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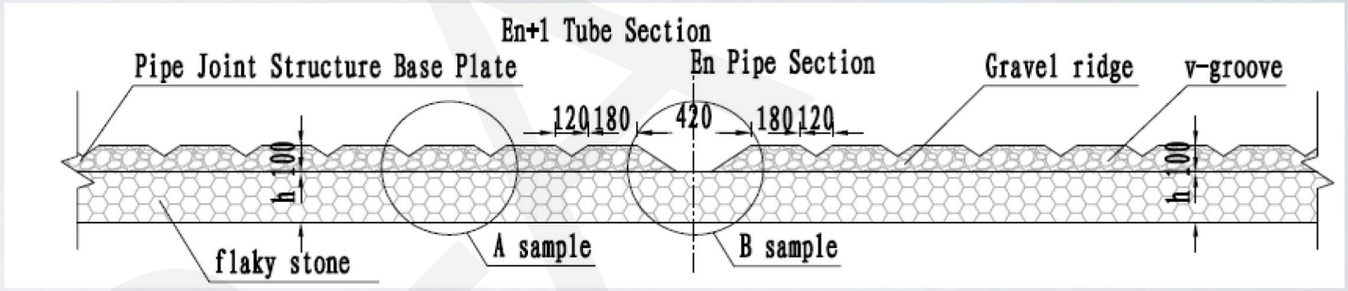
Experimental study on the mechanical behavior and deformation characteristics of gravel cushion in an immersed tube tunnel

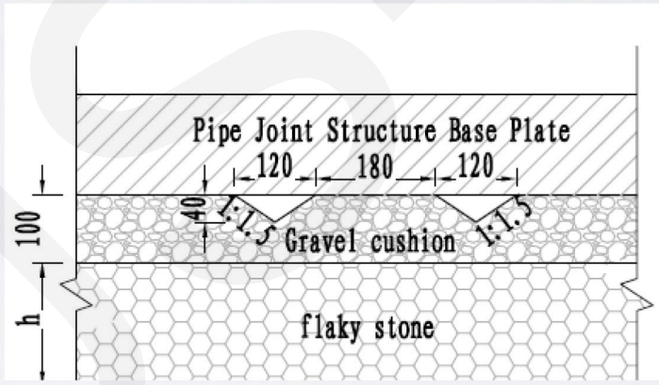
Key words:

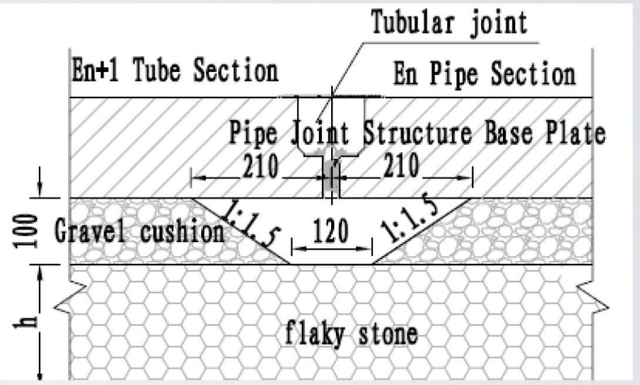
Immersed tube tunnel; Gravel cushion; Model experiment; Deformation characteristics

Research background

The immersed tube tunnel section of the ShenZhong Link exhibits complex geological conditions and high back sludge strength, the selection of the tunnel cushion layer should not only consider the flatness of the foundation but should also ensure the capacity of the cushion to hold silt. The design of the gravel cushion in the ShenZhong Link immersed tube tunnel includes a two-layer structure. The upper layer is a 1 m-thick gravel cushion, and the lower layer is a 0.7 m-thick flaky stone layer.





