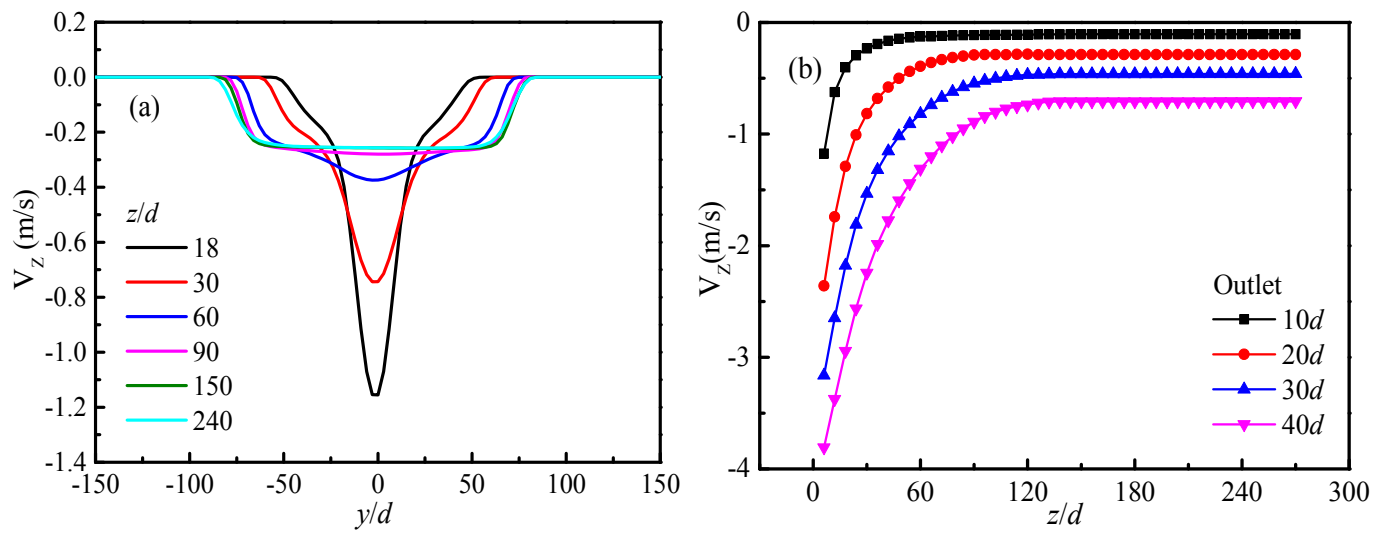


Fig.1 Schematic of the simulated flat-bottom silo.



