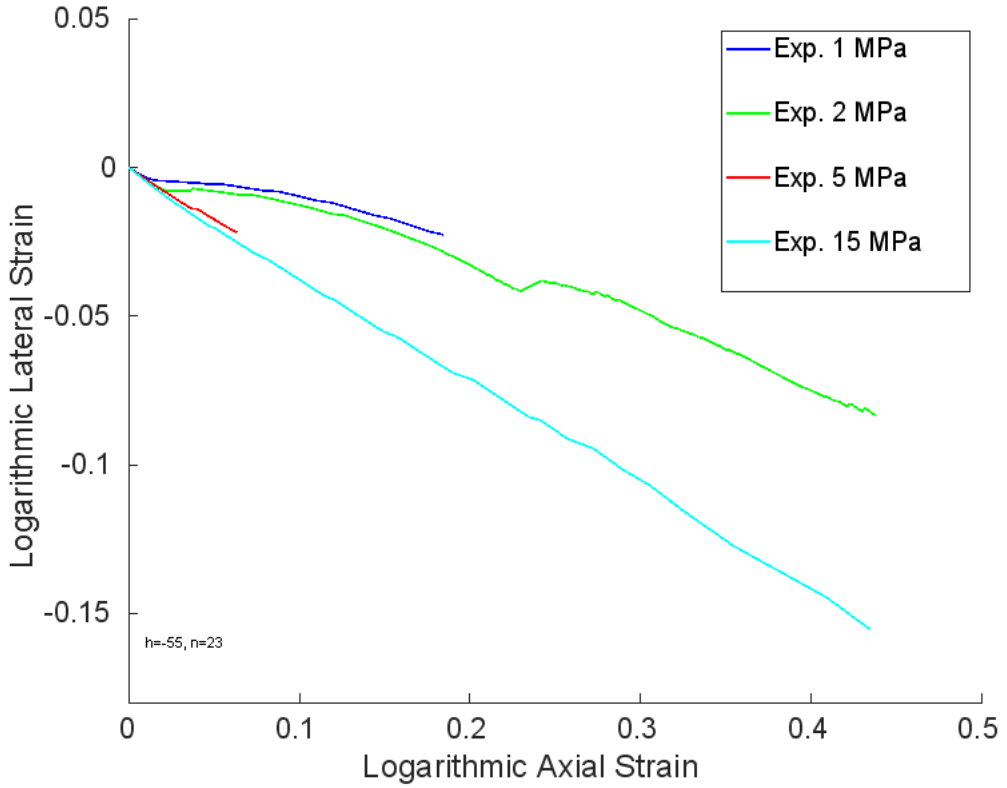



# Triaxial Stress Mechanical Responses



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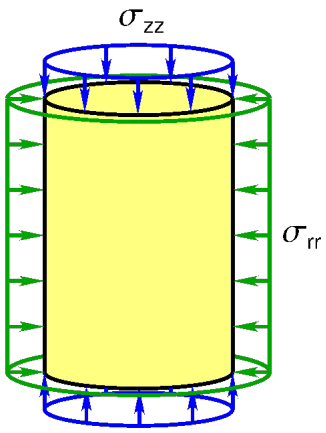
