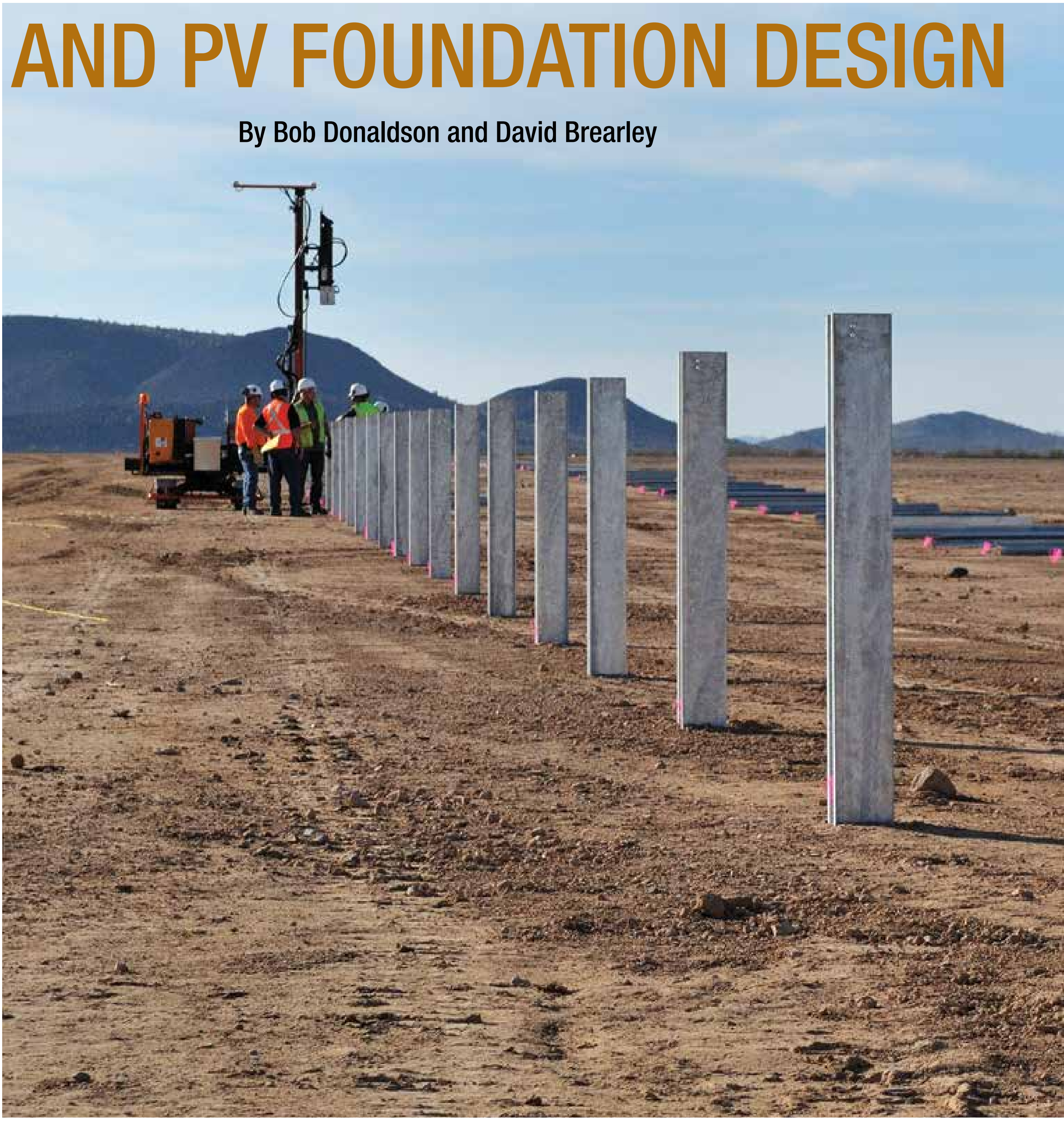
GEOTECHNICAL ANALYSIS AND PV FOUNDATION DESIGN

By Bob Donaldson and David Brearley



Courtesy Advanced Energy

Inadequate site assessments can lead to overengineered and unnecessarily expensive foundations. Worse, they can lead to costly foundation failures.

