The influence of microscopic parameters on deformation properties of rockfill materials

Jie Yang	TU Xi'an, China
Zenz Gerald	TU Graz, Austria
Chunhui Ma	Ph.D. student in TU Xi'an, China Guest researcher in TU Graz, Austria

Relation research results:

- Yang Jie, **Ma Chunhui**, Cheng Lin, et al. Calibration model for discrete element mesoscopic parameters of rockfill based on QGA-SVM. Advances in Science and Technology of Water Resources 2018,38(05):53-58+75. (in Chinese)
- **Chunhui Ma**, Zenz Gerald, Edwin Josef Staudacher, et al. The influence of microscopic parameters on deformation properties of rockfill materials, 15th International Benchmark Workshop on Numerical Analysis of Dams (in press)
- **Chunhui Ma**, Jie Yang, Zenz Gerald, et al. Study on calibration method of micro-parameters of rockfill based on its macro-parameters of constitutive model (submitting)

Supporter:

- The Key projects of natural science basic research program of Shaanxi province (Grant No. 2018JZ5010) ,
- The Water Science Plan Project of Shaanxi Province (Grant No. 2018SLKJ-5) ,
- Study on ultimate seismic capacity of high arch dam considering material and contact double nonlinearity province (Grant No. 51809212) ,
- Comprehensive Evaluation of Safety Appraisal of Shibianyu bast-fill dam in Xi'an City, Shaanxi Province

1. Why we do this and our route

1

Engineering measures

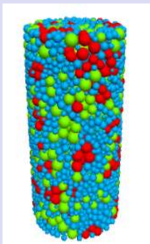
Application in rockfill tailings slop or dam

- Slope or dam stability
- A rock stone

2

Large-scale triaxial test

Refined simulation

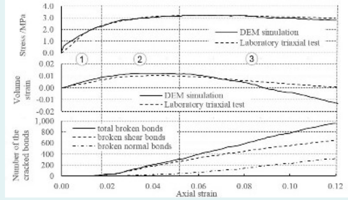


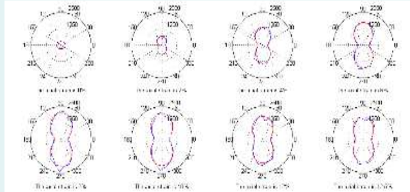
		Stiffness model		Slip model	Bond model	
		k_n	k_s	μ	b_n	b_s
Initial slope		↑↑		↑		
Peak	Volumetric strain	↑	↑	↑↑	↑	↑
	Axial strain	↓			↑	↓
Curve fluctuation after peak				↑		
Initial slope						
Peak	Volumetric strain	↓		↑↑	↑	↓
	Axial strain	↓				
Curve fluctuation after peak			↑	↑	↑	↓
broke normal bonds		↑↑			↓	
broke shear bonds		↑	↑			↓

Qualitative analysis the influence of micro-parameters

$$k_n, k_s, \mu, b_n, b_s$$

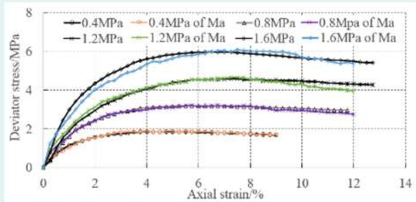
3





Microscopic mechanic behavior analysis

- Braken cluster analysis
- Microscopic Fabric analysis
- Engray analysis



Quantitative analysis the influence and calibration

- Curves
- Constitutive model
- Monitoring data

2. Introduction

Authors	Object	Research content
Zhou et al.	Size effects	The size effect under high confining pressure is significant.
Zhu et al.	Relative density	The porosity simulated by the relative density is feasible
Zhou et al.	Qualitatively analysis	The true triaxial test simulation of crushable granular materials and analyzed the correlation between microscopic parameters
Yang et al.	Quantitative analysis	Quantitative between microscopic parameters, young's modulus and Poisson's ratio of the rock parallel bonded model.
Yoon	Calibration	Experimental design and optimization in uniaxial compression simulation for calibrating contact-bonded particle models.
Xu et al.	Quantitative analysis	A set of empirical formulas to describe the correlation between macroscopic and microscopic elastic constants of sand material.
Zhao et al.	Qualitatively and quantitatively	Systematically the influence of microscopic parameters on the parallel bonded model, and the formulas between microscopic and macroscopic properties
Xu et al.	Qualitatively analysis	The creep and stress relaxation behavior of crushable granular material,
Li et al.	Quantitative analysis	The response surface function between the deformation data and the microscopic parameters of rockfill
……	……	……

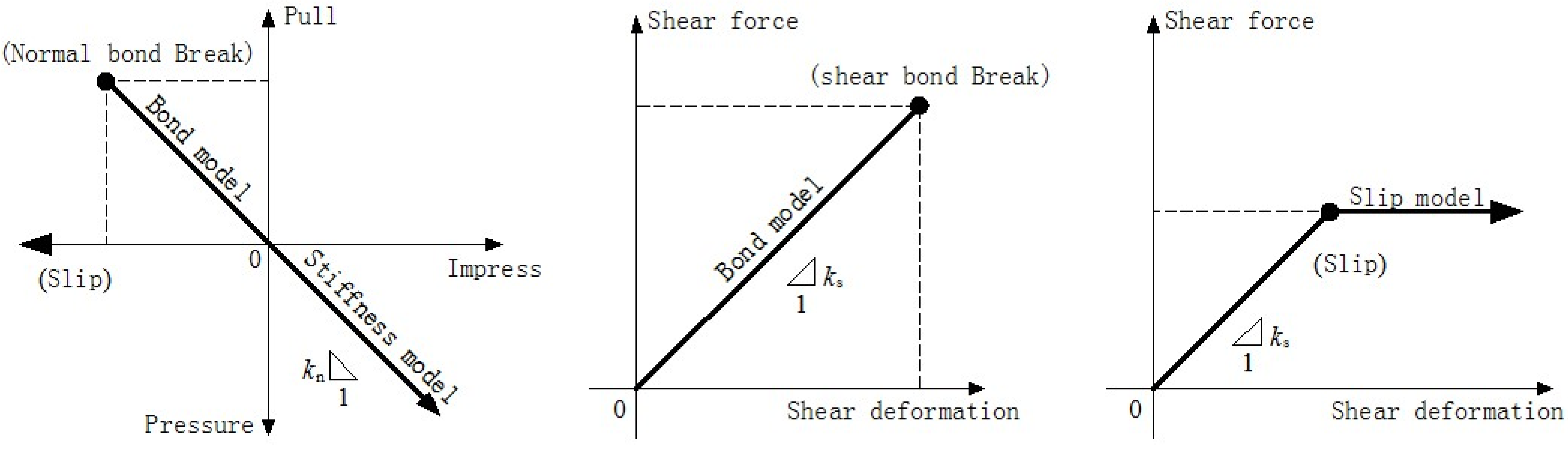
They are hard to apply to the microscopic simulation of rockfill materials directly.

