

Analysis of the breakage parameters of railway ballast based on the discrete element method

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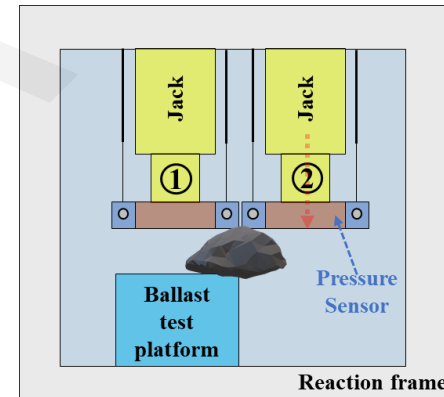
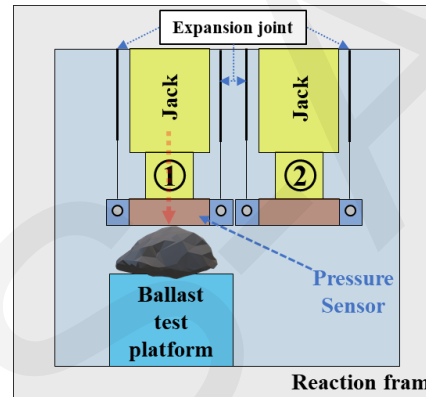
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Laboratory Ballast Uniaxial Breakage Test

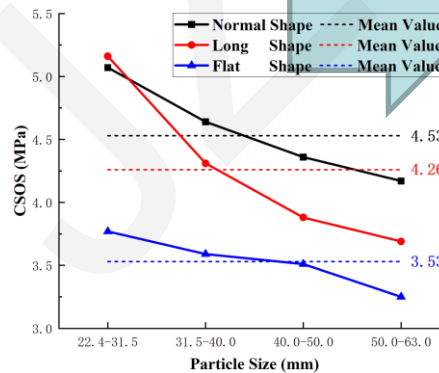
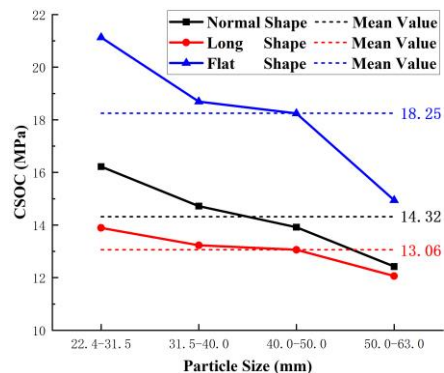
1. Test object

Particle size range (mm)	Number of long-shape ballasts	Number of flat-shape ballasts	Number of normal-shape ballasts
22.4 - 31.5	250	250	250
31.5 - 40.0	250	250	250
40.0 - 50.0	250	250	250
50.0 - 63.0	250	250	250
In total	1000	1000	1000

2. Test method



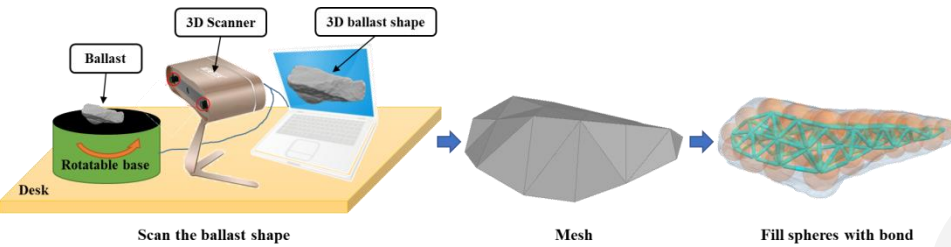
3. Test result



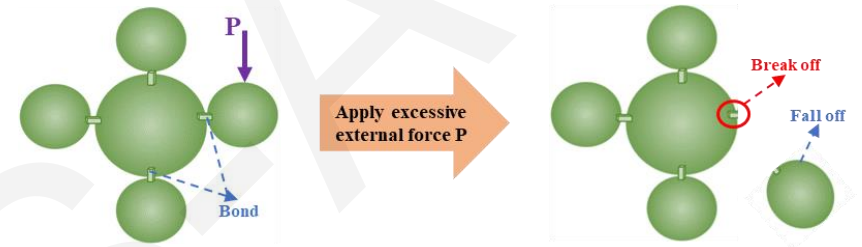
- The order of the CSOC values was **flat particles > normal particles > long particles**.
- The order of the CSOS values was **long particles > normal particles > flat particles**.
- For the ballast particles with a size range of 22.4-63 mm, the CSOC and CSOS were **not greatly affected by the particle size of the ballast**, but they were **greatly affected by the shape of the particles**.

