Application of Swedish Weight Sounding Test for the Geotechnical Assessment of Solar Power Plant

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ABSTRACT

As part of the global efforts to mitigate climate change and foster sustainable development, the construction of solar power plants has experienced significant growth in the Philippines over the past few years. This constitutes an increasing contribution to the renewable energy sector. This paper presents the applications of the Swedish Weight Sounding Test in the geotechnical assessment for solar power plant facilities. Utilizing SWST is a more portable and cost-effective way to evaluate the soil conditions crucial to establishing the solar panel arrays' foundation system and the project's overall feasibility. The penetration resistance data of SWST was employed to establish the soil stratification, soil strength, and consequently the foundation type and allowable bearing capacity. Moreover, the results were also used to assess the susceptibility of the project site to geohazards, such as liquefaction. Theoretical capacities of the helical and screw piles, the widely used foundation system for solar panels, can be derived and correlated with the results of the SWST.

This paper shall present the utilization of SWST, as a supplement to SPT, primarily on the geohazard and foundation assessment for solar power plants. This study is expected to provide a reliable reference on the advantages of SWST and the selection of foundation type based on the results obtained from this cost-effective geotechnical investigation method.

Keywords: Swedish weight sounding test, solar power plant, helical pile

1. Introduction

As part of the global efforts to minimize the effect of climate change and foster sustainable development, the Philippines has seen a rise in renewable energy projects, particularly the construction of solar power plants. Successful implementation of solar power plant facilities requires a comprehensive geotechnical investigation and assessment for site characterization and identification of geohazards. However, solar power plants typically require a very large area for their facilities, roughly 2-hectare land for every megawatt of power resulting in a relatively high cost for the investigation.

In situ testing is one of the most common techniques for describing the geotechnical characteristics underlying a particular area. It is an essential component of the pre-design stage or feasibility stage of engineering projects. The results of these tests, complemented with laboratory testing, are used to estimate geotechnical parameters which are necessary to come up with a cost-effective geotechnical design for a given project. Moreover, the results of in-situ tests are also used to establish the susceptibility of an area to liquefaction, excessive settlement, slope instability, and other geohazards.

The Standard Penetration Test (SPT) is the most common in-situ test conducted in the Philippines. Despite the limitations, relatively high cost, and current advances in geotechnical investigation, this has still been predominantly implemented.

Due to the relatively large cost incorporated with the common in situ testing (e.g. SPT, CPT), developers and owners often opt to have a reduced number of investigation points which is sometimes deemed to be an insufficient basis for efficient design purposes. A cheaper alternative is to use in situ penetrometers such as Swedish Weight Sounding Test. This can be considered a good supplement to the traditional SPT to cover a wider area. An advantage of SWST is its continuity of testing, instead of having an increment incremental penetration testing like in SPT. As such, thin interspersed soil layers can be identified.

This paper discusses the utilization of SWST for geotechnical investigation and subsurface characterization of solar power plant sites, as well as the selection of possible foundation options.

2. Geologic Settings and Considerations

The development of solar power plant facilities has extended to the northern portion of Luzon for the past years. This is primarily due to the presence of numerous expansive areas traditionally used for agricultural purposes. These areas are generally underlain by quaternary volcanics on the western side and recent deposits in the central area, often referred to as Central Luzon Basin. Moreover, most areas in Central Luzon are covered by lahar deposits due to the eruption of Mt. Pinatubo in 1991.

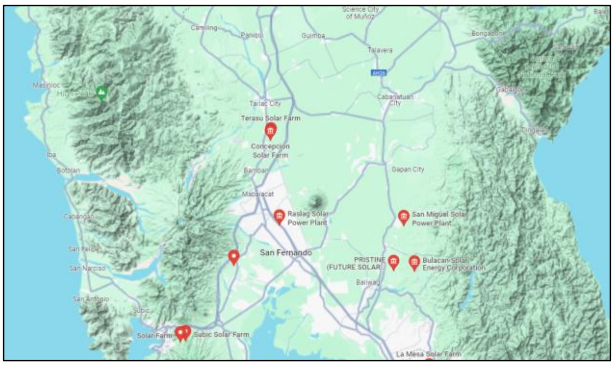

Figure 1. Location of existing solar power plants in Central Luzon (Google Maps)

