Towards image-based compaction forecasting: Comparison between laboratory experiments and X-ray CT images

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Outline

- Introduction
- Description of the study
- Testing apparatus and methods
- Tests results
- Image analysis
- Summary
Introduction

DRP as applied to rock mechanics

- Non linear response
- Hysteresis
- Significance?
- Stat/Dyn transform
- Behavior at grain contacts
- ...
Introduction

Compaction

- What constitutive law? exp, log, power, erf, elastoplastic, ..?
- Domains potentially impacted: Geomechanical forecasting, PP prediction, basin modeling, reservoir quality,..
- Most complex for DRP right now (brittle behavior at contacts, resolution, large strains, ..)
- Can we leverage the CT data in the mean time?
Description of the study

- Castlegate and Boise sandstones
- Experimental evaluation of compactive strength
- ~10 µm and ~4 µm CT scanning pre/post tests
- Parameter extraction from images and comparison with mechanical data

<table>
<thead>
<tr>
<th></th>
<th>Castlegate</th>
<th>Boise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity (%)</td>
<td>25-27</td>
<td>28-30</td>
</tr>
<tr>
<td>Mineralogy (%)</td>
<td>Qz (85) Cal+Dol (~10) Clay (~5)</td>
<td>Qz (45) F (45) Bio(5) Clay (~3)</td>
</tr>
</tbody>
</table>

Scoping tests — stress paths and strength envelope

- Mini plug (~8mm) CT scan
- Image analysis
- Full plug (1 in.) CT scan
- Uniaxial strain loading experiments
- Full plug post mortem CT scan

150 vx @ 3.5µm/vx  150 vx @ 4.3µm/vx
Tests conditions:

- 1in x 2in samples
- Water sat and measure of expelled pore fluid
- Axial ultrasonics (not shown)
- Pp of 5MPa throughout and Pc up to 45000 Psi
- Scoping with both strain gages and LVDT setups
- Triax, uniax strain and hydrostatic
Testing apparatus and methods

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Effective mean stress
$$P_{meff}=\frac{1}{3}(S_{ax}+2P_{c})-P_{p}$$

Differential stress
$$Q=S_{ax}-P_{c}$$
Results

Castlegate TRX

Axial strain (%)

Q (MPa)

Diff stress
AE rate
Results

Castlegate TRX

Q (MPa)

Axial strain (%)

Pceff=5MPa
Pceff=30MPa
Pceff=55MPa
Pceff=80MPa
Pceff=105MPa
Pceff=130MPa

Q (MPa)
Pmeff (MPa)

A01_TRX_135_5
A04_MTRX
CAS10A HYDRO
Results

Castlegate phi=25-27%

Boise phi=28-30%

P*=215MPa

P*=60MPa
Results

Wong et al., 2004

Castlegate

Boise
Image analysis

CASA2

Image porosity (%)

BS3

Image porosity (%)

CASA3

Image porosity (%)

Boise uniaxial strain (BS3)
Image analysis

Boise pre-test
Boise pre-test σ
Boise post-test
Boise post-test σ
Maximal inscribed sphere (MIS) algorithm

- Fast characterization without grain separation
- Grain and contact radius
- Demonstrate stress intensification

Segmented image  Pore space MIS  Framework MIS

Castlegate  Boise
Image analysis
Role of this ‘characteristic’ contact radius for elastic and mechanical properties? Similar to what pore entry radius is to flow?
Image analysis

A: average of MIS
B: average of MIS at BT
C: average of r^3 norm dist. at BT

Keulen et al., 2007 – Nojima Fault Zone
Image analysis

<table>
<thead>
<tr>
<th>Sample</th>
<th>( r_c ) (+4)</th>
<th>Rg MIS mean</th>
<th>Rg MIS mean BT</th>
<th>Rg r3 mean BT</th>
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<td>67</td>
<td>81</td>
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<tr>
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<td>61</td>
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Zhang-Wong model: Rg only

Critical Effective Pressure (P'), MPa
Assume similar porosities and mineralogy - **Target a 3.5 factor**…

Compute $r_c/R_g$ ratio and $r_c^2/R_g^3$ ratio to estimate potential contribution to strength.

$r_c^2/R_g^3$ leads to a substantial difference between Boise and Castlegate while keeping the scale sensitivity through $L^{-1}$.

$$P^* \propto \frac{r_c^2}{\phi R_g^3}$$

Taking the ‘weakest’ Boise volume:

$$\frac{P^*_C}{P^*_B} \sim 3.2$$
Ratio of grain contact surface area to grain volume helped accounting for strong differences in strength between Castlegate and Boise sandstones – Augmented the approach based on grain radius only

Relatively fast process for screening and detection of REV strength heterogeneities incl. anisotropy

Compaction modeling could be based on such distribution

The availability of the grain contact surface area allows incorporating shear at contacts for (1) further the modeling of the entire yield surface (2) connecting to elastic properties (compression and shear) – e.g. HS bounds
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