The optimum installation angle of reticulated root piles

La disposition angulaire optimale de pieux racines réticulés

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ABSTRACT: In order to investigate the influence of installation angle of reticulated root piles(RRP) on their bearing capacities, model tests with various installation angles(0°, 5°, 10°, 15°, 20°, and 25°) are carried out. According to the test results, optimum installation angles for compressive and uplift loadings are 12° and 13°, respectively, and their capacities are increased by 13% in compression tests and by 21% in uplifting tests compared to those of vertical RRP's. It is also appreciated that increase of the size of the installation angle makes the load-settlement behavior more hardened when compressive load is applied. For lateral loading, RRP's response is heavily influenced by the displacement level. At low displacement level(1mm), lateral load capacity increases as the installation angle is increased. But the value of the optimum installation angle decreases as the displacement level is increased. It is found to be 17.5° at 6mm lateral displacement.

RESUME: Dans le but d'examiner l'influence de la disposition angulaire des RRP sur leurs capacités portantes, des tests sur modèle ont été effectués pour différentes dispositions angulaires (0°, 5°, 10°, 15°, 20°, et 25°). Selon les résultats des tests, les dispositions angulaires optimales pour des forces de compression et de soulèvement sont, respectivement, de 12° et 13°; comparées aux RRP verticaux, leurs capacités portantes sont améliorées de 13% et 21%, respectivement, pour les tests de compression et de soulèvement. L'augmentation de la disposition angulaire renforce le comportement au tassement pour des charges compressives. Pour des forces latérales, les déplacements influencent fortement la réponse des RRP. Pour de petits déplacements (1mm), la capacité de la charge latérale augmente en proportion de la disposition angulaire. Cependant, la disposition angulaire optimale décroît si le déplacement augmente, et celle-ci est de 17,5° pour un déplacement latéral de 6mm.

1 INTRODUCTION

Reticulated root piles(RRP) consist of small diameter cast-in-place piles which have reinforcing elements in the center and their diameters are about 75~250mm. Trees can withstand external forces such as storms and heavy winds, for their roots are tightly bonded to surrounding soils. Engineers have recognized their high resisting capabilities against the external forces and tried to reinforce the earth by inserting artificial elements similiar to the roots of trees. RRP are now widely used as foundations, retaining structures, slope stabilizing structures and the system of underpinning the existing buildings whose stability is suspicious , and so forth(Lizzi, F. 1964).

Recently more efficient drilling machines have been developed in smaller sizes so that RRP's are applied to various types of soils in different situations such as in narrow job sites or urban areas packed with buildings.

In spite of these advantages of RRP in application, the optimum design criteria on an installation angle, arrangement, length, diameter of RRP are not well established. Therefore, RRP have been designed by empirical basis. The purpose of this study is to analyze the bearing characteristics of RRP, focused on the effect of installation angle, by performing model tests under compressive, uplift and lateral loading.

2 MODEL TEST

For the tests, sandy soils with specific gravity, 2.66 , relative density, 47%, internal friction angle, 35° and coefficient of uniformity, 1.93, are used. Foundation soils are prepared by raining technique in a model box with dimensions of 2m by 1m in area, by 2.5m in depth. Model RRP's are located at the top and the center of foundation soils in model box. Fig. 1, 2 and 3 show the compressive, uplift and lateral load test rigs, respectively.

Installation angles of RRP for the tests are 0°, 5°, 10°, 15°, 20°, and 25°. One set of RRP used in compressive and uplift load tests consists of 8 piles which are installed in circular patterns forming two concentric circles, each of which has 4 piles(Fig. 4)(Thorburn, S. & Littlejohn, G. S. 1993). One set of RRP used in lateral load tests consists of 12 piles which are installed in the same pattern as the compressive and uplift load tests but the number of piles forming one concentric circle is 6. Individual pile which is made of a steel bar of 5 mm in diameter, is coated with sand to be 6.5 mm in diameter. The length of individual pile under compression and uplifting is 300 mm and the length of individual pile under lateral load is 350 mm.

