Electronic supplementary materials

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Effect of tamping duration on mechanical properties of ballast beds: a DEM–MBD coupled investigation

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Fig. S1 Tamping machine

Table S1 Research dimensions of the tamping mechanical mechanism

Research dimension	Reference	Research method	Key findings
Macro indicators	(Abbasi et al., 2024)	Measurement of track geometry and supporting modulus	The support modulus decreases after tamping
	(Zhang et al.,2024b)	Field test of vibration transmission	Recommended tamping times less than 3
	(Wang et al., 2024)	On-site ballast bed resistance and support stiffness test	Tamping within 3 times
Microscopic response	(Zhou et al., 2024)	Intelligent ballast acquisition acceleration	Squeezing time 1.0 s is better than 0.6 s.
	(Wang et al., 2022)	Three-direction acceleration analysis of ballast	Ballast acceleration response diagnosis of track bed disease
	(Chi et al., 2022)	DEM-MBD coupling model	Influence of tamping on ballast bed in turnout area
Parameter optimization	(Shi et al., 2020)	DEM-MBD coupling model	Optimal at 35 Hz vibration frequency.
	(Zhang et al., 2023a)	DEM-MBD coupling model	Optimal at 7.8 kN squeezing clamping force.
	(Shi et al., 2024)	DEM-RBF-MOGA optimization algorithm	Optimization of tamping parameters for general sections.
	(Chi et al., 2024a)	Response surface methodology	Optimization of tamping parameters for turnout sections.