Ground-mounted PV power plants require two basic foundation design components: geotechnical engineering and structural engineering. Geotechnical engineering focuses on evaluating soil mechanics so that the foundation design can incorporate these characteristics. Structural engineering focuses on modeling the foundation as a supported beam to ensure that it can successfully support the design loads.

Of the factors that determine optimal foundation design, geotechnical site characterization is arguably the most challenging. This is partially due to the fact that feedback from the field about long-term foundation performance invariably lags behind project deployment. Given the risk associated with foundation problems, which can impact both short-term and long-term project profitability, geotechnical investigation is one of the solar industry's most overlooked site-selection criteria.

Here we briefly consider the unique nature of PV system foundations. We detail the challenges and basic components of a geotechnical site assessment. We explain why analyzing load-test data is essential to a site-optimized foundation design. Finally, we review why designing from the ground up is essential to your bottom line, in terms of both up-front costs and long-term profits.

Solar-Specific Foundation Design

Given that the utility sector has driven much of the US solar growth in recent years, it is easy to forget that large-scale ground-mounted PV power plants are a relatively recent phenomenon. Veteran project developers might have a decade of experience in designing and deploying solar farms. Further, the market has changed dramatically, in terms of both typical project capacity and average installed costs. As a result, solar-specific geotechnical engineering is in its infancy compared to geotechnical engineering for more conventional applications such as vertical construction, buildings, bridges or dams.

AquaSoli CEO Jürgen Schmid has specialized in solar-specific geotechnical analysis and foundation design since 2004. He notes that solar foundations present unique design challenges: "PV power plants have a very high number of relatively small piles. People tend to underestimate the skills required to use small piles effectively, because the design loads are very low compared to those for a high-rise building or a bridge. However, there is a considerable need for

> "Everyone knows that a structure is only as good as the foundation that supports it."
> —Daniel Stark, PE, CEO, Stark Foundations

pile optimization in terms of economic material utilization and embedment depth. Further, climatic effects that influence the first six feet of soil can lead to plastic deformation of soils and structural fatigue of the piles."

In other words, a well-designed solar foundation needs to be cost-effective without sacrificing reliability. While the design loads associated with ground-mounted PV systems may be small compared to those for other structures, the foundation still needs to support considerable dynamic loads. In the Boston area, for example, design wind loads approach 120 miles per hour and static snow loads are roughly 60 pounds per square foot. Some mounting systems have almost 70 square feet of rigid sail per foundation. Depending on rack design and static and dynamic loads, this can translate to as much as 5 tons of force per foundation. Any foundation system can fail over time when subjected to these forces, and foundation system failures are expensive to mitigate.

Quality geotechnical data are key to designing a reliable and cost-effective foundation. "Without the proper geotechnical information, we have to make conservative foundation design assumptions," notes Daniel Stark, PE, CEO of Stark Foundations. "While design conservatism is not necessarily a bad thing, being overly conservative can cost our clients money. This could make the difference between a project moving forward or not, between winning a project or not. The minimal expense to conduct a proper geotechnical analysis at the beginning of a project far outweighs the cost of an overdesigned foundation system on the back end of the project."

Costly foundation failure The small piles characteristic of PV system foundations are susceptible to climatic effects on the first six feet of soil. Weak and wet soils, for example, caused this foundation failure.

Courtesy AquaSoli

Given the considerable price pressures that factor into the development of large-scale PV plants, foundation design must be based on adequate site characterization. The better you understand these conditions, the more effectively you can work with your engineer to optimize the foundation. "Geotechnical engineering is the first step to a well-engineered project," explains Adam Tschida, PE, a principal engineer at Kleinfelder. "Proper geotechnical engineering requires a good understanding of what you will be building and how the development will interact with the earth and the environment. This is especially true for PV project development."

Geotechnical Site Assessment

The fundamental challenge in a solar-specific geotechnical site assessment is to gather enough data about site characteristics—including soil composition, bearing capacity, groundwater level and surface water runoff—so that you can characterize soil strength sufficiently to allow for foundation optimization. This is a tall order given that large-scale PV power plants typically range in area from 30 to 600 acres, and much larger projects are in the works. SunPower's 579 MW Solar Star Projects, for example, will cover approximately 3,200 acres. Of course, the scale of these projects is also why foundation optimization is so important.

