# EVALUATION OF VOID RATIO CHARACTERISTICS OF SAND-GRAVEL MIXTURES WITH DIFFERENT PSD CURVES BY 3D DEM SIMULATIONS

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## 1. INTRODUCTION

In railway tracks, ballasts mix with fine materials, which mainly come from underneath layers due to heavy train loads and also some due to particle crushing (Thakur et al., 2010). The change of particle size distribution (PSD) curves of original ballast layers due to intrusion of fines affect deformation properties of railway ballasts. Dense or loose state of ballast layers depends also on particle size distribution. Knowledge on void ratio characteristics can be used to understand change of dense or loose state of ballast layers. Therefore, it is necessary to understand how PSD curves affect minimum ($e_{min}$) and maximum void ratios ($e_{max}$) of ballast layers.

## 2. METHODOLOGY

DEM simulations were conducted using YADE (Smilauer et al., 2010). DEM simulations were conducted under two series (i.e., Series A and B). Fig. 1 shows a sample used in DEM simulations. In Series A, gravels (i.e., 1/5 size of ballasts) were mixed with medium size sands as shown in Fig. 2 (a). DEM simulations were conducted using input parameters given in Table 1. Laboratory density tests were also conducted on sand-gravel mixtures shown in Fig. 2 (b). In Series B, DEM simulations were conducted on samples shown in Fig. 5. In Series B, PSD curves were changed as shown in Fig. 5. In DEM simulations, $e_{max}$ and $e_{min}$ were measured at the end of isotropic compaction.

Table 1: Input parameters

| Input Parameters | Values |
|---|---|
| Local damping coefficient | 0.2 |
| Friction angle during compaction (degree) | 0 & 90 (Series A)<br>50 (Series B) |
| Density, $\rho_s$ | 2600 |
| No. of particle | 10000 |
| Confining stress (kPa) | 100 |
| Ratio of $K_s/K_n$ | 0.5 |
| Young's modulus (MPa) | 15 |
| Strain rate | 0.1 |

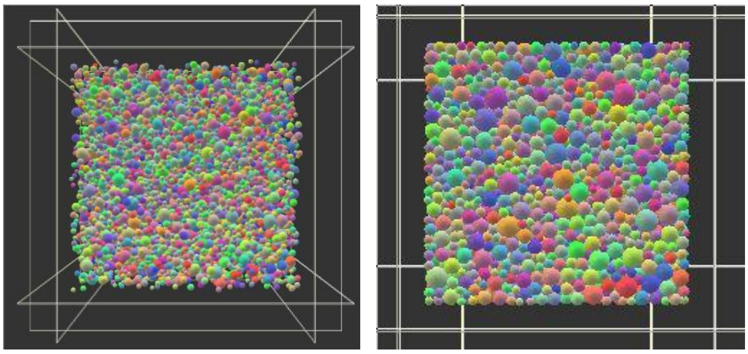

Fig. 1: A sample at (a) initial stage and (b) end of isotropic compaction

## 3. EXPERIMENTAL AND DEM SIMULATION RESULTS

Fig. 2 (a) and (b) show PSD curves of DEM and experimental samples respectively. Fig. 3 (a) shows variations of void ratios with fine percentages. In both experimental and DEM samples, $e_{max}$ and $e_{min}$ decreased until approximately 30% of fines. Then, $e_{max}$ and $e_{min}$ increased with addition of fines. As shown in Fig. 3 (a), experimental and DEM samples gave roughly same $e_{max}$ and $e_{min}$ results for binary mixtures with more than 50% fines. However, there are some gaps between experimental and DEM simulation results for binary samples with less than 50% fines. Fig. 3 (b) shows relations of $e_{max}$ and $e_{min}$ for experimental and DEM samples separately. Experimental and DEM results gave almost same trend, however, with higher values in experimental samples.

Fig. 4 shows $e_{min}$ results for DEM simulations using two different particle sizes (one is equal to the size of experimental particles and the other is 100 times larger than the size of experimental particles). This result indicated that same results (i.e., void ratio) can be obtained using large particles as well. In DEM simulations, use of large particles is important to reduce simulation time. Though particle size was increased, that affected to both gravel and sand as binary mixtures were used here. Therefore, more detailed analysis would be necessary to make concrete conclusions.

Fig. 5 shows different PSD curves used in DEM simulations in Series B. Fig. 6 (a) shows how $e_{max}$ and $e_{min}$ change with diameter ratio (i.e., $D_{min}/D_{max}$). The results showed that $e_{max}$ and $e_{min}$ decreased below 0.65 of $D_{min}/D_{max}$. It should be noted that ballast (standard) PSD curves is within 0.37 - 0.42 of $D_{min}/D_{max}$. Therefore, if ballast mix with fine materials (i.e., diameter ratio decrease), void ratios will decrease. Fig. 6 (b) shows relation of $e_{max}$ and $e_{min}$ obtained for DEM simulations under Series B. The relation is similar to the relations obtained in Fig. 3 (b).

Keywords: DEM simulations, PSD curves, Sand-gravel mixtures, Void ratios, YADE
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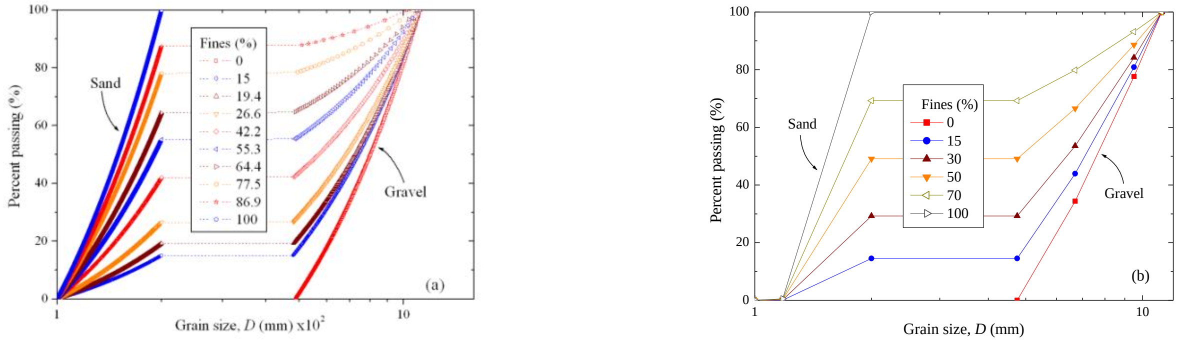


Fig. 2: Particles size distribution curves of (a) DEM simulations and (b) Experimental samples

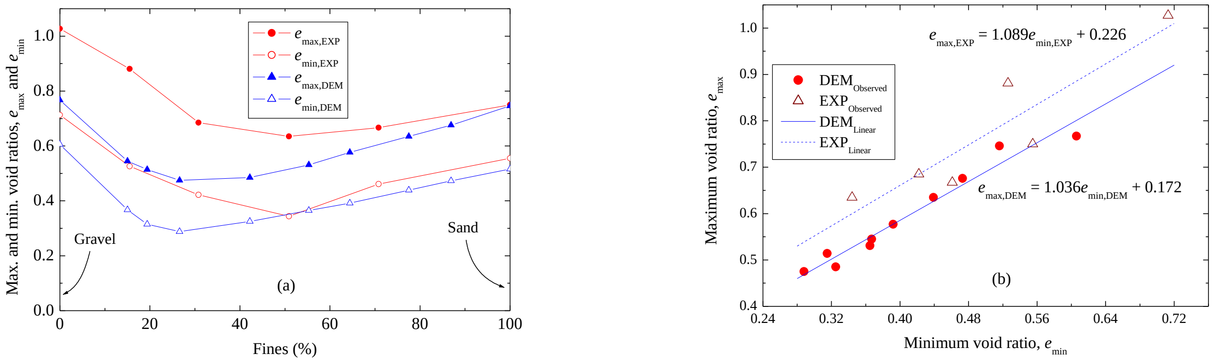


Fig. 3: (a) Results of void ratios and (b) Relations of $e_{min}$ and $e_{max}$ of binary mixtures (Series A)

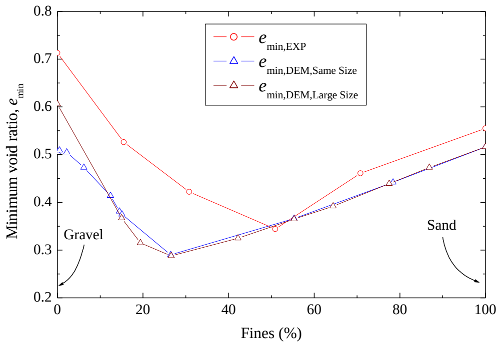


Fig. 4: Effects of particle size on void ratio (Series A)

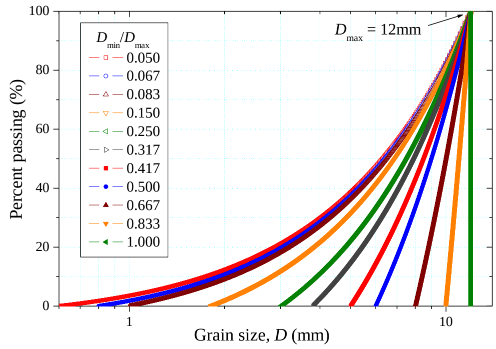


Fig. 5: Particles size distribution curves (Series B)

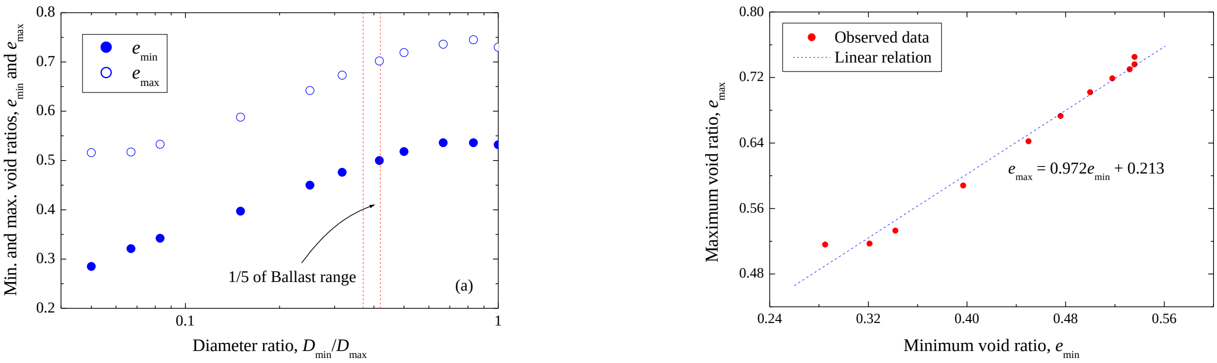


Fig. 6: (a) Void ratios vs. diameter ratio and (b) Relations of $e_{min}$ and $e_{max}$ (Series B)

## 4. CONCLUSIONS

The DEM simulation results showed that void ratio characteristics can be obtained same as experimental results for sand-gravel mixtures though there were some differences for samples with small amount of fines. The DEM results also showed that large particles (i.e., 100 times large) give same void ratio values. $e_{max}$ and $e_{min}$ decrease with diameter ratio, particularly, below 0.65 of diameter ratio.

## REFERENCES

Smilauer et al., Yade Reference Documentation, In Yade Documentation (Smilauer, ed.), The Yade Project, 1st ed., 2010 (http://yade-dem.org/doc/).

Thakur, P. K., Vinod, J.S. and Indraratna, B., Effect of particle breakage on cyclic densification of ballast: a DEM approach, IOP Conf. Series: Materials Science and Engineering, Sydney, Australia, 2010, 10, pp. 122-129.