横荷重を受ける太陽光パネル複合基礎の設計に関する研究

Design and Investigation of Single Pile Composite Foundation for Solar Panels Subjected to Lateral Loading

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Introduction

The rising queries on climate change and other environmental issues have demanded sustainable developments in recent year. Most research being done today in solar energy are mostly related to the development of various types of solar cells and the reduction in the size of solar panels while improving the operation and energy tapping efficiency. Very little research was conducted with the safety of foundation for solar panels. In this paper, the focus is on the design and testing of a composite single pile foundation taking into account the strength factor, bearing capacity and foundation safety factor as stipulated by Somekawa et. al. The foundation consists of a hollow steel pipe bonded to the ground by a thin layer of cement and sand mortar. The experiments done here aims at establishing the bearing capacity of single pile composite foundation during lateral loading on the structure upon full foundation installation and loading setup with a design load of 4kN. The analytical approach was then done as a step of in-depth understanding of the lateral loading behaviour. Ultimately, a numerical model considering soil-structure interaction is established using FLAC2D (Billaux, D., 2001) to determine the lateral capacity of the composite pile foundation. Finite difference method was adopted to solve the numerical model in large deformation condition, whilst FISH programming developed to facilitate the problem with automatic mesh generation and solver. The results show that the loads applied are capable to hold the entire structure subject to natural environmental condition with a good factor of safety.

Design Equation

The following equation 1, was derived from the limiting equilibrium state of the maximum ground reaction force and the passive soil pressure theory.

$$3K_p\gamma DHL_1^4 + 4D\,(K_p\gamma M + 4c\sqrt{(K_p)}H)\,L_1^3 - (9H2 - 24c\sqrt{(K_p)}DM)\,L_1^2 - 24MHL_1 - 16M^2 = 0 \quad (1)$$

Where H is the horizontal force which is the lateral force; M is the bending moment; D is the column width; γ is the unit weigh of the soil; c is soil cohesion; K_p is the passive earth pressure coefficient; L_1 is the pile foundation depth.

Structural component

Figure 1 shows a clear representation of the solar foundation structure with more focus on the foundation depth L_1, pile diameter D_1, foundation excavation diameter D_2 and pile clearance at the bottom L_2

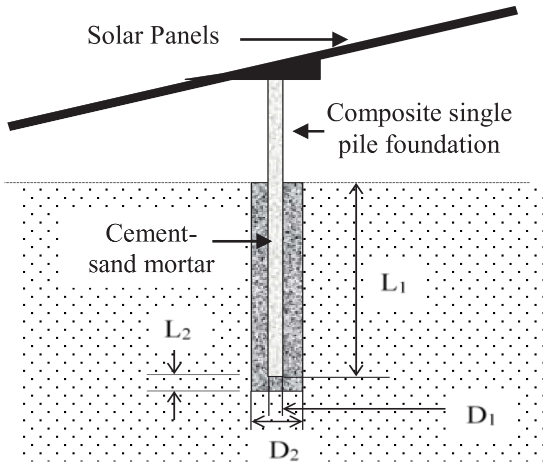

Fig. 1 Composite foundation structural component

Given the design load considerations, a foundation depth of *1.4 m* with *0.26m* diameter was determined and adopted for the full-scale testing, Analytical testing, and numerical model testing with FLAC2D

Full-scale testing approach

A full-scale experimental test was done at Matsusaka city (Silty soils), Mie Prefecture in Japan. After seven days of curing, the foundation was subject to continuous lateral displacement at pile tip to obtain the responses of lateral loadings until the pile collapsed. The load-deflection curve is shown in Figure 2, indicating a lateral collapse load at approximately 13.5 kN.

Analytical testing approach

Following Reese and Matlock approach (Matlock-Reese, 1961) the analytical study was conducted to obtain a theoretical deflection in comparison to the experimental results using the equation 2.

$$y = \beta\{H(T^3)/EI\}\,A_y + \beta\{M(T^2)/EI\}\,B_y;\; T = \sqrt[5]{(EI/K_h)} \quad (2)$$

Where y is pile deflection; H is the horizontal force; T is relative stiffness factor; EI is product of modulus

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of elasticity and the moment of Area of the pile material; K_h is unit modulus of subgrade reaction; β is the equation correction coefficient A_y and B_y are displacement coefficient at the top of the pile, *2.435* and *1.623* respectively. The Load Deflection curve shows a curvilinear relationship with a similar trend to the experimental deflection is as shown in Figure 2.

