Ground Mount System
Geotechnical Requirements

CONERGY

INTRODUCTION

When constructing a ground-mounted PV array on an open field, a geotechnical survey is typically required. The geotechnical survey provides information about the characteristics of the soil at the PV site. The survey determines first, whether the PV mounting system envisioned is feasible and, second, what, if any, modifications must be made to the mounting system to accommodate the site's soil conditions for necessary stability and durability to anchor the PV array.

To determine the geotechnical characteristics, a licensed, qualified geotechnical survey firm should be engaged. Site surveys performed by the geotechnical firm should be in accordance with local building code requirements and appropriate testing standards as promulgated by ASTM International. (American Society for Testing and Materials is one of the largest voluntary standards developing organizations worldwide.)

While full geotechnical testing and reporting can be lengthy, complex and expensive, the tests generally required for PV systems in open fields are relatively simple. The geotechnical testing for a building with deep excavations and large piers sunk deep into the earth is considerably more extensive than what is required for a PV array in which foundations are sunk only a few feet into the soil. This guide lists the tests required for Conergy's open field mounting systems and how the results are used for the final design of the foundation system.

GEOTECHNICAL TESTING REQUIREMENTS:

Ballasted systems: SolarGiant

Test specification:	Soil surface mounted ballast
Paramaters required:	Maximum soil bearing capacity
Optional parameters:	Slope stability
Maximum test depth:	As required for surface bearing capacity determination
Sample frequency:	As determined by: | ASTM standards/ local building code | Site size | Variations in site/soil characteristics

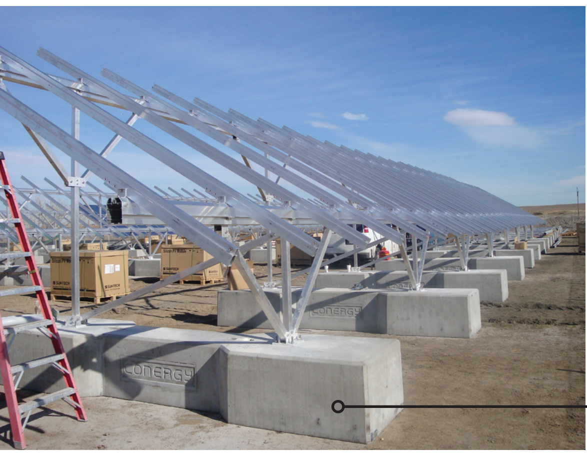
Penetrating systems: SolarLinea

Note: If the anchoring method has not been determined, and because virtually the same testing is required for driven piles, concrete footers and earth augers, it is recommended that the geotechnical test specification includes obtaining adequate data for each method.

Test specification:	Driven steel micropiles or concrete footer or steel earth auger
Paramaters required:	Soil friction values for steel micropiles and concrete footers Lateral bearing capacity Determination of the depth of unusable (non-structural) surface soil
Additional parameters for earth augers:	Soil shear value
Maximum test depth:	12' / 3.7m
Sample frequency:	As determined by: | ASTM standards/ local building code requirements | Site size | Variations in site/soil characteristics

Ballasted Foundation Systems

Ballasted foundation systems, such as the SolarGiant III, are designed to rest on the soil surface. The simplest of all open field foundation systems, it still requires knowledge of the site's soil characteristics.



Concrete ballast

The primary purpose of the footers on the SolarGiant III, or other ballasted foundation systems, is to provide enough weight to keep the array structure firmly on the ground under worst-case load conditions of wind speed and wind direction. The tilt of the array, at certain wind directions creates uplift forces. Without proper ballast, the worst-case combination of wind speed and direction can generate enough uplift to lift and move the array and foundation. The ballast must be heavy enough to resist this uplift. It is often the case that under conditions of maximum uplift, the uplift is not uniform across the array. That is, the array does not simply rise vertically, but develops an overturn moment, a tendency to tip over. Even when the uplift is not strong enough to lift the array, it may still be strong enough that the lateral force of the wind can slide it along the ground. All these load forces must be factored into the design and weight of the ballast. Further, snow and wind loading can create downforce on the array that increases the pressure of the array on the soil.