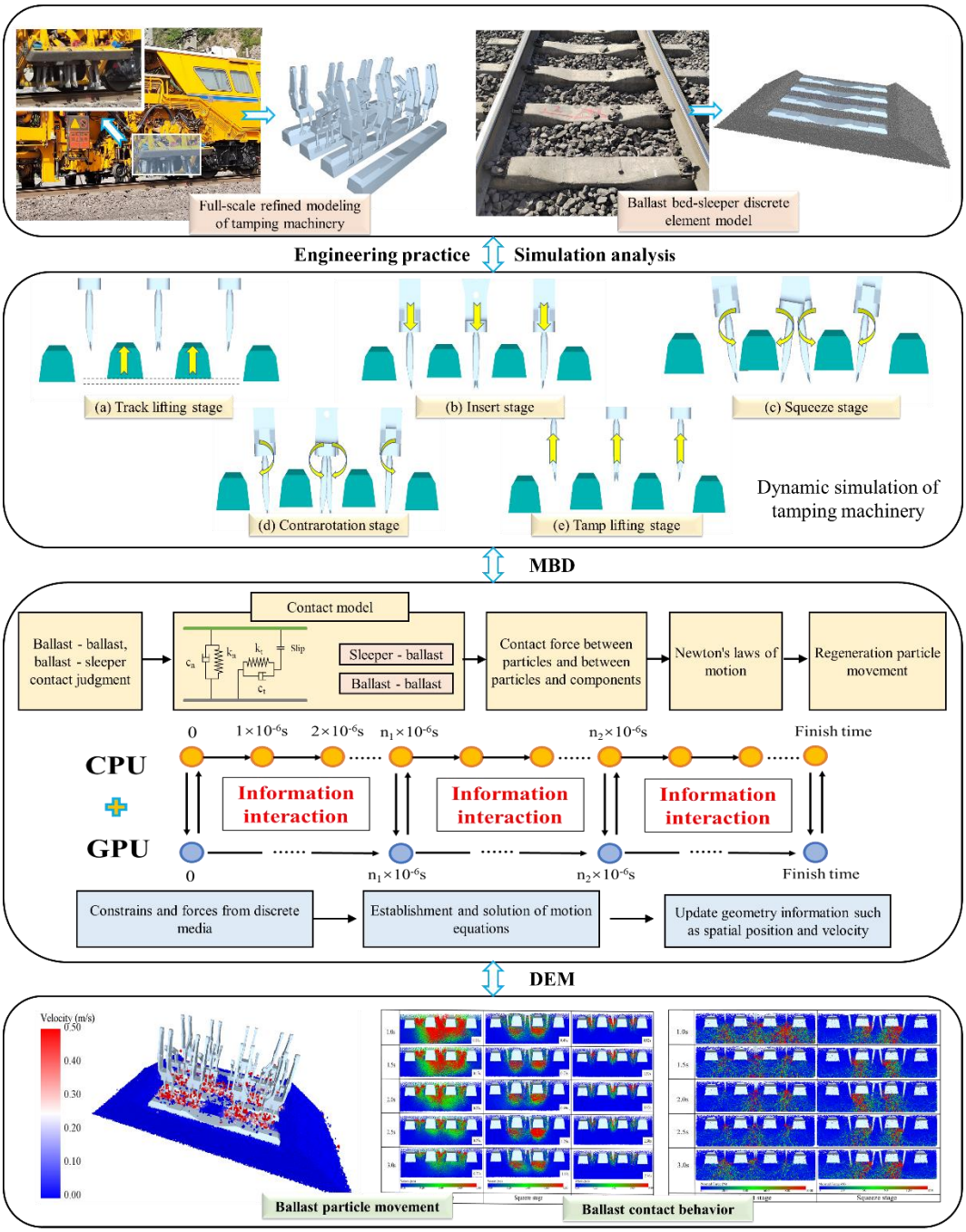

Fig. S2 Research flow chart

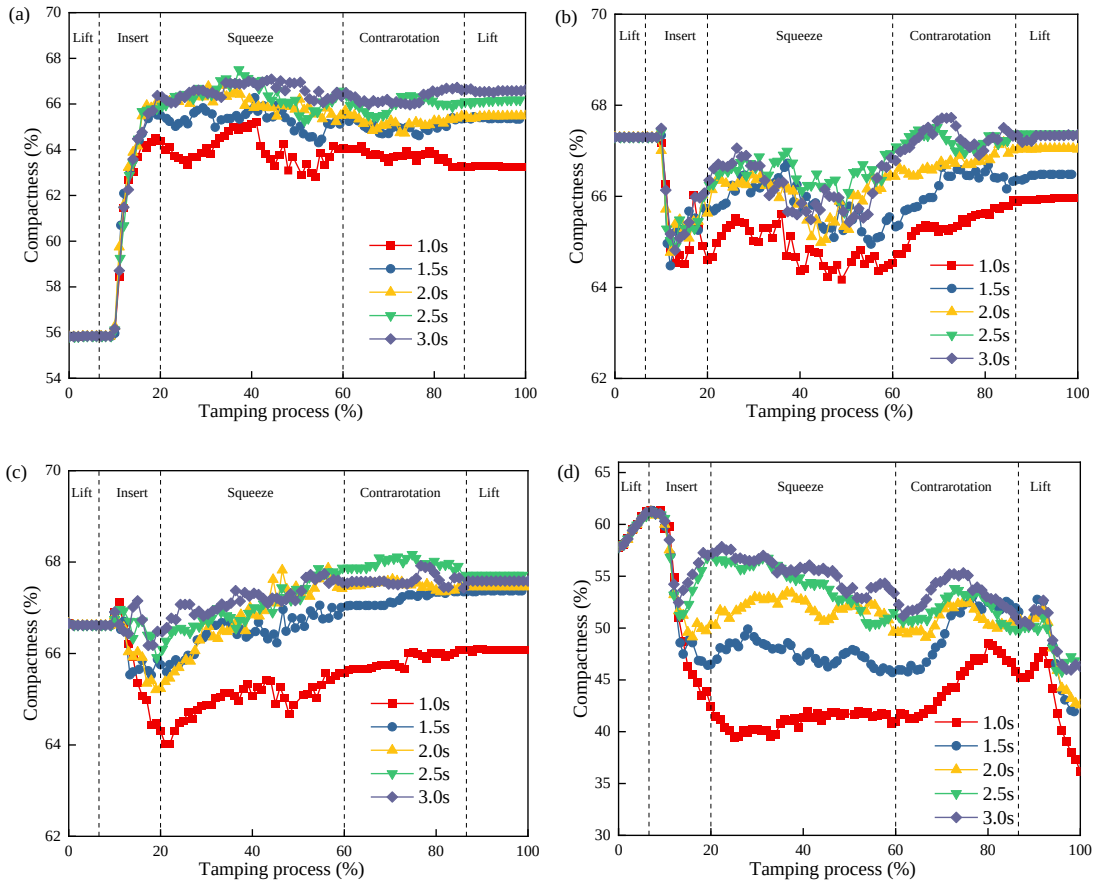

Fig. S3 Variation in ballast bed compactness: (a) area D1, (b) area D2, (c) area D3, (d) area J0.