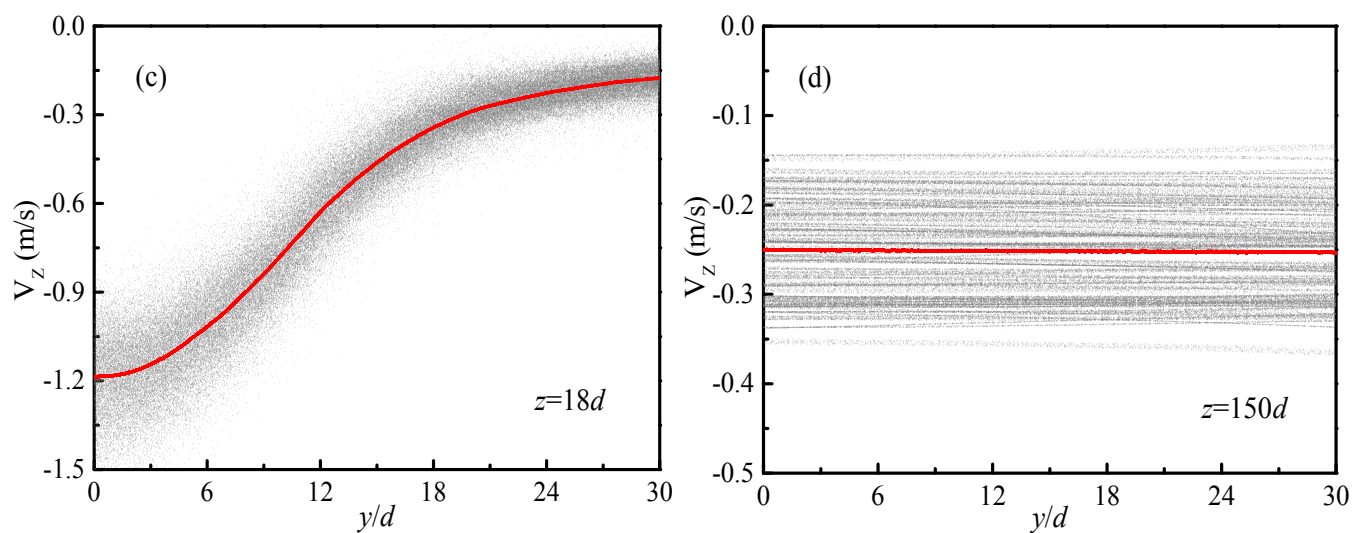
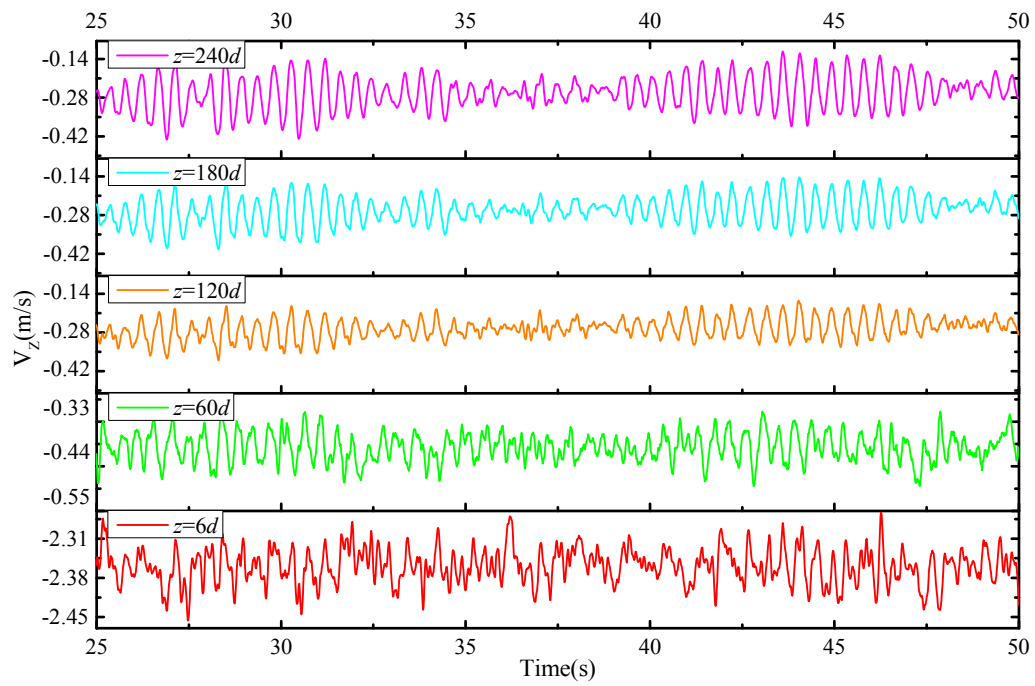


Fig.2 (a) Vertical velocity profiles at different z - positions, (b) the variations of particle vertical velocity along the z - direction at $y=0$ for different outlet sizes, (c) and (d) denote the instantaneous vertical velocities of individual particles collected at different moments.