- Brittle materials, such as rock and concrete, rockfill no specific damage
- Macroscopic behavior by using the Mohr Coulomb strength criterion, no the deformation property curves

3. Influence of microscopic parameters

3,1 Triaxial sample of Discrete element method (DEM)

- The contact model is the core principle in particle flow method
- For rockfill, the contact bond model was introduced to simulate breakage of rockfill



(a) **Normal force versus surface gap** (b) **Shear force versus surface gap** (c) Slip model

Microscopic Parameters

- Normal stiffness k_n
- Shear stiffness k_s
- Friction coefficient μ
- Normal bond strength b_n
- Shear bond strength b_s

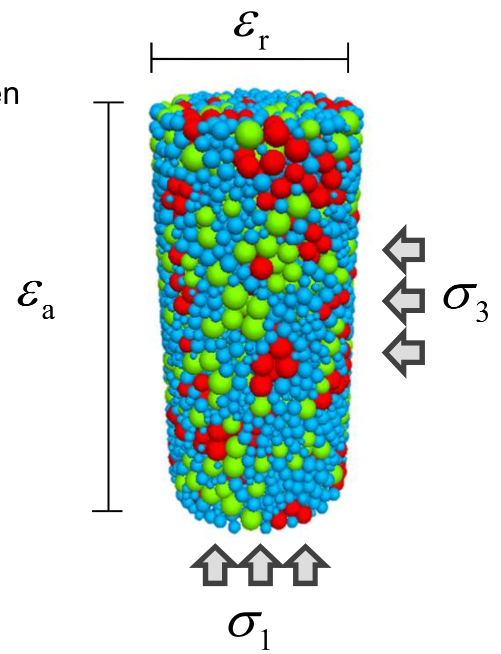
3,1 Triaxial sample of Discrete element method(DEM)

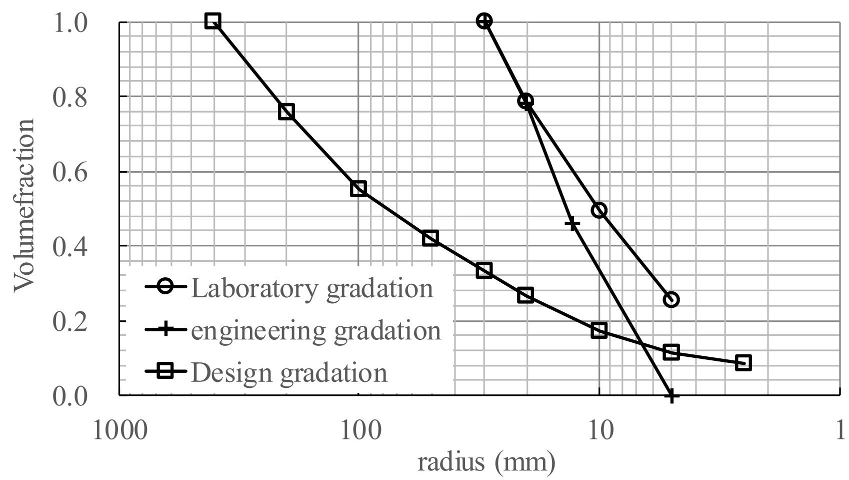
The particle size gradation and its laboratory triaxial test results of rockfill material from the Sujiahekou dam is adapted from Shao Lei

——Shao, L., Chi, S.C., Zhou, L.J. and Wang, Y.Z. (2013). Discrete element simulation of crushable rockfill materials, Water Science and Engineering, Vol.6 No.2 pp.215-229.

The triaxial test specimen

$$\varepsilon_v = \varepsilon_a - 2\varepsilon_r$$





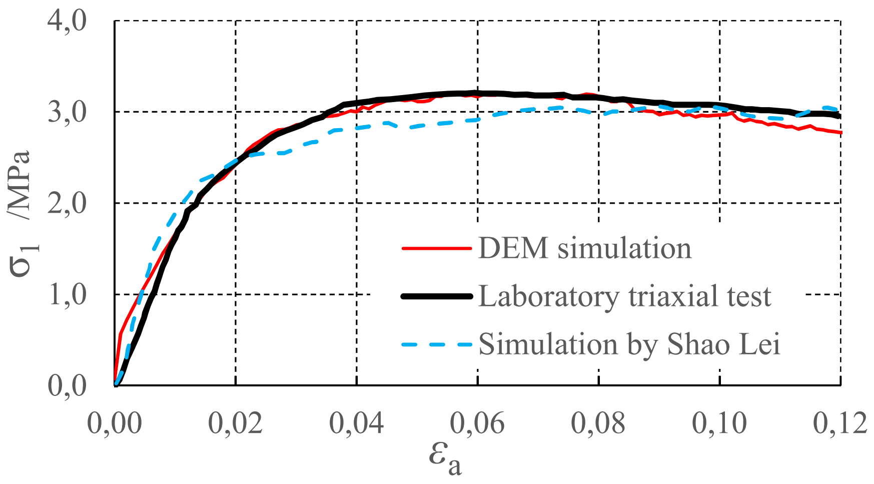
Gradation curves of rockfill materials

Φ300 × 650 mm	**0.40**	**5026**	**508**	**0.15 m/s**	**800 kPa**
Specimen size	Initial porosity ratio	Total balls	Clusters	Movement speed	Confining pressure

