Micro-CT Dataset of Cemented Sand Specimens under Uniaxial Compression with Varying Cementation Degree

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Computed tomography (CT) is an X-ray–based imaging technique that enables high-resolution analysis of the internal structure of materials. During scanning, X-rays are attenuated while passing through the specimen (depending on density and composition), and a three-dimensional volume is reconstructed from multiple two-dimensional projections acquired at different rotation angles.

In this study, CT was used to investigate the microstructure of cemented sand specimens subjected to uniaxial loading, with a focus on identifying the spatial distribution of grains and cement binder as well as the pore structure. The resulting volumetric data support microstructural characterization and serve as input for subsequent numerical (FEM) modelling.

The dataset provides the raw, unprocessed CT image stacks as acquired. The CT data consist of reconstructed slice images (i.e., cross-sectional slices already reconstructed from the original projection views). The CT data were acquired at the 3SR Laboratory at Université Grenoble Alpes. Note that the first and last slices are typically not suitable for quantitative evaluation (e.g., due to boundary effects and reconstruction artefacts) and may be excluded during post-processing.

Sample preparation

Cemented sand specimens were prepared using Hamburg sand, Dyckerhoff MIKRODUR® R-U microcement, and tap water. The mixture proportions were determined in advance to achieve a dense packing state (target relative density) and a prescribed cementation degree by adjusting the cement suspension-to-sand ratio, while maintaining a water-to-cement ratio of $w/c = 1$. Cylindrical specimens were produced with a diameter of $d = 10$ mm and a height of $h = 20$ mm.

Mixing was performed in two stages: (i) dry sand and cement were first blended thoroughly until the grains were uniformly coated; (ii) water was then added and the mixture was mixed again until a homogeneous consistency was achieved.

Immediately after mixing, acrylic moulds were cleaned, lubricated on the inner walls (to facilitate demoulding), and sealed at the bottom with an inert latex membrane. The paste-sand mixture was filled into the mould in five equal-mass layers (each 20% of the total mass) and each layer was compacted with a flat tamper to ensure uniform density. To improve interlayer bonding, notches were introduced between layers (except for the final layer). The top surface was levelled to minimise geometric scatter. Curing started directly after mould filling by sealing the specimen surface with an inert latex membrane to prevent evaporation. Specimens remained in the sealed mould for the first 24 hours to gain sufficient early strength for safe demoulding. After extraction, specimens were stored under water for at least 28 days to continue cement hydration and strength development.

The sample preparation process is shown in the flowchart in figure 1. In this dataset, the degree of cementation is defined on a volumetric basis (see Fig. 1) and is therefore denoted as C_{vol} in the following, which differs from the conventional mass-based definition commonly used in the literature. The volumetric cementation degree is defined as the ratio of the grout volume (dry cement plus mixing water) to the total void volume of the sand skeleton ($C_{\mathrm{vol}} = V_c/V_v$).

As further reading, macroscopic triaxial test results for cemented sand with similar cementation degrees and an analogous specimen preparation procedure are presented in Sekulic et al. (2024).

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Input				
Mixing parameters:	Requested relative density	D_r	$(\%)$	70
	Water to cement weight ratio	W/C	$(-)$	1.0
	Cement suspension to sand weight ratio	W_{cem}	$(-)$	
Sample dimensions:	Diameter of sample	d	(mm)	10
	Height of sample	h	(mm)	20
	Volume of sample	V	(cm^3)	1.57
Soil parameters:	Grain density	ρ_s	(g/cm^3)	2.639
	Minimum dry density	$\rho_{d,min}$	(g/cm^3)	1.470
	Maximum dry density	$\rho_{d,max}$	(g/cm^3)	1.740
Cement suspension parameter:	Cement density	ρ_c	(g/cm^3)	2.9
	Water density	ρ_w	(g/cm^3)	1.0

↓

Material properties of the sand				
Minimum void ratio	e_{min}	=	$\rho_s/\rho_{d,max} - 1$	$(-)$
Maximum void ratio	e_{max}	=	$\rho_s/\rho_{d,min} - 1$	$(-)$
Void ratio	e	=	$e_{max} - D_r/100 \cdot (e_{max} - e_{min})$	$(-)$
Porosity	n	=	$e/(1+e)$	$(-)$
Volume of voids	V_v	=	$n \cdot V$	(cm^3)
Volume of grains	V_s	=	V_v/e	(cm^3)
Dry specimen weight	m_d	=	$\rho_s \cdot V_s$	(g)
Dry specimen density	ρ_d	=	m_d/V	(g/cm^3)

