Table 6 The results comparison of RS pile model and lab experiment of soil reaction-depth from pile head

Load (KN)	**Maximum soil reaction of Li et al. (2021) Laboratory experiment (Kpa)**	**Maximum soil reaction of RS pile model (Kpa)**
H = 0, V = 0	0	0
H = 38, V = 0	28.68	68.80
H = 79, V = 0	59.71	126.87
H = 119, V = 0	90.09	210.42
H = 158, V = 0	119.88	278.90
H = 198, V = 0	150.66	401.25
H = 238, V = 0	181.72	476.65
H = 278, V = 0	213.12	555.82
H = 316, V = 0	243.29	635.00
H = 355, V = 0	274.67	708.59
H = 393, V = 0	310.66	748.65

Both models indicate that an increase in the horizontal force applied results in an increase in the soil reaction. As the applied force increases from 0KN to 355KN, the soil reaction increases to 274.67kpa for the RS pile and 708.59kpa for the lab experiment. The discrepancy between the laboratory result and the RS pile is about threefold in this instance.

As the applied force increases to 393KN, the soil reaction reaches around 310.66 for the RS pile and 748.65kpa for the lab experiment. In this instance, the discrepancy between the RS pile model and the laboratory result is about twofold.

4.3 Effect of pile diameter on lateral displacement for only horizontally loaded pile:

As mentioned above, the investigation utilised input parameters in a test done by (Finn and J. Dowling 2016). Eight different diameters of the pile are analysed: 0.324m, 0.5m, 0.75m, 1.0m,1.25m, 1.5m, 1.75m, and 2.0m. The results comparison of load-displacement are shown in Figure 11 and Table 7 below,

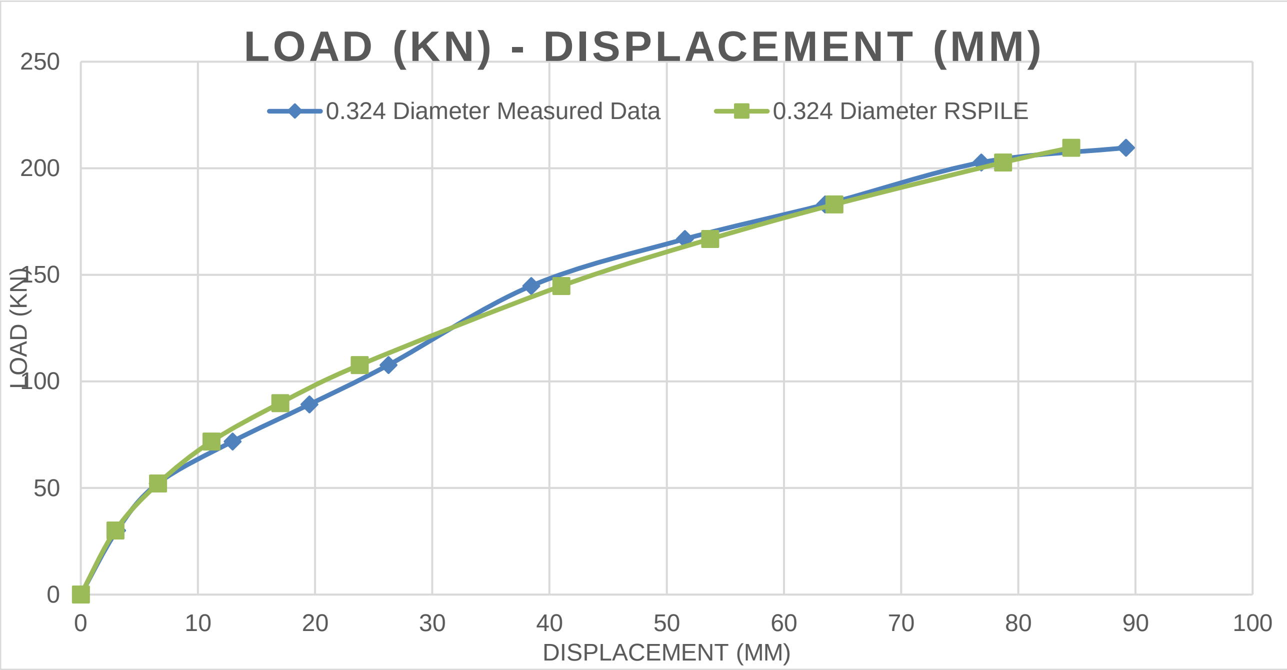

Figure 11 Results of Load - Displacement curve of 0.324m diameter.