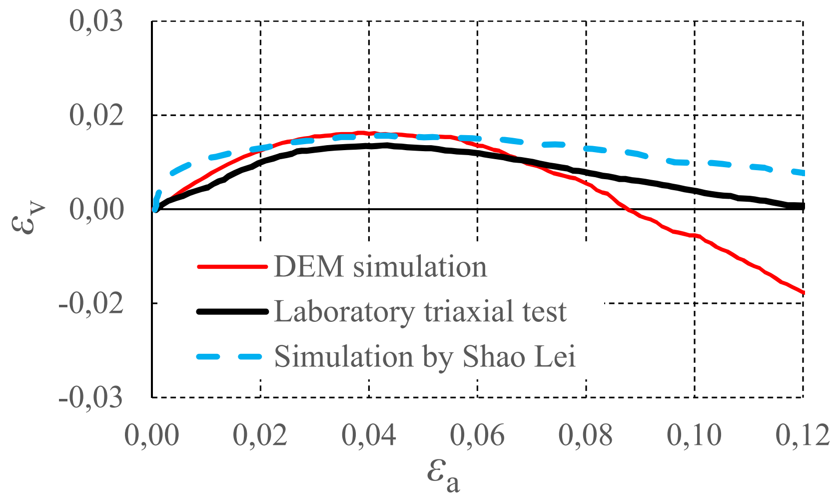
3,1 Triaxial sample of DEM

Normal stiffness	Shear stiffness	Friction coefficient
k_n=3.5 MN/m	k_s=2.6 MN/m	μ=0.09

Normal bond strength	Shear bond strength
b_n=2.2 kN	b_s=1.6 kN



（a）**stress against axial strain**



（b）**volumetric against axial strain**

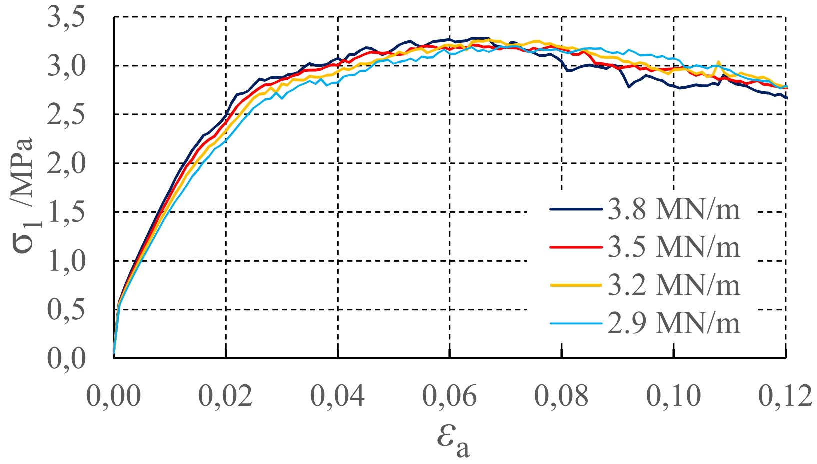
- DEM simulation has good fitting precision
- The simulation of breakage particle still has a narrow gap in the actual situation.

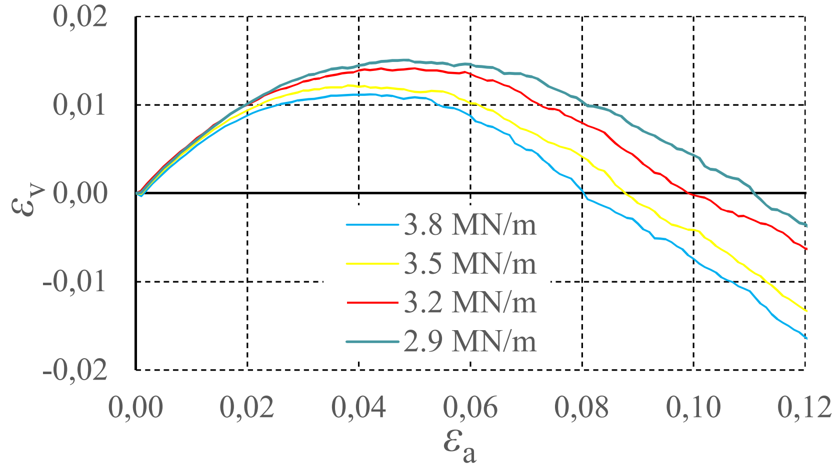
3,2 Normal stiffness k_n

To analyze the effect of microscopic parameters on deformation properties of rockfill materials in triaxial test simulation, a control variable method is adapted to determine the influence on stress-strain and volumetric strain curves.