↓

Material properties of the cement paste				
Total mass of cement to be added	m_c	=	$m_d \cdot W_{cem} \cdot 1/100$	(g)
Total mass of water to be added	m_w	=	$m_c \cdot W/C$	(g)
Total volume of cement to be added	V_c	=	m_c/ρ_c	(cm^3)
Total volume of water to be added	V_w	=	m_w/ρ_w	(cm^3)
General degree of void saturation	C_{vol}	=	$(V_c+V_w)/V_v \cdot 100$	$(\%)$

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Nominal sample weight according to the requested values: D_r | W_{cem} | W/C
$m = m_d + m_c + m_w$ (g)

Figure 1: Sample preparation process

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CT scanning procedure (in-situ uniaxial compression)

The cemented sand specimen was scanned in an in-situ uniaxial compression setup inside the CT scanner (see Fig. 2). Prior to installation, a thin silicone layer was applied to the top and bottom specimen faces to reduce boundary friction and edge effects and to avoid influencing the localization zone.
As illustrated in Fig. 2, the specimen was placed on the specimen holder, the load transfer caps were mounted, and a neoprene membrane was pulled over the specimen. The assembled specimen was then inserted into the plexiglass cell while ensuring that the piston was correctly positioned to prevent unintended contact. After fastening the specimen holder to the cell, the piston was brought into contact with the specimen by applying a small preload (e.g., 5 N) to ensure stable positioning. The contact condition could be verified using the activated X-ray beam.
Before the first scan, the CT scanner was warmed up using a protective cap in front of the X-ray beam to avoid degrading beam quality during warm-up. Subsequently, a black calibration was performed (required prior to the first scan). A gain calibration was then conducted by moving the specimen out of the beam so that only the detector was irradiated. This calibration step was repeated until a homogeneous detector image was obtained in order to mitigate ghosting artefacts. After completion, the specimen was repositioned between source and detector and the scan was started.

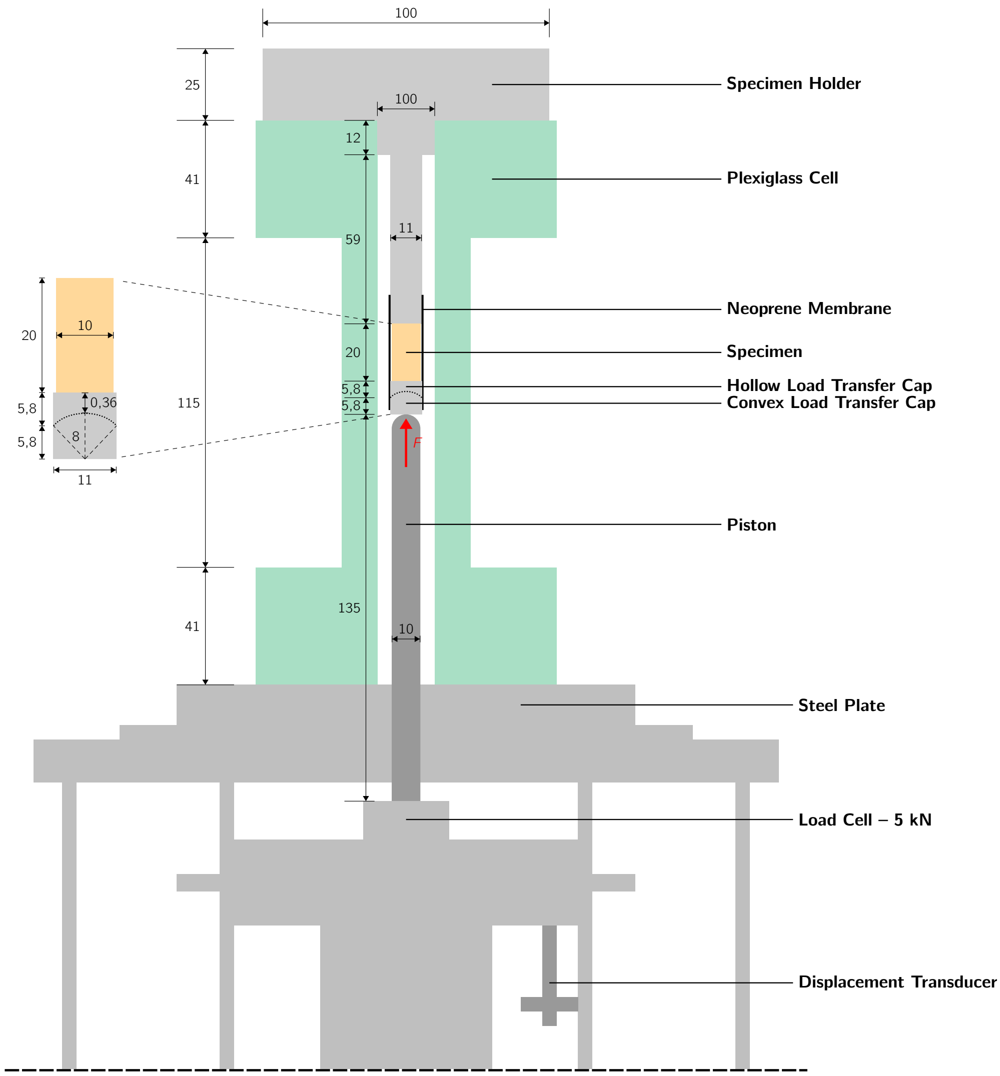

Figure 2: Sketch of the loading frame for uniaxial compression tests with the specimen installed with lengths in mm and angles in degree, adapted from Stamati (2020)

