RESEARCH ARTICLE | NOVEMBER 07 2019

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AIP Conf. Proc. 2169, 040005 (2019)
https://doi.org/10.1063/1.5132668

The Granular Buoyant Force in A Two-Dimensional Intruder-Particles Bed System

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Abstract. A two-dimensional granular system consists of a single intruder and particle board. All particles are frictionless and placed in a fluid with a specific density and viscosity. This work aims to investigate how particle bed can support the intruder in the way similar to how buoyant force can support a floating object. The final condition of the intruder is limited to the partially floating condition since the sinking condition will give any supporting information in formulating granular buoyant force. Considered types of forces are the gravitational force, fluid buoyant force, fluid viscous force, particle-particle and particle-wall normal force with elastic and damping constants, and particle-particle binding force for the intruder. Simulation is performed using the molecular dynamics method implementing the Euler algorithm. Only one kind of parameter variation is used in this work, which is a variation of intruder particle density. As the results, it is observed that an intruder with larger particle density sinks deeper than the smaller ones, but how it floats is still inaccurate. Finally, it can be concluded that the granular buoyant force will show similar characteristics as a fluid buoyant force, but not the same due to nature of granular particles that built the system.

INTRODUCTION

Small objects can float on water surface, even with a density higher than water as it was reportedly written about 150 years ago [1], but for larger ones only objects with smaller density than water can float as taught in nowadays textbooks [2]. These phenomena are related to buoyancy, where ordinarily only density plays a critical role. The concept can be taught through an experiment in a real laboratory [3] or in a virtual laboratory [4], where graphical illustration can be beneficial [5]. In this work object and the fluid are modeled in two-dimension using spherical granular particles with the same size. By varying density and diameter of the particles, the macroscopic phenomenon of buoyancy is observed and interpreted in the term of granular particles point of view.

METHOD

The system consists of two types of spherical granular particles with different densities but the same diameter that can only move in two-dimension. All particles are placed in fluid with density ρ_f, which gives them a buoyant force in the form of

$$\vec{B}_i = -\rho_f V_i' \vec{g} \tag{1}$$

for particle *i,* with V_i' is the immersed volume, which in this case is the same as V_i, volume of a particle. Against force in Eqn. (1) There is the gravitational force

The 8th National Physics Seminar 2019
AIP Conf. Proc. 2169, 040005-1–040005-6; https://doi.org/10.1063/1.5132668
Published by AIP Publishing. 978-0-7354-1916-2/$30.00

$$\vec{G}_i = \rho_i V_i \vec{g} \tag{2}$$

is due to earth gravity. Between two particles there with diameter D_i and D_j that are located at position $\vec{r}_i$ and $\vec{r}_j$ an overlap can be defined as

$$\xi_{ij} = \max\left[0, \tfrac{1}{2}\left(D_i + D_j\right) - r_{ij}\right] , \tag{3}$$

also, it's time derivative

$$\dot{\xi}_{ij} = -v_{ij} \operatorname{sign}(\xi_{ij}) . \tag{4}$$

Eqns. (3) and (4) are used to obtain the normal force

$$\vec{N}_{ij} = k_N \xi_{ij} \hat{r}_{ij} - \gamma_N \dot{\xi}_{ij} \hat{v}_{ij} . \tag{5}$$

Besides the normal force, there is also a binding force in the form of spring force

$$\vec{S}_{ij} = k_S \left[\tfrac{1}{2}\left(D_i + D_j\right) - r_{ij}\right] \hat{r}_{ij} - \gamma_S \vec{v}_{ij} . \tag{6}$$

Which binds some particles to form a solid object, that will be used to investigate the granular buoyant force. The last considered force is drag force

$$\vec{D}_i = -3\pi \eta_f D_i \left(\vec{v}_i - \vec{v}_f\right), \tag{7}$$

due to the fluid viscosity, η_f.