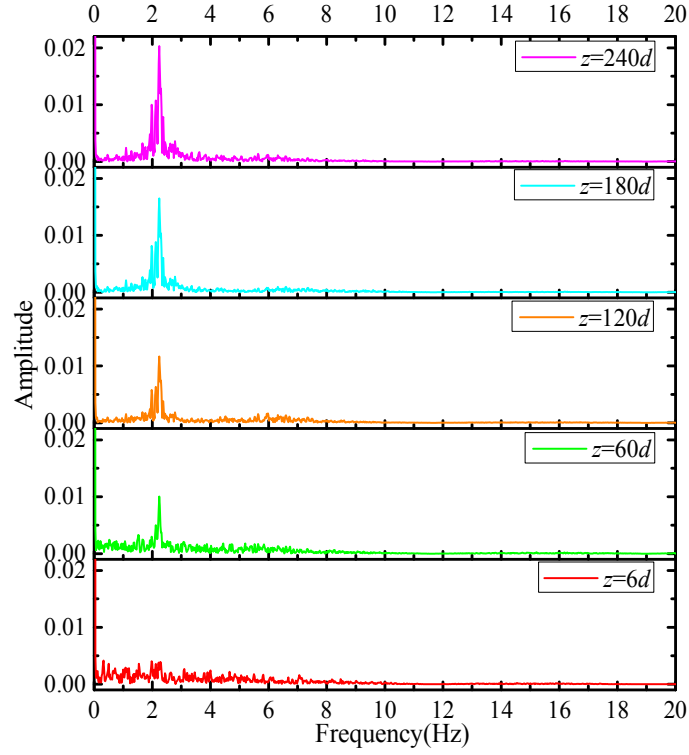
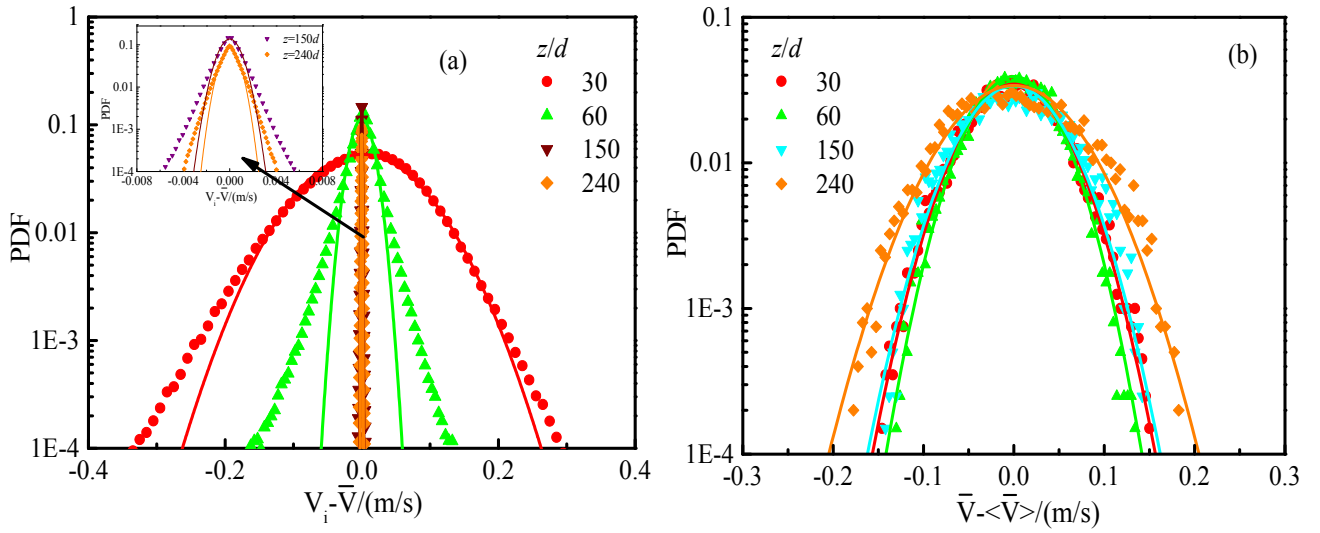


Fig.3 (a) The temporal variations of spatially averaged vertical velocity at different z - positions($v=0d$), (b) the corresponding Fourier spectrums.