Stress-strain curve		
Initial slope	Peak	
	Axial stress	Axial strain
↑↑	↑	↓

Volumetric strain curve		
Initial slope	Peak	
	Vol strain	Axial strain
	↓	↓





Higher stress to produce the same strain	The peak reach at less strain

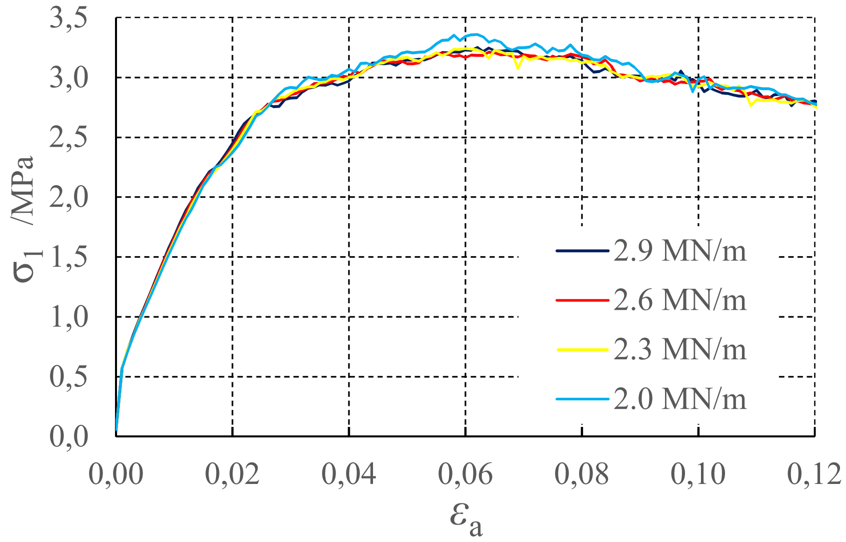
The axial strain of the triaxial sample will decrease under the same loading, so the peak value of the volumetric strain decreases

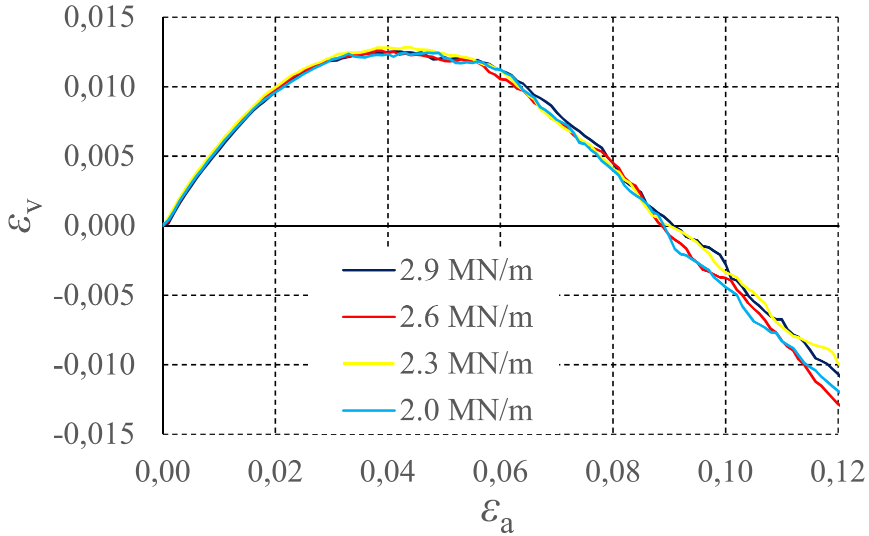
$$\varepsilon_v = \varepsilon_a - 2\varepsilon_r$$

3,2 Shear stiffness k_s

Stress-strain curve		
Initial slope	Peak	
	Axial stress	Axial strain

Volumetric strain curve		
Initial slope	Peak	
	Vol strain	Axial strain





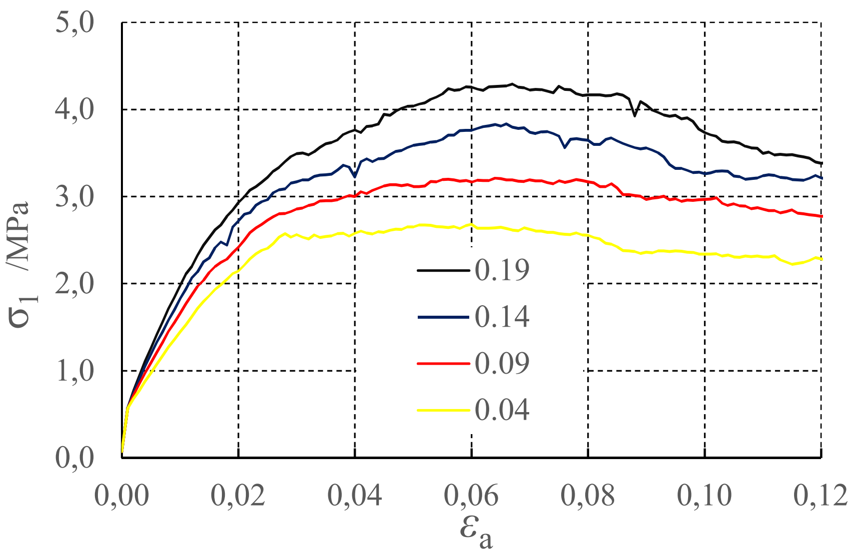
Compared with the normal stiffness, the shear stiffness is very limited on the deformation properties curve

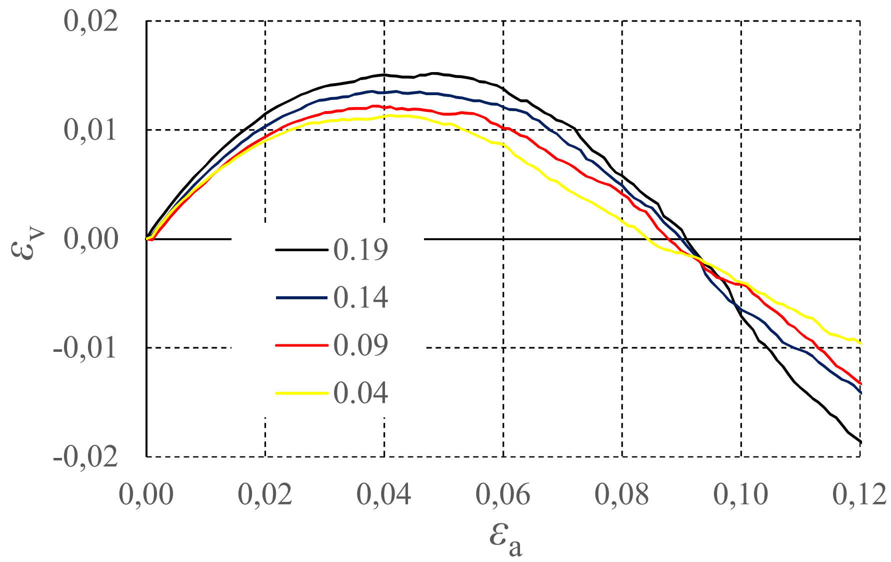
A certain fluctuation effect after the dilatancy in the volumetric strain curve

