ENGINEERED POWER SOLUTIONS

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STRUCTURAL OVERVIEW OF EARTH ANCHORS FOR PV GROUND MOUNTED ARRAYS

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Subject: Structural Overview of Earth Anchors
For PV Ground Mounted Arrays

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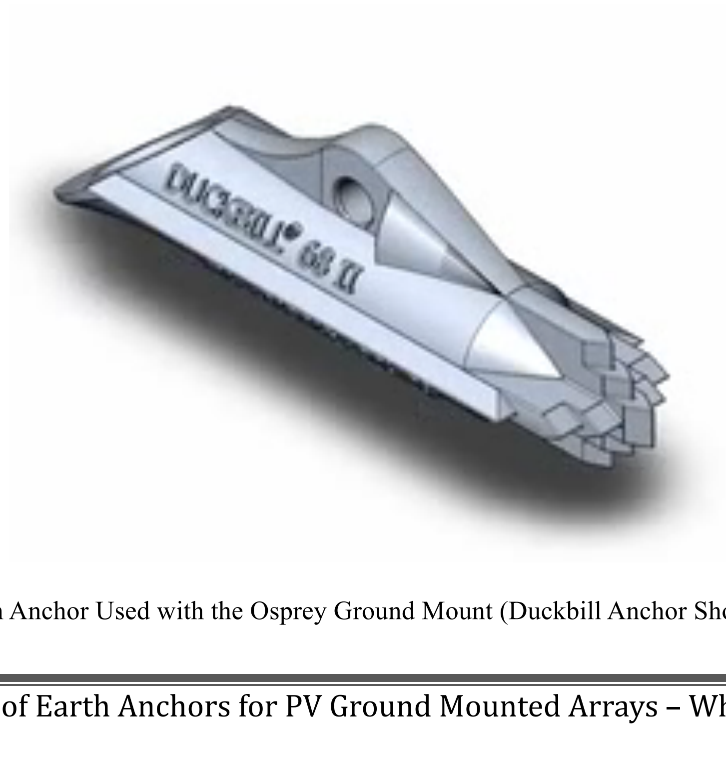
INTRODUCTION

As the demand for ground mounted Photovoltaic (PV) arrays increases, so does the demand for more cost efficient foundation options. Drilled concrete piers and driven steel piles have been, and remain the most typical foundation support for ground mounted PV arrays, but more recently there has been a push for “out-of-the-box” foundation design options including shallow grade beams, ballast blocks, helical anchors, and ground screws. The earth anchor provides a reliable alternative to traditional anchorage methods at a fraction of the cost, and has additional benefits not typically provided by other foundation options.



Typical Earth Anchor Used with the Osprey Ground Mount (Duckbill Anchor Shown as Example)

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CONVENTIONAL FOUNDATIONS

To fully understand how the earth anchor compares to the other options, an understanding of the design requirements and installation practices of the various foundation types is needed. The purpose of any foundation is to support and anchor the structure above to the ground. A typical concrete slab-on-grade foundation for a building is designed to transfer the vertical loads of the building above to the earth without crumbling, deflecting, or experiencing excess settlement.

The purpose of a foundation for a ground mounted PV racking structure is no different, except that due to the lightweight nature of the racking and the relatively large surface areas of the modules, the foundation also must resist high wind uplift loads. Many ground mounted arrays can also experience a significant amount of lateral (horizontal) force due to wind and/or seismic loads and therefore, the foundation must also keep the system from excessive lateral deflection or sliding.

Drilled and cast-in-place concrete piers have been the typical foundation type for small to medium sized projects. The advantages of concrete piers are that minimal equipment is required for installation, and they can be relatively shallow compared to driven steel piles. The disadvantages are that they use concrete, take days to cure, are labor intensive, and require the steel post to be embedded the full depth of the pier (or the use of rebar cages).

Driven steel piles solve many of these issues in that they don’t require concrete or rebar, don’t take time to cure, and can be installed very quickly with a pile driver. The issues is that piles are typically only cost effective for larger projects because of the high costs of mobilizing the pile driving equipment, and the depth to which the piles are driven is typically deeper than concrete piers which increases the potential for running into cobbles, boulders, or bedrock. The deeper depth requirement also rules out their use on most landfill sites, over leech fields, areas with rocky terrain, and areas with shallow bedrock.