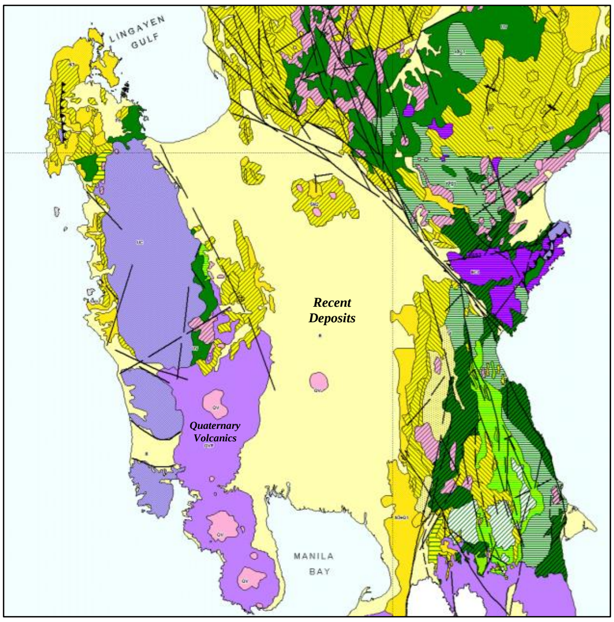

Figure 2. Extract from the geology map of Luzon (Source: Mines and Geosciences Bureau)

There are also several active seismic sources within the region namely; Iba Fault, East Zambales Fault, Digdig Segment of the Philippine Fault Zone, and West Valley Fault.

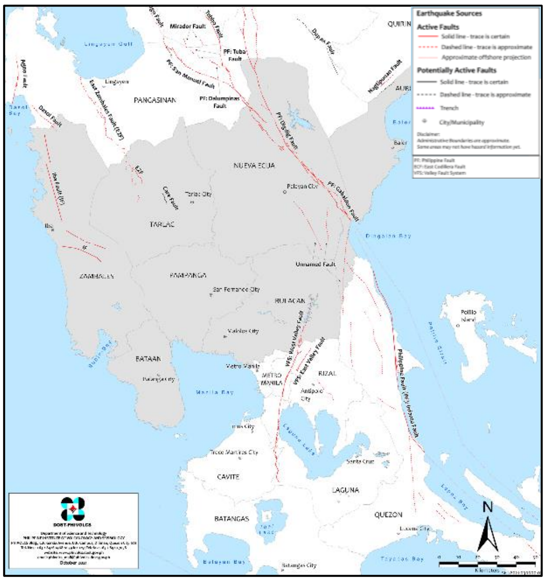

Figure 3. Distribution of Active Faults in Region III (Central Luzon), Philippines (PHIVOLCS)

3. Swedish Weight Sounding Test

Swedish weight sounding test is one of the oldest penetration testing methods and the most common in Scandinavian countries and Finland (Aas, 1969, Broms, 1974). They use this method primarily for the investigation of the railway embankments and in the exploratory phase of site investigation. Aside from the Scandinavian countries, Japan also utilizes this test, and it is very evident in several research that was published discussing the application and developments of this technology. Moreover, it is used in Japan for the evaluation of foundation strength for residential construction in accordance with the Japan Housing Quality Act of 2000 and for reconnaissance and surveys of landslides and earthquake-disaster-stricken sites.

3.1. Equipment and Procedures

The SWST equipment is composed of a screw point, sounding rods, a rotating handle, 10 weights of 10 kg each, making a total of 100kg, and a bottom plate. Figure 2.1 shows the SWS equipment and its parts.

As presented by Peckley (2007) in a UNESCO report, the following are the highlights of the procedures for conducting SWST.

The bottom plate is first placed in the location where the test is desired. The screw point attached to the rods marked every 25 cm, is placed in the hole in the base plate. The handle is then attached to the vertical rod; this assembly will also hold the 10 weights. The 10kg weights are gradually assembled in the system until the total of 100kg (1.0kN) weight is in place. The penetration of the sounding equipment as each load is placed is recorded.

When the equipment does not penetrate any further when it is loaded to 1.0 kN it is rotated and the number of half-turns for every 25cm penetration is recorded. The number of half-rotations for every 25-cm depth is multiplied by four to obtain the equivalent number of rotations (Nsw) for a 1-meter penetration.

SWS equipment can reach 10 to 15 meters depth, depending on the soil conditions. Based on the documented use of the equipment, the difficulty was encountered in penetrating dense sand and hard clay.