3,2 Friction coefficient μ

Stress-strain curve		
Initial slope	Peak	
	Axial stress	Axial strain
↑	↑↑	

Volumetric strain curve		
Initial slope	Peak	
	Vol strain	Axial strain
	↑↑	





The slip of the particles and the radial deformation of the triaxial test samples are limited, and therefore the resistance against deformation has increased

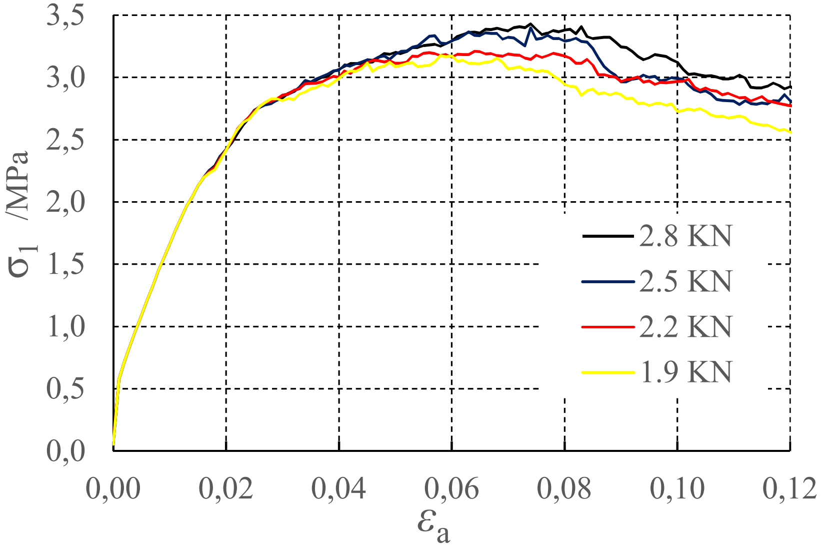
The radial deformation of the triaxial sample is reduced

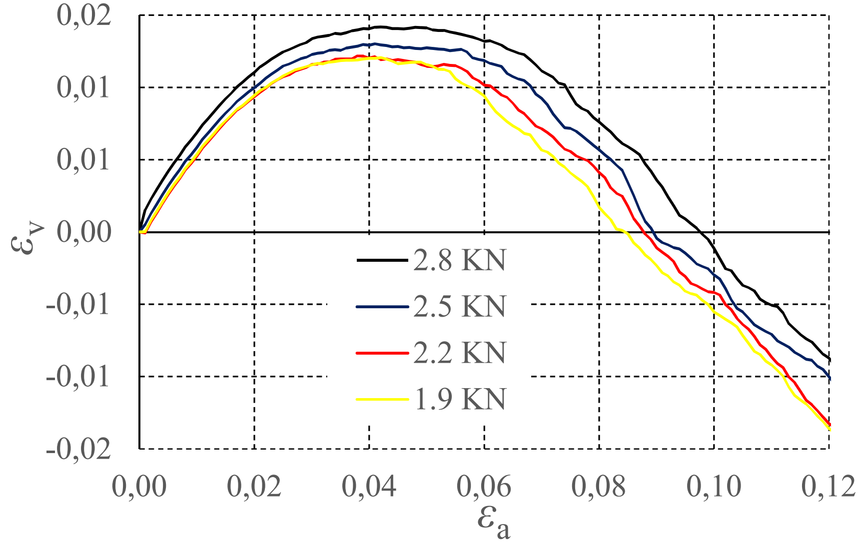
$$\varepsilon_{\mathrm{v}} = \varepsilon_{\mathrm{a}} - 2\varepsilon_{\mathrm{r}}$$

3,2 Normal bond strength b_n

Stress-strain curve		
Initial slope	Peak	
	Axial stress	Axial strain
	↑	↑

Volumetric strain curve		
Initial slope	Peak	
	Vol strain	Axial strain
	↑	





As the normal bond strength increases, the peak value and its axial strain increases.

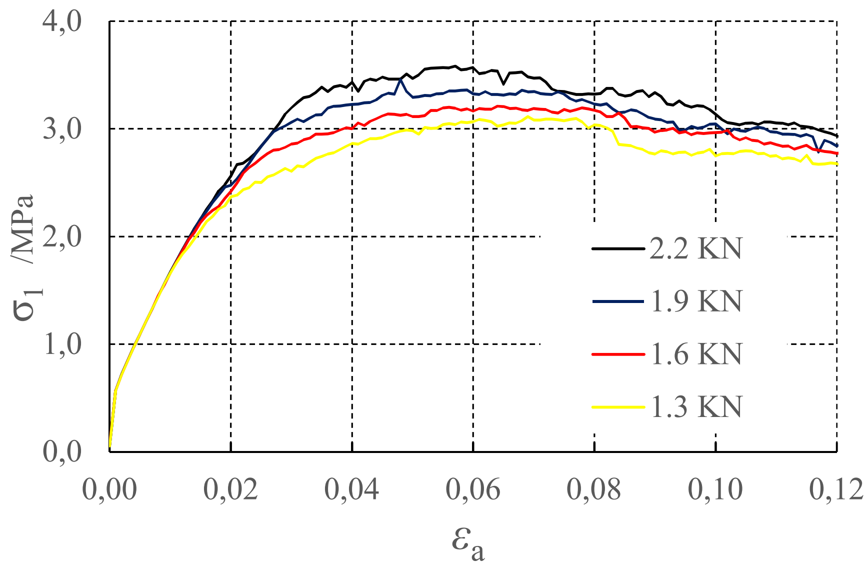
The axial deformation capacity expands with the increase in the normal bond strength.