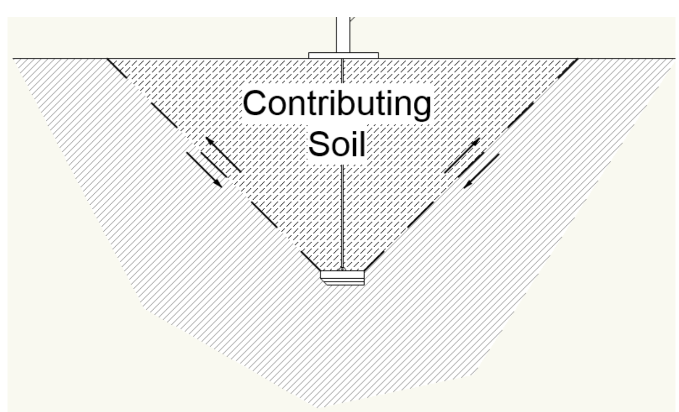
Both of these options also require hiring a geotechnical engineer to provide the soil design values used to determine the required pier/pile depth. If a geotechnical engineer is not hired, the presumptive soil design values listed in the building code, which are often overly conservative, must be used. Being overly conservative on the required foundation depth by even a foot or two can lead to significant increases in material and labor costs on projects, especially when hundreds, or thousands, of foundations are required. On-site pile testing for driven piles can greatly assist in determining an adequate depth without being too conservative, but the cost of the testing can be high and since only a small fraction of the piles are tested, a higher factor of safety is still used to ensure the results will be adequate for all of the untested piles.

The use of a ballasted-type foundation system such as concrete ballast blocks or a shallow grade beam (trench dug with a back-hoe and filled with concrete) don't require deep foundations or geotechnical reports, but at the cost of a much larger quantity of concrete. The load combinations in the building code dictate that when dead weight is used to resist a wind uplift force, only 60% of the provided dead weight may be used (factor of safety for ballasted systems). Therefore a post with a worst-case wind uplift load of 1000 lbs. would need to have close to 1700 lbs. of concrete provided at that post. This almost doubles the concrete cost for the project. Formwork and rebar requirements also add to the labor and material costs.

Helical piles and ground screws resist uplift loads by engaging the soil around them to resist the applied wind loads and are commonly tested to ensure the most efficient depth is specified for the site specific soil conditions. Helical piles and ground screws often come in preset lengths which can make in-field modifications difficult and they require specialized installation equipment in order to install them to the required depths.

EARTH ANCHORS

The earth anchor used on the Osprey units provides a safe and reliable foundation solution with a lower material and labor cost than the typical foundation options. Essentially, earth anchors work the same way as helical piles and ground screws but with much less steel, greater adjustability, and without the need for the specialized installation equipment. Although a few different earth anchor products are on the market, in general they all work similar to a toggle bolt by driving a small (few inches long) steel tip into the ground using a steel rod. The steel tip is driven into the ground with a pneumatic hammer, or by hand with a sledge hammer, and is attached to a steel cable. For the Osprey Unit, they are typically driven to a depth of around 2 to 4 feet below grade. Once in place the steel rod is removed leaving behind the steel



tip and cable. The above grade portion of the cable is then attached to a hand-cranked wench which is cranked until the cable resists in tension. Below grade, the tension on the cable causes the steel tip to rotate 90 degrees which then causes the longer side of the steel tip to be in direct bearing with the soil. The steel tip is held in place by the weight of the soil above and the internal friction within the soil. The angle that this internal friction spreads out at varies depending on the soil type but if this angle was taken as 45 degrees, an earth anchor driven down 3 feet would engage a cone of soil above it with a volume of almost 30 cubic feet. This high volume of soil provides great uplift resistance for a minimal amount of material and labor all while using the existing soil (instead of concrete) to provide uplift resistance.

The most appealing aspect to an engineer or building official, is that every single earth anchor can be load tested to provide the most accurate and reliable results. The results of each test can be summarized and provided to the engineer of record and building official for review and approval. Since the earth anchor assembly requires the cable to be in tension in order to engage the anchor portion, it is easy to install a gage to measure the cable tension when the cable is cranked. This allows the anchors to be installed in most soil types and to any depth as long as the anchor is loaded to the tension requirements pre-determined by the engineer. The factor of safety can be kept at a minimum since every single anchor can be tested.

For example, if the engineer determines that the uplift demand on an anchor is 500 lbs., the engineer may require the anchor to be tested to 750 lbs. (factor of safety of 1.5). The installer would then drive the earth anchor, and crank each cable to 1,000 lbs. of tension. If the level of tension is reached without the earth anchor pulling out of the ground, the anchor passes the test regardless of the embedment depth, soil type, etc. If the earth anchor pulls out of the ground, it can be re-driven to a deeper depth and the test repeated. This way, the exact capacity of the anchor is known and proven without the need for an expensive geotechnical report, large scale pile driving equipment, or any amount of concrete.