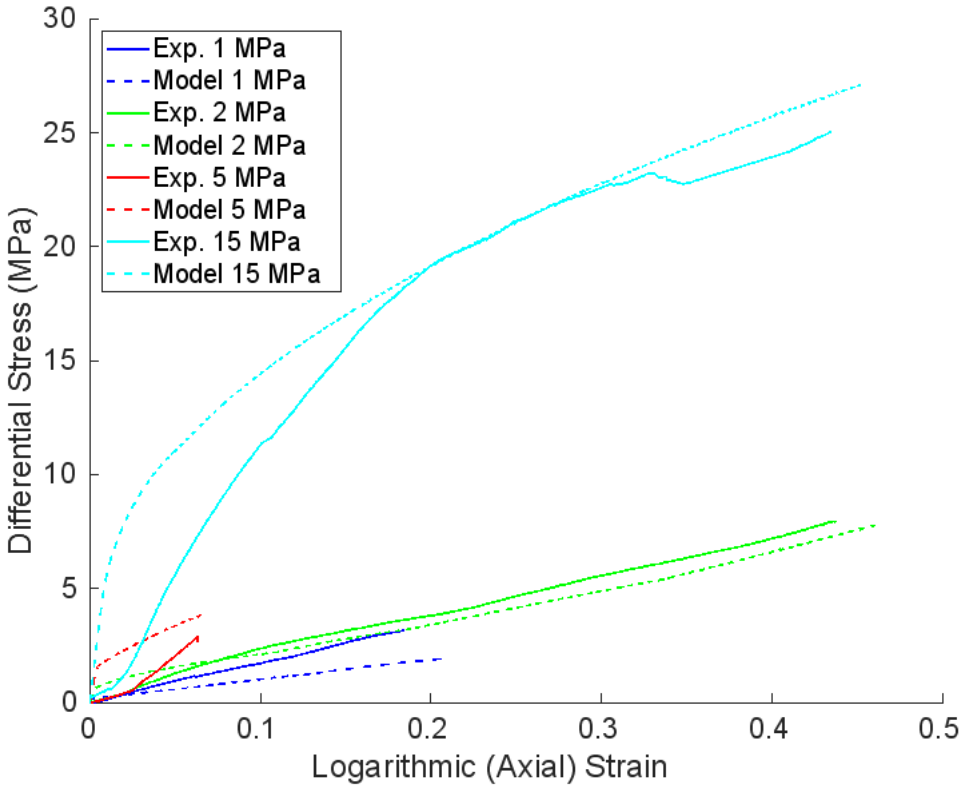
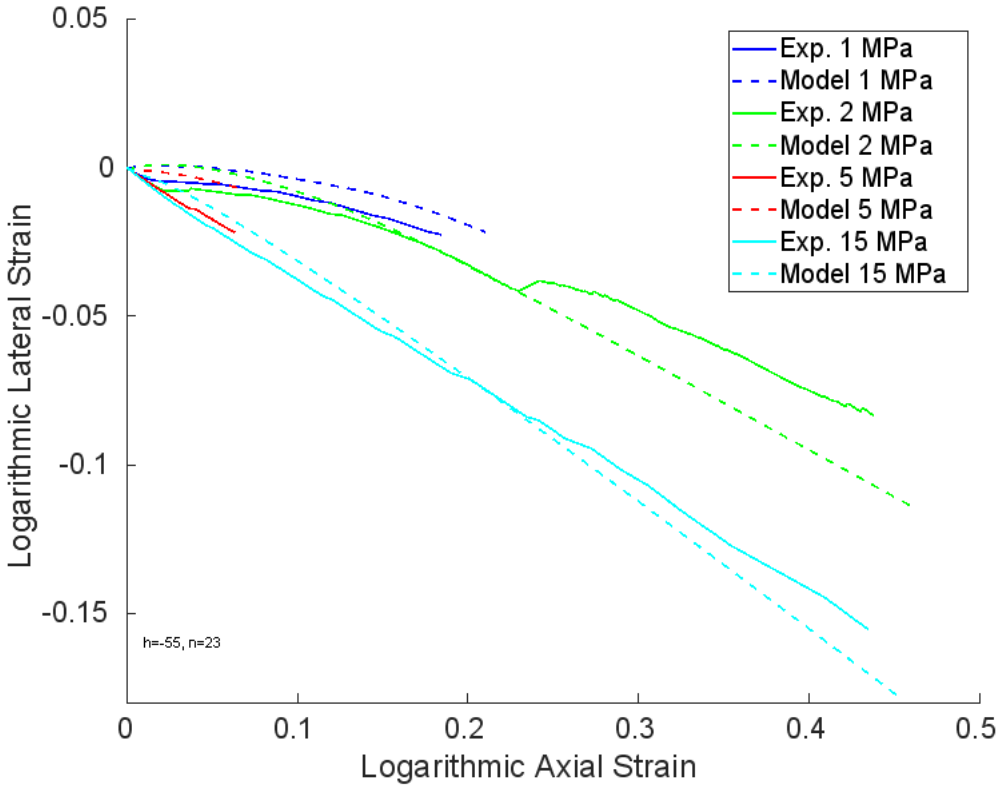
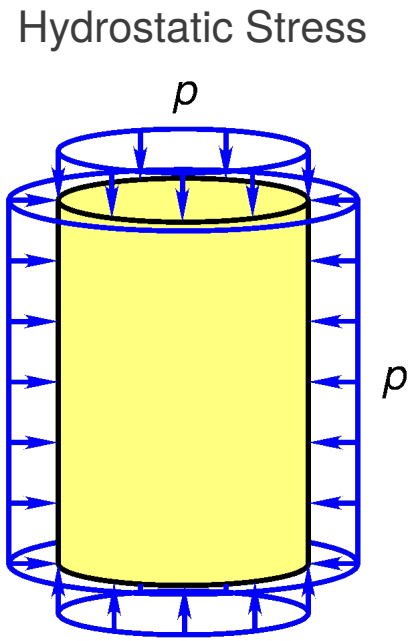
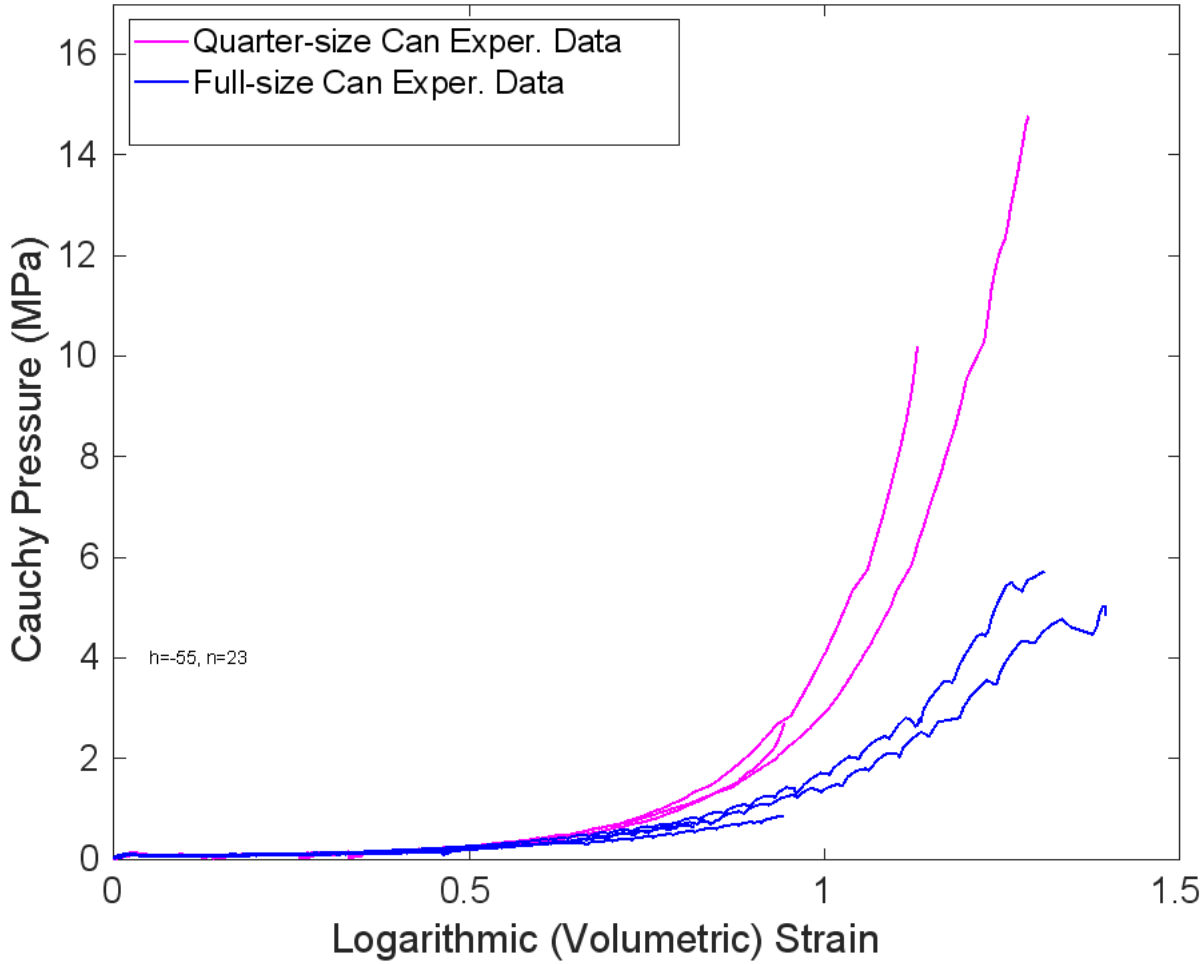