The combination of the actual weight of the PV array structure, the ballast and the downforce must be borne by the soil. It is important to be sure that the soil is capable of bearing that pressure so that the array remains intact and properly aligned.

GEOTECHNICAL REQUIREMENTS FOR BALLASTED SYSTEMS

For ballasted PV arrays, the only geotechnical characteristic that is normally required is "**soil bearing pressure**" or "**soil bearing capacity**". This is the maximum pressure, expressed as a force per unit of area such as pounds per square foot (psf or lbs/ft²), that the soil can bear without compacting so much that the structural integrity or functionality of the structure being supported is compromised.

The SolarGiant III can tolerate up to about 6" of *differential misalignment* between ballasts without structural or module damage. It is worth noting that SolarGiant ballasts will be close enough to each other that differential misalignment will not be a problem – a geotechnical characteristic or condition that might cause ballast movement is likely to affect both ballasts equally.

In some instances in which the SolarGiant III is installed on slopes, embankments or excavations, whether man-made or natural, it is recommended that the ground be leveled under the ballast foundations and the soil bearing pressure for the leveled area be determined. Conergy recommends that the leveled "pad" where the foundation is to be located be covered with approximately 3-4 inches / 7-10 cm of rough gravel to prevent washout and frost heaving.

Ballasted systems have a few advantages over ground penetrating mounting systems. First, ballasted systems can often be used in site and soil conditions where ground penetration is either not possible or impractical. These conditions include:

- Rocky soil where the size, density and number of rocks would make excavation or pile driving impractical
- Soft or sandy soil which cannot provide adequate support for penetrating methods
- High water tables which cannot provide adequate support and may also lead to accelerated corrosion or erosion of a penetrating anchor
- Land fills which are capped by a polymer membrane which may not be penetrated

In these conditions, a ballasted mounting method may be the only practical solution. In that case, another advantage of a ballasted system is that once the total weight requirement for the ballast has been met, the ballast itself can be configured to accommodate the maximum bearing pressure limits of the soil. This is done by designing the ballast so that the total weight of the ballast is spread over a large enough base area to remain within the bearing capacity limits of the soil.

Ground Penetrating Foundation Systems

The three most common ground penetrating foundation systems are: driven piles, concrete footings and earth screws. Ground penetrating foundation systems rely on the interaction between the soil and the foundation members to resist the uplift, downforce and lateral loads (also referred to as "reaction forces") applied to the foundation members by the mounting system super-structure (the mounting system components attached to the foundation). Reaction forces are generated by wind, snow and seismic forces acting on the superstructure.

DRIVEN PILES

Driven piles (which may also be called "driven posts", "rammed posts" or "rammed piles"), the preferred foundation system for Conergy's SolarLinea, rely on a combination of **soil friction** and **lateral bearing pressure** to resist the reaction forces applied by the superstructure.

The reaction forces applied by the SolarLinea superstructure on the foundation are dependent on: a) module size, b) module configuration, c) module tilt, d) maximum design wind speed, e) maximum design snow load and f) maximum seismic loading. Conergy calculates the reaction forces for each foundation attachment point based upon these parameters, and determines the worst-case reaction forces that the superstructure will apply to the foundation. The foundation is then designed to withstand these forces with a suitable margin of safety. For a driven pile foundation system, the total pile length and soil penetration depth will depend upon the reaction forces to be supported, the height of the post above ground where these forces are applied, and the characteristics of the soil into which the pile is driven.