All forces in Eqns. (1), (2), (5), (6) and (7) are summed to get the acceleration

$$\vec{a}_i = \frac{1}{m_i}\left(\vec{D}_i + \vec{G}_i + \vec{B}_i + \sum_{j \neq i} \vec{N}_{ij} + \vec{S}_{ij}\right) \tag{8}$$

Using Newton's second law of motion. Eqn. (8) is actually the equation of motion for every particle, which is coupled to the other particle equation of motion. Eqn. (3) tells that Eqn. (5) is a short-range type of force which makes Eqn. (8) more difficult to solve. The numerical approach is an alternative to solve Eqn. (8), wherein this work Euler method is used

$$\vec{v}_i\left(t + \Delta t\right) = \vec{v}_i\left(t\right) + \vec{a}_i \Delta t \tag{9}$$

for velocity and

$$\vec{r}_i\left(t + \Delta t\right) = \vec{r}_i\left(t\right) + \vec{v}_i\left(t\right) \Delta t \tag{10}$$

for position. From Eqns. (8) and (9) we can get new velocity and position, which change Eqns. (1), (2), (5), and (6), and later change Eqn. (7). Repetition these equations from an initial time *begs* for final time t_{end} with time step Δt, gives the dynamics of the system.

RESULT AND DISCUSSION

The simulation system consists of spherical particles has been performed using parameter's value listed in Table 1, where multiple values indicate variation of a parameter, e.g. ρ_2 which is for particles forming the solid.

TABLE 1. Simulation parameters.

Parameter	Value	Unit
N_1, N_2	154, 20	-
D_1, D_2	0.01	m
ρ_1, ρ_2	2000, 2000 – 9000	kg/m^3
z_{int}	0.12	m
t_{int}	0.3	m
Δt, t_{beg}, t_{end}, t_{data}	0.001, 0, 5, 0.01	s
G	9.807	m/s^2
η_f	0.00089	Pa·s
ρ_f	1000	kg/m^3
k_N	400	N/m
γ_N	0.1	kg/s
k_S	500	N/m
γ_S	0.01	kg/s

In this system, spherical particles will have two roles. The former is for granular fluid (particle bed, lower index 1) and the last is for granular solid (intruder, lower index 2). The whole system is placed in a real fluid with density ρ_f and viscosity η_f.

There are three stages in the simulation. The first stage is where particles are generated and condensed to form a granular fluid (particle bed), second stage is where granular solid (intruder) falling to the bed, and final, stage is where both types of particles interacting and performing granular buoyancy, which is the center of this work.

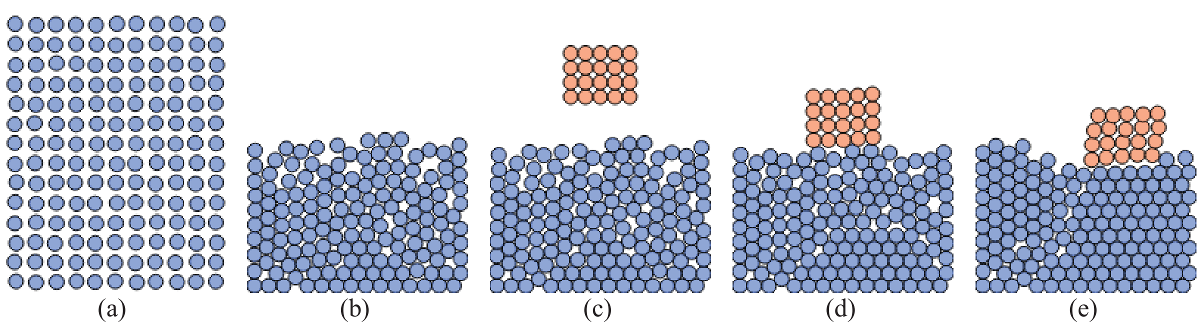

FIGURE 1. Simulations stages: particles bed generation and condensation (a–b), intruder falling (c–d), and buoyancy (e).

The three stages are shown in Fig. 1. The first stage is about 0.3 s or indicates with t_{int} in Table 1, and the simulation will stop after 5 s (t_{end}) from the beginning of the simulation (t_{beg}) with time step Δt = 0.001 s, where data in the form of time series are produced every 0.01 s as indicated by *t data*.

The density of bed particles ρ_1 is kept constant at a value of 2000 kg/m^3, while the density of intruder particles ρ_2 varies from 2000 kg/m^3 to 9000 kg/m^3. The initial state of the systems with different ρ_2 is similar to Fig. 1 (a – d) but different in the final shot as shown in Fig. 2.