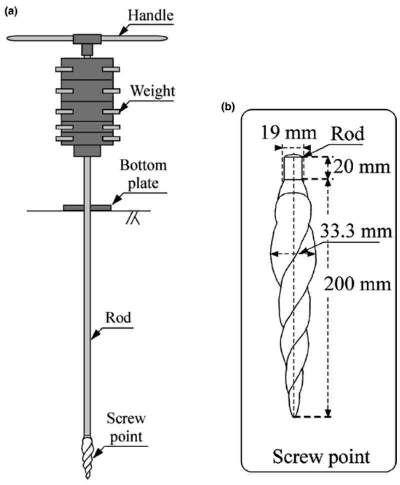

Figure 4. Swedish Weight Sounding Equipment (Tsukamoto, et. al., 2004)

The penetration testing is terminated when the desired penetration resistance or depth is achieved. It should also be terminated when the screw point doesn't sink when rotated or when driven by at least 10 blows of a 3.0 kg sledgehammer. Another termination condition is when two adjacent 25 cm thick layers are encountered with increasing penetration resistance exceeding 50 half turns per 25 cm, or penetration is less than 1 cm per blow after 5 blows of the sledgehammer.

3.2. Geotechnical Investigation Program

Standard Penetration Tests (SPT) are often conducted for solar power plant developments, with depths between 3m to 6m for solar panel areas and relatively deeper for other structures. Considering the substantial cost associated with the investigations and the expansive scale of the project sites, the ratio of area coverage to in situ tests is often sparse, ranging from 1 borehole per 1 hectare for smaller project sites to 1 borehole for every 5 hectares for larger ones. This limited distribution of investigation points presents challenges, particularly in the identification of geohazards and the cost-effectiveness of foundation evaluation.

To address these concerns, supplementing the SPT with SWST presents a viable solution. SWST offers a relatively economical and expedited alternative, enhancing spatial coverage of geotechnical data and providing valuable insights into subsurface conditions.

3.3. SWST Results and Correlation with SPT N-value

The results of SWST are typically expressed as Nsw or the number of half rotations per 1 meter of penetration.

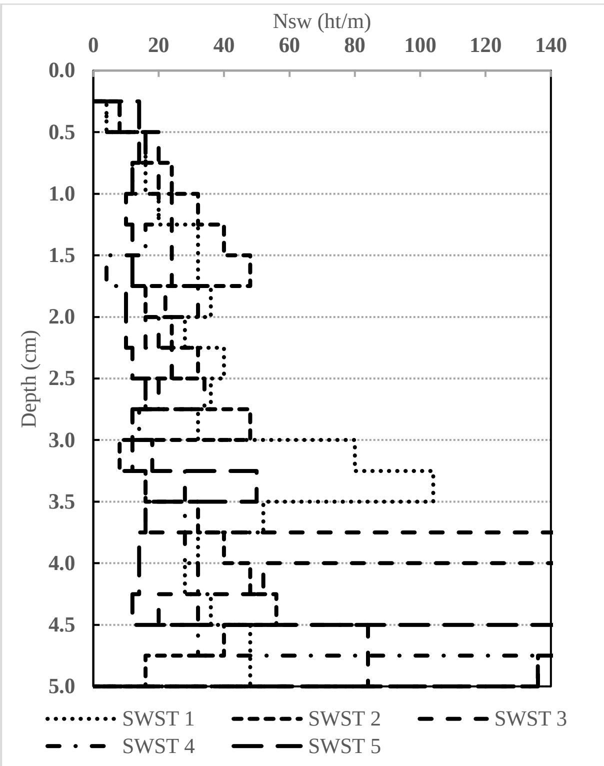

Figure 5. Swedish Weight Sounding Test Results

The results of SWST are most of the time correlated with SPT N-value. One of the most prominent correlations that are used in practice is the one proposed by Inada (1960). He proposed formulas between the N-value of a standard penetration test, and Wsw (N) and Nsw (half-turns/m) of the Swedish weight sounding test for the Meishin highway as follows :

For gravel, sand, and sandy soil,

$$N = 2 + 0.067Nsw. \quad (1.\ a)$$

For clay and clayey soil,

$$N = 3 + 0.050\ Nsw. \quad (1.\ b)$$

where

N = SPT N-value,
Wsw = added dead weight (kgf), and
Nsw = the number of half rotations per 1-meter penetration.

Should there be sufficient information, a site-specific correlation can also be done by doing side-by-side SPT and SWST investigations at multiple locations.

4. Liquefaction Assessment

The Philippines is in a seismically and tectonically active region. Most areas in Central Luzon, where several solar power plants are located, particularly those underlain by Recent Deposits, are susceptible to liquefaction based on hazard maps published by PHIVOLCS. As such, identification of the extent of liquefiable layers is essential to estimate the possible liquefaction-induced settlement.