Table 7 The results comparison of Rs pile and Verset 3D model of load-displacement curve

0.324m Diameter of pile		
Load (KN)	Measured Displacement (Verset 3D) (mm)	RS pile displacement (mm)
0	0	0
30.11	3.088	2.95
52.12	6.56	6.59
71.81	12.93	11.14
89.81	19.49	17
107.72	26.25	23.8
144.78	38.41	41
166.79	51.54	53.7
183.011	63.51	64.3
202.7	76.83	78.7
209.65	89.19	84.5

Both models indicate that an increase in the horizontal force applied results in an increase in the displacement. As the applied force increases from 0KN to 209.65KN, the displacement increases to

84.5mm for the RS pile and 89.19mm for the Verset 3D. The discrepancy between the Verset 3D and the RS pile is about 2% in this instance.

The calibrated software is used to construct load-deflection curves for various pile diameters ranging from 0.5 to 2.0 m.

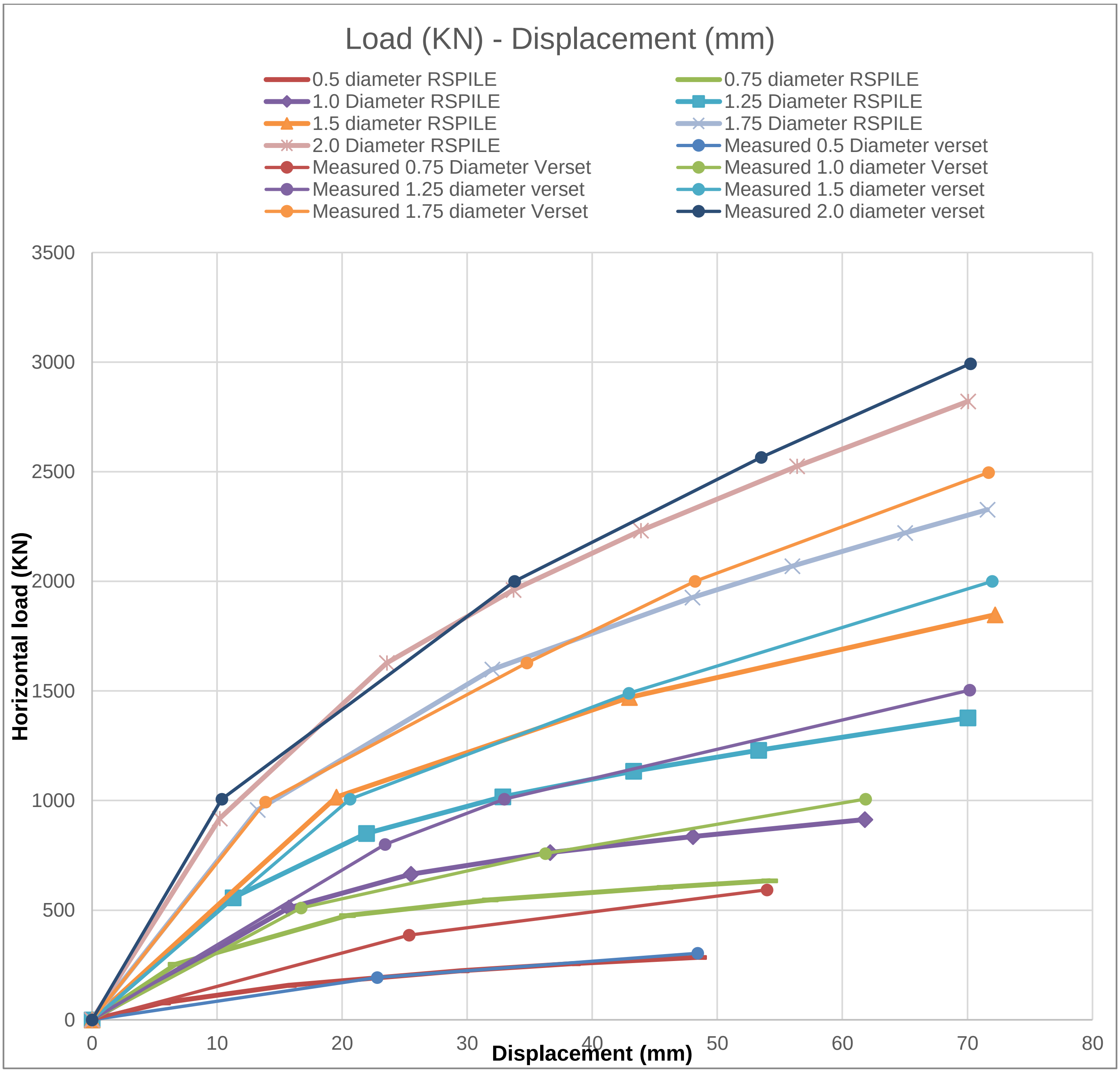

Figure 12 Results comparison of Verset 3D and Rs pile model of load-displacement curve.

Upon comparing the outputs of the Verset 3D and RS pile models, it is evident that both programmes yield identical outcomes. The maximum displacements for different pile diameters were as follows: 48.41mm for a 0.5m diameter, 53.97mm for a 0.75m diameter, 61.98mm for a 1.0m diameter, 70.028mm for a 1.25m diameter, 72.2mm for a 1.5m diameter, 71.6mm for a 1.75m diameter, and 70.06mm for a 2.0m diameter. Based on a comprehensive examination of all the results, it can be concluded that the displacement is slightly reduced when the pile diameter increases from 1.5m to 2.0m.

(Finn and J. Dowling 2016) derived a linear connection by summarising the numerical analysis results of the displacement of piles with varying diameters in different soil layers. It converts the load-displacement curve and moment-depth curve into logarithmic equations and plots all the data on a rectangular coordinate system. Figures 13 and 14 illustrate the linear relationship between load-diameter and moment-diameter.