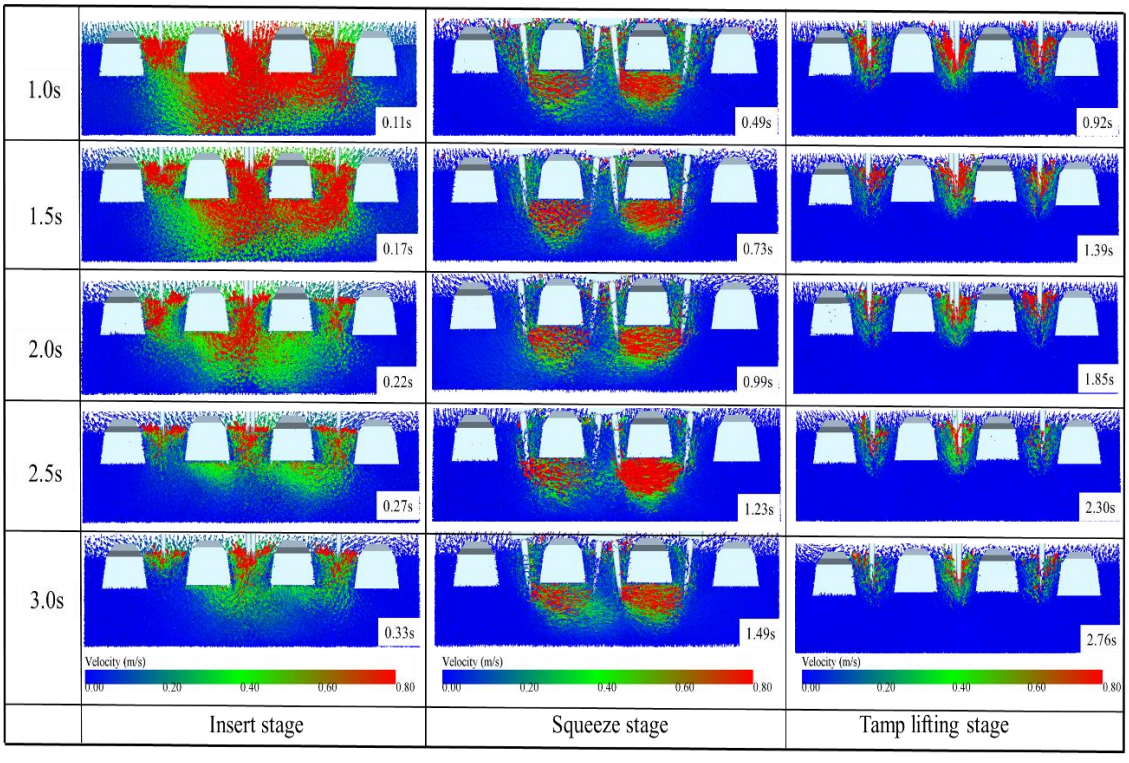

Fig. S4 Velocity distribution of ballast movement

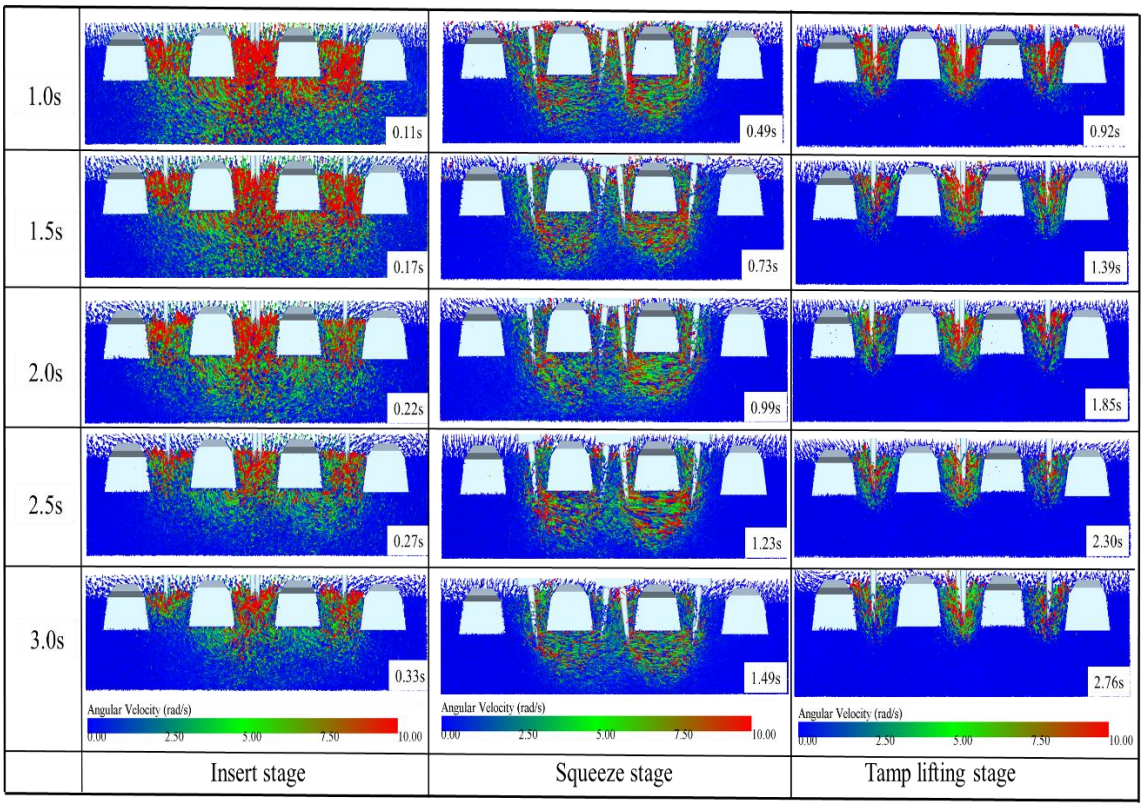

Fig. S5 Angular velocity distribution of ballast movement

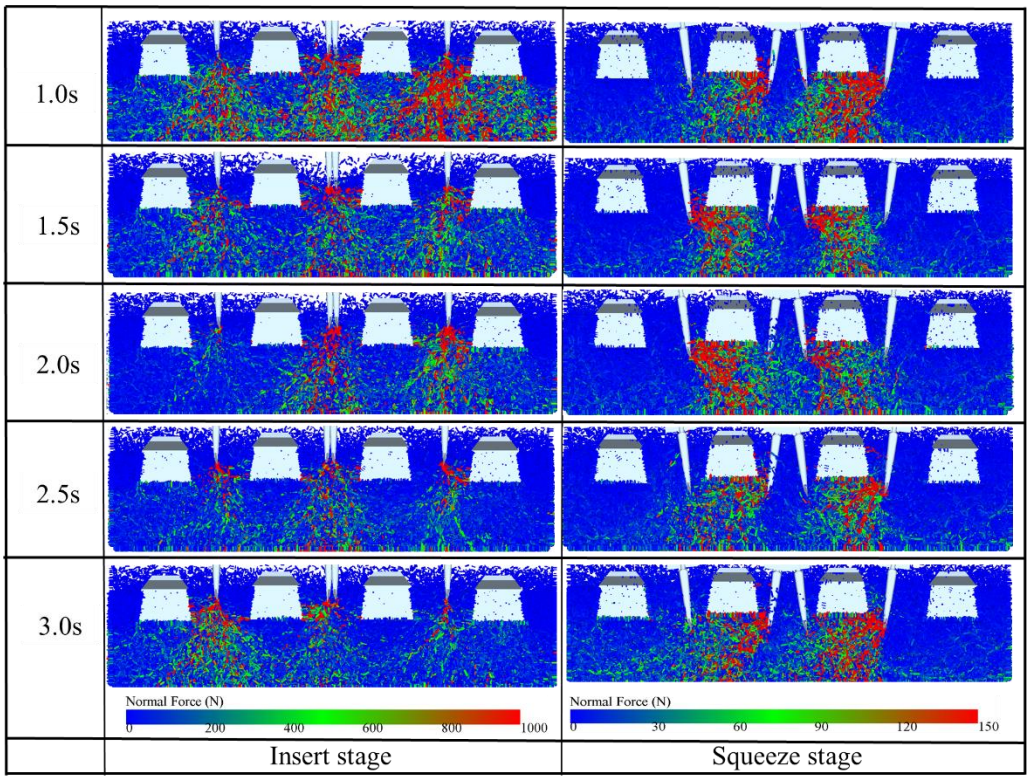

Fig. S6 Distribution of normal contact forces of ballast