# Hydrostatic Stress Mechanical Responses



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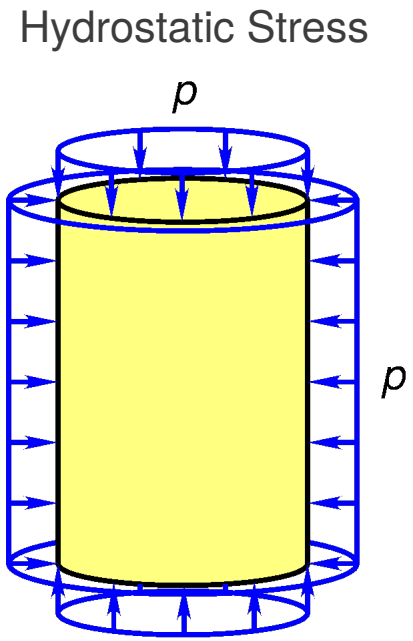
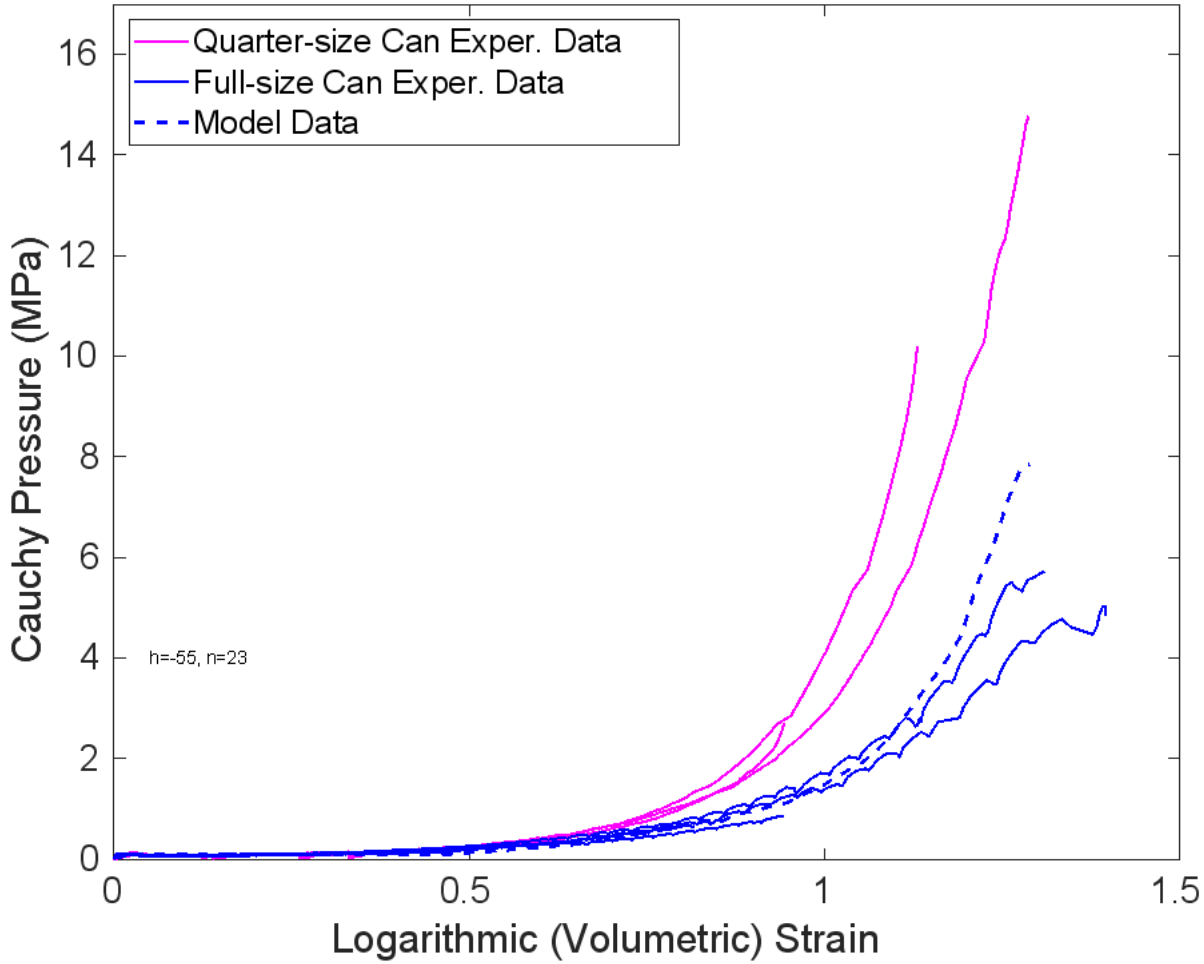
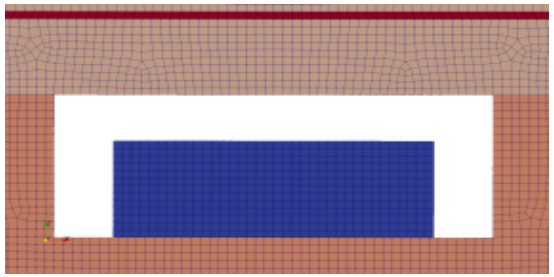