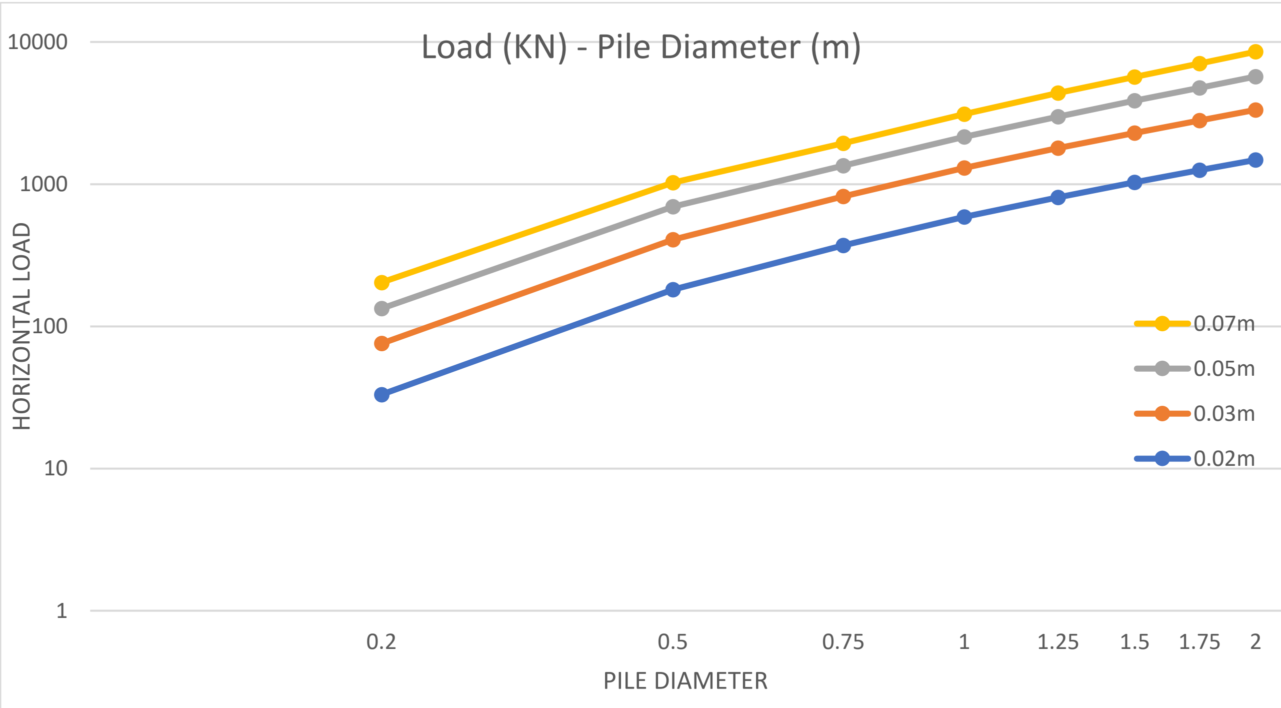

Figure 13 The logarithmic curve of Horizontal load-pile diameter.

Table 8 The results of load-pile diameter for displacement

	Displacement (m)			
Diameter (m)	0.02m	0.03m	0.05m	0.07m
0.2	33.141	42.567	57.757	70.191
0.5	181.264	225.877	288.75	328.784
0.75	371.612	447.114	530.304	590.551