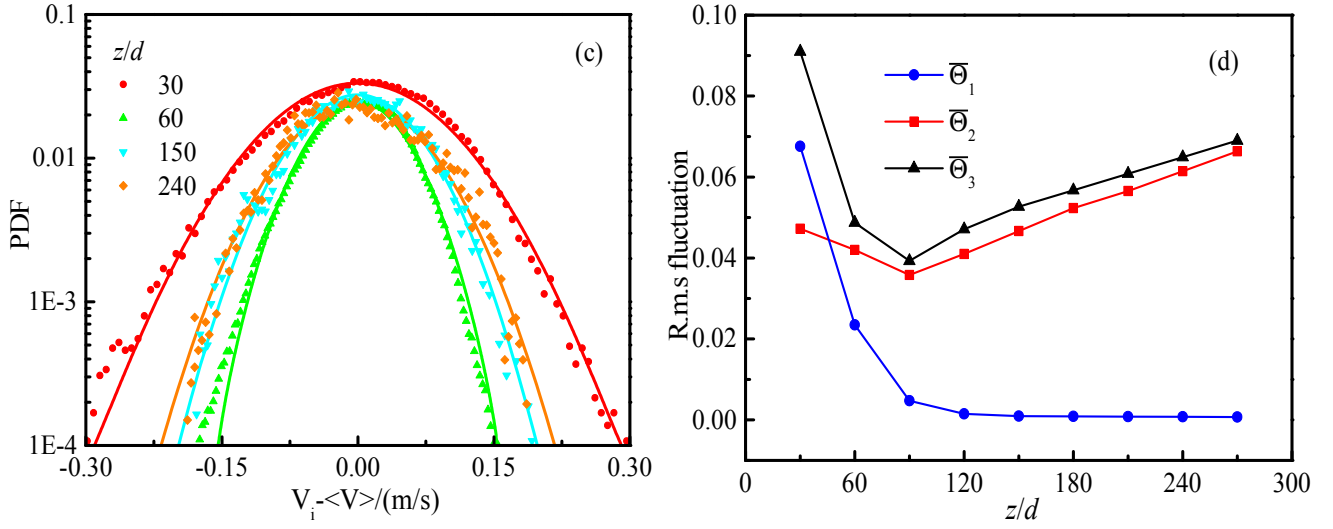
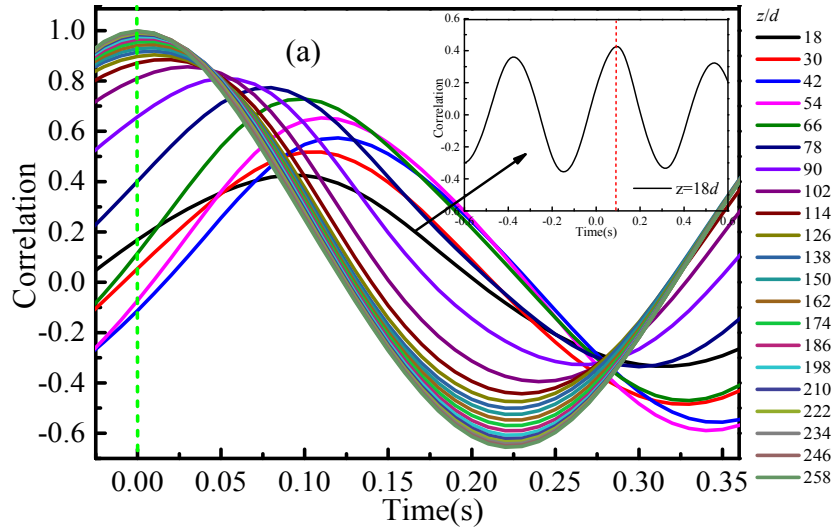


Fig.4 (a), (b) and (c) denotes the PDFs of δV_i , δV_j and $\delta V_i'$ at different z - positions($y=0d$), respectively. The insert in Fig.4 (a) is the zooms of the PDFs at $z=150d$ and $z=240d$ positions($y=0d$). (d) The variations of r.m.s. vertical velocity fluctuations along vertical direction.



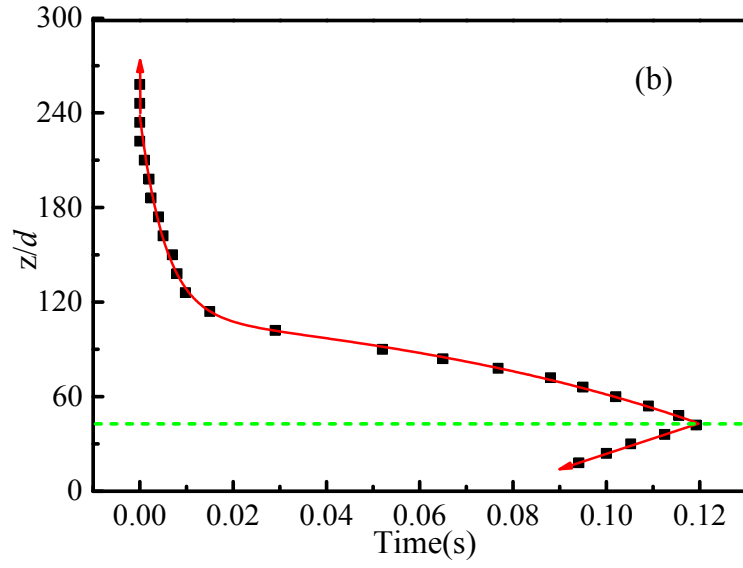
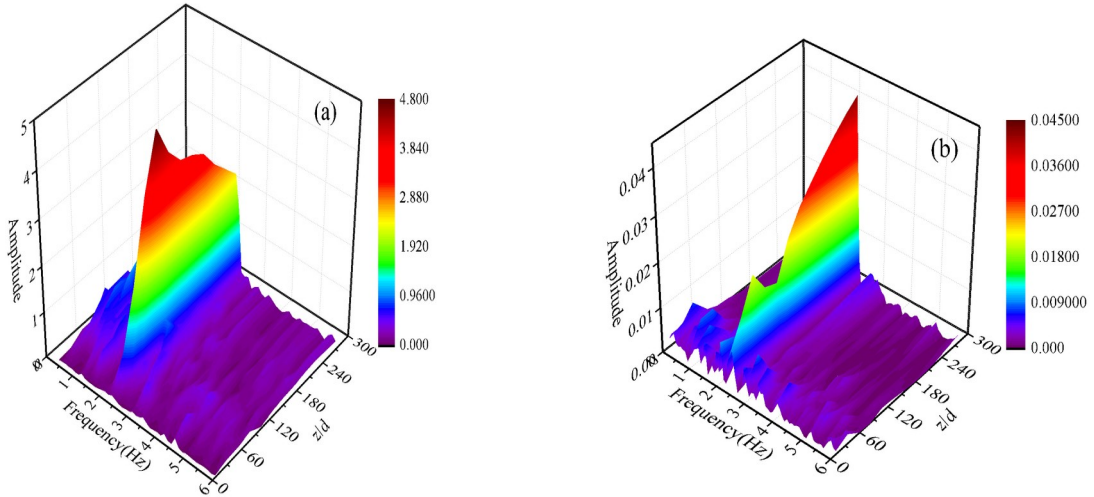