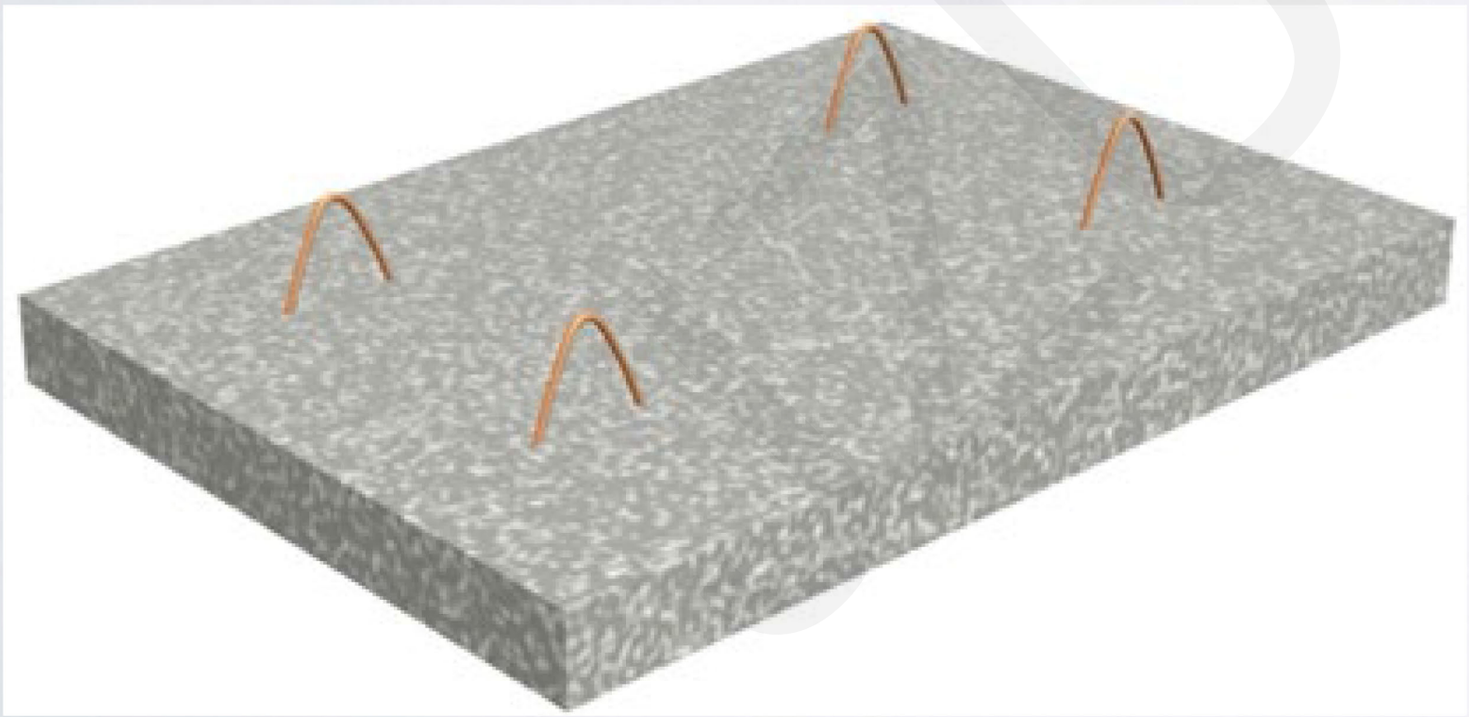


A mechanical performance test of the flaky stone and gravel cushion combination scheme is conducted in this study through indoor physical and mechanical model tests based on the ShenZhong Link. The influences of laying thickness, gradation, and pre-loading load caused by the chute method are quantitatively analyzed. This study proposes a structural scheme for gravel cushion, the corresponding secant modulus, the bearing capacity, and other mechanical indexes, providing scientific basis for reasonably determining cushion thickness and feasible construction technology, accurately evaluating foundation stiffness deviation, and ensuring the stress safety of an immersed tube structure.

Test equipment

The experiment device includes four parts: the experiment box with a furrow mold, the load plate, the experiment material, and the experiment equip-ment and auxiliary equipment.