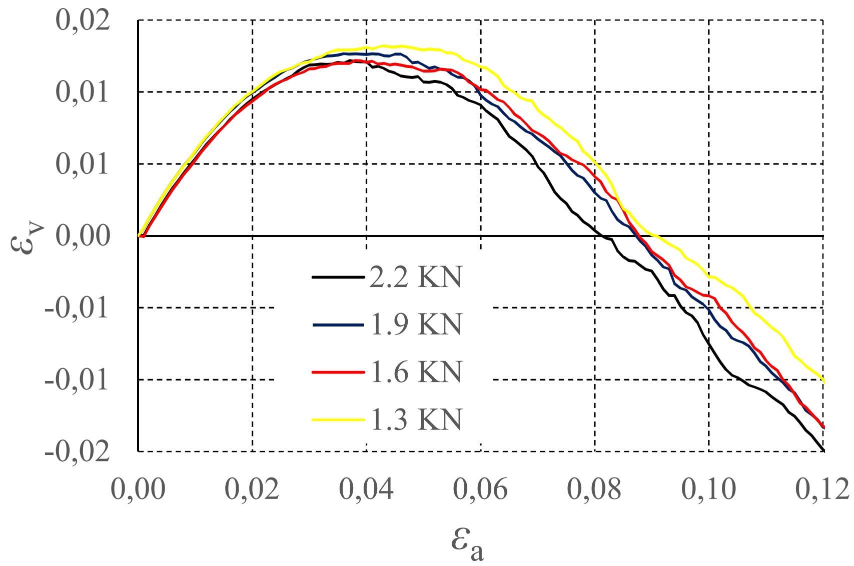
$$\varepsilon_v = \varepsilon_a - 2\varepsilon_r$$

3,2 Shear bond strength b_s

Stress-strain curve		
Initial slope	Peak	
	Axial stress	Axial strain
	↑	↓

Volumetric strain curve		
Initial slope	Peak	
	Vol strain	Axial strain
	↓	





The influence of shear bond strength appeared earlier, indicating that the damage of the shear bond was initiated at lower strains.

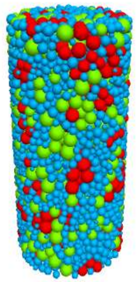
The peak value of the Volumetric strain curve decreases

$$\varepsilon_v = \varepsilon_a - 2\varepsilon_r$$

3,2 Microscopic parameters k_n, k_s, μ, b_n, b_s

- complex nonlinear relationship
- There is a possibility that the abovementioned laws are needed the sensitivity analysis, because one of the microscopic parameters exceeds its range too much

The influence of microscopic parameters on deformation properties of rockfill materials



			Stiffness model		Slip model	Bond model	
			k_n	k_s	μ	b_n	b_s
Stress-strain curve	Initial slope		↑↑		↑		
	Peak	Axial stress	↑		↑↑	↑	↑
		Axial strain	↓			↑	↓
	Curve fluctuation after peak				↑		
Volumetric strain curve	Initial slope						
	Peak	Volumetric strain	↓		↑↑	↑	↓
		Axial strain	↓				
	Curve fluctuation after peak			↑	↑	↑	↓
broke bonds	broke normal bonds		↑↑			↓	
	broke shear bonds		↑	↑			↓