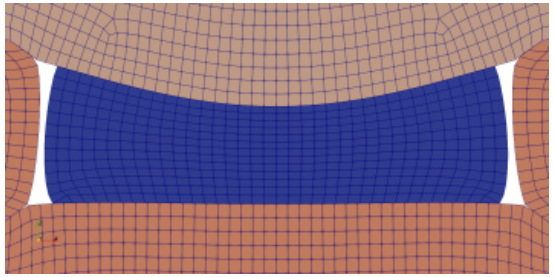



# Waste Deformation and Stress Paths in a Disposal Room Simulation

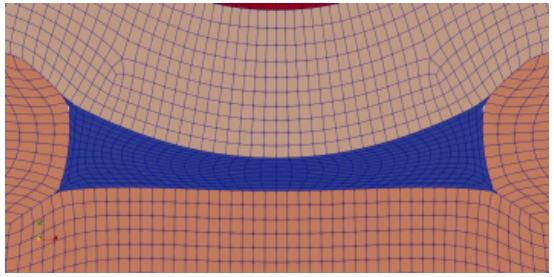
0 yr



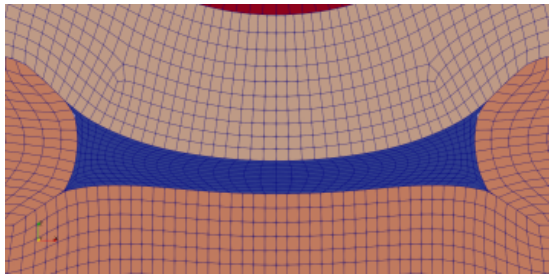
A. 90 yr

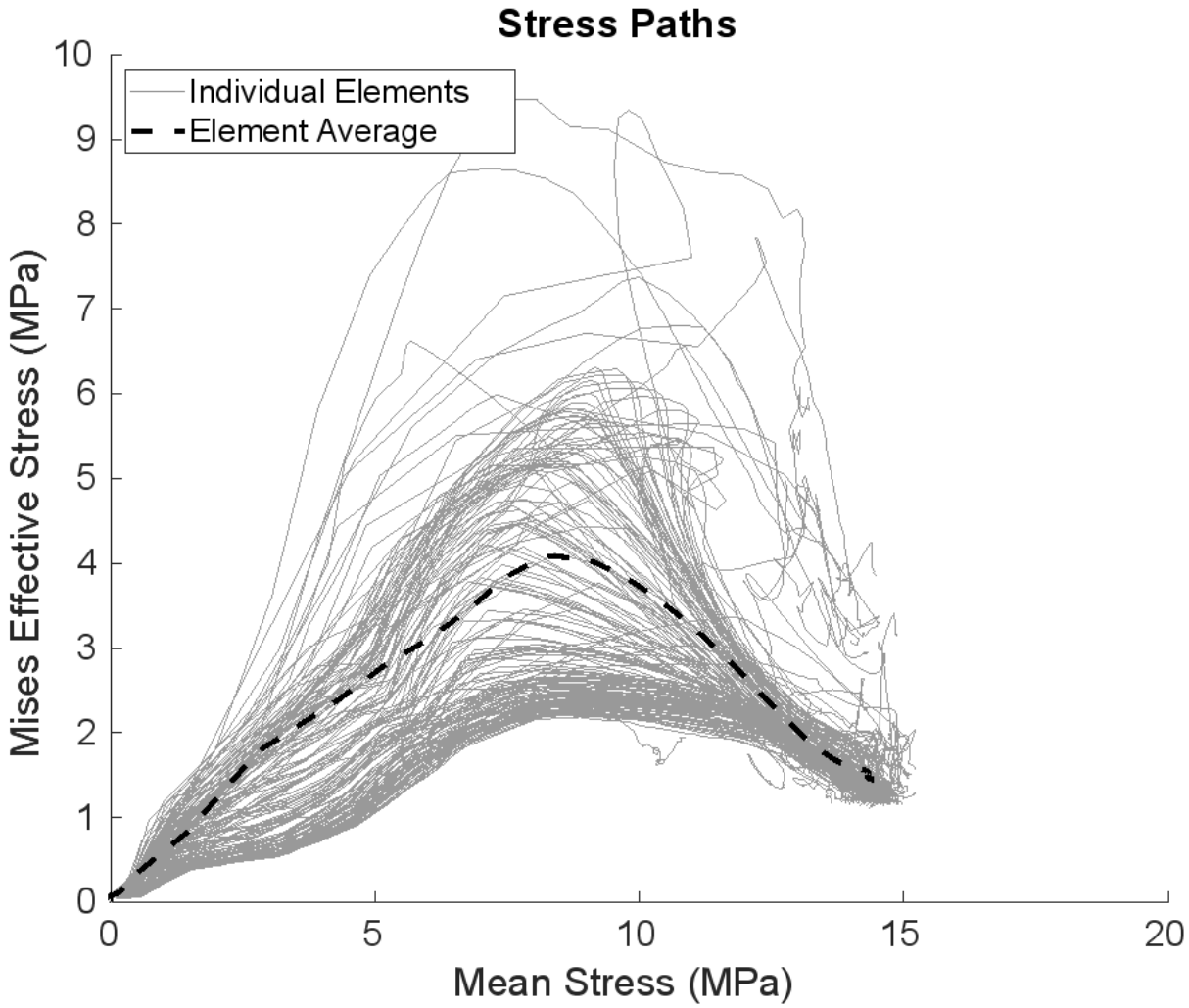


B. 120 yr



F. 10000 yr





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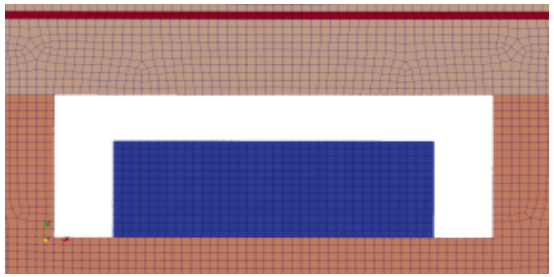
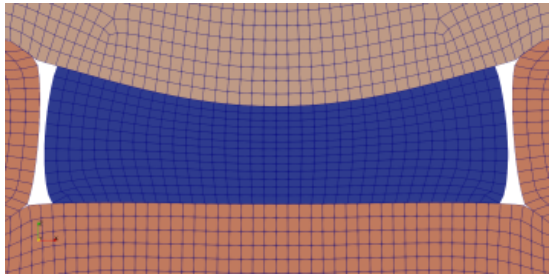
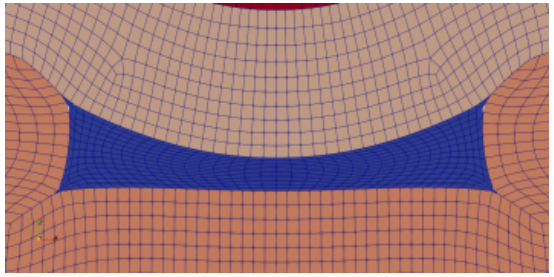
0 yr