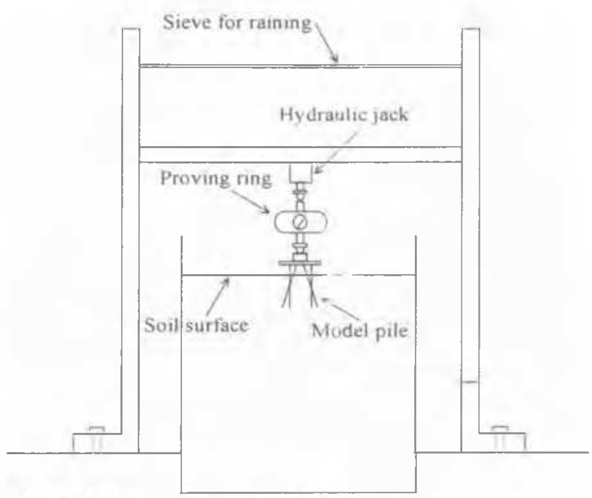

Fig. 1. Compressive load test rig

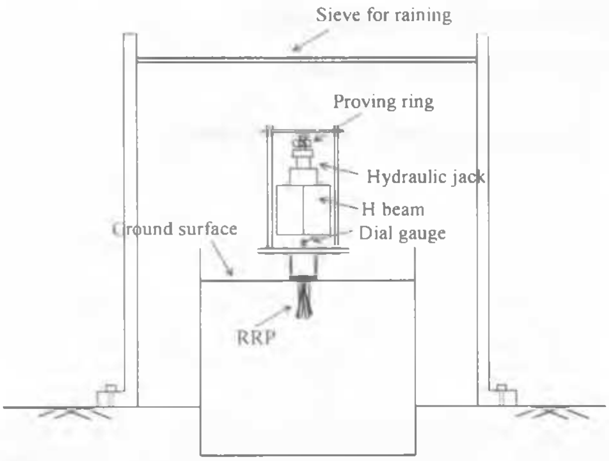

Fig. 2. Uplift test rig

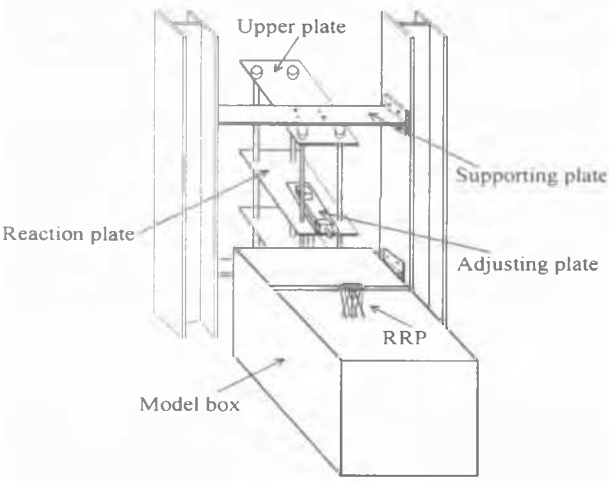

Fig. 3. Lateral load test rig

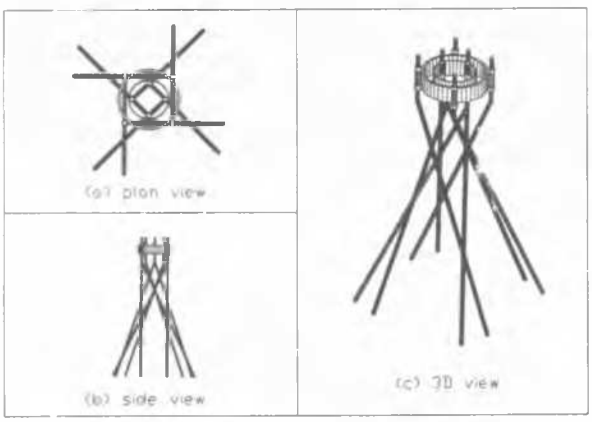

Fig. 4. Shape of RRP under axial loading

In addition to the RRP model tests, compressive load tests on shallow circular footing whose diameter is the same as the outer circle of RRP are carried out. All types of the model tests are replicated four times.