The basic components of a quality solar-specific geotechnical investigation—site research, soil investigation and load testing—lead to a site-optimized foundation design.

SITE RESEARCH

A geological site assessment starts with site research. This process is important because it informs subsequent on-site investigations. Armed with basic data—such as site address or coordinates and property boundaries—investigators can research soil maps, topographical maps, aerial imagery and so forth. Published records may describe the typical geological setting of the area, bedrock depth, soil types, seasonal water table height or fault lines.

Public records may also detail land uses. "Most sites near urban areas have some percentage of nonnative fill," notes Ed Ayala, president of Eco Foundation Systems. "In some cases, major site improvements—such as roads or grading activities—make it difficult to identify the origin and level of compaction of recent substrates. We can identify potential issues such as fill, compaction or

CONTINUED ON PAGE 24

underground utilities by paying attention to the recent site history."

Geotechnical engineers can learn a great deal about what to expect at a site from these resources. For example, they may be able to identify subsurface soil anomalies, contact zones between soil types, manmade features or disturbed agricultural areas. They can also gain insight into seismic risk and susceptibility to frost, erosion and flooding. They can use these data to identify potential soil problems and prioritize on-site investigations.

Courtesy AquaSoli

Test pit This test pit turned up not only shallow groundwater, which reduces soil-bearing capacity, but also the construction debris shown on the right, which was causing foundation refusal. AquaSoli completed this work to support a foundation installer's change order claim for unanticipated soil conditions.

SOIL INVESTIGATION

Soil conditions vary across any site, both vertically and horizontally. Basic soils are horizontally layered deposits comprised of particles eroded and transported from their parent material over time by motive forces such as water, wind, volcanism, glaciation and seismic activity. The size of the materials transported depends on the energy of the motive force. Subsequent geologic activity changes the deposited soils. A flood may wash away the top of a soil column. Other soils may replace removed material so that two different soil columns end up adjacent to or even on top of each other.

From a foundation design perspective, one of the primary goals of a geotechnical site assessment is to evaluate the ability of these soils to resist and support loads from the mounting structure. The strength of a soil column depends on its composition and its density. Soil composition is a function of the texture and grain of constituent parts, such as clays, silt, sands and gravels. Soil density is a function of the age, materials and methods of the original deposition, as well as the material depth. Soils compact over time, and deeply buried soils are generally more compacted than those located closer to the surface.

> "When a project is new, the inaccurate application of geotechnical design may not be visible. However, with time, poorly designed foundations can become a major problem."
> —Ken Allen, COO, Principal Solar

In addition to observing general surface conditions, geotechnical soil investigators employ subsurface exploration, soil corrosivity and resistivity testing, and laboratory testing.

Subsurface exploration. The primary subsurface investigation methods are to either drill boreholes into the ground or dig test pits. Both of these sampling methods allow geotechnical engineers to vertically classify soil composition and stratification at specific locations. However, drilled boreholes can miss or misidentify important soil features, such as the percentage of rocks and cobbles, that test pits are more likely to characterize. For example, when drilled boreholes reach refusal—the depth at which the drill encounters an impenetrable bottom—the operator cannot distinguish between a boulder and bedrock, which is an important distinction.

Operators typically drill boreholes with a truck-mounted drill rig equipped with a 4-inch hollow-stem auger. Investigators can insert a 2-inch diameter sampling device through this hollow stem to collect soil core samples, either continuously or at 2- to 4-foot intervals. However, a 2-inch diameter sampling device cannot recover material larger than coarse gravel, and in some cases this boring technique does not identify cobbles and boulders that will cause foundation refusal during installation. While soil samples collected using 6- or 8-inch–diameter hollow-stem augers are generally more representative, the cause of boring refusal may still remain unclear.

The best soil sampling method for proposed PV project development, therefore, is to dig test pits to a depth of at least 10 feet below ground level. The process is relatively simple and affordable, since excavators typically dig test pits with a rubber-tired backhoe or similar equipment. This process allows the geotechnical engineer to directly inspect 10 cubic yards or more of soil, which makes it easy to identify and document soil boundaries, the seasonal high-groundwater level, the percentage and size of rock fragments, unsuitable soil horizons, depth to bedrock and so forth.