Refined DEM Modeling of Railway Ballast

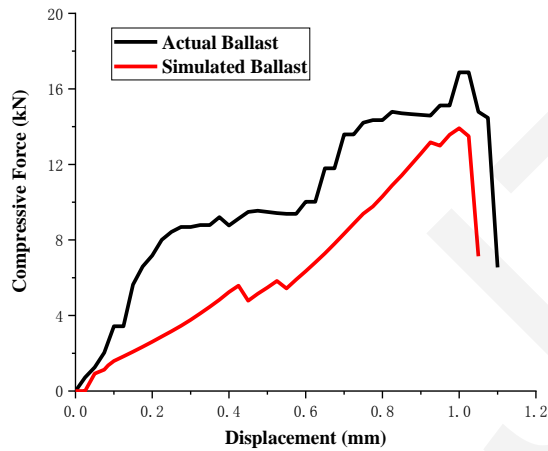
1. Modeling method



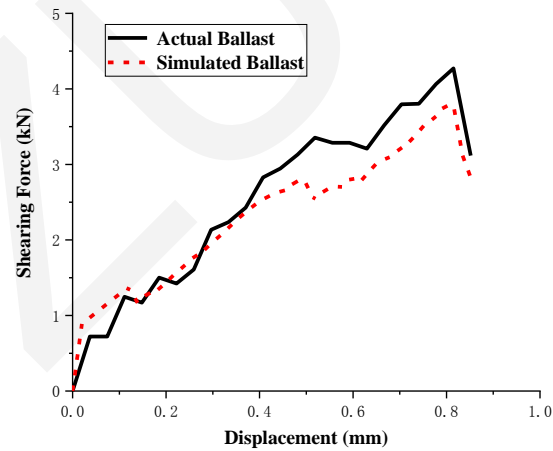
2. DEM constitutive model



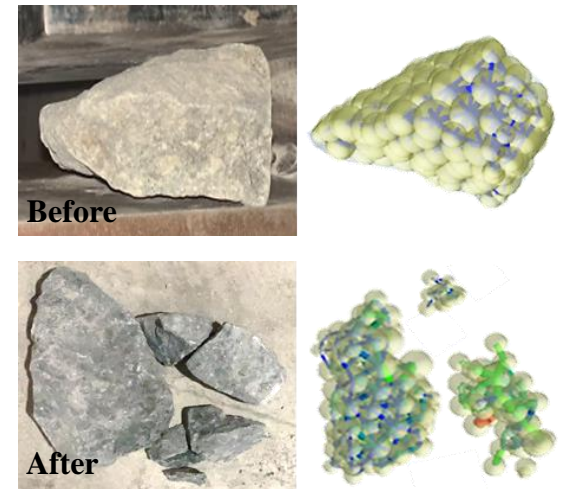
3. Verification of ballast DEM model



Uniaxial compression tests



Uniaxial shear tests

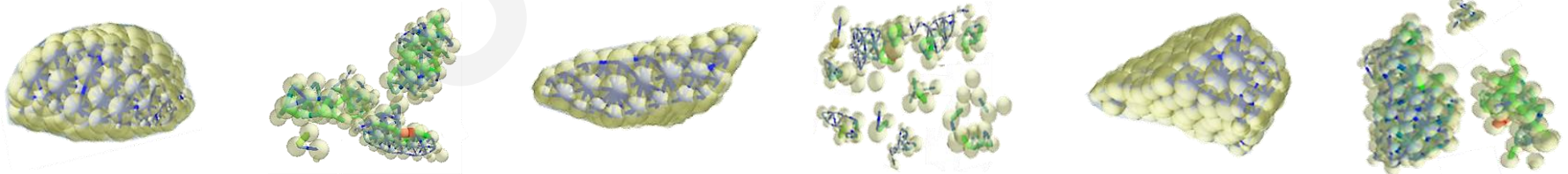


Breakage Parameters Based on RSM

With the initial design point of the optimized model as the starting point, the CBSC and CBSS obtained in the physical tests were the optimization targets, and the breakage parameters of the three shapes of ballast were optimized.