Fig.5 (a) The delayed correlations between the normalized fluctuation velocity at the reference height $z=270d$ ($y=0$) and those at lower vertical positions ($y=0$), the insert is the delayed correlation between the velocity fluctuations at $z=18d$ and $z=270d$ ($y=0$). (b) The vertical variation of the delayed time.



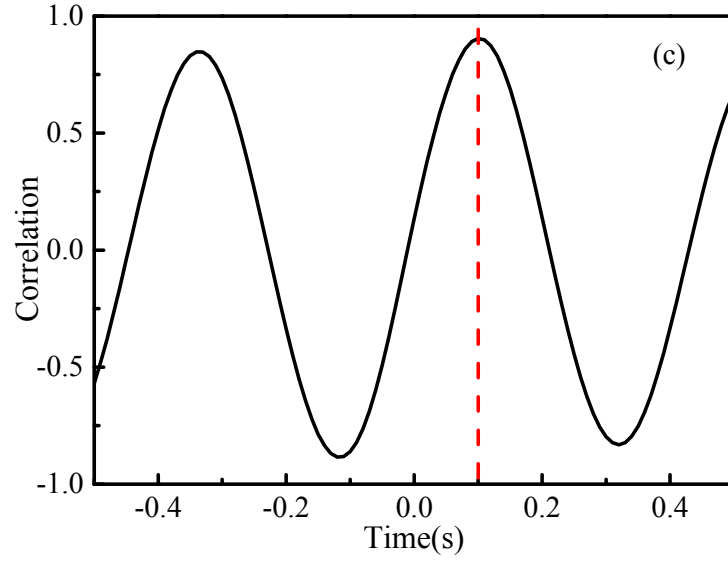
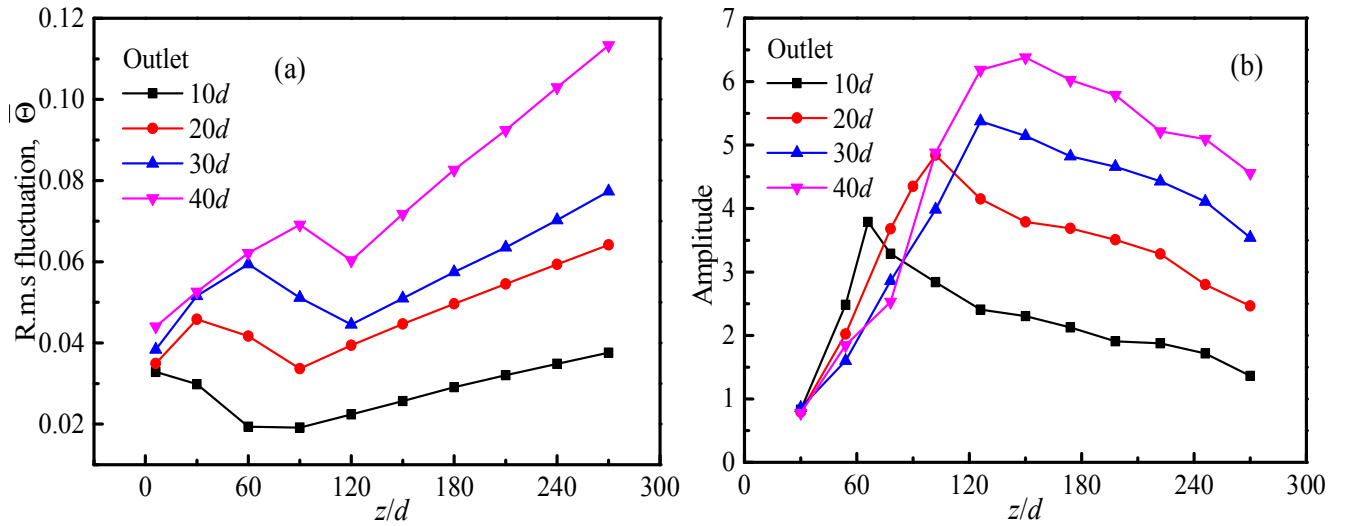