Regardless of the sampling method, a geotechnical engineer maintains a log of the soils encountered and the sampling depth. The subsequent geotechnical report identifies the approximate location of all boreholes or test pits on the site map. The report also includes a log entry for each location that identifies the soil classification (according to the Unified Soil Classification System) in relation to the sampling depth, plus the depth of any groundwater encountered.

Soil corrosivity and resistivity testing. A comprehensive geotechnical investigation also characterizes soil corrosivity, which oxygen, moisture and chemicals influence. Ensuring foundation longevity in corrosive soils requires protective coatings, thicker piles or sacrificial anodes. (See "Corrosion Impacts on Steel Piles," *SolarPro* magazine, December/January 2012.)

Soil corrosivity is inversely related to soil resistivity. Technicians evaluate in-situ soil resistivity by performing a Wenner four-pin test (see p. 30), which directly measures resistivity between four metal electrodes driven into the ground at equal distances from one another. The final geotechnical report includes these results.

Laboratory testing. During on-site investigations, a geotechnical engineer collects soil samples from boreholes or test pits, as well as samples of relatively undisturbed soils, and then sends them off for laboratory testing. The investigation typically optimizes these tests to the application. For example, a solar site assessment might include thermal resistivity testing, because electrical engineers can use these results to calculate allowable ampacities for directly buried cables. Laboratories can also conduct chemical analyses to evaluate the soil's corrosive potential in relation to concrete and steel, generating useful data for structural engineers. Laboratory tests may also be useful for identifying and mitigating expansive soils.

In some cases, the assessment uses laboratory tests to classify and describe soils according to engineering parameters such as soil strength, compressibility and relative density—but any conclusions about soil-bearing capacity or foundation-embedment depth based on lab results are too conservative for design purposes. To optimize PV power plant foundations, your geotechnical engineer needs to collect load-test data in the field, and you need to base your foundation design on an analysis of these data.

Courtesy AquaSoli

Load testing A typical foundation load-test setup is shown here. The strain gauge (top center) measures the vertical force that heavy construction equipment applies (out of frame to right); the string gauge (bottom center) measures displacement. Both gauges are connected to a laptop (not shown), allowing the geotechnical engineer to view, analyze and graph data in real time. Real-time data analysis informs the testing parameters for more-accurate foundation design optimization.

LOAD TESTING

To collect load-test data, geotechnical engineers install full-scale, site-appropriate test foundations. The engineer can then use heavy equipment, hydraulic jacks or chain hoists to apply horizontal and vertical foundation design loads. Applying the down forces for compression tests requires heavy equipment. For example, a horizontal load test quantifies how much a foundation deflects laterally when subjected to expected design loads. An axial tension test quantifies how well a foundation resists uplift forces and estimates the ultimate pull-out load. An axial compression test describes how well the foundation withstands down forces. CONTINUED ON PAGE 28

4/14
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Collectively, these tests directly measure soil bearing capacity based on the specific design loads and foundation type.

Geotechnical engineers typically plan preliminary load-test locations for a site in advance and then adapt the plan in the field based on subsurface discoveries. For optimal coverage, your geotechnical engineer might perform load tests at regular intervals around the perimeter and across the interior of a site. In many cases, however, engineers have to prioritize field activities based on the number of days they have on-site, which means they must adequately characterize major soil types and boundaries, and then prioritize further testing based on those data.

In many cases, geotechnical engineers perform load tests at different foundation depths, such as 6 feet and 8 feet below ground. In some cases, they use a single-pile profile—such as a W6x9 wide-flange steel I-beam or H-pile—for all the load tests conducted across a site. This does not mean the final mounting system has to use this pile profile; your foundation engineer can extrapolate these measured load-test results to different pile profiles. In other cases, engineers conduct groups of load tests across a site using multiple pile profiles, such as W6x7, W6x9 and W6x15. These additional data may allow you to consider different mounting options (fixed tilt versus tracking) and mounting-system geometries (single post versus double post), or may simply permit more-detailed foundation design optimization across a site with variable soils.