Experiment device box



Load plate

Loading device

Test group

First, physical model tests are conducted on flaky stone and gravel to determine their mechanical deformation characteristics. Combined with the test results, targeted tests of flaky stone and gravel composite cushion are then performed to analyze the influences of laying thickness, grading, preloading load, and other factors of flaky stone and gravel cushion.

Gravel experiment method

Working condition	Grading (mm)	Cushion thickness (m)	Preloading load (kPa)	Stone ridge size (m)
B2-1	20–40	1.0	30	1.8×1.2
B2-2	20–40	1.0	30	1.8×1.2
B2-3	20–40	1.0	30	1.8×1.2
B2-4	20–40	1.7	30	1.8×1.2

Flaky stone experiment method

Working condition	Grading (mm)	Cushion thickness (m)	Preloading load (kPa)	Stone ridge size
B1-1	80–200	0.7+0	0	3 m without ditch
B1-2	80–200	0.7+0	0	3 m without ditch
B1-3	80–200	0.7+0	0	3 m without ditch
B1-4	80–200	0.7+0	0	3 m without ditch, top gravel leveled off
B1-5	80–200	0.7+0	0	3 m without ditch, top gravel leveled off
B1-6	80–200	0.7+0	40	3 m without ditch, top gravel leveled off
B1-7	80–200	0.7+0	40	3 m without ditch, top gravel leveled off
B1-8	80–200	0.7+0	40	3 m without ditch
B1-9	50–100	0.7+0	30	3 m without ditch

Flaky stone and gravel combination cushion experiment under different working conditions

Working condition	Grading (mm)	Cushion thickness (m)	Preloading load (kPa)	Stone ridge size (m)
B3-1	Flaky stone: 80–200 Gravel: 20–40	0.7+1.0	30	Flaky stone: fully filled Gravel: 1.8×1.2
B3-2	Flaky stone: 80–200 Gravel: 20–40	0.7+1.0	30	Flaky stone: fully filled Gravel: 1.8×1.2
B3-3	Flaky stone: 50–100 Gravel: 20–40	0.7+1.0	30	Flaky stone: fully filled Gravel: 1.8×1.2