Uplift forces are generated by the interaction of the wind with the SolarLinea superstructure and are primarily related to module tilt. For driven piles, the uplift (pull-out) resistance of the pile is the result of friction between the sides of the pile and the soil itself. Friction is measured as a force per unit of area. The total friction on a pile – its ability to resist uplift forces - is the product of the skin friction between the soil and the post (per unit area of post surface in contact with the soil), and the total surface area of the SolarLinea pile driven into the soil. The deeper the post is driven into the soil, the greater the pile surface area in contact with the soil. Thus, for a given soil type, the deeper the post is driven, the greater the uplift force that can be resisted.

The wind also imposes lateral loads on the SolarLinea system. The ability of the SolarLinea to resist these lateral loads depends on a combination of the lateral bearing pressure or lateral bearing capacity of the soil, the pile's physical characteristics and its depth.

Each complete SolarLinea design includes a table of the reaction forces which the foundation piles must be able to support. SolarLinea support posts are fabricated from custom-specified galvanized steel, and are optimized for the SolarLinea mounting system. They provide the best, most economical balance of bearing capacity, material usage and ease of assembly. Therefore, the only variable left to specify for a SolarLinea installation is the depth to which the posts must be sunk to withstand the applied reaction forces, and that depends on two primary factors – soil friction and soil lateral bearing pressure. These values can be readily and economically determined by geotechnical testing.

GEOTECHNICAL TESTING FOR DRIVEN PILES

For geotechnical reporting purposes, the SolarLinea posts are considered to be steel micropiles. In this case, steel micropiles are differentiated from the large, driven steel beams used for anchoring and structure on buildings, bridges and other large structures.

When contracting for geotechnical services for a SolarLinea installation, one should specify geotechnical testing for only the following parameters:

- A non-residential, uninhabited structure
- Determination of soil friction for a PV array using steel micropiles
- Determination of soil lateral bearing capacity (lateral bearing pressure)
- Determination of the depth of unusable (non-structural) surface soil
- Testing to be done to a maximum depth of 12' (NOTE: building codes prohibit the use of micropiles sunk more than 12')

CONCRETE FOOTINGS

In general, concrete footings also rely on soil friction and lateral bearing capacity to resist structural loads. Concrete poured into an open excavation will form a rough surface which increases the friction coefficient and provides weight for resisting uplift forces. The larger area of the concrete footing provides greater resistance to lateral loads. The same geotechnical data required for driven posts is also applicable to concrete footings. From a geotechnical standpoint, it does not matter if the superstructure is attached to a steel post embedded in the concrete or is attached to a foundation plate bolted to the top of the footer.

GEOTECHNICAL TESTING FOR CONCRETE FOOTINGS

Geotechnical test specifications for concrete footings will be much the same as for driven piles. It is necessary to specify that the soil friction tests are to assume a concrete footing.

EARTH SCREWS

Also called “earth augers”, earth screws are embedded in the soil the same way that wood screws are embedded in wood and provide resistance to loads in much the same way. Maximum allowable uplift forces for a given auger size are determined primarily by the soil’s shear resistance and the depth to which the auger is sunk. Soil shear strength is the only additional value required to specify earth augers and this data can be easily obtained during the tests required for driven piles on concrete footers.

GEOTECHNICAL TESTING FOR EARTH AUGERS

Geotechnical testing for earth augers is nearly identical to the testing required for driven piles or concrete footers. The work required to determine the additional soil values needed to specify earth augers is minimal and the data can be generated from the same tests for driven piles or concrete footers.

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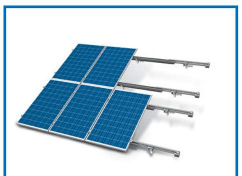
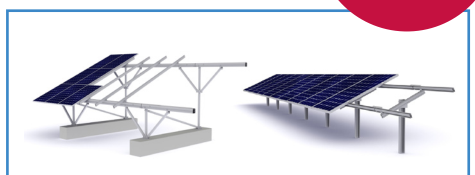


Pitched Roof

Flat Roof



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