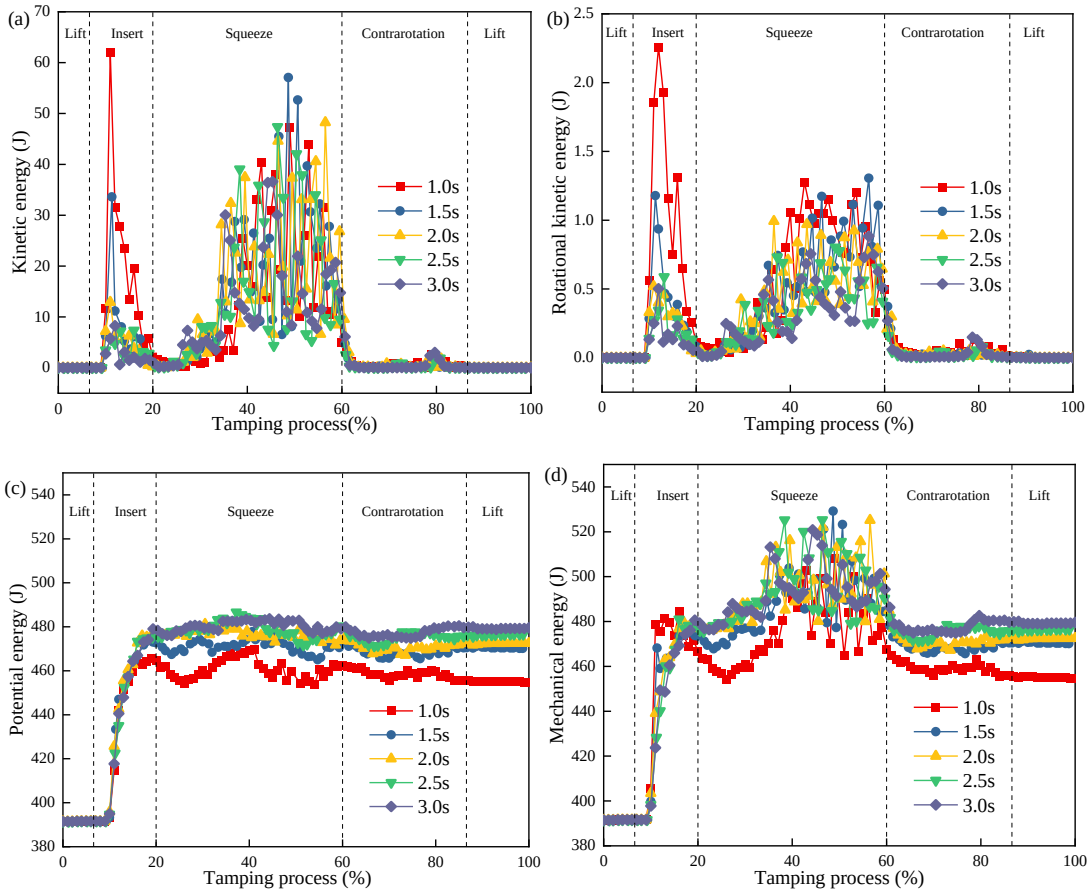

Fig. S7 Energy evolution: (a) kinetic energy, (b) rotational kinetic energy, (c) potential energy, (b) mechanical energy

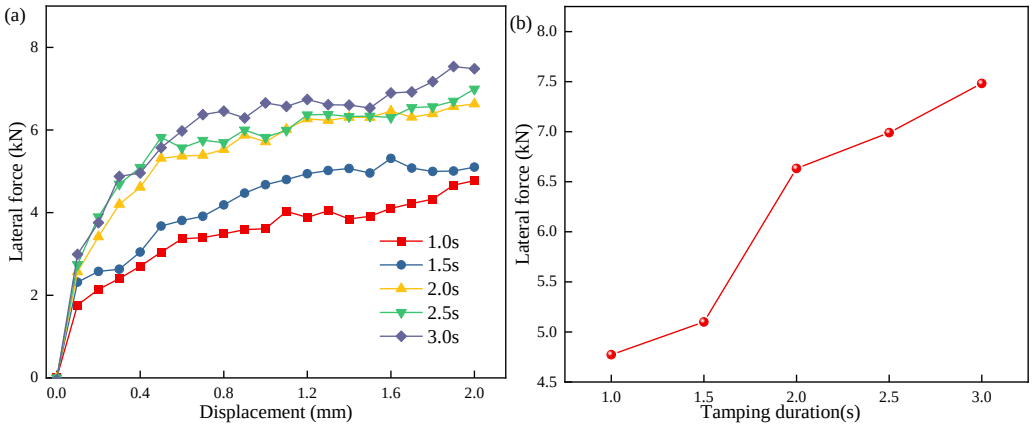

Fig. S8 Influence on the resistance of the ballast bed: (a) lateral force-displacement relationship, (b) lateral resistance change

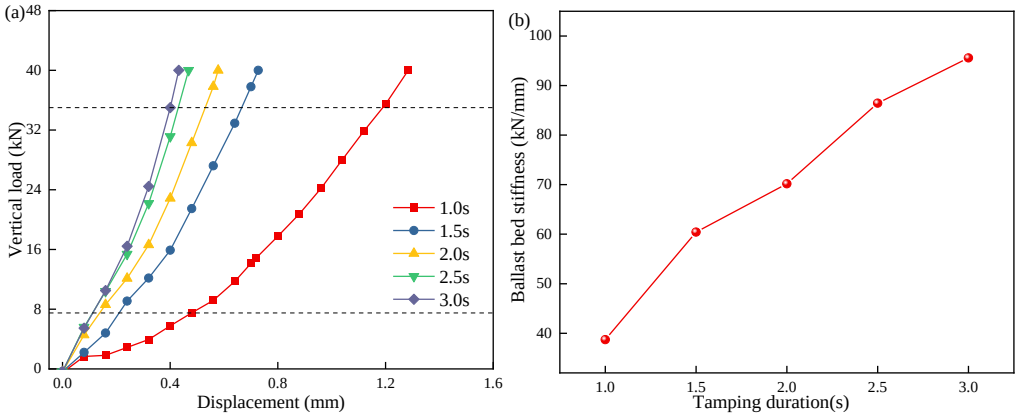

Fig. S9 Influence on supporting stiffness: (a) vertical force-displacement relationship, (b) variation of support stiffness