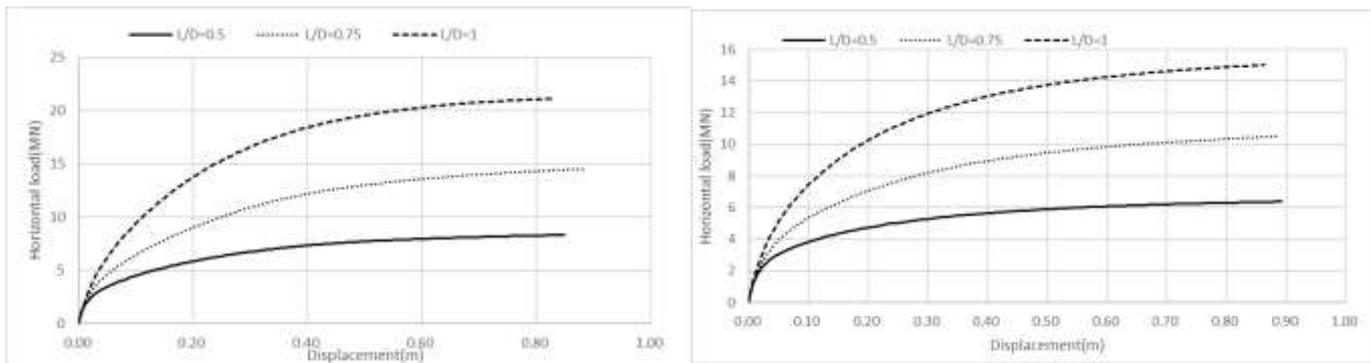


Fig. 7 In comparison to the displacement of the composite suction foundation upper lid diameter DI=12m,24m with different bucket L/D when load eccentricity $h=70\text{m}$ in dense sand

Fixed $h=30\text{m}$ and $D1=20\text{m}$, variation of lateral capacity under different bucket length ($L=6\text{m}$, 9m , and 12m ; and $L/D=0.5$, 0.75 , and 1) is shown in Fig. 8. Whether the soil condition is dense or medium dense, we can find the lateral capacity increases with increasing of bucket length. At the displacement 0.8m , the lateral capacity increases about $63.5\%\sim 72.9\%$ when the bucket length increasing from 6m to 9m . For the case increasing from 9m to 12m , the capacity increases about $44.1\%\sim 46.9\%$.

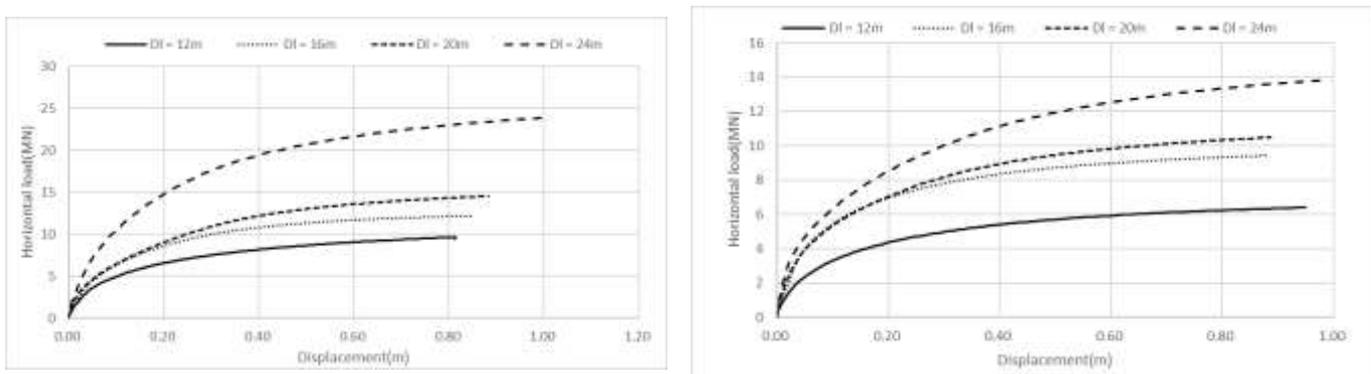


(a) in dense sand

(b) in medium dense sand

Fig. 8 Horizontal load–displacement interaction diagram (upper lid diameter $D_1=20\text{m}$, load eccentricity $h=30\text{m}$, with different bucket length)

Fixed $h=30\text{m}$ and $L=9\text{m}$, variation of lateral capacity under different lid diameter ($D_1=12\text{m}, 16\text{m}, 20\text{m}$, and 24m) is shown in Fig. 9. As shown in the figure, the lateral capacity increases with increasing of lid size. At the displacement 0.8m , the lateral capacity increases about $25.8\% \sim 49.7\%$ when the bucket length increasing from 12m to 16m .