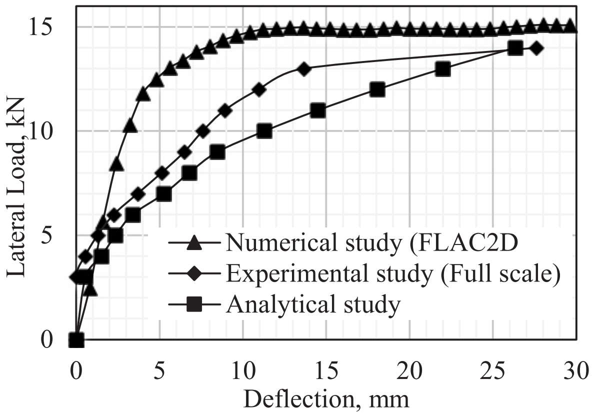

Figure 2 Load-deflection curve at Matsusaka testing site

Numerical model testing approach

A numerical model considering soil-structure interaction is established using FLAC2D to determine the lateral capacity of a pile. Finite difference method is adopted to solve the numerical model in large deformation condition, whilst FISH programming developed to facilitate the problem with automatic mesh generation and solver. Figures 3-5 present some typical output plots directly from the developed FISH program. Pile deflection, soil movements, ground reactions to lateral loading, bending moment, and normal stress distribution are presented in these figures. A load-displacement curve is shown in Figure 2, indicates a numerical prediction of failure lateral load at approximately 14.3 kN, which is in good agreement with the experimental and analytical results.

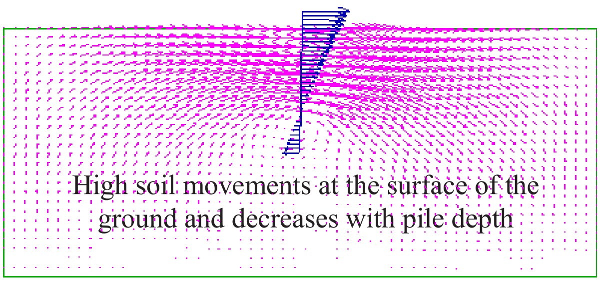

Figure 3 Soil movement and pile displacement pattern

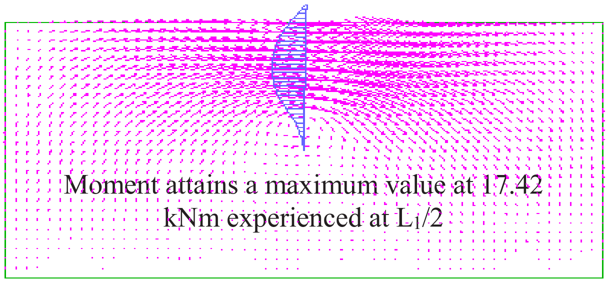

Figure 4 Soil movement and pile bending moment

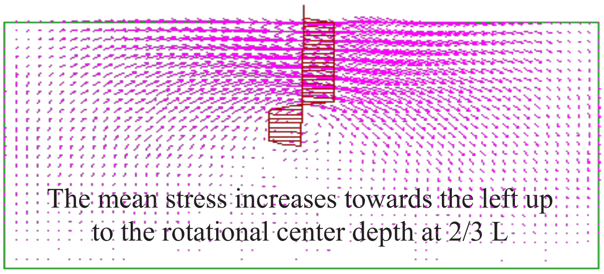

Figure 5 Soil movement and pile normal pressure distribution

Conclusions

The single pile composite foundation portrays good lateral capacity in accordance with the specified design loads. With design loads set at 4 kN, the composite foundation can support ultimate lateral load up to 15 kN which gives a factor safety of greater than 3. Ultimately, the design of composite foundation can be achieved using very simple techniques in the construction industry taking into consideration the economic factors such as minimum cost evaluation and minimum material usage.

Acknowledgements

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