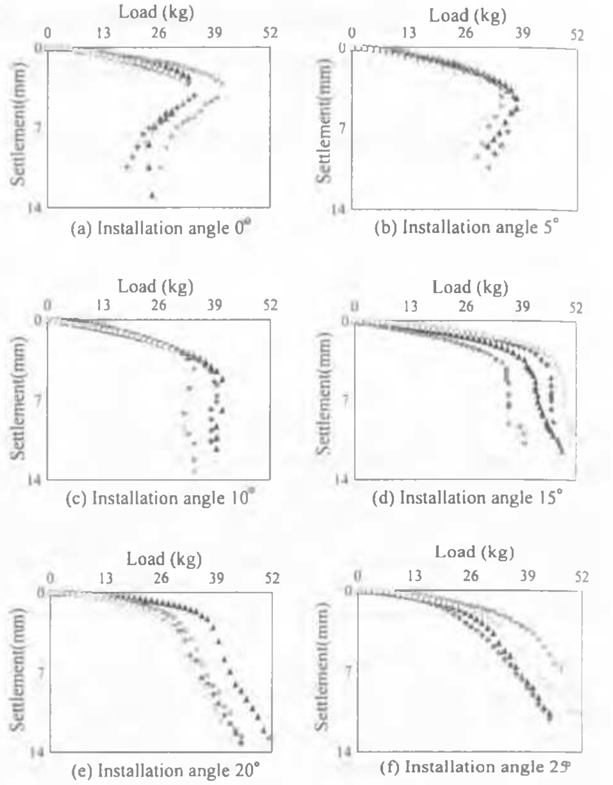

Fig. 5. Load-settlement curves for different installation angles

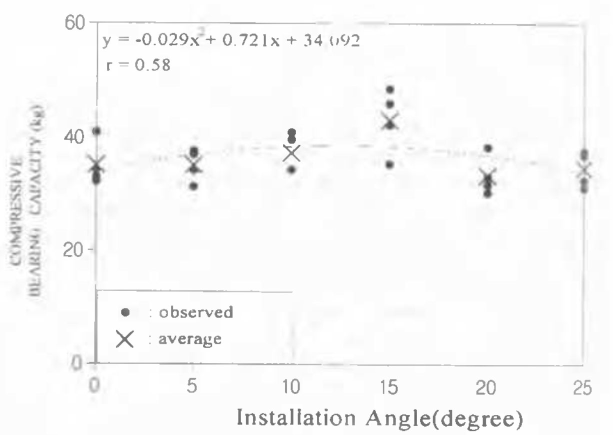

Fig. 6. Bearing capacities of RRP in compression vs. installation angles

3 TEST RESULTS AND ANALYSIS

3.1 *Results of compressive load tests*

3.1.1 Bearing capacity

For the compression tests on RRP, ultimate bearing capacities are obtained from the load-settlement curves, shown in Fig. 5. In case of unclear peak points, Terzaghi/Yelinek method is utilized to define the ultimate value(Dieter Salden 1980).

From the load tests executed on shallow model footing, the ultimate bearing capacity of the shallow footing is estimated to be 19.78kg.

Fig. 6 shows that the maximum bearing capacity of the RRP in compression, after regression analysis, is obtained at about 12° of installation angle. Its value is estimated to be 13% larger than that of the vertical RRP and 95% larger than that of the model circular footing.

3.1.2 *Load-settlement curve*

Load-settlement behavior is influenced by the values of the installation angles. At low installation angles(0°, 5°), load reaches the peak and thereafter it decreases showing softening behavior. With increasing installation angle, the load-settlement response is changed. At 10° of installation angle, load reaches the maximum and remains constant, and at higher installation angles(15°, 20°, 25°), load continues to increase after reaching the ultimate load. Therefore, it is expected that the increase of the installation angle makes the load-settlement behavior getting more hardened for the case of compressive loading.

3.2 *Results of uplift load tests*

A couple of load-movement curves of different sizes of installation angles are shown in Fig. 7. Uplift resistances obtained from the load-movement curves and the regression line are presented in Fig. 8.

Test results show that the maximum uplift resistance after regression analysis, is obtained at about 13° of installation angle and its value is 21% larger than that of the vertical RRP(Fig. 8).

3.3 *Results of lateral load tests*

A couple of load-displacement curves are shown in Fig. 9.

Since the standard procedure is not yet established for the interpretation of lateral loading test(Prakash Shamsher & Hari D. Sharma 1990), the lateral resistance is analyzed for each different displacement level(Sands, M.J. 1992). It is carried out with different values of installation angles starting from at 1mm lateral displacement magnitude to 6mm by increasing 1mm in each stage. The lateral resistance vs. installation angles are plotted in Fig. 10 for the displacement of 1mm and 6mm.

The overall test data are tabulated in Table 1, and plotted in Fig. 11.

From Fig. 10, and Table 1, it is observed that the lateral load resisting capacity at low displacement level(e.g., 1mm)

Table 1 Optimum installation angles and lateral resistance ratios for different displacement levels (after regression analysis)

Displacement (mm)	Optimum installation angle	Lateral resistance for optimum installation angle(kg)	Lateral resistance for the vertical RRP(kg)	Lateral resistance ratio
1	(25°)*	9.15	6.27	1.46
2	(25°)	12.5	8.79	1.42
3	24.6°	14.8	10.57	1.40
4	22.6°	16.7	12.10	1.38
5	18°	18.1	13.24	1.37
6	17.5°	19.3	14.41	1.34

* : The values in parentheses may not be the optimum angle because the maximum point in the regression curves have not occurred under the displacements.