The process of driving test foundations also provides valuable information about how practical it is to install a specific type of foundation. For example, if you drive 50 piles across a site and 10 of them encounter refusal, then you may need a different type of foundation. At a minimum, you need to ask your foundation engineer to design an alternative for occasions when the pile encounters rejection. Installability can also be an issue with thin-walled foundations, which can buckle and fail in hard soils.

According to Steve Swern, project engineer at Standard Solar, load testing is nearly as important as geotechnical analysis. He notes: "We can avoid major installation problems in the field by performing pull tests. We can validate pile-driving feasibility in high-blow count soils. We can determine pile performance in loose or wet soils. We can identify things such as widespread buried construction debris that a standard geotechnical analysis might not discover or characterize."

Courtesy AquaSoli

Foundation refusal After encountering unacceptably high refusal rates with the earth screw foundation specified for this site, the EPC used test pit findings collected by AquaSoli to justify a change order. The customer could have avoided this if the original geotechnical investigation had included load testing and high-volume test pitting.

Site-Optimized Foundation Design

The ultimate goal of a solar-specific geotechnical analysis is to use site research, soil investigation and empirical load-test data to optimize the foundation for the specific site. For example, site research might give you an idea about the basic distribution of soil types. Geotechnical engineers can then use soil investigation to verify soil classification and map distribution more accurately. After collecting load-test data for these soil types, they can correlate these results to areas across the site with analogous soil conditions.

Foundation engineers can analyze all these data and optimize PV power plant foundation designs in terms of foundation type and geometry, embedment depth, corrosion control, mounting-system geometry, material costs, installation costs and so forth. Some foundation types and geometries better suit specific soil or site conditions than others. On smaller projects, it often makes sense to design around a single foundation type to simplify project logistics. However, an optimized design for larger sites often eschews a one-size-fits-all approach in favor of multiple pile profiles, embedment depths or even foundation types.

Driven pile. From a foundation optimization standpoint, driven-pile foundations are appealing because they generally offer the most attractive price point while providing good lateral and vertical bearing. Driven piles are most appropriate where soils are firm and compacted, with enough fine-grain materials

"In cases where project developers do not conduct soil investigations in advance, racking companies often use disclaimers and ceiling amounts to mitigate their risk."

—Wolfgang Fritz, VP of engineering and product development, Schletter (silt or clay) to offer high skin friction. Softer soils require deeper embedment depths and larger cross-sectional profiles. Driven piles are problematic in soils that resist installation, such as soils with very coarse gravel or rock fragments, very hard soils or bedrock.

Andrew Worden, CEO of GameChange Racking, notes that installers have three options when a site refuses a pile: "One option is to conduct a pull test to see if the driven pile has sufficient pull-out resistance as it is installed, in which case you can cut the pile to the desired height and use it. A second option is to remove the pile and reinstall it nearby, provided that the mounting-system tolerances allow for this. The third option is to remove the pile, drill an oversized hole, insert the pile into the hole and use cement, as detailed by a structural engineer, to grout the pile in place."

Steel piles are available in a wide variety of profiles, providing design flexibility. Options for pile driving equipment provide installation flexibility. Worden elaborates: "Some of these machines are highly sophisticated—with GPS guidance and automated installation technology—and allow for a very low pile-installation cost, considerably below that of other foundations." However, equipment access limitations typically constrain driven pile foundations to slopes less than 15°.

Earth screw. Compared to driven piles, earth screws can adapt to a wider range of soil and site conditions. If you predrill pilot holes, you can install earth screws in rocky soils and even bedrock. While drilling pilot holes typically increases the

Courtesy Terra Posts PV

Driven piles Each of the GAYK pile drivers shown here can install an average of 200 piles per day, which makes driven piles the most economical foundation for soils with good cohesion and low refusal rates.

"A complete and concise geotechnical report is imperative to foundation design and ground-mount project feasibility. Not only is it a matter of structural integrity, it also ensures that the owner receives accurate pricing for the scope of the mechanical installation."
—David Sharrow, director of operations, Terra Posts PV

foundation cost compared to driven piles, using earth screws may increase the deployable area. For example, earth screw installation is feasible on slopes up to roughly 30°. In softer soils, you can install earth screws without pilot holes. However, softer soils require deeper embedment depths.

For sites with high refusal rates, earth screws may be more economical than driven piles, simply because of the high costs associated with using drilled and grouted piles whenever you encounter refusal.

Earth screws offer good pullout resistance. While the screws offer good lateral resistance in firm soils, foundation engineers may need to find ways to increase lateral bearing in softer soils. A structural engineer may also need to adapt the mounting-system design for an earth screw foundation.

Helical anchor. All else being equal, helical anchors are generally less economical than driven piles or earth screws. However, they suit soft soils such as clean sand or weak saturated soil especially well. The anchor consists of a helical bearing plate welded near the bottom of a narrow central shaft.

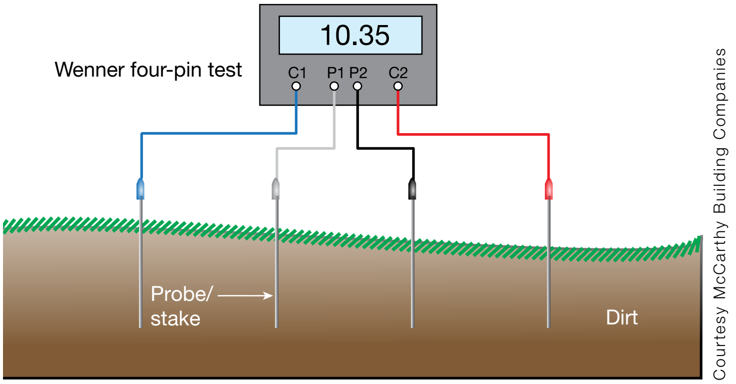
Lessons Learned:
A Project Developer's Perspective

Standard Solar is a full-service PV system provider based in Rockville, Maryland. We develop, design, engineer, finance and construct solar electric systems for nonresidential and utility applications. Many of our largest projects are ground-mounted PV arrays with geotechnical engineering and foundation design requirements. Following are some of the real-world lessons that we have learned.

Pull tests are essential. It is impossible to overstate the importance of pull tests. Pull tests allow us to identify hidden conditions and plan accordingly. We use pull-test results not only to validate engineering assumptions, but also to reduce costs by optimizing our use of structural materials or minimizing pile embedment depth. We also use pull tests to confirm the practical viability of a proposed foundation design before ordering large quantities of materials and deploying a full crew.

The best time to perform pull tests is when a crew is in the field collecting boring samples for the geotechnical analysis. The pull-test results are effectively supplier agnostic. A qualified geotechnical engineer can use load-test data from any driven pile to calculate the required embedment depth for every driven-beam cross section. If you hire a subcontractor to perform pull tests up front, you may be able to capture some savings later. While mounting system vendors are ideally positioned to commission or perform pull tests—and some include pull tests in their total delivered costs—collecting these data early in project development offers advantages.

The schedule—expiring incentives, liquidated damages, weather and seasonal constructability and so on—drives most solar projects to some degree, so any opportunity to gain float in the timetable or mitigate delays is of benefit. Selecting a racking vendor can take time, and you might not finalize the process until the 30% design stage, at which point engineering needs to move quickly to develop permitting and construction design documentation. Waiting for a racking provider to mobilize to a site, perform pull tests and then analyze these results can delay the project construction schedule a month. To avoid this delay, spend a little more during due diligence by having a third-party geotechnical engineer and subcontractor perform pull tests during the geotechnical analysis.



Corrosion impacts To characterize soil corrosivity, Standard Solar recommends conducting Wenner four-pin resistivity tests on ground-mounted projects over 1 MW.

The surface area of the bearing plate provides high pullout resistance, even in loose soils. However, the narrow shaft offers minimal lateral bearing capacity. As is the case with earth screws, you would use construction equipment with an auger attachment to drive helical anchors into the ground.

While helical anchors are ideal for sites with poor soil cohesion, they are not well suited to hard soils and soils with very coarse gravel or rock fragments. A structural engineer needs to ensure that design elements minimize horizontal loading, and may also need to adapt the mounting system design to use a helical anchor foundation.