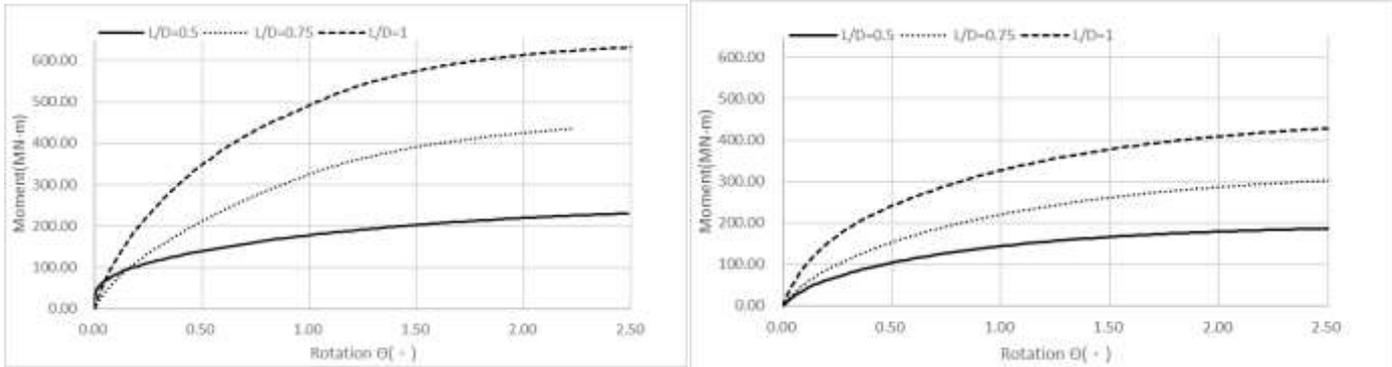
(a) in dense sand

(b) in medium dense sand

Fig. 9 Horizontal load–displacement interaction diagram ($L/D=0.75$, load eccentricity $h=30\text{m}$, with different upper lid diameter D_1)

If we assume $h=30\text{m}$ and $D_1=20\text{m}$, the moment versus rotation relationships

under different bucket length ($L=6\text{m}$, 9m , and 12m ; and $L/D=0.5$, 0.75 , and 1) are shown in Fig. 10. Increasing the bucket length also increases the bending resistance of the bucket. Under the same moment ($M=150\text{MN}\cdot\text{m}$), the rotation angle under bucket length of $L=6\text{m}$, $L=9\text{m}$, and $L=12\text{m}$ is 0.6 , 0.3 and 0.14 degree, respectively.

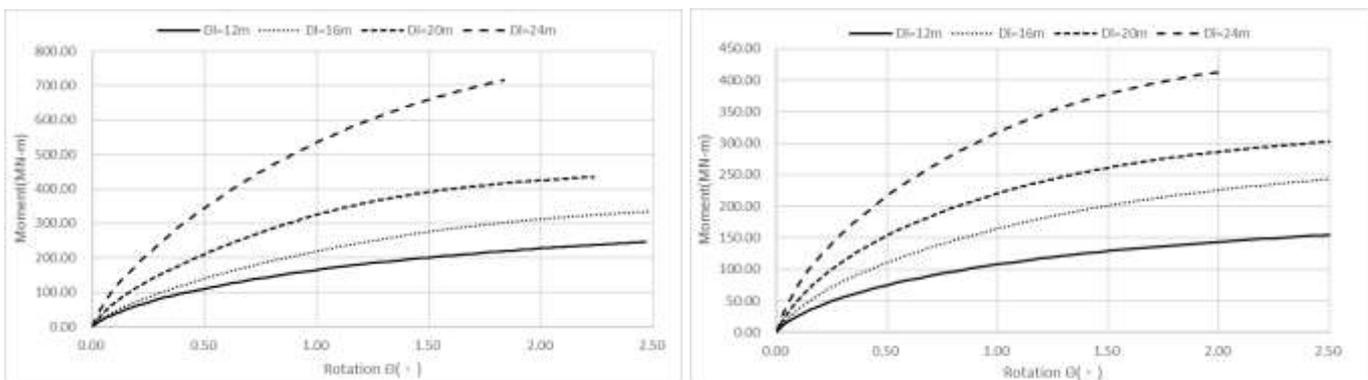


(a) in dense sand

(b) in medium dense sand

Fig. 10 Moment–rotation interaction diagram (upper lid diameter $D_l=20\text{m}$, load eccentricity $h=30\text{m}$, with different bucket length)

The relationships of moment versus rotation of the foundation with $h=30\text{m}$ and $L=9\text{m}$ under various lid size ($D_l=12\text{m}$, 16m , 20m , and 24m) are shown in Fig. 11. The figures showed the bending moment resistance of the foundation increases with increasing of the lid size, whether in medium dense sand or dense sand. Based on Figs. 10 and 11 we can find that the bending moment resistance of the foundation is improved by increasing the size of the lid or the length of the bucket.



