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Photo-voltaic Systems Constructed on Steel Piles

Soil qualities and sounding depth

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Solar power systems on steel piles

A brief exposition on decisive factors for evaluating founding depths for solar power systems

Trial pile driving or borehole detection?

Steel piles driven into the soil are a popular and cost-effective footing for the foundation of solar power systems, especially as they are perfectly adjustable to various soil characteristics. A decisive factor to ensure secure positioning of the solar power plant is the transmission of the supporting structures' loads into the soil.
It is important to determine the ideal seat depth of the piles in the initial planning phase and as a result it has become customary to plan and conduct pile driving tests. In these trials a steel pile is usually driven into the soil that needs to be examined. Next, force is applied to the pile horizontally and vertically in order to measure its reaction above the ground (deformation). Finally, the profile is usually pulled from the ground, whereby the strength applied is registered.

This method thus procures information about deformations and the influence of different forces occurring at a recently inserted steel pile. However, it only provides limited information about the actual soil structure and soil-mechanical qualities. Ideally, the trial shows that the pile driven into the ground is, in this condition, able to withstand the stress afflicted by the super-structure, which leads to the conclusion that the same conditions apply after construction of the supporting structures.

Advantage:
An experiment is conducted in situ and proves that the pile can – under the conditions of the experiment - bear the load afflicted. Reliability is fairly high.

Disadvantages:
The soil structure, the general soil-mechanical qualities and the situation of the solar field are not explored from an engineering-geological perspective.
The quality and structure of the ground below the inserted piles, although affected by the forces applied, remain unknown.

Expenditures for tensile tests are comparatively high (a pile-driving team with trucks, a pile driving machine on a mount, a wheel loader; furthermore, a geologist or at least a geotechnical engineer with respective equipment and measuring instruments are needed for conducting the experiment.)
Moreover, test measures are obtained in conditions subject to alteration before plans are finally put into practice: Often test canals created by the piles driven into the soil still exist and lead to a considerable weakening of frictional resistance of the pile in the soil. The pile surface is still very smooth, sometimes even greasy, after production, which also notably tampers with the tensile force values measured.
Exploring the ground always leads to changes and disruption of the object of investigation (i.e. the soil). The disruption caused by pile driving is immense (e.g. compaction of surrounding soil, grain rearrangement, displacement of certain soil components). In the course of time these disruptions partly and gradually disappear, but when conducting tensile tests this time is not available.
In order to procure enough data about the uppermost 2 metres of the stratum (i.e. the area of soil which later is to bear the loads of the solar construction), it would be necessary to precisely measure the depth of penetration caused by the pile driving machines after a specific number of blows afflicted by the ram. Only this procedure can ensure minimum disruption of the soil and should, therefore, be adhered to during the whole process of pile driving. However, these measurements are not carried out during the trial pile driving, mostly because machine technology does not allow it.

Fortunately all the disadvantages listed above are “safe”, which means that the calculated hypothetical load-bearing capacity of the footings is lower than the actual capacity reached after completing the full installation of the solar field. Thus, this method of examination can be applied in many cases, even if the calculated pile seat depths exceed the actual necessity. Moreover, all factors influencing the geotechnical stability of the whole field, rather than of individual piles, are not registered.

An alternative method:

Considerations are based on the fact that the parameters determining the load-bearing capacity of the steel piles derive from varying soil structures and their respective different force-bearing capacities. It is, therefore, advisable to pay special attention to the examination of the uppermost 2 to 4 metres of the soil stratum. With measuring methods taken from the evaluation of founding depths for noise barriers and adapted to the prerequisites of solar power plants, it is possible to reliably calculate the necessary founding depths for all kinds of steel piles, if the following parameters are known:

- The engineering properties of the ground
- The dimensions and measurements of the pile
- Forces and momenta operating on the piles

In addition the vertical application of force and its transmission into the soil have to be examined, drawing on information about the contact stress between piles and surrounding soil. Usually, the pile seat depths calculated from tilting torques and horizontally operating forces are sufficient for the piles to also bear vertically afflicted loads. On rare occasions (very light soils), however, it is necessary to increase the pile seat depth in order to effectively transmit vertical stress.

The evaluation system is computerised and homologated according to ZTVE Lsw 88/03 (Additional Technical Terms of Contract for constructing noise barriers alongside roads). It is based on the norms for permitted encumbrance to the site (DIN/EN 1054).

If the ground structure is well known, the seat depth of most types of piles can be calculated. Should a decision to change slabs be made during the planning phase, the depth has to be newly calculated, but an additional examination in situ can be omitted.