Fig.6 Fourier spectrums of the time-signals of the spatially averaged compressive force (a) and vertical velocity (b). (c) The correlation between the normalized fluctuations of compressive force and vertical velocity as a function of the delayed time for an observation window at $z=180d$.



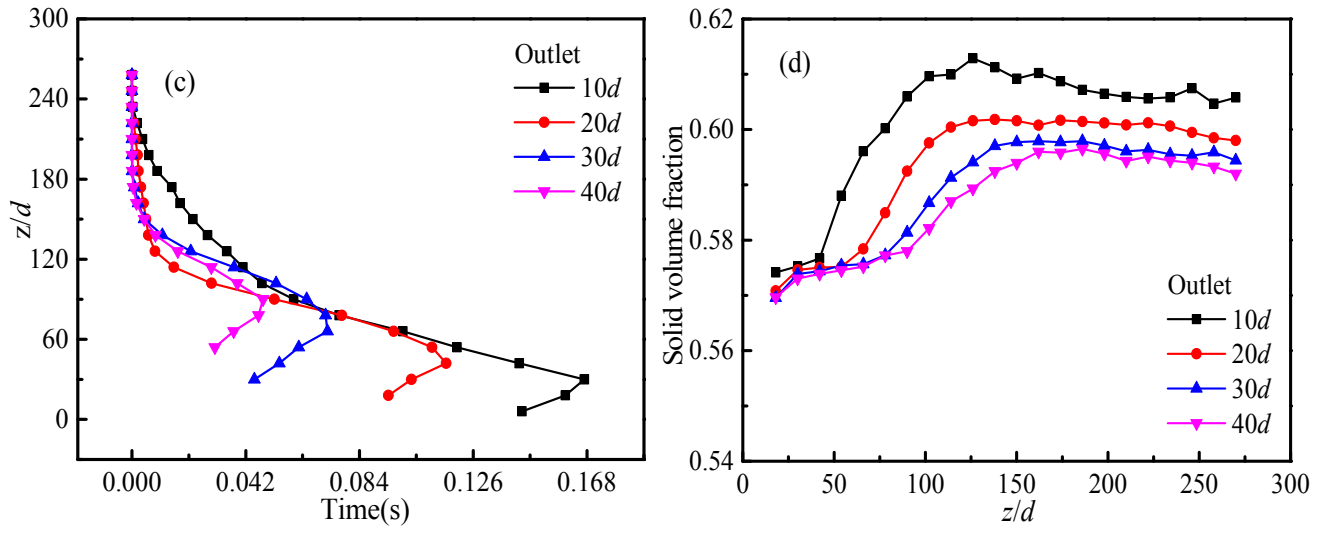


Fig.7 Vertical profiles of r.m.s fluctuation of spatially averaged vertical velocity (a), fluctuation amplitude of compressive force(b), delayed time (c) and solid volume fraction (d).

Table 1 Summary of simulation parameters

Type	Parameters	Value
Particle	Solids density, ρ_p (kg/m ³)	2500
	Poisson ratio, ν_p	0.25
	Shear modulus, G_p (Pa)	1.5×10^8
	Diameter, d (mm)	20
Silo	Density, ρ_p (kg/m ³)	7800
	Poisson ratio, ν_p	0.25
	Shear modulus, G_p (Pa)	7×10^{10}
Particle-particle	Restitution coefficient, e_{p-p}	0.9
	Coefficient of static friction, μ_s	0.6
	Coefficient of static friction, μ_r	0.01
Particle-silo	Restitution coefficient, e_{p-s}	0.5
	Coefficient of static friction, μ_s	0.6
	Coefficient of static friction, μ_r	0.01
Simulation	Time step, Δt (s)	1×10^{-6}