

THE LATERAL LOAD CAPACITY OF GROUND SCREW PILE IN SOLAR PV FARM

Attasit Sirivachiraporn^{1,2,*} and Chaisiri Wattanachannarong³

Received: March 08, 2018; Revised: April 22, 2018; Accepted: May 06, 2018

Abstract

Thailand's clean energy consumption has increased continuously due to the policy of alternative energy development, and it is intended to add more alternative energy sources which can be produced in the country, for example, solar energy. In 2015, the total installed capacity of electricity generation using solar photovoltaics (PV) was 1,419.6 MW, a 9.3% increase from the previous year. Most solar farm projects are the solar ground type in which PV panels are installed on a steel mounting structure. Ground screw steel piling is applied for the foundation because of both the convenience of installation and the fastening of the PV panels to the mounting frame. A ground screw load test was performed to prove both the vertical and horizontal pile capacity for the advantageous engineering design of the PV panels' mounting structure. The lateral load test method conformed to the ASTM Standard D3966-90. The loading sequence and the maintenance period of different load increments were carried out and the pile head movement was also monitored. The test results revealed that the ground screw pile capacity can support and maintain a lateral load between 500 to 700 kg depending on the pile length and subsoil condition in each location. The displacements of the piling in the load direction were observed at less than 15% of the ground screw diameter.

Keywords: Ground screw pile, alternative energy, lateral load capacity, solar PV farm

¹ Department of Civil Engineering, Faculty of Engineering, Srinakharinwirot University, Thailand.

² Research Unit in Sustainable Innovation in Civil and Environmental Engineering, Srinakharinwirot University, Thailand; E-mail: attasit@swu.ac.th

³ Gunkul Engineering Public Co., Ltd. Thailand.

* Corresponding author

Introduction

Thailand is located in a tropical area and, therefore, contains an abundant solar power source from solar heat gain. Solar is one of the clean natural energy sources that can be transformed into heat and electricity. Thailand has several areas with great solar power potential including the southern and northern parts of the Northeastern region and certain areas in the Central region. The total solar potential area accounts for around 14.3% of the country's overall area, with an average daily solar exposure at around 19-20 MJ/m²-day, while the other 50% of the country gains around 18-19 MJ/m²-day. Compared with 6 other countries, Thailand ranks fourth behind the United States of America but ahead of Japan (Department of Alternative Energy Development and Efficiency of Thailand, 2017). Since 2013, the government has been taking steps to increase the share of renewable energy in the country by tapping into Thailand's abundant solar potential. The total installed capacity of electricity generation using solar PV was 1,419.6 MW in 2015, a 9.3% increase from 2014, and a substantial increase from the previous 10 years as shown in Table 1 (Department of Alternative Energy Development and Efficiency of Thailand, 2016).

The recent high fuel price crisis has brought closer attention to Thailand's interest in all possible alternative energy sources with a national agenda for an action plan to promote renewable energy; solar energy is one of the major sources of sustainable renewable energy that has been mentioned in the strategic development plan. Solar cells or photovoltaic (PV) cells are large area semiconductor diodes that convert sunlight into electrical current to produce usable power.

Solar PV mounting structure

The PV mounting structure is a steel frame assembly which is installed into the ground with a steel screw pile as shown in Figure 1. All the steel structural members, bolts, and nuts were protected by hot dip galvanization after fabrication in accordance with ASTM Standard D3966-90 (American Society for Testing and Materials, 1995).

Loads distributed through the frame are comprised of dead loads, live loads, and wind loads. Dead loads comprise the weight of the PV panels, steel frames, purlins, and piles. Walking or standing on a PV panel is prohibited and, as there are no such activities working directly on the panels, no live loads were considered. Wind loads depend on the location of the terrain (whether on a flat area or with wind obstacles), height of the frame, and the opening and slope of the structure. The purlin span length varied between 2.80 m to 3.00 m depending on the arrangement of the frame. The steel sections of any parts were determined by the Working Stress Design according to the Thailand Standard which is based on the American Institute of Steel Construction standard. From the load combinations, the compressive load on 1 pile is between 400-600 kg, the tension load (pull-

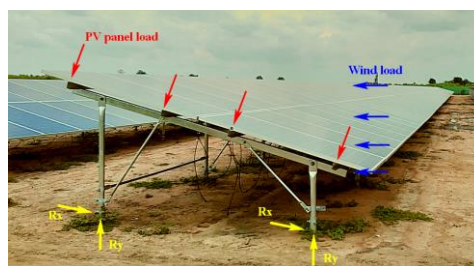


Figure 1. PV panels on steel frame fixed with steel screw piles

Table 1. The installed capacity of solar PV in Thailand

Solar PV installed capacity (MW)					
2010	2011	2012	2013	2014	2015
48.6	78.7	376.7	823.5	1,298.5	1,419.6