1	588.92	709.775	847.448	958.662
1.25	809.17	980.893	1199.131	1377.37
1.5	1029.39	1260.63	1570.061	1821.771
1.75	1252.654	1550.279	1962.697	2301.544
2	1479.047	1849.982	2378.93	2820.174

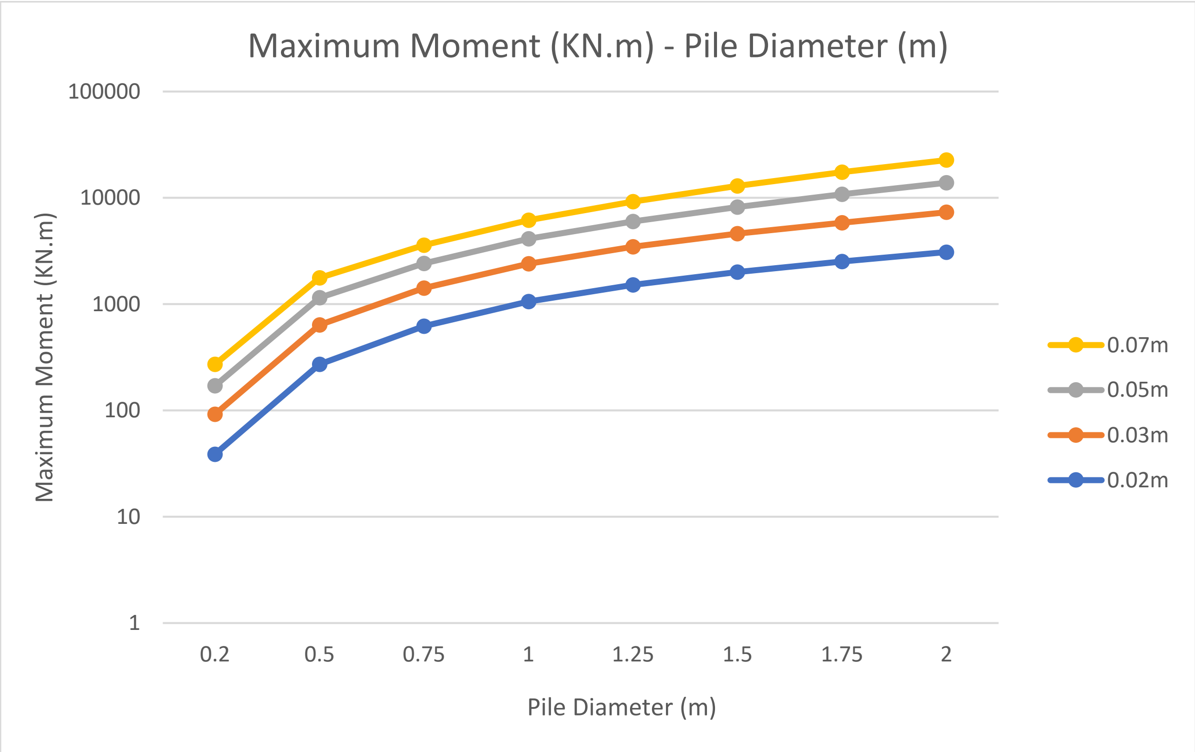

Figure 14 The Logarithmic curve of maximum moment-pile diameter.