Essentially, earth anchors work the same way as helical piles and ground screws but with much less steel and without the need for the specialized installation equipment. Helical piles and ground screws resist uplift loads in the same way and are commonly tested to ensure the most efficient depth is specified for the site specific soil conditions, but unlike earth anchors, helical piles and ground screws often come in preset lengths making in field modifications more difficult than earth anchors.

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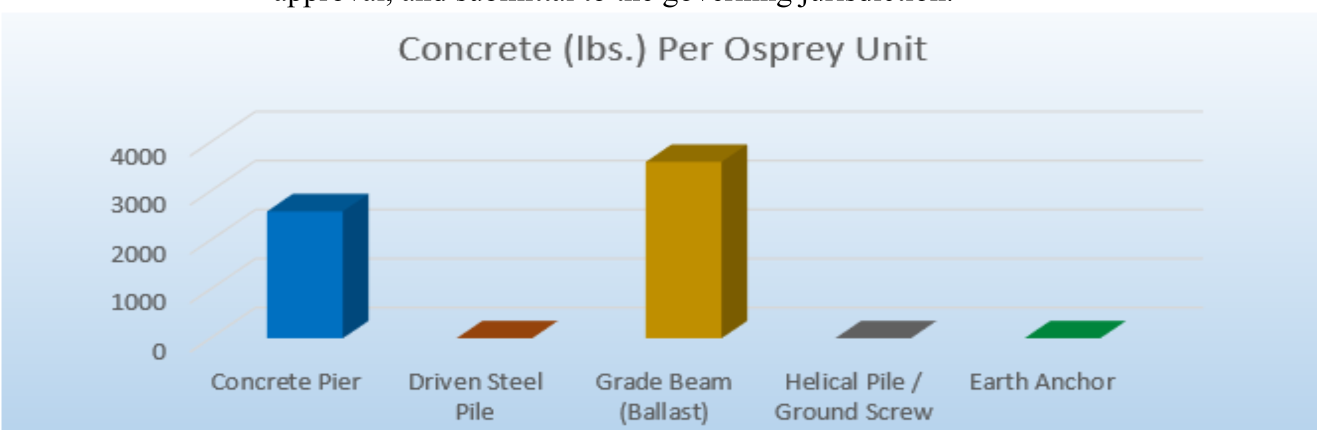
EXAMPLE FOR COMPARISON

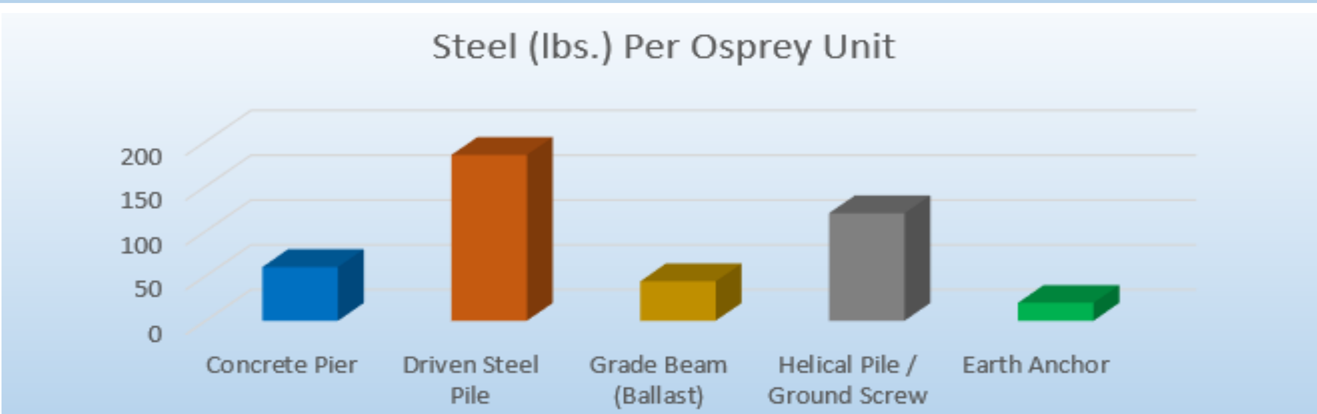
- **Design Conditions (consistent for all foundation types):**
    - Typical 60 Cell Module – Standard Osprey Power Platform Unit
    - Racking Tilt: 25 degrees
    - Design Wind Speed: 100 MPH (3 second gust speed)
    - Wind Exposure Cat.: C
    - Module Size: 65.55” x 39.02”
    - Calculated Uplift: -915 lbs. (Back Leg); -280 lbs. (Front Leg)
    - Calculated Lateral: 480 lbs. (Back Leg); 300 lbs. (Front Leg)
    - Soil Conditions: Unknown so Code Presumptive Values Used:
        - Lateral Passive: 200 psf per foot of depth
        - Skin Friction: 250 psf (1/6 of 1500 psf Bearing allowed per code)
        - Ignore top 1 ft. of soil (typical for topsoil, frost depth, etc.)