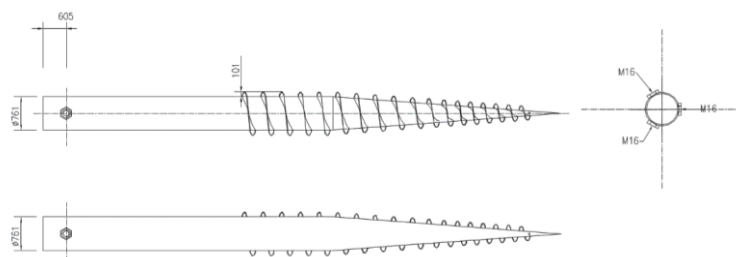


Figure 2. Drawing of ground screw pile



Figure 3. Ground screw pile installation by piling machine

out) is between 600-900 kg, and the horizontal or lateral load is between 250-350 kg. The foundation of the steel frame uses a ground screw steel pile, also known as a helical pile, which is manufactured from steel tubing with a diameter of 76 mm and is welded with a 10 mm width spiral steel plate along the pile shaft as shown in Figure 2. The advantage of this foundation type is the installation time with a piling machine and the fast assembly to the upper part of the steel frame. The piling installation machine is based on an excavator chassis with a small track and is equipped with a pile guide and rotation device for connecting, rotating, and pushing the screw pile into its precise location. Screw piles are embedded into the soil by the application of a turning movement to the pile head, causing the helices to penetrate the ground in a screwing motion without creating vibration or spoil as shown in Figure 3. Sirivachiraporn and Wattanachannarong (2016) carried out ground screw pile load and pull-out testing at 12 solar farm projects

around Thailand in which the pile lengths were between 1.00-1.60 m. The ground screw pile can support a test load of 800-1,200 kg for the compression test and 1,200-1,800 kg for the pull-out test (Sirivachiraporn and Wattanachannarong, 2016).

Ground Screw Pile Testing

This testing proved the pile compression load capacity of the ground screw steel pile PV panel mounting structure. The verification of the horizontal pile capacity was performed with the pile under lateral load testing loaded to 200% of the calculation load. The pile under lateral load testing followed ASTM Standard D 3966-90. The apparatus used in the load test program was comprised of the reaction force, loading system, and measurement device. For the reaction force, an excavator or piling machine on site was used as the reaction force during the test. It was mounted beside the test pile. The loading system (applied by a hydraulic jack that had a capacity greater than the tested load) was used to apply the test load. Calibration of the hydraulic jack needed to be performed before each testing program. Two dial gauges were mounted with magnetic stands on a reference beam to measure the test pile horizontal displacement in the applied load and perpendicular directions. Another dial gauge was installed behind the counterweight to ensure that there was no movement of the excavator and that all the applied load was acting to test the pile. The gauges had a travel length of 50 mm with an

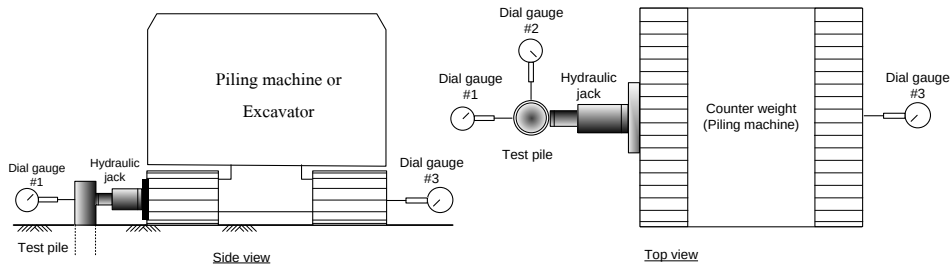


Figure 4. Devices' installation diagram for side view and top view, respectively



Figure 5. In-situ devices set up for testing

accuracy of 0.01 mm. A small steel beam was cross-connected and laid on a support firmly embedded in the ground which acted as a reference beam. Pictures of the devices' installation diagram and the in-situ devices setup are shown in Figures 4 and 5, respectively.

Unless a failure occurred, the pile would be loaded to 200% of the maximum calculation load, applying the load in increments of 25% of the calculation load and maintaining each load increment until the rate of movement was not greater than 0.25 mm/h. Each test load increment would be maintained until the rate of movement was less than 0.25 mm/h or until 2 h had elapsed whichever occurred first, and then increased to the next load increment. The pile head lateral movement reading would be recorded after the application of each test load increment at 0, 1, 5, and 10 min elapsed time for the corresponding test load. After the required load, the maximum load was held for at least 1 h and the test load reduced in decrements of 25% of the total test load with 1 h between decrements. From the results of the testing, the relationship of the test load and pile lateral movement was plotted as shown in Figure 6. The test results showed that the