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The scan settings were kept constant for all scans:

- X-ray tube: $P = 9.6$ W, $U = 120$ kV, $I = 80$ μA
- Filter: aluminium, 0.5 mm
- Imaging: mode (`1x1 0.5pF VG1`), frame rate 1.5 fps, image averaging $n = 7$
- Reconstruction resolution: voxel size 13 μm
- Scan duration: approximately 2 hours per scan
- Sample size: height 20 mm, diameter 10 mm, 1700 slices

To capture microstructural changes during loading, five scans were acquired at predefined axial strain levels:

1. $\varepsilon = 0\%$ (unloaded reference state),
2. $\varepsilon \approx 1\%$ (linear-elastic regime),
3. $\varepsilon \approx 2\%$ (peak stress),
4. $\varepsilon \approx 3\%$ (post-peak stress drop),
5. $\varepsilon \approx 5\%$ (residual stress / final state).

At each scan point, the mechanical loading was interrupted and the specimen was allowed to relax for 10 minutes to dissipate stresses and prevent motion during scanning. In parallel, the scanner was moved to the calibration position and a gain calibration was performed. Once relaxation and calibration were complete and no specimen movement was observed, the scanner was returned to the scan position and the next scan was started. This sequence was repeated until all five scans were completed. For one scan ($C_{\text{vol}} = 30\%$) only four loading stages were scanned.

Quantitative results

In the following Figure 3, the quantitative results of the CT scans acquired during uniaxial loading are shown as a stress–strain diagram.

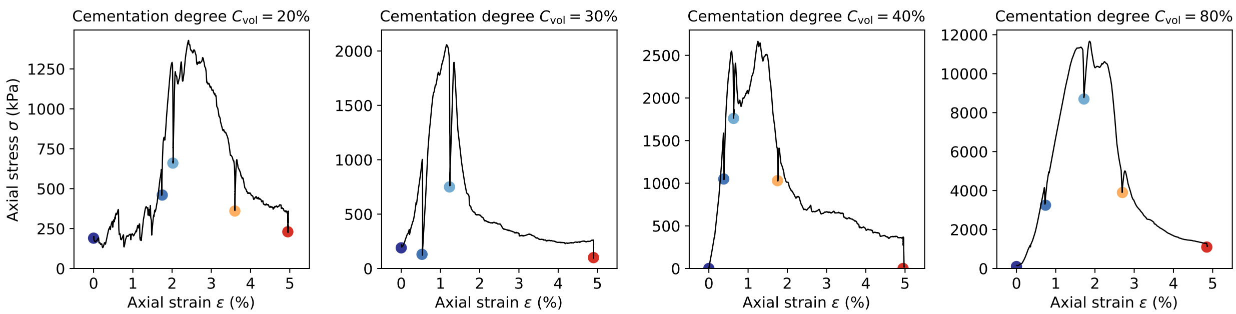

Figure 3: Stress–strain curves for different cementation degrees under uniaxial compression

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List of Files

The dataset includes the following items:

- $\mathbf{C}_{\text{vol}} = \mathbf{20}\%$: five TIFF image stacks each with 1700 slices
  - `SlicesY-20_0`: reference state (unloaded, $\varepsilon \approx 0\%$)
  - `SlicesY-20_1`: subsequent loading stage 1
  - `SlicesY-20_2`: subsequent loading stage 2
  - `SlicesY-20_3`: subsequent loading stage 3
  - `SlicesY-20_4`: subsequent loading stage 4
- $\mathbf{C}_{\text{vol}} = \mathbf{30}\%$: four TIFF image stacks (same naming convention: `SlicesY-30_0` = reference state; `SlicesY-30_1`–`SlicesY-30_4` = subsequent loading stages)
- $\mathbf{C}_{\text{vol}} = \mathbf{40}\%$: five TIFF image stacks (same naming convention: `SlicesY-40_0` = reference state; `SlicesY-40_1`–`SlicesY-40_3` = subsequent loading stages)
- $\mathbf{C}_{\text{vol}} = \mathbf{80}\%$: five TIFF image stacks (same naming convention: `SlicesY-80_0` = reference state; `SlicesY-80_1`–`SlicesY-80_4` = subsequent loading stages)

References

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