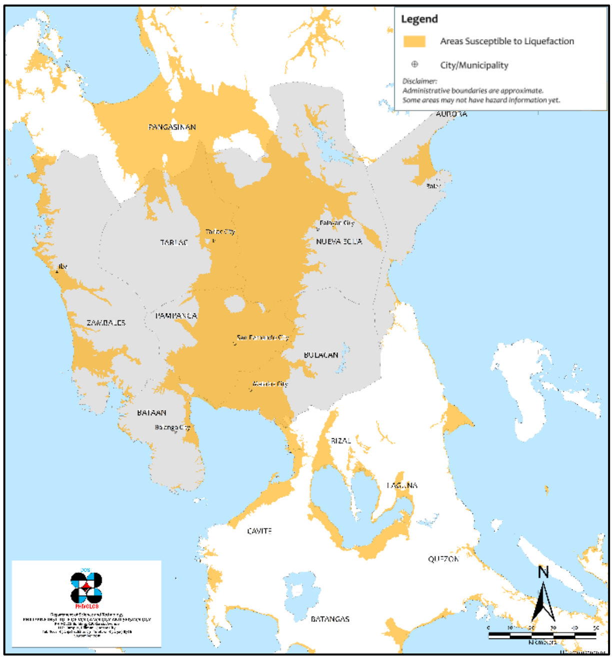

Figure 6. Liquefaction Susceptibility Map of Region III (Central Luzon), Philippines (PHIVOLCS)

SWST can be used in the evaluation of subsoil conditions at sites where liquefaction may occur or has occurred. Compared to other methods of assessment, this test is relatively cheaper and portable. The results of

SWST are often correlated to equivalent SPT N-value which is then used on these soil dynamics analyses. Japan, being one of the most earthquake-stricken countries in the world, extensively used this method in their soil investigations that relate to liquefaction (Towhata et al, 2004). For the past decade, SWSTs have been used for earthquake reconnaissance geotechnical investigations (Tsukamoto, 2015). A procedure was proposed by Tsukamoto (2015) for earthquake reconnaissance investigation using SWSTs. The procedure would be able to analyze the seismic stability of both natural and reclaimed deposits, ranging from flow and slip failures to post-liquefaction settlement and laterally spreading displacement.

SWS was also used for liquefaction assessment in several regions in Japan for the assessment of the damages following the Great Japan Earthquake in 2011, Similarly, there are also several published papers on the use of SWS for post-liquefaction assessment in Christchurch, New Zealand after the series of strong earthquakes occurred between September 2010 and February 2011.

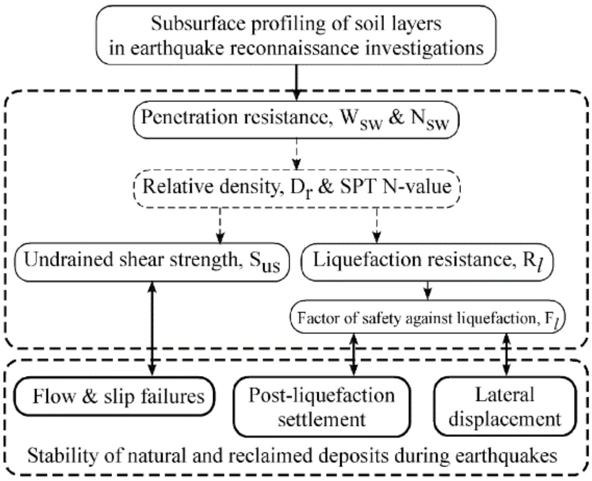

Figure 7. Procedure of earthquake reconnaissance investigations using SWS tests (after Tsukamoto 2015)

Furthermore, there have been few liquefaction assessments conducted here in the Philippines employing this method. In 1993, Alexis Acacio, Kenji Ishihara, and Ikuo Towhata conducted SWST in Dagupan to investigate liquefaction-induced damage in Dagupan in the 1990 earthquake (Ishihara, et.al., 1993).

With the correlations between the results of SWST and SPT N-value, established either based on site-specific data or based on Inada (1960), liquefaction analysis can be established. It was evident from the previous investigations conducted that the typical depth for SPT is insufficient to establish the extent of liquefiable layers which may consequently lead to underestimating the possible impacts of liquefaction.