Table 9 The Results of maximum moment-pile diameter

Maximum Moment (KN.m)				
Diameter (m)	0.02m	0.03m	0.05m	0.07m
0.2	38.826	53.305	78.512	101
0.5	272	367	514	614
0.75	620	793	1003	1170
1	1060	1340	1710	2040
1.25	1520	1940	2550	3220
1.5	2000	2590	3600	4780
1.75	2520	3320	4960	6640
2	3090	4220	6540	8800

4.4 Effect of pile diameter on displacement for both horizontally and vertically loaded piles:

In this case study, the investigation utilised input parameters in a test done by (Finn and J. Dowling 2016). There are eight different diameters of the pile analysed: 0.324m, 0.5m, 0.75m, 1.0m,1.25m, 1.5m, 1.75m, and 2.0m. We assumed a vertical load of 100KN for the pile with a diameter of 0.324m, and a vertical load of 500KN for the remaining seven piles. The results of load-displacement are shown in Figure 15, Figure 16 and Table 10 below,

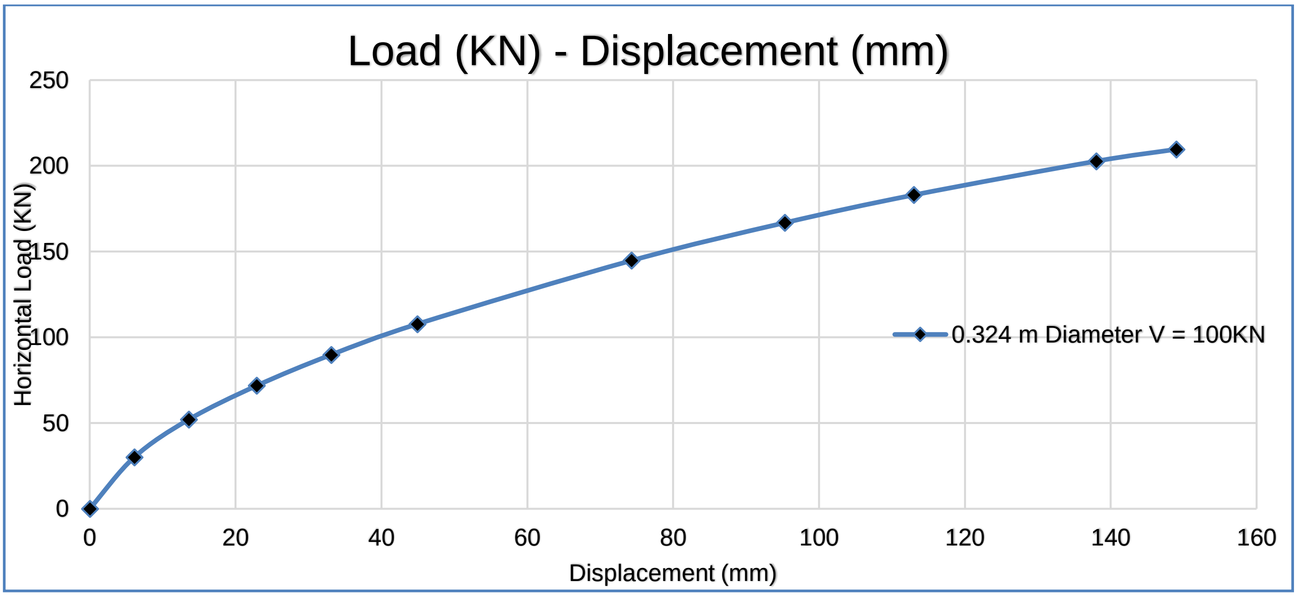

Figure 15 Load-displacement curve of 0.324m diameter of pile, V=100KN.

Table 10 The results of load-displacement for 0.324m diameter, V=100KN

0.324m diameter of pile, V=100KN	
horizontal load (KN)	**Displacement (mm)**
0	0
30.11	6.12
52.12	13.6
71.81	22.9
89.81	33.1
107.722	44.9
144.78	74.3
166.79	95.3
183.011	113
202.7	138
209.65	149

This case study displays the load-displacement characteristics of a pile with a diameter of 0.324m when subjected to a vertical force of 100 KN. At first, the pile exhibits a high level of rigidity and experiences a substantial rise in load for tiny displacements, such as 30.11 kilonewtons at 6.12 mm. As the displacement grows, the rate at which the load increments slows down, suggesting a decrease in stiffness (e.g., the load is 144.78 KN at a displacement of 74.3 mm). The stack demonstrates non-linear elastic characteristics that shift to yielding at greater displacements. The pile exhibited a significant load-bearing capacity and deformation tolerance under horizontal loading, with a maximum recorded load of 209.65 KN at a displacement of 149 mm.