Ballast. Precast or pour-in-place concrete ballast foundations best suit sites where soil penetration is undesirable or impractical. For example, project developers often deploy ballast foundations at PV power plants installed over landfills or

Courtesy AquaSoli

Earth screw Developers can deploy earth screw foundations in soils and on slopes that will not accommodate driven piles. With a predrilled pilot hole, crews can even install earth screws in bedrock.

Define the scope of work. The geotechnical analysis should include soil corrosivity and resistivity testing. For 1 MW and larger PV systems, we recommend performing Wenner four-pin soil resistivity tests during the initial geotechnical investigation. For systems under 1 MW, we suggest performing four-pin resistivity tests if laboratory tests for soil corrosivity indicate that the site requires cost-prohibitive materials such as epoxy coatings or highly galvanized racking foundations.

The geotechnical analysis should also include water level observations, and the report should note any potential issues related to water table height. With driven-beam foundations, for example, a high water table can significantly reduce soil load-bearing capacity. Water level can also be an issue with drilled holes that you must fill with concrete, as might be the case with a carport foundation. Sometimes it is feasible to use pumps to deal with this water; if so, it is best to have the pumps and the water discharge management plan in place before beginning construction. These are the types of system stability and foundation installation issues that a solar-specific geotechnical site assessment report should include.

Connect the dots. It is important for the project developer to manage responsibilities between the geotechnical engineer and the racking supplier's structural engineer, particularly when sharing reports and calculations. In the assessment report, for example, the geotechnical engineer might recommend a particular foundation size or type and detail assumptions and safety factors. If so, the project developer needs to communicate this information clearly to the racking supplier's structural engineer to avoid overly conservative designs. If the structural engineer applies redundant safety factors, the result could be foundation embedment details that are unnecessary for the site conditions.

Expect the unexpected. Make sure that subsurface exploration is adequate to properly characterize soil conditions. With soil boring samples, for instance, this is a function of the number or volume of samples collected across a site, as well as the equipment used. We do not recommend hand-operated boring equipment because it may hit refusal before reaching the depth needed for a full analysis.

Disturbed or contaminated soils present challenges that geotechnical engineers are uniquely qualified to address. If you want to develop an inner-city parking lot as a solar carport, for example, it is important to investigate whether there is a reason that others have not already developed the site. A geotechnical site assessment can identify whether the site contains undesirable fill, such as large rocks, concrete or bricks; if so, the geotechnical engineer can suggest engineering responses, such as a spread-footing foundation, that avoid the costs associated with drilling into buried debris. For contaminated soil, the geotechnical engineer can help navigate environmental permitting requirements and determine whether you need a contaminated material management plan.

Understand AHJ requirements. Some AHJs require that a licensed geotechnical engineer supervise the work on-site and certify that workers complete the foundation and mounting structure as designed. If the project requires construction verification, integrate this scope of work into the development schedule and budget as early as possible. Communication is essential. The project development team needs to know which activities the geotechnical engineer has to supervise, and the geotechnical engineer needs to know the schedule for these activities. The engineer of record needs to evaluate any changes made to the mounting structure or foundation and provide documentation approving the change.

—Steve Swern, project engineer, Standard Solar

brownfields. Sites with bedrock, a high water table or unconsolidated soils with high refusal rates may also benefit from a ballasted foundation. The mass of the ballast material resists the applied load, and the foundation distributes these loads across a large bearing surface.

Drilled and grouted piles. The best application for drilled and grouted piles in PV power plants is as an engineered foundation used in case of pile rejection. Drilled and grouted piles are otherwise prohibitively expensive, as they require drilling and concrete equipment. Further, the concrete needs to cure before you install the mounting system. However, drilled and grouted piles are suitable for most soil types and provide good load resistance.

Foundation geometry. The two basic geometries used for PV power plants are center-post foundations and double-post foundations. In a center-post foundation, a single row of foundations supports each mechanical array section or table. In a double-post foundation, two rows of foundations—a north row and a south row—support each table.

Typically, vertical and horizontal loads are greater with center-post designs than with double-post designs. Each center-post foundation usually supports a relatively large surface area, and a comparatively longer lever arm applies horizontal forces to the foundation. In contrast, double-post foundations typically support a smaller surface area, and the structural design shortens the lever arm. These load characteristics are useful in some applications. For example, structural engineers almost always use double-post foundations with helical anchors, and specify longitudinal bars between the rows to reduce horizontal loads.