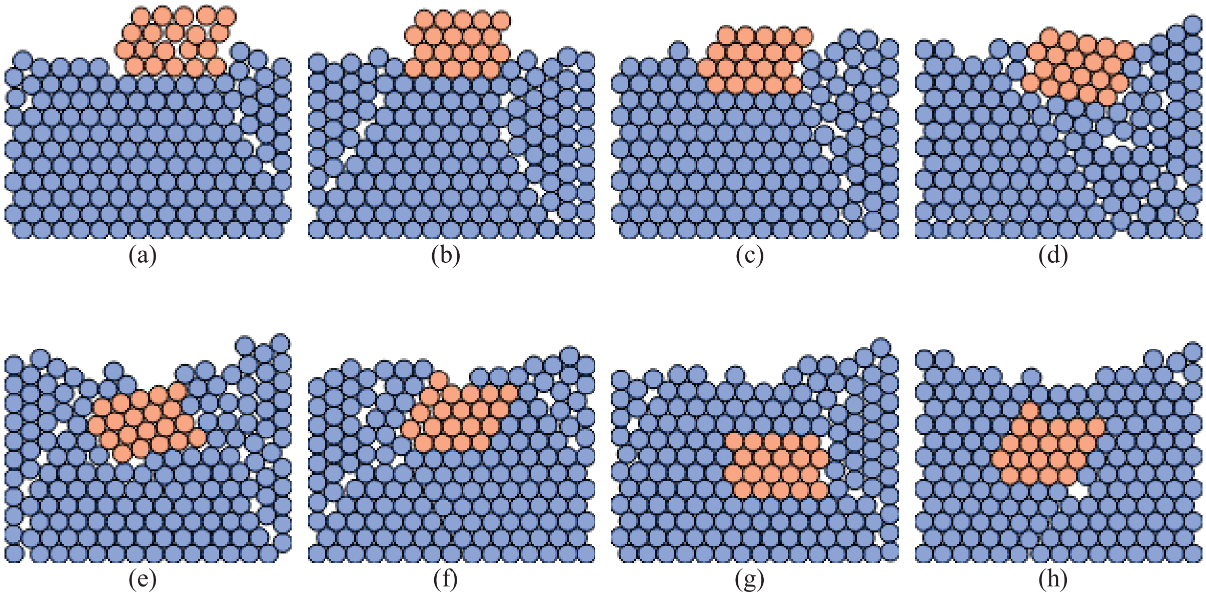

FIGURE 2. System final state with ρ_2/ρ_1: (a) 2/2, (b) 3/2, (c) 4/2, (d) 5/2, (e) 6/2, (f) 7/2, (g) 8/2, and (h) 9/2.

Similar to buoyancy in the real system Fig. 2 shows that intruder particles with larger density will also sink deeper than the smaller ones. Theoretically, using the concept of buoyancy when $\rho_2/\rho_1 = 1$ intruder should float with immersed part is about half-height and for other values intruder should sink as shown in Fig 3.

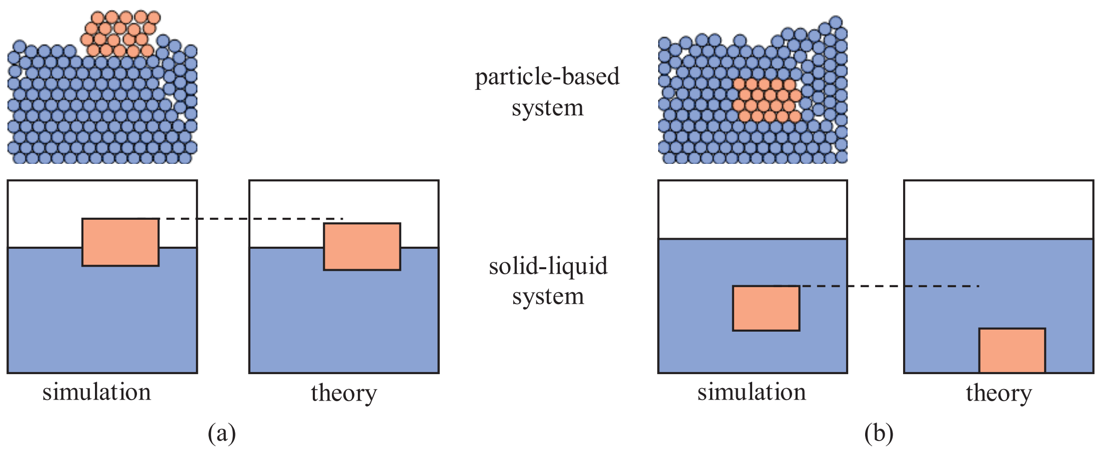

FIGURE 3. Comparison of the simulation system and theoretical prediction for ρ_2/ρ_1: (a) 2/2 and (g) 8/2.

Three vertical position part of the system is shown in Fig. 4 to get qualitative detail. The first is average of intruder particle's vertical position (ziavg), the second is maximum of bed particle's vertical position (zbmax), and the last is average of bed particle’s vertical position (zbavg). By comparing these three values in the form of time series, how the final state is, can be interpreted, e.g. Sinking is when ziavg lower than zbmax as in Fig 4. (b–h).

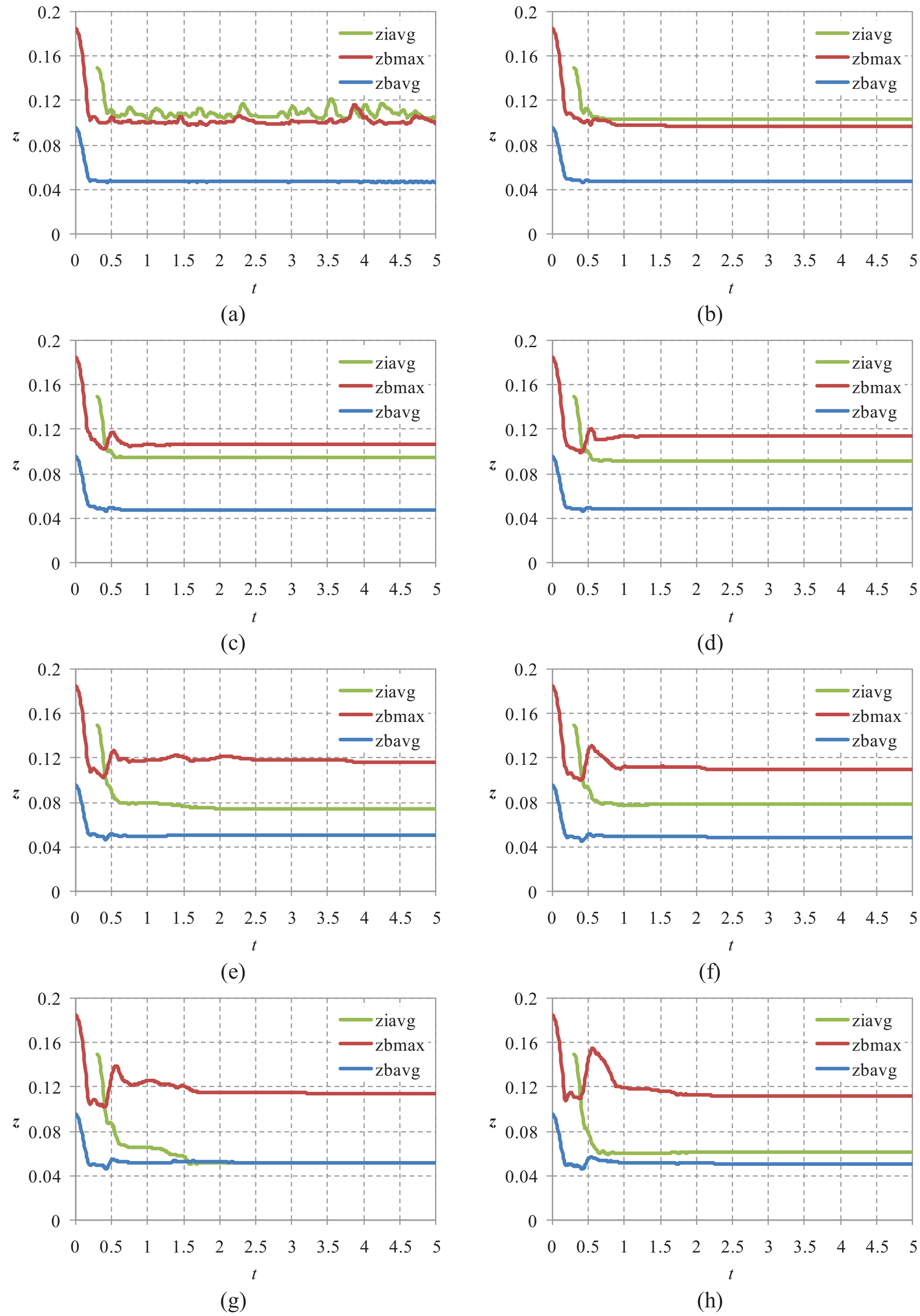

FIGURE 4. Intruder particles average vertical position (ziavg), bed particles maximum vertical position (zbmax), and bed particles average vertical position (zbavg) for ρ_2/ρ_1: (a) 2/2, (b) 3/2, (c) 4/2, (d) 5/2, (e) 6/2, (f) 7/2, (g) 8/2, and (h) 9/2.

Partially buoyancy can not be observed in detail due to closed packed state, which can inhibit the Brazil-nut effect [6], wherein this work it inhibits further floating and sinking process. Therefore, introducing fluidization for the better granular buoyancy phenomenon is required, which can be performed using fluid surface propagating wave [7] or an internal vertical flow [8]. The rigidity of the granular solid can also be enhanced by modifying the current interaction between particles, wherein this work it is still based on previous study [9].

CONCLUSION

Simulation to show granular buoyant force in a two-dimensional intruder-particles bed system has been performed. Buoyancy is observed, but partial floating can not be observed in detail due to the nature of granular particles, which tends to form close-packed structure and prevent the system in further evolving. Fluidization could be a solution to overcome this problem.

ACKNOWLEDGMENTS