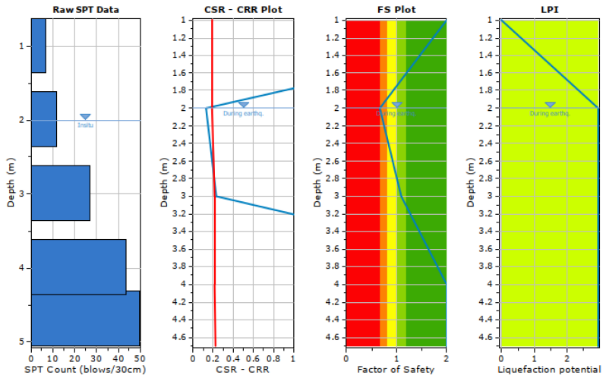

Figure 8. Sample liquefaction analysis results for a solar power plant site

5. Foundation Assessment

Solar panels, which occupy most of the area required for the solar power plant facilities, require a robust foundation system to ensure its stability against pull-out due to wind load, and seismic loadings. Typical foundation systems are concrete pads, driven piles, and helical or screw piles. Recently, the utilization of helical piles has been gaining popularity in the country because of their rapid installation and versatility in different soil types.

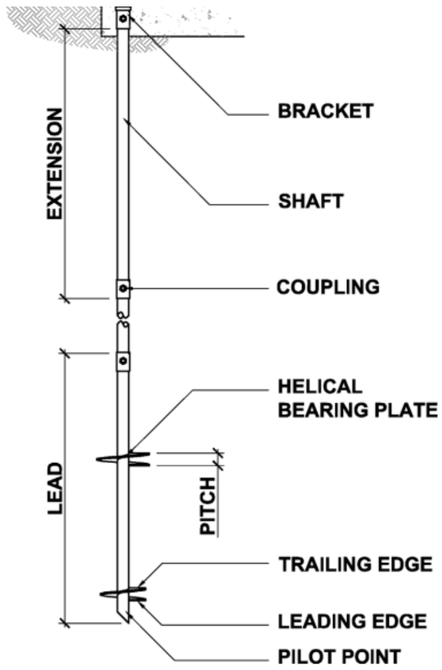

Figure 9. Elements of a screw pile (after Perko, H.A., 2009)

Helical piles are made of steel and are rotated into the ground to support the solar panel assembly. The basic components of a helical pile include the lead, extensions, and helical-bearing plates. The capacity of the pile depends on the soil conditions, the number of bearing plates, and embedment depth. The typical length of piles ranges from 2m to 5m, depending on the load requirements and soil conditions.

A simplified formula for individual helix capacity is represented by the following:

$$Q_h = A_h(cN_c + q'N_q) \quad (3)$$

Q_h = individual helix capacity
A_h = projected helix area
c = cohesion
q' = effective overburden pressure
N_c, N_q = bearing capacity factors

With the results of SWST correlated to SPT N-values, cohesion, and angle friction can be estimated. Consequently, bearing capacity can be calculated, and the required pile length and number of helixes can be established to support the solar panel assembly. Moreover, a bearing capacity correlated with the number of SWS number of half-turns can be generated for the initial foundation solutions assessment.

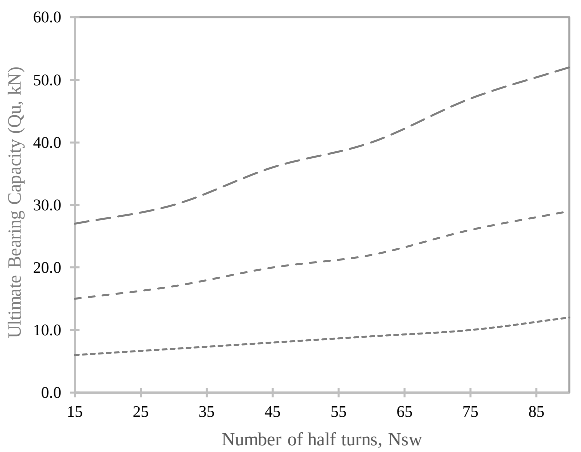

Figure 10. Ultimate bearing capacity chart for helical pile

6. Conclusions

This paper presents the utilization of the Swedish Weight Sounding Test (SWST) as a supplementary in-situ test alongside the Standard Penetration Test (SPT) as part of the geotechnical investigation framework for solar power plant projects. The limited distribution of shallow boreholes presents challenges in assessing the geohazards and optimizing foundation solutions. By integrating SWST into the investigation program, developers and proponents can address the shortcomings of the sparse data distribution while optimizing the efficiency and reliability of foundation design and construction processes.

This paper can be extended by developing a specific protocol for liquefaction assessment and correlating SWST results with the pile capacities based on the pile load testing results.

Acknowledgments

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