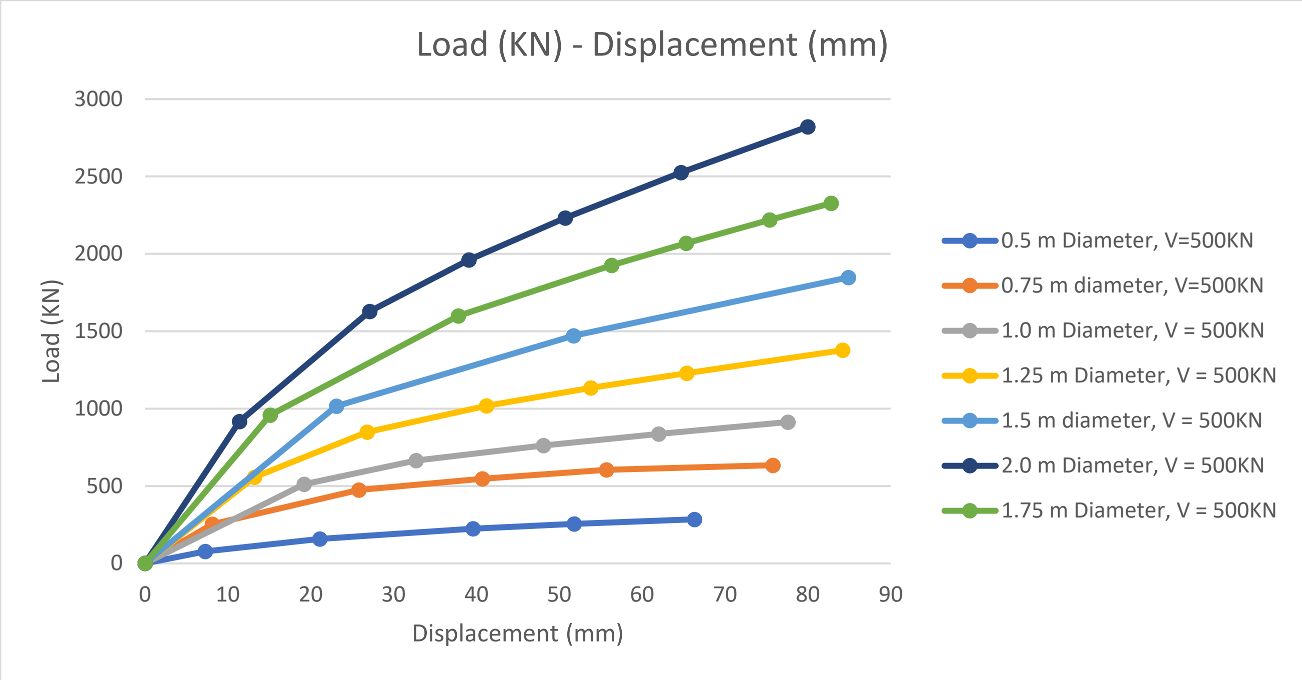

Figure 16 The load-displacement curve of seven different diameters, V=500KN.

The detailed results of load-displacement for every diameter of pile are shown in the Appendices below, the load-displacement characteristics of piles spanning a diameter of 0.5m to 2.0m while subjected to a consistent vertical load of 500KN are illustrated in the graph. The load causes a rapid increase in displacement for the pile with the smallest diameter (0.5m), which reaches a maximum of 800 KN at 80 mm and carries approximately 500 KN at 30 mm of displacement, indicating a lower capacity and greater flexibility. The moderate improvement is evident in the 0.75m pile's support of 750 KN at 40 mm displacement and 900 KN at 80 mm displacement. At 40 mm and 80 mm, the 1.0m pile bears approximately 900 KN and 1100 KN, respectively, indicating increased rigidity. 1100 KN is supported at 40 mm by the 1.25m pile, with a maximum of 1300 KN at 80 mm, indicating further performance enhancement. The 1.5-meter pile is capable of withstanding 1250 KN at 40 mm and 1500 KN at 80 mm, demonstrating a markedly increased capacity and rigidity. The 1.75-meter pile exhibits robust performance, with a maximum support of 1800 KN at 80 mm and an approximate 1500 KN at 40 mm. With a maximum capacity of 2200 KN at 80 mm and a minimum capacity of 1800 KN at 40 mm, the pile with the largest diameter (2.0 m) exhibits the greatest rigidity and least displacement when subjected to strain. In general, piles of greater diameter demonstrate enhanced load-bearing capacity and structural rigidity when subjected to the same horizontal load as smaller-diameter piles.