We gratefully acknowledge support from the Hibah Penelitian Unggulan Universitas – Universitas Negeri Jakarta under the contract number 43/KOMP-UNJ/LPPM-UNJ/V/2019. All of our calculations were done using QC cluster in the Advanced Computational Physics Laboratory, Department of Physics-Institut Teknologi Bandung and in the Digital Laboratory, Department of Physics Education-Universitas Negeri Jakarta.

REFERENCES

1. G. Sigerson, "On a Cause of the Buoyancy of Bodies of a Greater Density than Water", *Proceedings of the Royal Irish Academy, Science*, vol. **2**, no. 2, pp. 22-25 (1875).
2. T. C. Hsu, S. Kissel, P. Eldrigde, S. Gutman, J. Selco, K. McAlister, M. Vela, M. Vela, "CPO Focus on Physical Sicence", *CPO Science, Nashua, 1st Edition*, pp. 84-86 (2007).
3. P. R. Espindola, C. R. Cena, D. C. B. Alves, D. F. Bozano, A. M. B. Goncalves, "Use of an Arduino to Study Buoyancy Force", *Physics Education [Phys. Educ.]*, vol. **53**, no. 3, pp. 035010 (2018).
4. J. M. Vitale, M. C. Linn, "Designing Virtual Laboratories to Foster Knowledge Integration: Buoyancy and Density", in *Cyber-Physical Laboratories in Engineering and Science Education*, edited by M. Auer, A. Azad, A. Edwards, T. de Jong, Springer, Cham, pp. 163-189 (2018).
5. J. M. Vitale, L. Applebaum, M. C. Linn, "Coordinating between Graphs and Science Concepts: Density and Buoyancy", *Cognition and Instruction [Cogn Instr.]*, vol. **37**, no. 1, pp. 38-72 (2019).
6. T. N. Ain, H. A. C. Wibowo, S. N. Khotimah, S. Viridi, *Journal of Physics: Conference Series [J. Phys. Conf. Ser.]*, vol. 739, no. 1, p. 012135 (2016).
7. S. Viridi, Nurhayati, J. Sabaryati, D. Muliyati, *SPEKTRA: Jurnal Fisika dan Aplikasinya*, vol. **3**, no. 3, pp. 133-142 (2018).
8. A. N. F. Rudiawan, K. N. Sari, H. Notsu, S. Viridi, *SPEKTRA: Jurnal Fisika dan Aplikasinya*, vol. **4**, no. 2, pp. 73-80 (2019).
9. S. Viridi, Widayani, S. N. Khotimah, "2-D Granular Model of Composite Elasticity using Molecular Dynamics Simulation", *AIP Conference Proceedings [AIP Conf. Proc.]*, vol. **1454**, no. 1, pp. 219-222 (2012).