4. Influence of broke bond

Normal stiffness k_n=3.5 MN/m

Shear stiffness k_s=2.6 MN/m

Friction coefficient μ=0.09

Normal bond strength b_n=2.2 kN

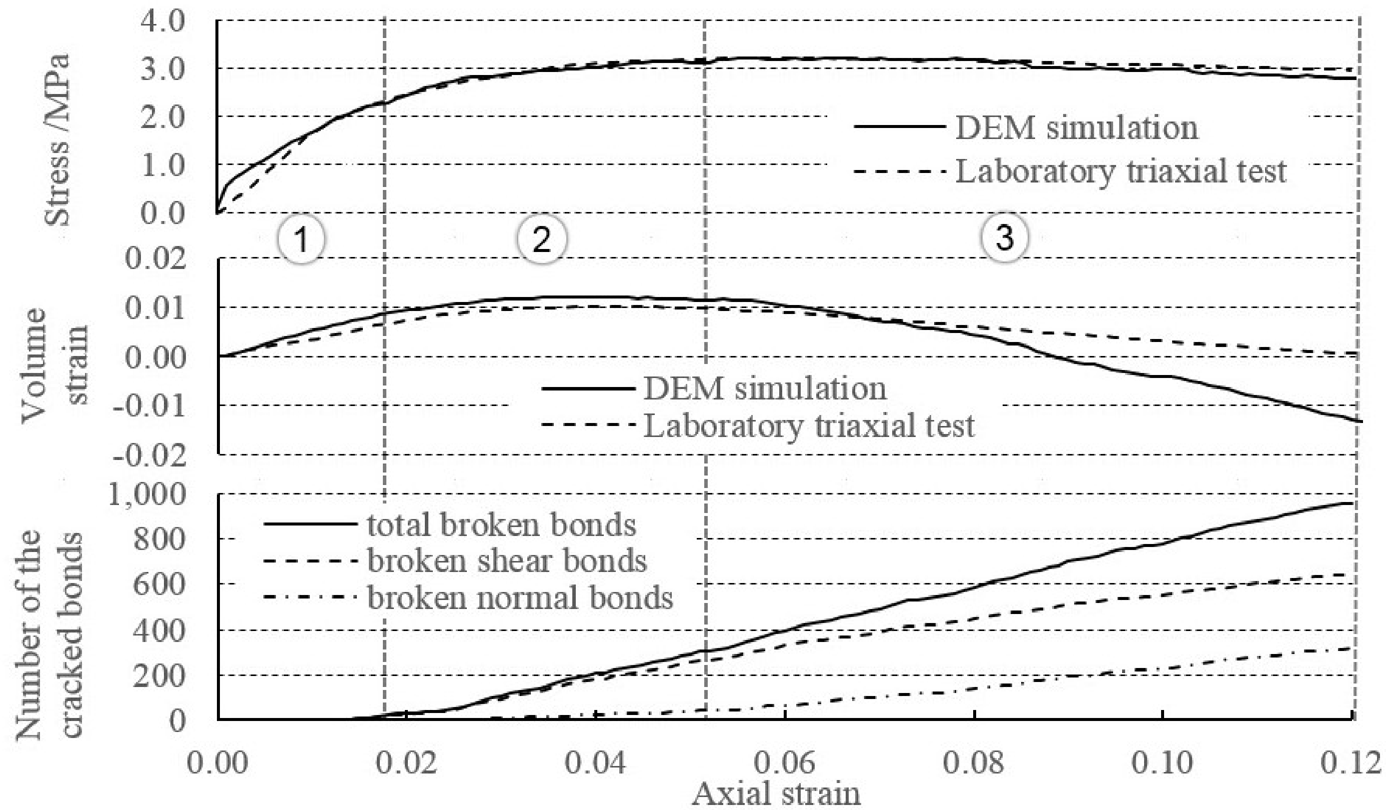
Shear bond strength b_s=1.6 kN

Stage:	Elastic	Transitional	Plastic
Affected by:	Stiffness	Friction coefficient	Bond strength

The stress-strain curve will remain or fall

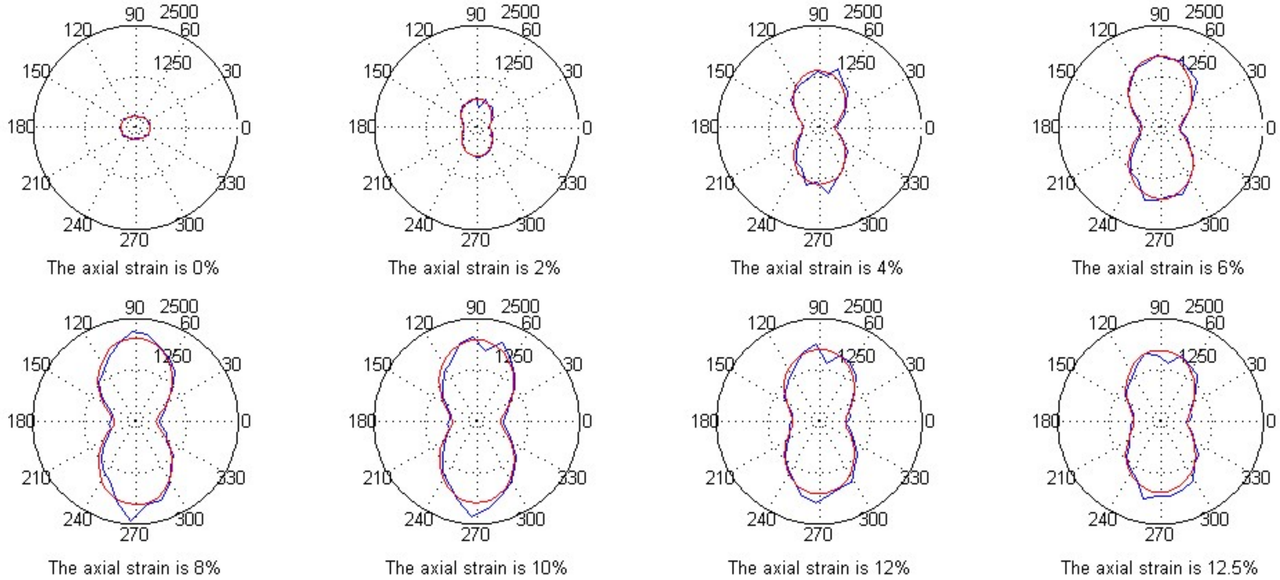
The volumetric strain curve begins to fall

A large number of stable particles will break and slip

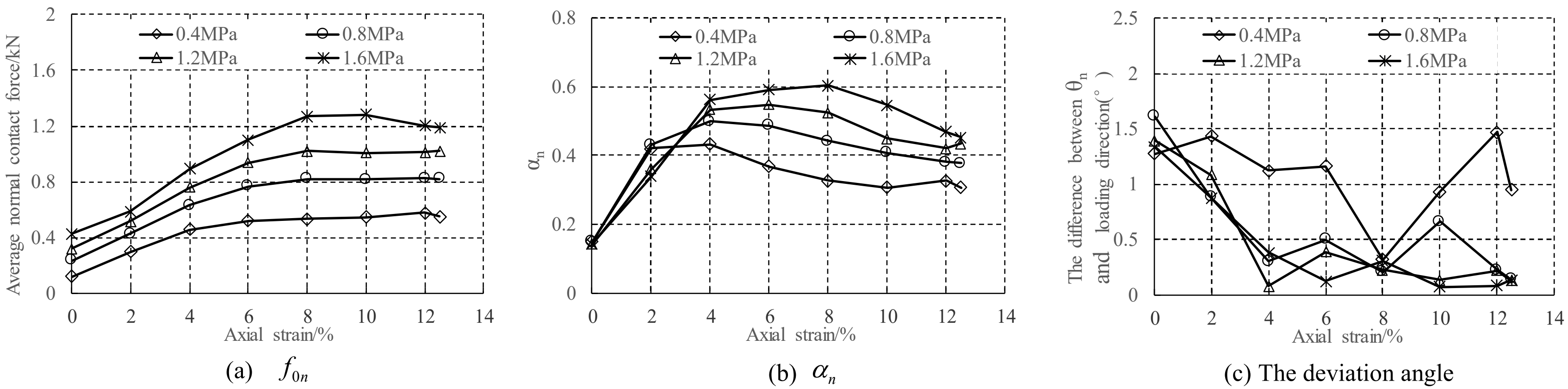


There is a close relationship between the breakage particle and the macroscopic mechanical behavior of rockfill. The macroscopic parameters have a noticeable influence on the break of the particles.