CHAPTER 5: CONCLUSION AND FUTURE WORK

5.1 Conclusion:

This study has developed the impact of vertical loading on the lateral behaviour of piles in the sand by using RS pile numerical simulation software.

A correlation was observed between the RSPILE model and laboratory experiments conducted by Li et al. (2021), which demonstrated that as horizontal force increases, pile head displacement also increases. In general, the RSPILE model forecasted greater displacements than the laboratory experiments. The main cause of this disparity, which is approximately two to three times more pronounced in the RSPILE model, is the utilisation of elastic piles in RSPILE as opposed to rigid piles utilised in laboratory experiments.

In the laboratory investigations conducted by Li et al. (2021), the soil reaction results were greater than those predicted by the RS pile model. The laboratory findings estimated soil reactions that were roughly two to three times more intense than those predicted by the Rs pile model, suggesting that the numerical model adopted a more cautious approach. The distinctions underscore the significance of material properties and model assumptions in simulations.

The investigation additionally assessed the correlation between pile diameter and lateral displacement for piles subjected to both horizontal and combined horizontal and vertical loads. The displacement of horizontally laden piles exhibited consistent patterns in both the RSPILE and VERSET 3D models (Finn and J. Dowling 2016), wherein an increase in pile diameter resulted in a marginal reduction. Increased diameters of piles exhibited improved load-bearing capacity and decreased displacements under combined loading conditions, thereby underscoring the structural advantages associated with such increases.

To conclude, putting a 500KN vertical load on the pile caused it to move 18 mm for a 0.5 m diameter, 19 mm for a 0.75 m diameter, 15 mm for a 1.0 m diameter, 14.2 mm for a 1.25 m diameter, 12 mm for a 1.5 mm diameter, and 10 mm for a 1.75 m diameter and a 2.0 m diameter. The difference in movement between piles loaded horizontally and those loaded vertically and horizontally is about 12%.

5.2 Future work:

Due to the limitation of time and resources, this study only focuses on numerical analysis methods in RS pile software.

Study the long-term performance and durability of piles subjected to combined vertical and lateral loads. This includes examining the effects of cyclic loading and the potential degradation of materials over time.

Conduct full-scale field tests, and centrifuge tests for soil reaction - displacement (p-y) in the lab.

Examine the impact of various pile materials, such as steel, concrete, and composite materials, on the ability to withstand both horizontal and vertical loads. Additionally, analyse the impact of the pile's cross-section shape, such as a square shape, on its ability to sustain both lateral and vertical loads.

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APPENDICES

Table 11 The results of load-displacement for 0.5m diameter of pile, V=500KN

0.5 m Diameter, V=500KN			
Displacement (m)	**Horizontal LOAD (KN)**	**Moment (KN.M)**	**VERTICAL LOAD (KN)**
0	0	0	0
7.27	77.072	37.225776	500
21.1	157.543	76.093269	500
39.6	223.951	108.168333	500
51.8	255.731	123.518073	500
66.3	284.892	137.602836	500

Table 12 The results of load-displacement for 0.75m diameter of pile, V=500KN

0.75 m diameter, V=500KN			
Displacement (m)	**Horizontal Load (kn)**	**moment (kn.m)**	**VERTICAL LOAD (KN)**
0	0	0	0
8.11	253.25	122.31975	500
25.8	475.072	229.459776	500
40.7	546.83	264.11889	500
55.68	603.905	291.686115	500
75.8	634.397	306.413751	500