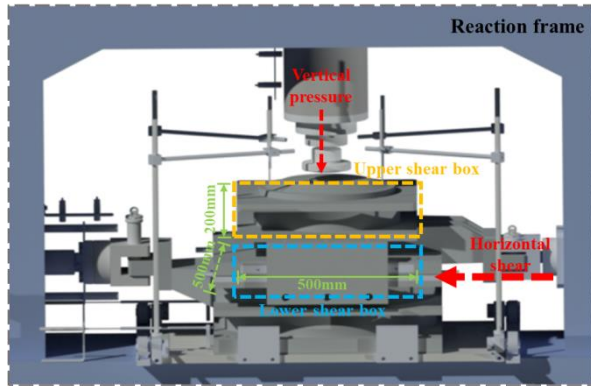
Morphology	CNS (MPa)	CSS (MPa)	NS (kN/mm)	SS (kN/mm)
Normal	31.75	2.24	176	141
Long	12.5	3.64	295	295
Flat	30.44	3.17	166	379

A paired t-test (two-tailed) was performed on the laboratory test and simulation results, and for all the results, $p > 0.05$, indicating that the simulation results using the optimal parameters were not significantly different from the test results.

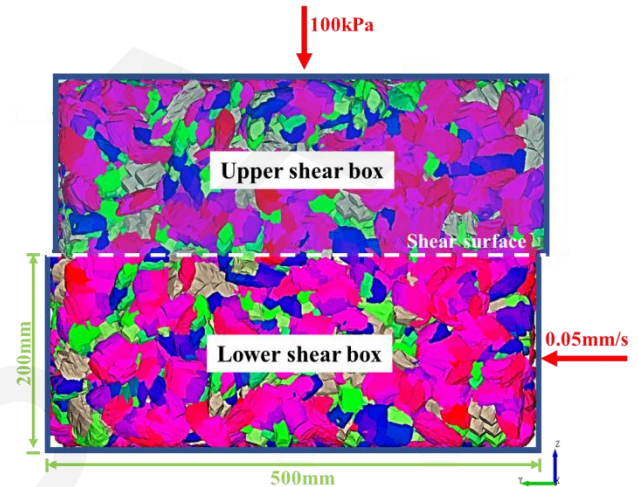


Direct Shear Test Based on Optimal Parameters

1. Test object

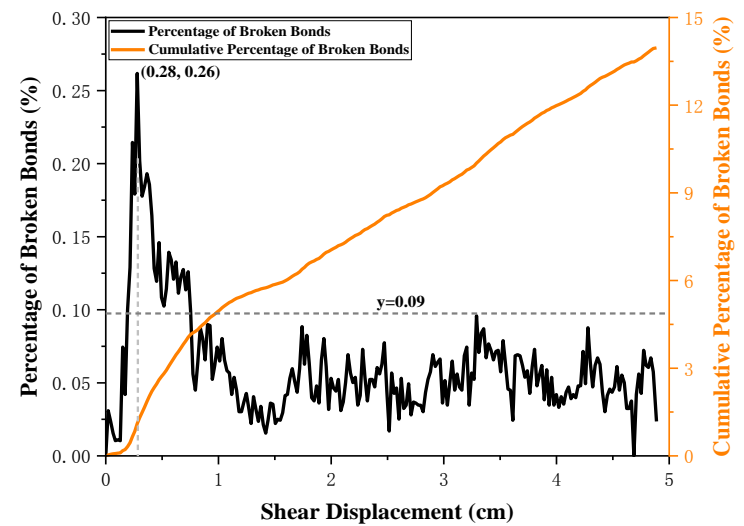
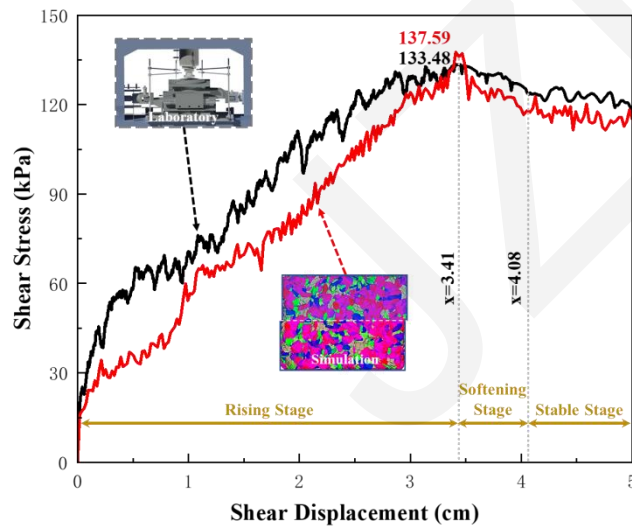