Test flow

Crushed stone agitation

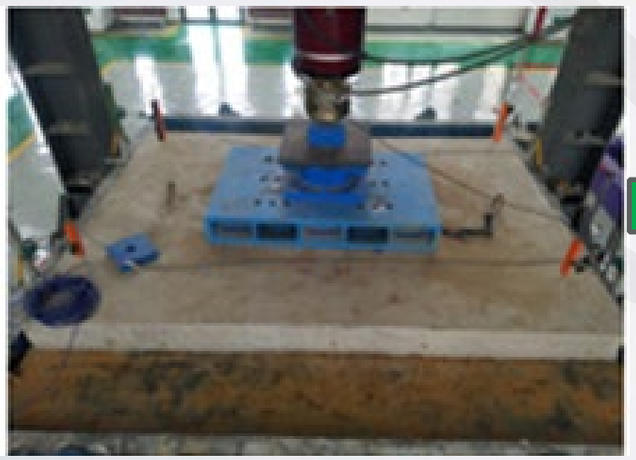
Model box in place

Model box loading

Cushion water injection

Leveling of gravel top

Earth pressure box

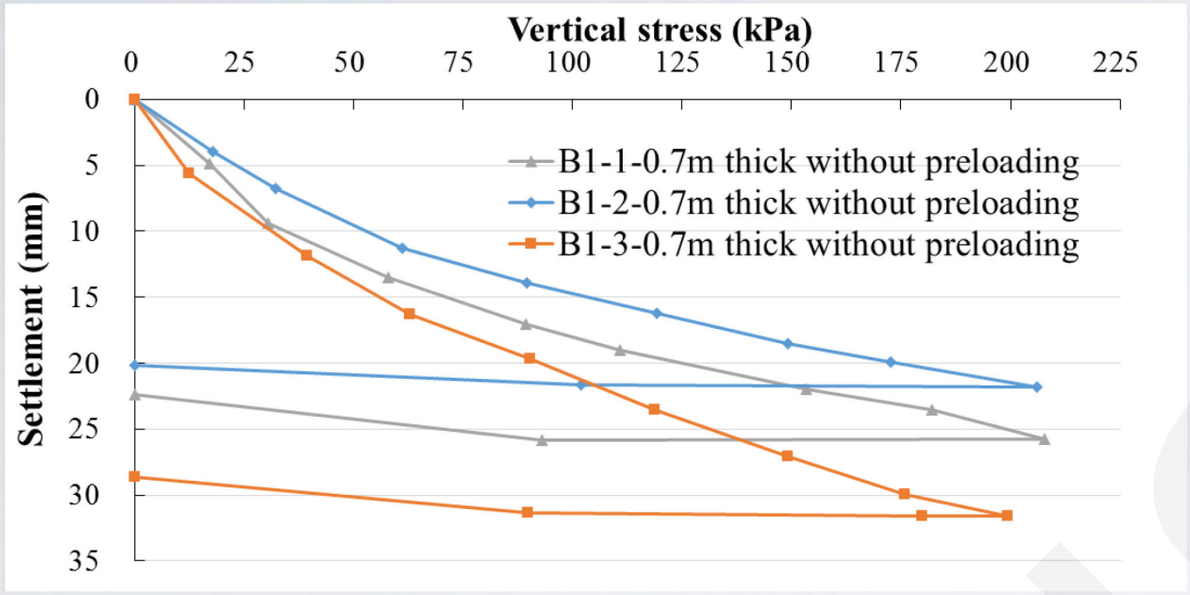


Loading plate and displacement sensor installation