Table 13 The results of load-displacement for 1.0m diameter of pile, V=500KN

1.0 m Diameter, V = 500KN			
Displacement (m)	**moment (KN.m)**	**Horizontal Load (KN)**	**VERTICAL LOAD**
0	0	0	0
19.2	246.678726	510.722	500
32.7	320.636169	663.843	500
48.1	368.417427	762.769	500
62	403.784619	835.993	500
77.6	441.207942	913.474	500

Table 14 The results of load-displacement for 1.25m diameter of pile, V=500KN

1.25 m Diameter, V = 500KN			
Displacement (m)	**Horizontal Load (KN)**	**moment (kn.m)**	**VERTICAL LOAD**
0	0	0	0
13.2	556.561	268.818963	500
26.8	849.666	410.388678	500
41.2	1017.822	491.608026	500
53.8	1133.802	547.626366	500
65.4	1229.897	594.040251	500
84.2	1377.609	665.385	500

Table 15 The results of load-displacement for 1.75m diameter of pile, V=500KN

1.75 m Diameter, V = 500KN			
Displacement (m)	**Horizontal Load (KN)**	**moment (kn.m)**	**VERTICAL LOAD**
0	0	0	0
15.1	957.472	462.458976	500
37.8	1598.572	772.110276	500
56.3	1926.148	930.329484	500
65.3	2068.796	999.228468	500
75.4	2220.49	1072.49667	500
82.8	2327.042	1123.96	500

Table 16 The results of load-displacement for 2.0m diameter of pile, V=500KN

2.0 m Diameter, V = 500KN			
Displacement (m)	**Horizontal Load (KN)**	**moment (kn.m)**	**VERTICAL LOAD**
0	0	0	0
11.4	917.781	443.288223	500
27.1	1627.694	786.176202	500
39.1	1961.145	947.233035	500
50.7	2231.66	1077.89178	500
64.7	2525.326	1219.732458	500
80	2821.42	1362.75	500

Risk Assessment Form:

RISK ASSESSMENT FORM

Flinders University

List identified hazards and detail measures taken to eliminate / minimise the risks:
(boxes on this form will expand to fit text)

Click to add image

Risk Assessment No.	1
Reference to SWP/SWMS No.	

College/Portfolio	civil	**Area/Unit**		**Location**	Tonsely pods - flinders university	**Area/Unit Manager**	
Task/Procedure	centrifuge test	**Workers consulted / involved**		**Date**	08/09/2023	**Review Date**	

Identified Hazard before controls		Risk Assessment			Risk Controls	Residual risk			Implementation
No.	**Description**	**Consequences**	**Likelihood**	**Risk Measure** (see matrix)	**Control measures**	**Consequences**	**Likelihood**	**Risk Measure** (see matrix)	**Date controls implemented / reviewed**
1	Heavy equipment handling	Major Injury	Unlikely	Medium	check the weight of materials prior to lifting/ moving it use trolly cart to move objects/materials.	First Aid	Possible	Medium	
2	pile driving hazards	Major Injury	Unlikely	Medium	Adequate hearing protection and vibration monitoring should be provided to protect the health of researchers and nearby workers.	First Aid	Highly Unli	Low	
3	load testing	First Aid	Possible	Medium	Researchers need to ensure that the testing apparatus is well-designed and adequately secured to prevent accidents during load application.	First Aid	Possible	Medium	
4	sinking hazard	Minor Injury	Unlikely	Medium	Proper safety measures, such as using appropriate footwear and equipment, should be employed.	First Aid	Possible	Medium	
5	soil contamination	Minor Injury	Unlikely	Medium	Environmental impact assessments should be conducted to minimize the risks of soil contamination.	Minor Injury	Possible	Medium	
6		-Select -	- Select -			- Select -	- Select -		

Review the risk measured, and the controls implemented are still relevant and effective, then please select one of the following:

A The assessment reveals that the potential risk to health and safety from the use of the plant/equipment/procedure is not currently significant. ☐

B The assessment reveals that the potential risk to health and safety from the use of the plant/equipment/procedure is significant. However controls are in place that reduce risk as low as is reasonably practicable. ☐

Note: If the risk level is still **Extreme/High** after controls are in place, then cease the activity, identify and implement further controls and consult with your manager/supervisor until the risk is reduced as low as reasonably practicable.

Risk Assessment Form - revised 15 February 2021 centrifuge test Page 1 of 3