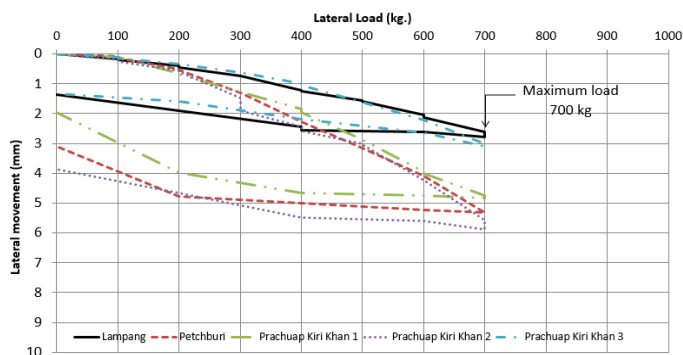
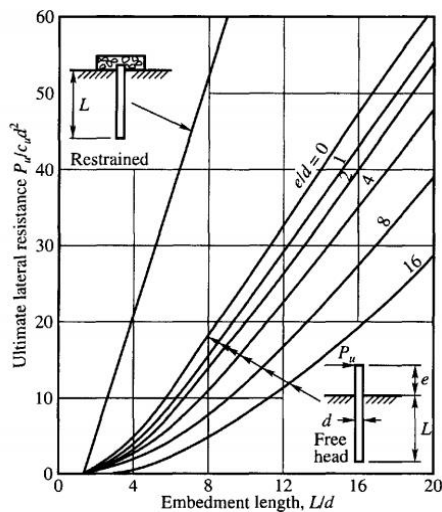


Figure 6. The relationship of lateral test load and pile movement

Table 2. The calculation of ultimate lateral load from Broms's theory

Location	SPT (1st layer)	Su (t/m ²)	Pile length	Ultimate lateral load (tons)
Lampang	22	15	1.0	1,993
Petchburi	14	9	1.4	2,131
Prachuap Kiri Khan 1	15	10	1.2	1,848
Prachuap Kiri Khan 2	14	9	1.2	1,663
Prachuap Kiri Khan 3	20	14	1.2	2,588

**Figure 7. Ultimate lateral resistance of a short pile in cohesive soil related to embedded length (Broms, 1964)**

ground screw pile can support a lateral test load at 700 kg.

Theory for Laterally Loaded Piles

Broms (1964) provided solutions for both short and long piles installed in cohesive and cohesionless soils and considered piles that were fixed or were free to rotate at the head. Figure 7 gives solutions for the ultimate soil resistance of piles in cohesive soils. The calculation of Broms's lateral resisting for 5 locations are revealed in Table 2. In Table 2, the standard penetration test (SPT) values are collected from subsoil investigation and converted for the undrained shear strength

following Peck *et al.* (1974). The ultimate lateral load for each location was calculated following Broms's theory (1964).

Conclusions

The lateral capacity of steel ground screw piling used for the foundation of a PV panel mounting structure can be proved by an in-situ load test in accordance with ASTM Standard D3966-90. From a design report on a solar farm in Thailand (Department of Civil Engineering, Srinakharinwirot University, 2015), the pile horizontal reaction load is between 250-400 kg depending on the project's location, terrain, and especially the wind velocity. The lateral pile capacity load tests were performed at 5 solar farm projects around Thailand. The pile length in each project varied between 1.00-1.40 m depending upon the characteristics of the sub-soil properties. The testing reports revealed that the ground screw piles can support a lateral test load of 500-700 kg with a pile head movement not greater than 15% of the pile diameter. The ultimate lateral loads which were calculated from Broms's theory are set out in Table 2. For a safety factor of 2.5, the allowable lateral load from calculations was close to the field test results.

References

- American Society for Testing and Materials. (1995). D3966-90. Standard Test Method for Piles under Lateral Load. American Society for Testing and Materials, West Conshohocken, PA, USA.
- Broms, B.B. (1964). Lateral resistance of piles in cohesive soils. *J. Soil Mech. Found. Div., American Society of Civil Engineers*, 89(SM2):27-63.

- Department of Alternative Energy Development and Efficiency of Thailand. (2017). Areas with Solar Power Potential. Bangkok, Thailand: Ministry of Energy. Available from: <http://weben.dede.go.th/webmax/content/areas-solar-power-potential>. Accessed date: June 22, 2017.
- Department of Alternative Energy Development and Efficiency of Thailand. (2016). Alternative Energy Situation in Thailand 2015. Ministry of Energy, Bangkok, Thailand.
- Department of Civil Engineering, Srinakharinwirot University. (2015). The ground screw load test report of Solar Power Plant Project, Nakorn-Nayok, Thailand. Department of Civil Engineering, Srinakharinwirot University, Nakhon Nayok, Thailand.
- Peck, R. B., Hansen, W. E., and Thornburn, T. H. (1974). Foundation Engineering. 2nd ed. John Wiley & Sons, New York, NY, USA, 544p.
- Sirivachiraporn, A. and Wattanachannarong, C. (2016). The using of ground screw pile as mounting structure foundation in Solar PV farm. Proceedings of the 5th International Congress on Engineering and Information; May 10- 12, 2016; Osaka, Japan, p. 294-301.