5. Further research



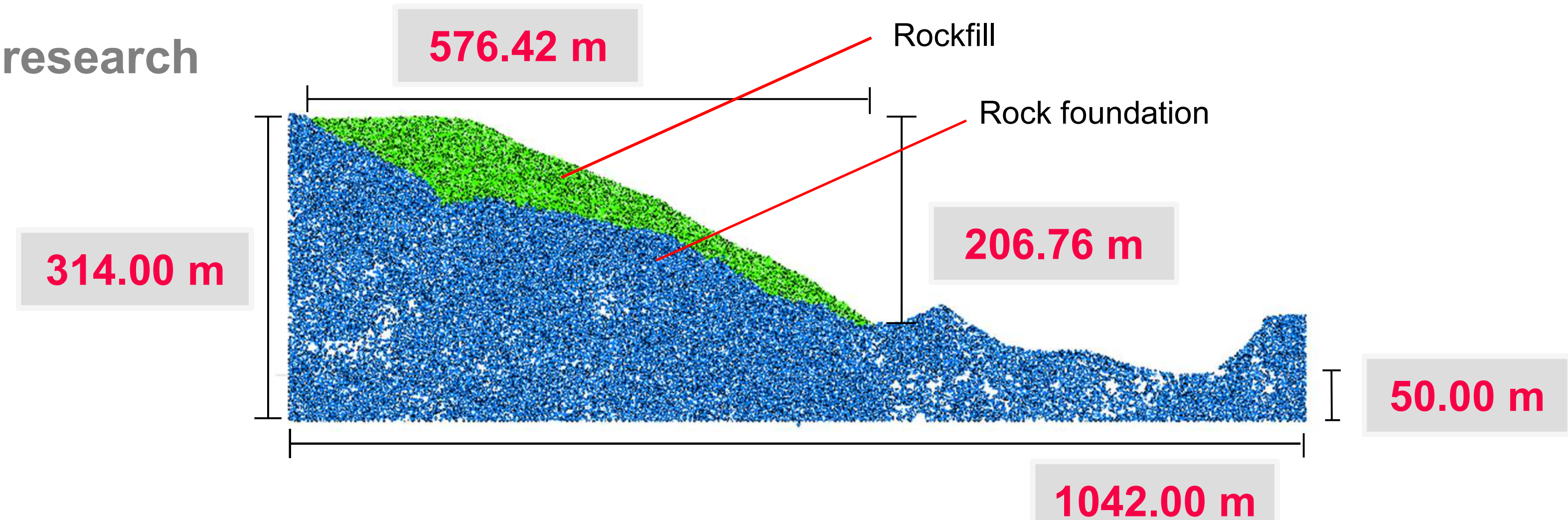
Distribution of the average normal contact force under 1.6MPa confining pressure



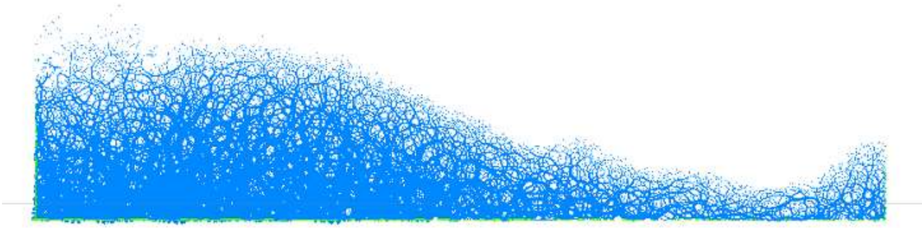
(a) f_{0n} (b) α_n (c) The deviation angle

The change of fabric parameters of normal contact force under different confining pressures

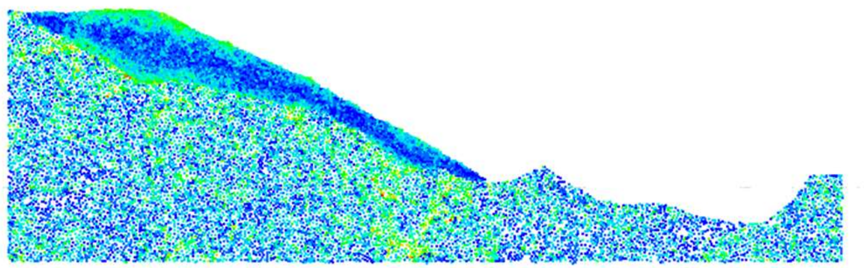
5. Further research



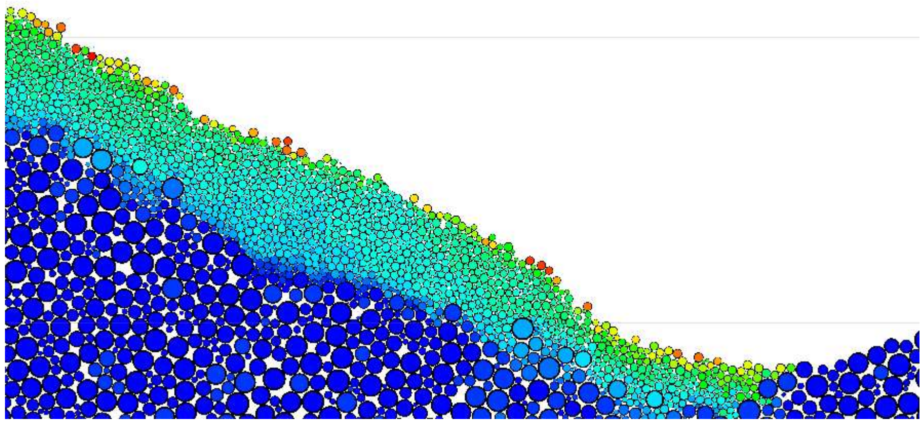
The geometry of rockfill tailing slop



The force chain in the initial stage



The slip surface of rockfill tailing slop



Rockfall in the slop