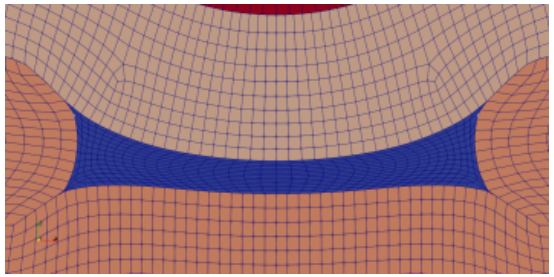
A. 90 yr

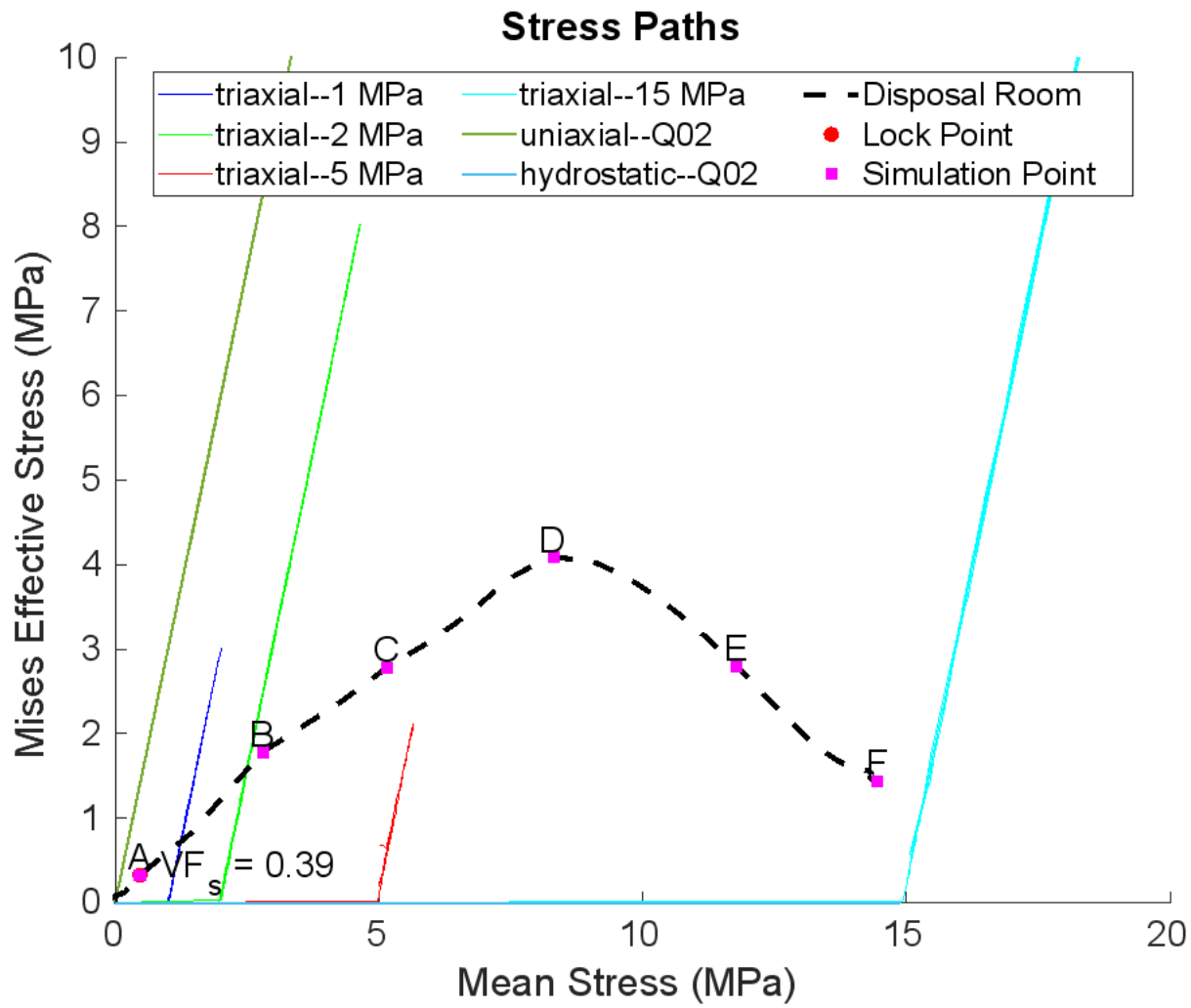


B. 120 yr

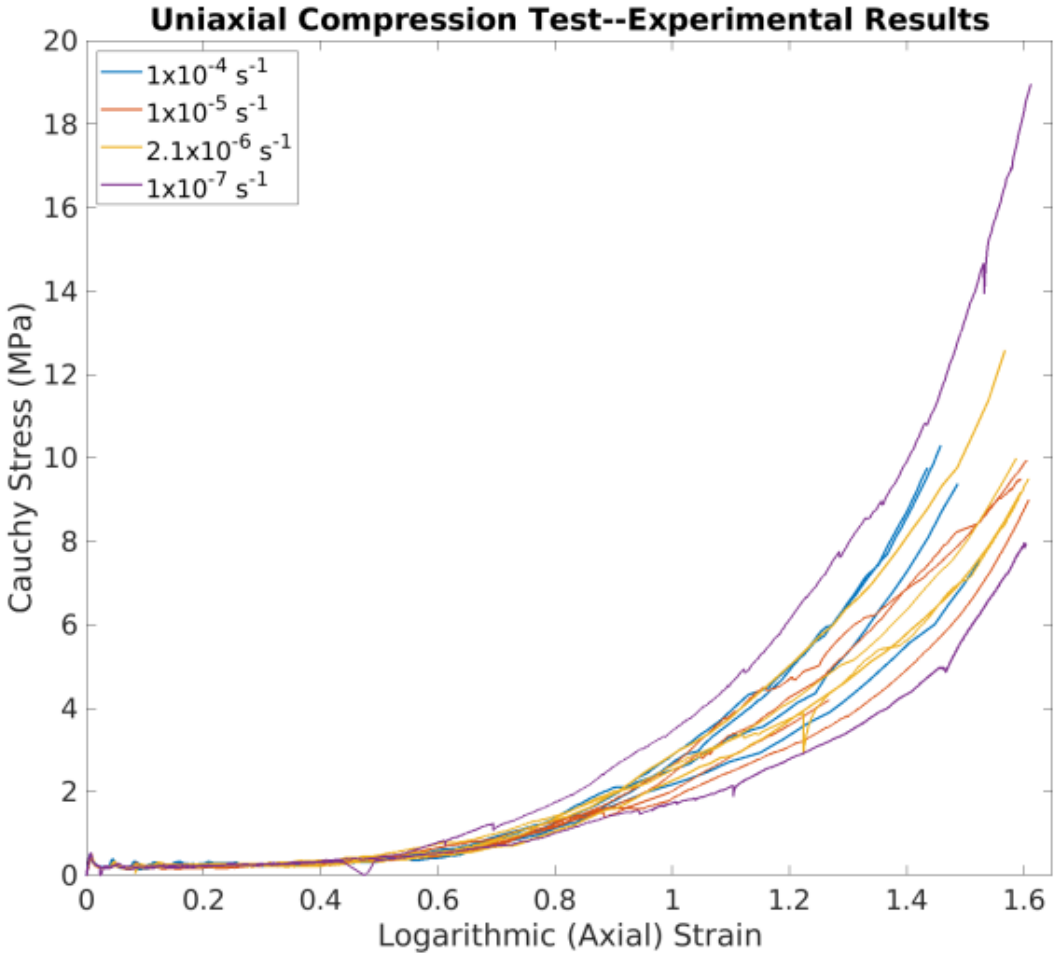


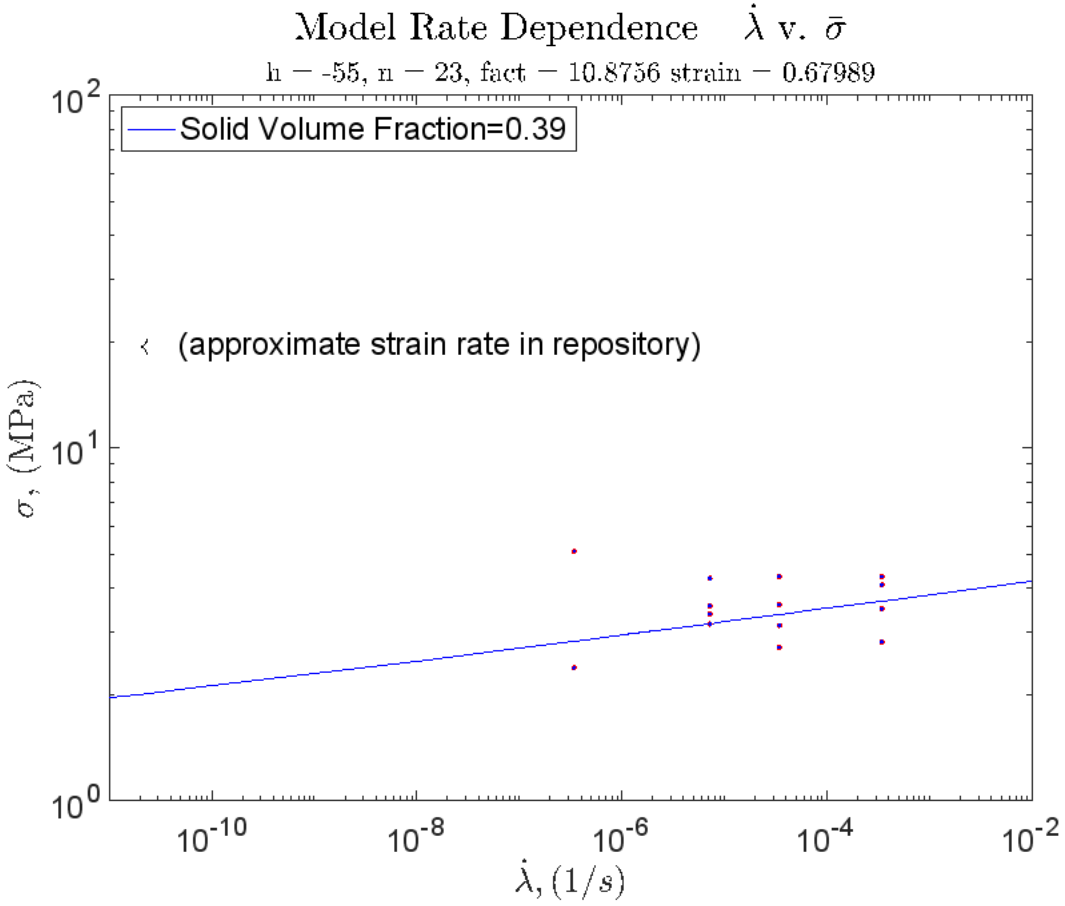
F. 10000 yr





# Strain Rate Dependence

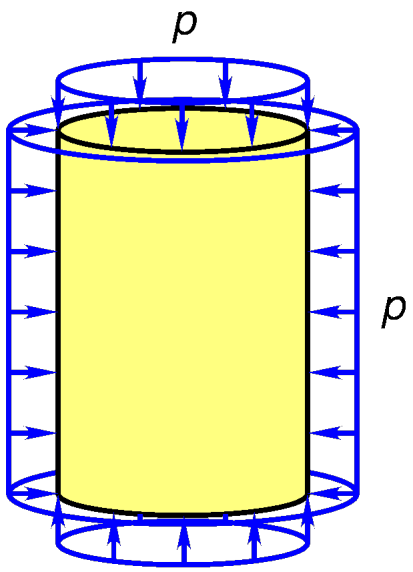


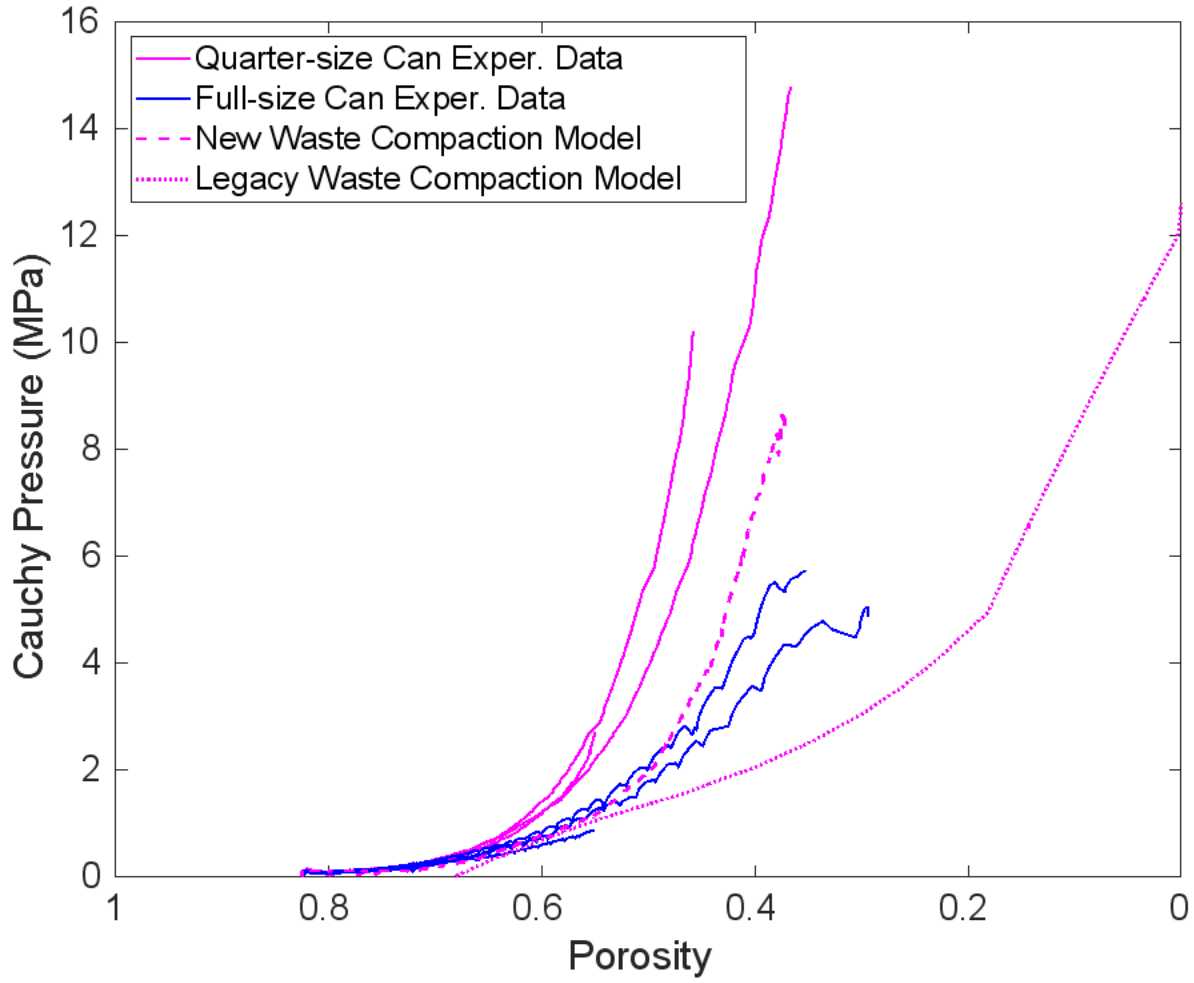



# Legacy vs. New Model Behavior

# Legacy vs. New Model: Hydrostatic Behavior

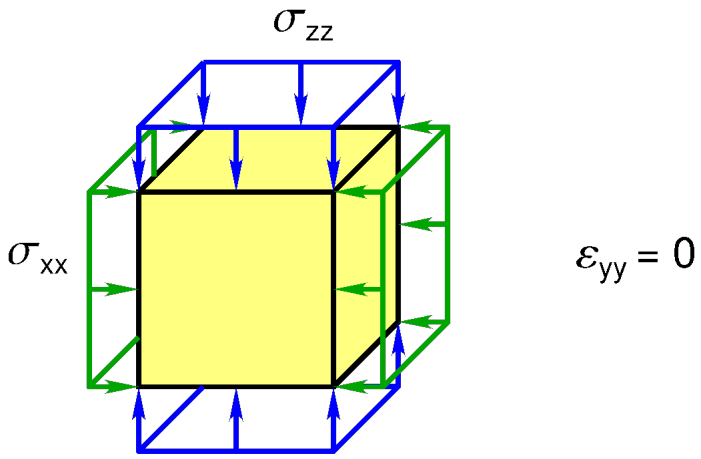