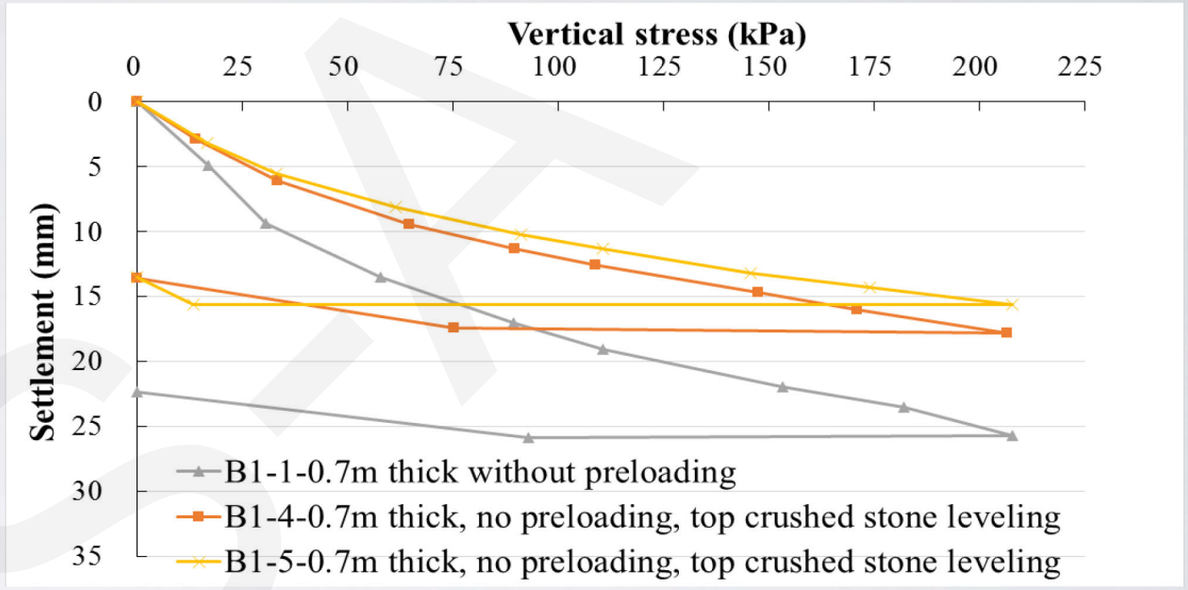
Load

Gravel state after loading

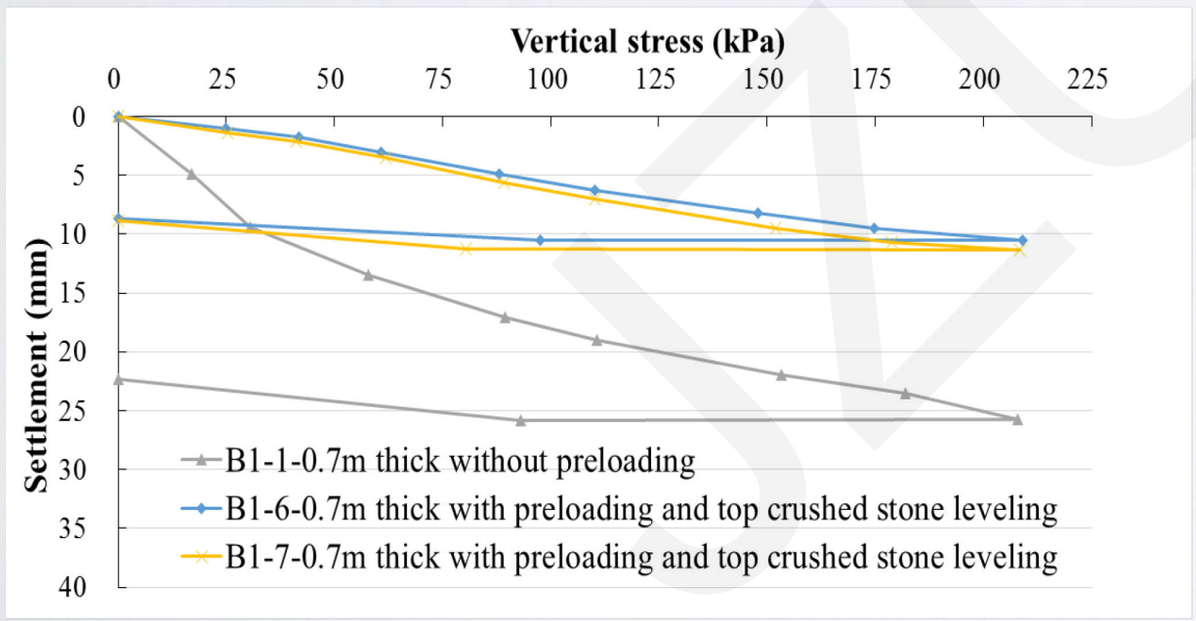
Experimental results- Flaky stone experiment



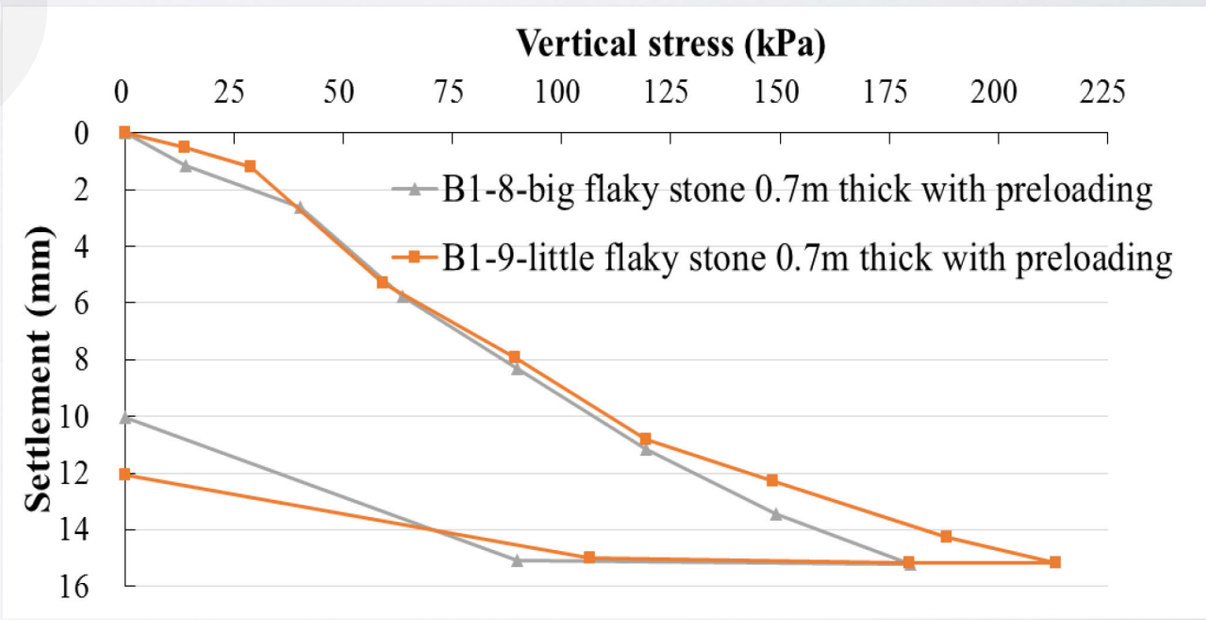
Parallel experiment repetitive load–settlement curves of three sets of 0.7 m-thick flaky stone