So far our team has used the method described to examine more than 200 sites of solar power systems in the following countries:

- Germany
- Belgium
- Italy
- France
- Spain, incl. The Canaries
- Bulgaria
- Czech Republic
- Slovakia

- Greece
- Israel

In all cases a reliable evaluation of the pile seat depth was possible. Especially at the beginning, calculations were followed by tensile tests to ensure stability against collapse. The results proved absolutely dependable.

The method was applied to all types of unconsolidated rock, as well as rather unusual soils, such as peat layers of great depth or loose volcanic ashes.

The examination is usually carried out by using a pile hammer system (DPL or DPM), which is well-suited for obtaining an accurate picture of the soil structure of the uppermost layers (i.e. a few metres); as opposed to heavier machinery that are often unsuitable for usage on layers immediately underlying the surface of the earth. The exploration of the soil always trespasses the foundation line until all layers present have been examined with respect to their influence on the stability of the footing. In addition the soil is explored using driven probes or core drilling methods. This procedure also makes the collection of soil samples possible, if wished for (e.g. for preservation of evidence against toxic eluviations from metal piles).

Another advantage of this method is the flexible usage of the measuring instruments. They can be transported on an off-road vehicle; truck, mini-excavator, wheel loader and heavy carrier units are dispensable and, thus, the expenditures resulting from equipment and personnel are limited to the absolute minimum. Access to the site is, therefore, even possible under difficult conditions (field paths, abundant vegetation) and slopes with an incline of more than 20 degrees.
Under extremely adverse conditions (e.g. softened ground) the pile driver can be manually carried to the examination site. A cable connects it with the vehicle over a distance of 100 metres and supplies it with power.

If demand of examination comes from distant countries, a complete portable pile driving set is available, which can also be checked in as luggage at airports. It enables the team to calculate founding depths within a span of ten days after the order was placed.

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In addition to analytical evaluation of pile seat depths the following factors are assessed:

- Risk of corrosion
- Long-term stability against subsidence
- Appraisal of general stability of the solar field (e.g. against extensive landslides on slopes)
- Risk of floodings
- Influence of soil frost on the foundation
- Interaction with groundwater
- Danger from earthquakes

Furthermore, advice is provided on how to ensure surface-stability (e.g. by directed vegetation growth), as well as useful information for the foundation of fixed structures, like transformer units.

It is these advices and this information that are indispensable in order to guarantee long-term reliability of solar power systems (a minimum life-span of 20 years is standard). In evaluations based on tensile tests alone this information is often omitted. Many areas in southern Italy and Spain, for example, yield excellent results; however, the slopes are unstable. This instability has often been concealed by earlier agricultural use and soil maintenance, but can easily be detected by an experienced geologist.

Thus, our team had to examine several sites after considerable damages due to landslides. The sites' founding depths had been evaluated correctly via soil-mechanical experiments, but their general situation had not been coherently and adequately assessed and, therefore, we had to find new possible solutions.

The expenditures of reconstruction work often amount to the overall value of the solar installation and make its reconstruction economically nigh on impossible.

Aichach, May 2010

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Company vehicle on farmland

Operation in Sicilian mountains; on the left: scoop for taking samples

Adverse conditions in southern France, Alpes-de-Haute-Provence:

20 cm of fresh snow, Mistral storm, slope incline: 20°

Examination site in the Negev desert, Israel

(Probing equipment checked in as flight luggage)

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Examination site not accessible via vehicle!
(Villeneuve-de-Marsan, south-west France)

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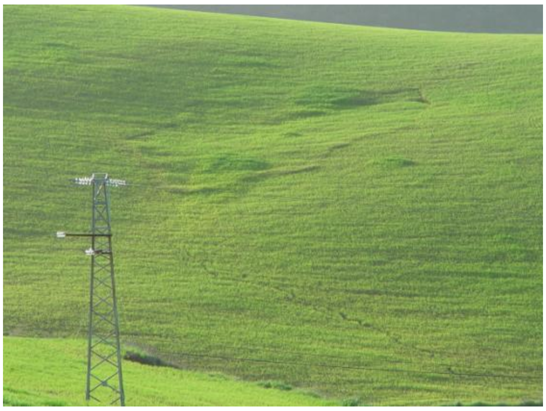
Pictures of a damaged solar power system, planned on the basis of the results of pile driving and tensile tests. Risk of landslides and avalanches remained undetected at the time of the examination.

Individual pylons are still sitting firmly in the ground, but the entire slope is sliding!



Parts damaged by avalanche

Field on the opposite slope affected by landslide

Destroyed sub-structures and damaged panels

Foundation-pads of the transformer units, underground cables, supporting walls and fence were also afflicted by damage. Previous tensile tests had predicted enough retention force.

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This map shows part of the sites examined by our team since 2008: