Fig. 1 Schematic illustration of proposed model for normal contact interaction.

Fig. 2 Comparison of proposed model with published relationships: variation in rough/smooth contact radius ratio with roughness index.

Fig. 3 Proposed model response for two particles in contact: (a) Normal contact force – Overlap, and (b) Normal contact stiffness - Normal contact force.
Fig. 4 (a) RLP sample and (b) FCC sample at $\sigma' = 1$ kPa with periodic boundaries in X and Y, and wall boundaries in Z. Particle shading indicates coordination number ($C_N$) in (a); (c) Time history of wall input motion in X direction.

Fig. 5 Time history of particle displacements in excitation (X) direction at distances from transmitter wall (z) at $\sigma' = 100$ kPa (RDP sample) for (a) $S_q = 0$ $\mu$m (smooth), and (b) $S_q = 1.0$ $\mu$m.
Fig. 6 Time history of increment in shear stress in excitation (X) direction on transmitter and receiver walls ($\Delta \sigma_X$) for $S_q = 0.0 \ \mu m$ and 1.0 $\mu m$ at $\sigma' = 0.1 \ MPa$, 0.3 MPa and 1 MPa for: (a) FCC, and (b) RDP.
Fig. 7 Gain factor of incremental shear stress on transmitter and receiver walls for $S_q=0$ and $S_q=1.0\ \mu m$ at: (a) $\sigma'=0.1\ \text{MPa}$, and (b) $\sigma'=1\ \text{MPa}$. 
Fig. 8 Influence of surface roughness on small-strain shear modulus obtained by analytical approach and DEM results – relationship between $G_0$ and $\sigma'$: (a) FCC, (b) RDP, and (c) RLP.
Fig. 9 Cumulative distributions of normal contact forces for different packings at $p' = 100$ kPa: (a) $S_q = 0.5 \, \mu m$, and (b) $S_q = 1.0 \, \mu m$. 