(a) in dense sand

(b) in medium dense sand

Fig. 11 Moment–rotation interaction diagram ($L/D=0.75$, load eccentricity $h=30\text{m}$, with

different upper lid diameter D_l)

5. CONCLUSIONS

In this paper, a proposed composite foundation in medium dense sand or in dense sand subjected to combined loading is investigated using numerical simulation. The conclusions based on the results of the numerical studies can be drawn as in the following:

1. The rotating center of the foundation appeared to be higher under larger applied moment resulted from larger eccentricity. In addition, the lateral capacity of the foundation decreases when the bending.
2. Based on the variation of the effective normal stress on either side of the bucket, higher normal stress was observed below rotating center due to higher passive soil pressure. However, the effective normal stress above the rotating center appeared to be linearly increased along depth. In addition, the rotating center of the foundation appeared to be higher with increasing of the lid diameter (D_l).
3. Based on the failure mechanism of the composite foundation with $D_1=12\text{m}$, the foundation not only inclined under combined loading but also displaced in the horizontal direction. The soil condition on the right side of the bucket appeared to be passive failure while on the left side bucket appeared to have separation between soil and bucket. Above the rotating center of the bucket, passive failure was observed. For the composite foundation with $D_1=24\text{m}$, uplifting of the soil was observed on the right side of the lid. In addition, passive failure was observed on the left side of the bucket. The rotating center of the $D_1=24\text{m}$ case was higher than that of the $D_1=12\text{m}$ case, which indicated that the composite foundation has higher bending moment resistance than that of the conventional bucket foundation.
4. The lateral capacity of the composite foundation improved with increasing lid diameter or bucket depth. The foundation rotating degree became lower with increasing of lid diameter or bucket depth. Hence, the bending moment resistance of the composite foundation was also increased.

REFERENCES

Achmus, M., Akdag, C.T., Thieken, K. (2013), "Load-bearing behavior of suction bucket

- foundations in sand. "Ocean Research.43,157-165.
- Andersen, K.H., Jostad,H.P., Dyvik,R.(2008), "Penetration resistance of offshore skirted foundation sand anchors in dense sand. "J.Geotech.Geoenviron.Eng. 134(1),106–116.
- Byrne, B.W., Houlsby, G.T. (2004), "Experimental Investigations of the response of suction caissons to transient combined loading. "J.Geotech. Geoenviron.Eng.2004.130.pp240-253.
- Houlsby,G.T., Ibsen,L.B., Byrne,B.W.(2005), "Suction caissons for wind turbines. "Key note lecture.In:Proceeding sof the International Symposiumon Frontiers in Offshore Geotechnics.Perth,Western Australia,75–94.
- Houlsby, G.T., Richard, B., Kelly, R.B., Byrne, B.W.(2005), "The tensile capacity of suction caissons in sand under rapid loading. "ISFOG 2005,405-410.
- Ibsen, L.B., Larsen, K.A., Barari. (2014), "Calibration of failure criteria for bucket foundation on drained sand under general loading. "J.Geotech. Geoenviron.Eng.2014.140(7).
- Jaky, J.(1944), "The coefficient of earth pressure at-rest. " Journal of Society of Hungarian Architects and Engineers, 355–358.
- Kelly, R.B., Houlsby, G.T., Byrne, B.W. (2006), " A comparison of field and laboratory tests of caisson foundations in sand and clay. " Geotechnique. 56(9),617–626.
- Lian, J., Chen, F., Wang, H. (2014), "Laboratory tests on soil-skirt interaction and penetration resistance of suction caissons during installation in sand. "Ocean Engineering.84(2014),1-13.
- Plaxis user's manual,version2013.
- Ravichandran, V., Ramesh, R., Babu, S.M., Ramadass, G.A., Ramanamoorthy, Atmanand, M.A.(2014), "Field scale tests for determination of pullout capacity of suction pile anchors under varying loading conditions. "Geotechnical Engineering Journal of the SEAGS & AGSSEA.2014.45(3).49-51.
- Tran, M.N., Randolph, M.F.(2008) "Variation of suction pressure during caisson installation in sand. " Geotechnique. 58(1),1-11
- Tran, M.N., Randolph, M.F., Airey, D.W.(2007), "Installation of suction caissons in sand with silt layers. " J.Geotech. Geoenviron.Eng.2007.133,1183-1191.
- Villalobos, F.A., Byrne, B.W., Houlsby, G.T.(2005), "Moment loading of caissons installed in saturated sand. "In: Proceedings of international symposium on frontiers in Geotechnics, ISFOG. University of Western;411–16 .
- Villalobos, F.A., Byrne, B.W., Houlsby, G.T. (2009), "An experimental study of the

drained capacity of suction caisson foundations under monotonic loading for offshore applications. "Soils and Foundations;49:477–88 .

Zhang, J.H., Chen, Z.Y., Li, F. (2010), "Three dimensional limit analysis of suction bucket foundations. "Ocean Engineering;37:790–9 .

Zhu, B., Byrne, B.W., Houlsby, G.T. (2013), "Long-term lateral cyclic response of suction caisson foundation in sand. "J.Geotech. Geoenviron . Eng . 2013 . 139 , 73-83