- **Requirements per Foundation Type:**
    - Drilled Cast-in-Place Concrete Piers:
        - 12” diameter piers
        - 6’-0” deep piers for the (2) Back Legs; 5’-0” deep piers for the (2) Front Legs
        - Rebar cages required (amount dependent on seismic design category of site)
    - Driven Steel Piles:
        - W6x7 pile assumed (4” wide by 6” deep with a steel weight of 7 lbs. per foot)
        - 7’-3” deep piles for the (2) Back Legs; 6’-0” deep piles for the (2) Front Legs
    - Ballast Blocks (or Grade Beams):
        - 800 lbs. of concrete required for Each Back Leg
        - 500 lbs. of concrete required for Each Front Leg
        - Concrete block shall have enough surface area to resist the lateral load through friction or be embedded into the ground to resist.
        - Due to the amount of weight and surface area required at each leg and the space available, it is typical to link the front and back legs together with a single ballast block. Each block would need to be 8 ft. long x 1 ft. wide x 1.5 ft. deep.

- <u>Helical Pile or Ground Screw:</u>
    - Each helical pile or grounds screw is installed in the range of 5 to 6 ft. (typical).
    - Load tests required using a minimum factor of safety of 1.5 and typically higher when only a select number of anchors are tested (per anchor manufacturer).
    - Provide a summary of the tested loads to the Engineer of Record for review, approval, and submittal to the governing jurisdiction.

- <u>Earth Anchor:</u>
    - Each anchor driven to around 2 ft. deep (average for most Osprey installations)
    - Load test Back Leg anchors to 1400 lbs. and Front Leg anchors to 500 lbs. (factor of safety of 1.5).
    - Provide a summary of the tested loads to the Engineer of Record for review, approval, and submittal to the governing jurisdiction.





Comparisons of Material and Foundation Depths for Each Foundation Option

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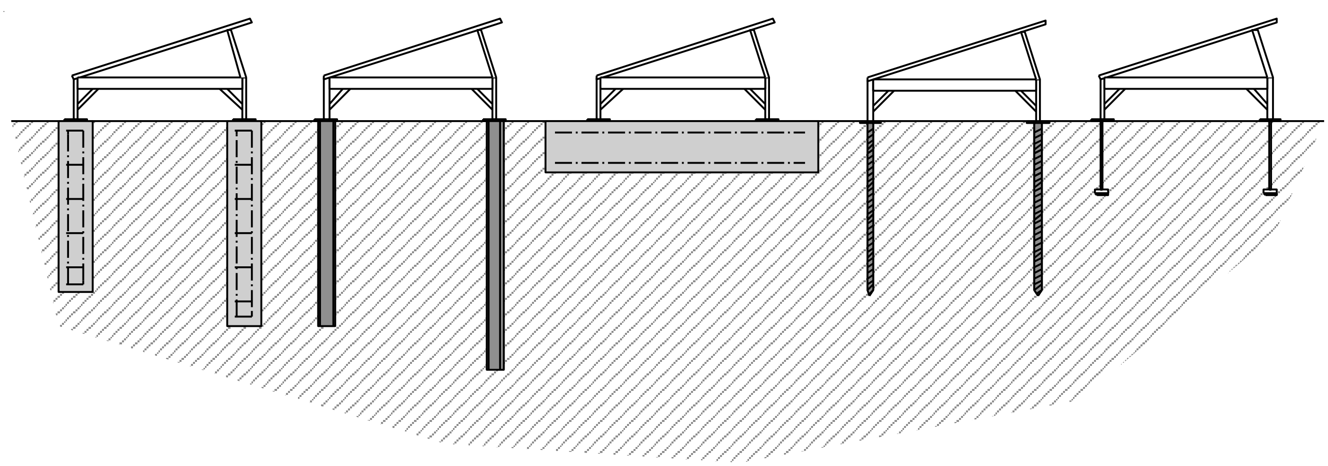

Comparisons of Material and Foundation Depths for Each Foundation Option

As shown, the earth anchor is a structurally reliable and cost-effective alternative to conventional foundations for ground mounted PV arrays, and is a large part of why the Osprey Power Platform System remains an efficient solution for residential, agricultural, commercial, and utility scale ground mounted PV systems.

Sincerely,

Matthew B. Gilliss, P.E., LEED AP
Engineered Power Solutions