Load–settlement curves of different loading faces



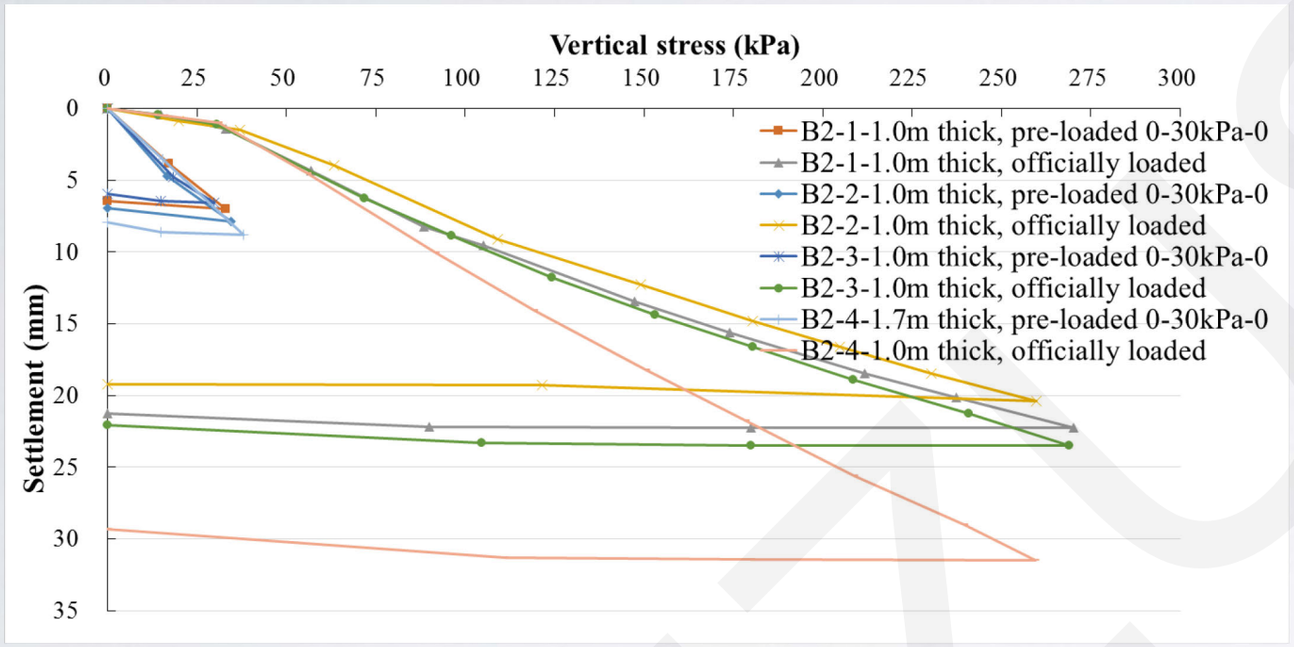
Load–settlement curves under different preload pressure conditions