Hydrostatic Stress



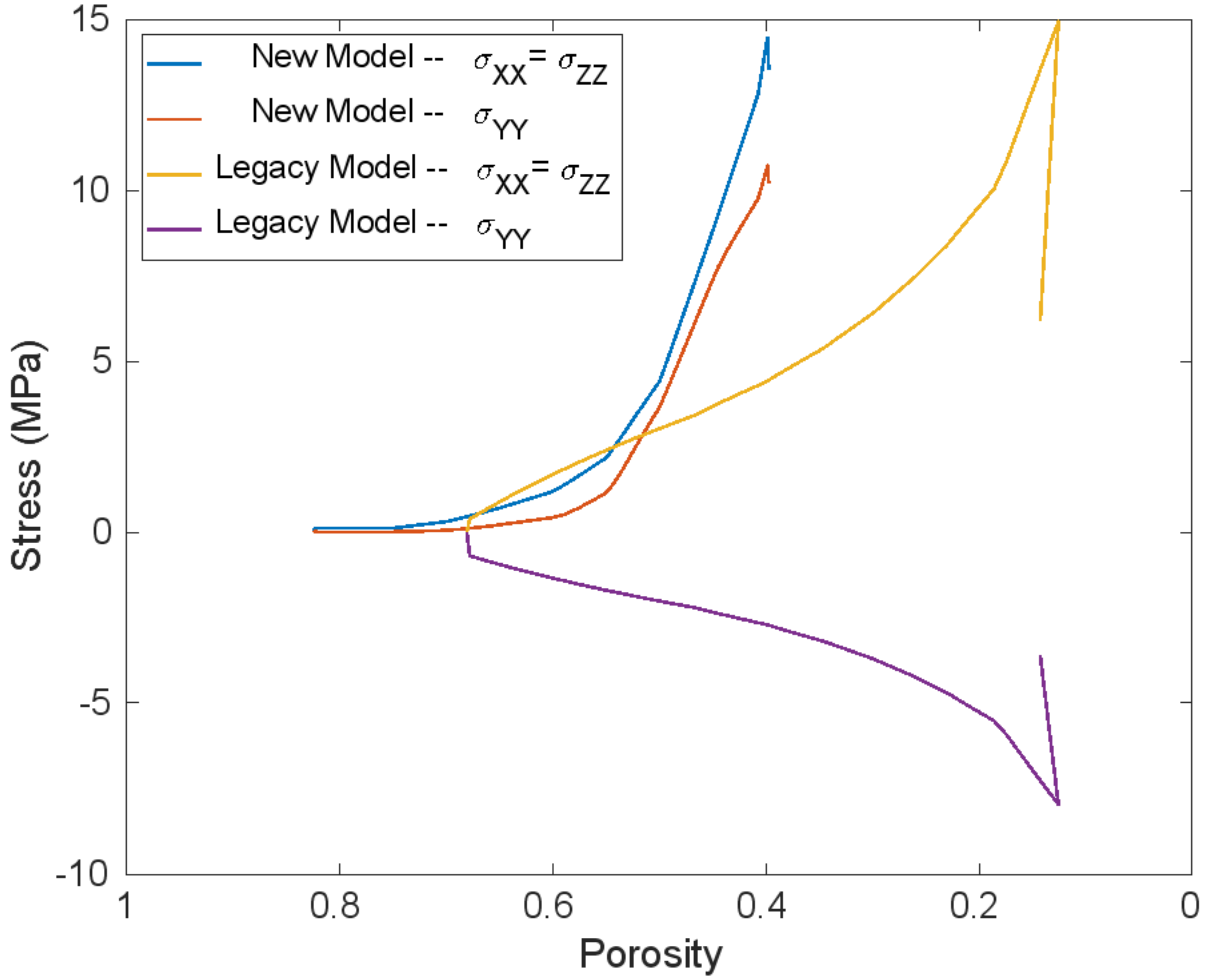



# Legacy vs. New Model: Plane Strain Behavior

Plane Strain




$\varepsilon_{yy} = 0$



# Summary

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1. Legacy model
    1. Assumes drums are 100 % full
    2. Produces overly compliant response due to dubious assumption of zero lateral stress in uniaxial strain tests used to calibrate model
    3. Predicts non-physical tensile stresses in out-of-plane direction in plane strain simulations
2. New Waste Compaction Tests
    1. Drums 66 % full
    2. Observed substantial lateral expansion as waste porosity decreased
3. Calibration of a New Waste Compaction Model
    1. Calibration focused on matching triaxial and hydrostatic behavior, which are more relevant for the long-term porosity of the disposal rooms than uniaxial stress.
    2. Lateral expansion calibrated to accelerate as porosity reduces
4. Legacy vs. New Model
    1. New model significantly stronger for the same porosity.
    2. New model predicts compressive stresses in the out-of-plane direction in plane strain simulations.