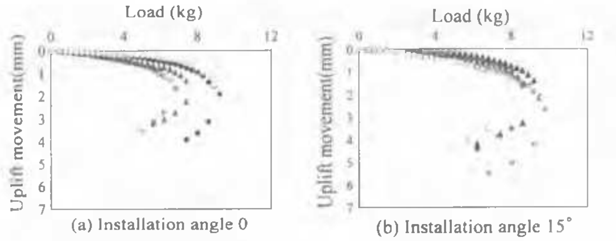

Fig. 7. Load-movement curves with the installation angles of 0° and 15°

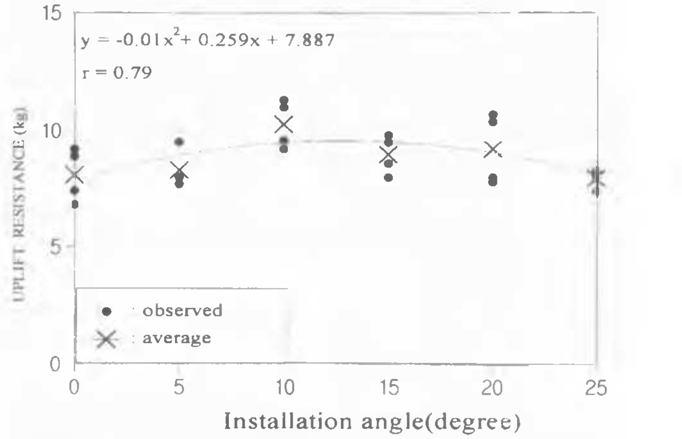

Fig. 8. Uplift resistance vs. installation angles

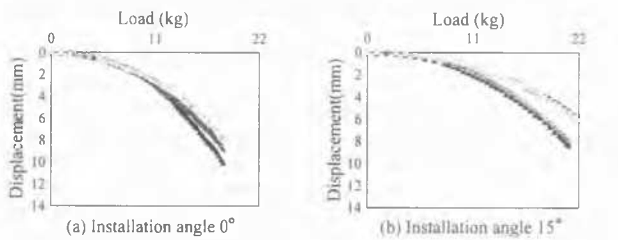

Fig. 9. Load-displacement curves for the installation angles of 0° and 15°

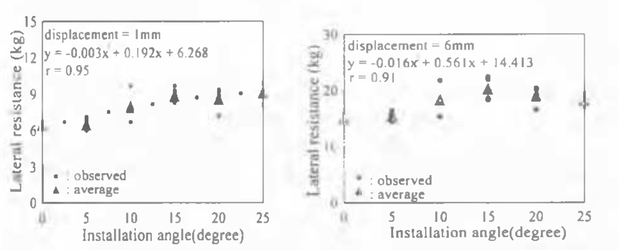

Fig. 10. Lateral resistance vs. installation angles

increases as the installation angle is increased resulting the test limit installation angle(25°) to be the optimum angle. Meanwhile, the optimum installation angle decreases as the displacement level is increased and becomes 17.5° at 6mm lateral displacement.

In Fig. 11, a regression line is drawn for the data range covering 3mm and larger displacements. The optimum angle data of 1mm and 2mm are excluded in the regression analysis because the optimum angle may be bigger than the test limit angle of 25°, if tests are executed with beyond the maximum angle.

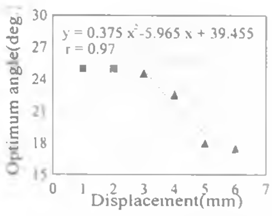

Fig. 11. Optimum angle vs. displacement level

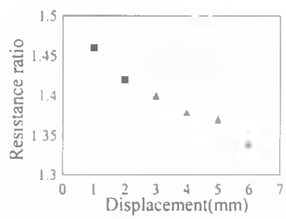

Fig. 12. Resistance ratio vs. displacement level

The lateral resistance ratios are also tabulated in Table 1. Lateral resistance ratio means the ratio of the lateral resistance for the optimum installation angle to that of the vertical RRP. Variations of the lateral resistance ratios for various displacement level are shown in Fig. 12. As can be seen in Fig. 12, lateral resistance ratios decrease as the lateral displacements are increased. It could mean that the effect of slanting angle of RRP may possibly be reduced at higher level of lateral displacement.

4. CONCLUSIONS

Based on the results of the model tests on RRP under compression, uplifting and lateral loading, the following conclusions have been drawn:

1. Optimum installation angles for compressive and uplift loadings are 12°and 13°, respectively. And their capacities are increased by 13% in compression tests and by 21% in uplifting test compared to those of vertical RRP's.
2. For compressive loading, increase of the value of the installation angle makes the load-settlement behavior more hardened.
3. For lateral loading, RRP's response is heavily influenced by the displacement level. At low displacement level(1mm), lateral load capacity increases as the installation angle is increased. But the optimum installation angle decreases as the displacement level is increased. It is found to be 17.5° at 6mm lateral displacement.
4. The ratios of the lateral resistances for the optimum installation angles to those for the vertical RRP decrease as the lateral displacements are increased. Thus the effect of slanting angle of RRP can be reduced at higher level of lateral displacement.

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