Comparison of load–settlement curves of two different sizes of flaky stone

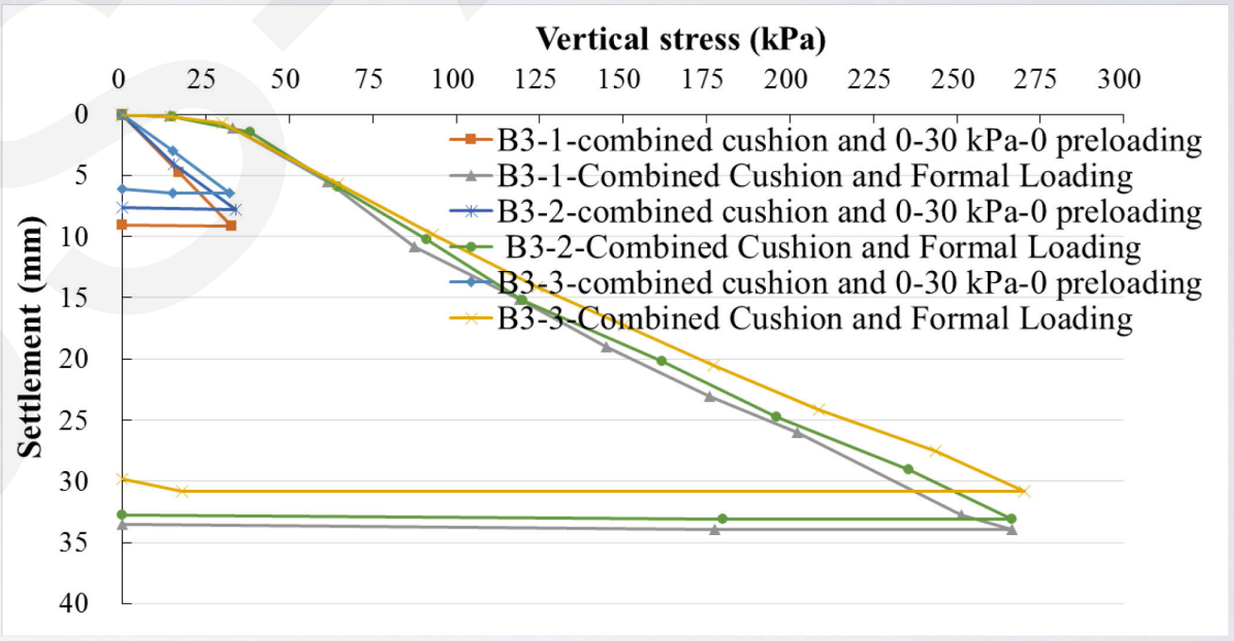
Experimental results- Gravel experiment, Flaky stone and gravel combination cushion experiment

Gravel experiment



Comparison of load–settlement curves under different working conditions

Flaky stone and gravel combination cushion experiment



Combined cushion parallel experiment load–settlement curves under basic working conditions

Conclusions

- The load–settlement curves of the flaky stone cushions become more compact with a dense increment under the design load. These curves can be regarded as nonlinear mechanical characteristics. The load–settlement curves of the gravel cushion and the gravel and flaky stone composite cushion exhibit the characteristics of a two-stage linear change.
- The flatness of the top flaky stone cushion considerably affects settlement and secant modulus. The flatness of the top flaky stone should be ensured during construction.
- Gradation and thickness exert no evident effect on the compressibility of a cushion. The preloading load caused by the construction height difference of the cushion materials plays an important role in improving the initial stiffness of a cushion and reducing initial settlement and overall settlement.
- This study investigates the preloading under 30 kPa of the 0.7 m flaky stone and 1.0 m gravel combination cushion. It recommends the following secant modulus values: 48.89 MPa for the 0–30 kPa section and 10.47 MPa for the 30–110 kPa section.