Laboratory

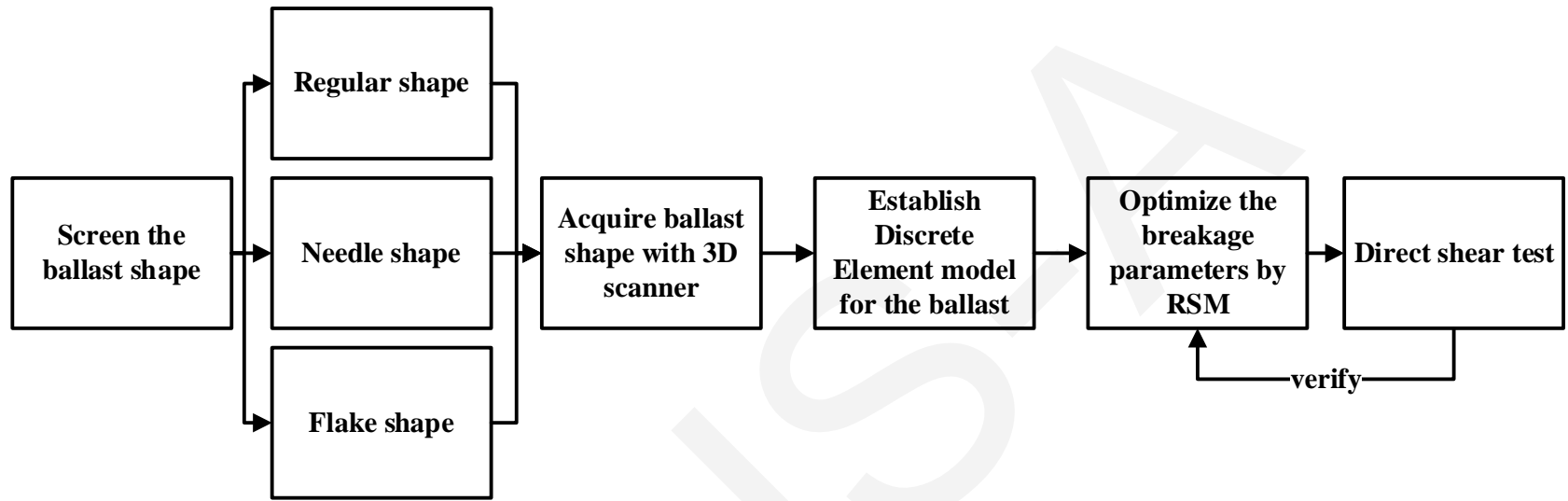


Simulation

2. Test result



Conclusions



- (1) For ballast particles with sizes in the range of 22.4–63 mm, the CSOC and CSOS were not significantly affected by the particle size, but were greatly affected by the shape of the ballast. In particular, long ballast particles were greatly impacted.
- (2) The direct shear test results of ballast aggregates could be divided into three stages: the ascending stage, softening stage, and stable stage. When the shear displacement was 0.28 cm, the ballast breakage ratio reached a maximum of 0.26%. The cumulative ballast breakage ratio gradually increased to 13.97% at the end of the test.
- (3) Under long-term repeated loading of a train, the cumulative breakage ratio of the ballasted bed gradually increased. Thus, it would be necessary to replace the ballast regularly to ensure the stability of the ballasted bed.
- (4) The CNS, CSS, NS, and SS of ballast particles with different morphologies and the optimal parameter combination were respectively 31.75 MPa, 2.24 MPa, 176 kN/mm, and 141 kN/mm for the normal shape, 12.5 MPa, 3.64 MPa, 295 kN/mm, and 295 kN/mm for the long shape, and 30.44 MPa, 3.17 MPa, 166 kN/mm, and 379 kN/mm for the flat shape.