Site variability. Economies of scale favor using a single foundation type on small projects, even if that foundation is overdesigned for some site locations. The opposite is true on large projects, where it is most cost effective to vary foundation design, type and embedment depth according to different soil conditions. For example, soil investigation at the proposed site for a 20 MW PV power plant in the Philippines identified five layers of soil in seven horizontal combinations. The soils included beach sand; cemented sand; clean stream deposits of mixed sand, gravel and cobbles; mud slide deposits of sand, clay, silt, gravel, cobbles and boulders; and decomposed volcanic ash. This site required five foundation details to account for different soil bearing capacities, mitigate the potential for foundation refusal, and optimize material and installation costs.

"If I were to make one recommendation," says David Sharrow, director of operations at Terra Posts PV, CONTINUED ON PAGE 34

4/14
_v10

Courtesy AquaSoli

Inadequate site assessment AquaSoli's remedial investigation at this site revealed why 3,000 posts failed due to frost heaving. The foundation designers did not account for shallow groundwater at the site.

"it would be that developers choose a racking system that conforms to their geotechnical and topographical conditions. I have seen too many projects where the design team chose a racking system based solely on price per watt, neglecting grade and soil conditions, and expecting a result that will not and cannot meet expectations."

According to Worden at GameChange Racking, a quality geotechnical analysis is essential for a well-planned and executed project: "In the context of developing a ground-mounted PV power plant, a thorough geotechnical investigation with high-volume test pitting is analogous to the carpenter's proverb, 'Measure twice and cut once.' For 1 MW–2 MW projects, we recommend drilling boreholes and conducting a complete geotechnical investigation at five to nine locations, as well as digging roughly five times as many test pits across the site to evaluate soil type and water table level. These investigations need to scale according to project size. For example, 3 MW–5 MW sites might require a geotechnical investigation of 10 to 15 boreholes, and larger sites will require even more."

Wolfgang Fritz, VP of engineering and product development for Schletter, agrees: "From a risk management perspective—both for the client and for us—it is quite important to perform geotechnical investigations. As soils can vary significantly across project sites, it is almost negligent to work off assumptions not backed by testing data that may lead to cost overruns for which the client has not budgeted."

"Skimping on the geotech investigation is a very bad idea that comes with the potential for substantial negative impacts to short- and long-term profitability."
—Andrew Worden, CEO, GameChange Racking

Designing from the Ground Up

Some in the industry have the perception that solar foundation design is simple—dirt simple, in fact. The fact that in the planning stage the foundation typically represents about 6% of the total project budget reinforces this perception. During construction, however, the foundation is more likely to run significantly over budget than big-ticket items such as modules and inverters. Geotechnical-related change orders and project delays can triple foundation costs. Once the project is complete, foundation failure is the single greatest risk to long-term profitability. In worst-case scenarios, the cost to remediate failures can exceed the initial installation costs. In best-case scenarios, ongoing O&M costs may increase beyond projections.

"We've acquired systems with foundation issues," notes Ken Allen, COO at Principal Solar, "that forced us to divert funds set aside for making improvements to the maintenance of a failing support system—simply to keep things from breaking. These problems divert manpower and resources to activities that do not enhance return on investment. A little extra money spent to gather good geotechnical information oftentimes can eliminate these problems."

AquaSoli's Schmid has more than 10 years of experience with remediating solar foundation failures. He notes: "Forensic analyses demonstrate that foundations generally do not fail because the system exceeded design loads. Foundations fail for reasons such as loss of soil-bearing capacity due to high groundwater level, or soil erosion and liquefaction. Foundations fail from frost heaving or because of expansive clay soils. They fail because construction activities destabilize the soil or impair drainage. These are all failures that we can avoid with better geotechnical data."

"The primary way to mitigate these issues," concludes Kleinfelder's Tschida, "is to engage a firm that provides both geotechnical engineering and PV foundation design. This option provides an integrated design approach where each discipline is not working in a silo, but rather will engage the other to provide an efficient design for the project."

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