Influence of vibration on granular flowability and its mechanism of aided flow

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Abstract: Regarding flowing granular media as weak transverse isotropic media, the phase velocity expressions of wave P, wave SH and wave SV were deduced, the propagation characteristics of waves in flowing granular media were analyzed. The experiments show that vibration has great influence on granular fluidity. The wavefront of wave P is elliptic or closely elliptic, the wavefront of wave SH is elliptic, and the wavefront of wave SV is not elliptic. Wave propagation in the granular flowing field attenuates layer after layer. The theory and experiment both substantiate that the density difference is the key factor which leads to the attenuation of vibrating energy. In terms of characteristics of wave propagation one can deduce that vibrating waves have less influence on flowability of granules when the amplitude and frequency are small. However, when the amplitude and frequency increase gradually, the eccentricity of ellipsoid, the viscosity resistance and inner friction among granules, and shear intensity of granules decrease, and the loosening coefficient of granules increases, which shows the granules have better flowability.

Key words: granular media; vibrating aided flow; body wave; mechanism

1 Experiment of vibrating aided flow

The experimental apparatus is a lucite cylinder installed on an upright bracket. The vibrating table vibrates the granular samples in the cylinder by a steel plate, which has an opening to draw out the granules. The initial vibration effect. The opening is switched on, then begins to vibrate. The signal of granular wave by the sensor is extremely

is not generally caused. For drawing viscous fine-ores, the laboratory and field experimental results indicated that installing vibrating walls, vibrating brackets or building vibrating bedplates etc. are effective vibrating aided flow measures, which have the distinct effect on avoiding ore-arching or restricting the ores' pipe flow.

1) The initial vibration effect. The opening is switched on, then begins to vibrate. The signal of granular wave by the sensor is extremely
disordered (shown in Fig. 1). It shows the relation between time $t$ and acceleration $a$ ($a_{\text{max}} = 75.00 \text{ m/s}^2$, $a_{\text{min}} = -19.92 \text{ m/s}^2$). The ordinate value is $J \cdot a_{\text{max}}$, where $J$ is the ratio of acceleration. It indicates that the positive acceleration value continuously changes and that the granular samples are looser and have the obvious pulsation phenomenon. The granular samples are in a dynamic process: the structure is destroyed, the new structure is formed and is destroyed again. Moreover, the whole effect of vibration is continuously loose.

2) The vibration effect in the steadily flowing phase. If the opening can easily discharge, after a certain time the granular wave signal by sensor is steady (shown in Fig. 2). The curve of wave signal has the same meaning as that in Fig. 1 ($a_{\text{max}} = 38.87 \text{ m/s}^2$, $a_{\text{min}} = -23.44 \text{ m/s}^2$). The positive and negative acceleration are more steady, but the difference of absolute value is obvious. In this time the granules are looser, and have a steady flow and a steady loose density. To be looser, the intensity of vibration must be increased.

2 Wave propagation in granular flowing field

The granules do not flow from the random body, and the experiments testify that when the granules are drawn from one hopper not all granules but partial granules on the hopper opening are turned into the state of motion. The body has the approximate ellipsoid shape and secondary looseness.$^{[2,5]}$

The body wave in the granular media is fallen into wave $P$ and wave $S$$^{[3]}$. If the appropriate coordinate plane $(x, O, y)$ is chosen the wave propagation direction $n$ will be always parallel to the plane. The wave is not dependent on $z$ coordinate. For the longitudinal wave (wave $P$), the displacement vector is perpendicular to the wave front; so the wave propagation direction will be always parallel to the plane $(x, O, y)$. For the transverse wave (wave $S$), the displacement vector is parallel to the wave front. The displacement vector of wave $S$ can be resolved into two components: one is parallel to $(x, O, y)$ plane, and the other is perpendicular to the plane. The former is called wave $SV$ (erective polarized shearing wave); the latter is called wave $SH$ (level polarized shearing wave). Wave $P$ and wave $SV$ form the motion in the plane (plane strain problem); wave $SH$ forms the motion outside the plane$^{[6,7]}$.

2.1 Propagation characteristics of wave $P$ and wave $SV$

If the granular state in the flowing field is an ellipsoid then it is thought that the granular media here are weak transverse isotropic media, and the velocity expressions of wave $P$ and wave $SV$ are:

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\begin{align*}
V_{p} &= \frac{1}{2\rho} \left\{ 2C_{44} + (C_{11} - C_{44})\sin^2 \theta + (C_{33} - C_{44})\cos^2 \theta + \left[ (C_{11} - C_{44})\sin^2 \theta + (C_{33} - C_{44})\cos^2 \theta \right]^2 + \left[ (C_{13} + C_{44}) + (C_{11} - C_{44})(C_{33} - C_{44}) \right] \sin^2 \theta \right\}^{1/2} \\
V_{sv} &= \frac{1}{2\rho} \left\{ 2C_{44} + (C_{11} - C_{44})\sin^2 \theta + (C_{33} - C_{44})\cos^2 \theta - \left[ (C_{11} - C_{44})\sin^2 \theta + (C_{33} - C_{44})\cos^2 \theta \right]^2 + \left[ (C_{13} + C_{44}) - (C_{11} - C_{44})(C_{33} - C_{44}) \right] \sin^2 \theta \right\}^{1/2} 
\end{align*}
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(1)