ERTHOS

Permeability of Earth Mount Solar

White Paper

Abstract

Erthos has developed an entirely novel approach to utility-scale solar, eliminating almost all of the steel previously considered a necessary part of solar installations. This is achieved by deploying solar modules with their frames directly in contact with the earth and securing the system using a cross-pattern steel cabling system that is fastened to concrete balasts at the edge of each Erthos “Island”. Each solar module is spaced 1/8” on all sides from adjacent solar modules using permanent grommets to provide standard gaps between each panel. Erthos installations implement off-the-shelf solar modules with modified aluminum frames. The standard frames are modified by suppliers to include eight 13mm holes to facilitate securing the Erthos system via mesh cables, and eight 9mm weep holes to allow for pressure equalization and facilitate the movement of water to the soil underneath the panels.

This system creates a condition in which the Erthos system as a whole is, in fact, more permeable than any native dirt located beneath the system, boasting an infiltation rate equivalent to approximately 57.61 inches per hour.

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ErthCompatible Solar Modules

Along with other features related mainly to the ingress protection (IP) rating of ErthCompatible modules, one ErthCompatible specification that module suppliers must meet is to modify the aluminum frames of modules with eight 13mm mesh cable holes and eight 9mm weep holes, as shown below in Figures 1-3.

Figure 1 – Mesh Cable Holes and Weep Holes (Short Edge and Long Edge)

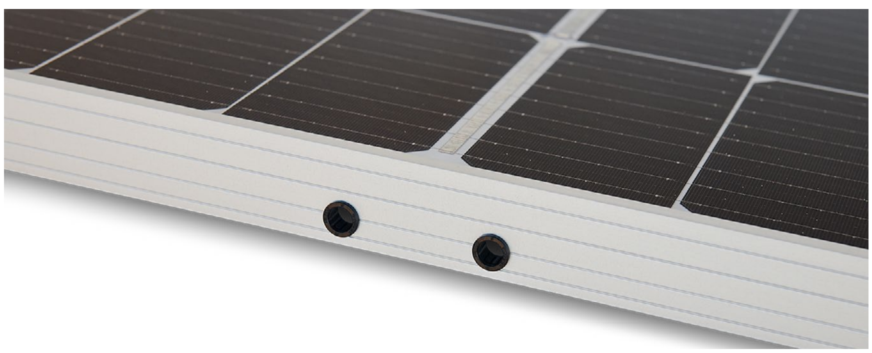

Figure 2 – Mesh Cable Holes (Long Edge)

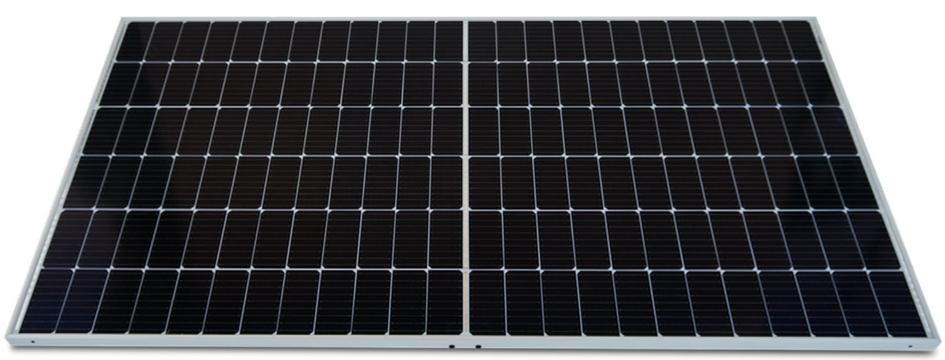

Figure 3 – Mesh Cable Holes and Weep Holes (Long Edge)

Gaps Between Modules

Prior to installation of solar modules in an Erthos system, field installation crews install four 13mm snap-in grommets, one per each edge of the module frame. These grommets serve two purposes in the Erthos system: 1) providing easy pass-through of mesh cables during installation by reducing friction, and 2) creating the 1/8” gap between each solar module and its adjacent modules, as shown in Figure 4.

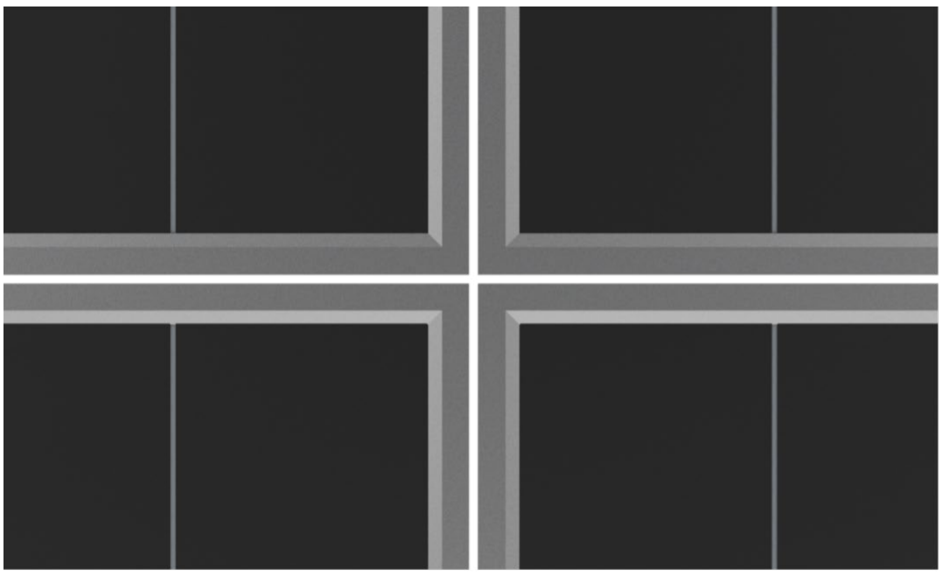

Figure 4 – 1/8” Module Gap (Same on all four sides)

Calculations and Discussion

Infiltration of the Erthos Solar Array

“Infiltration” Into the Gap

Taking into account that each pair of adjacent modules share the outlet to the 1/8” gap, the corresponding gap attributed to each module is 1/16” on all four sides. To determine the cross sectional area of the gap utilized by each module, simply multiply the perimeter of the module frame by 1/16”.

Determine the total area of the gap attributed to each module:

$$Area_{Gap} = Perimeter_{module} * Width_{Gap}$$

$$Area_{Gap} = (2278\ mm + 1\,134\ mm) * 2 * 1/16\ in$$

$$Area_{Gap} = (89.685\ in + 44.646\ in) * 2 * 1/16\ in$$

$$Area_{Gap} = 16.79\ in^2$$

Correlating this area to an equivalent pipe size diameter yields the following:

$$A_{pipe} = \pi r^2_{pipe}$$

$$16.79\ in^2 = \pi r^2_{pipe}$$

$$r_{pipe} = \sqrt{}(16.79\ in^2 / \pi)$$

$$r_{pipe} = 2.31\ in$$

A pipe radius of 2.31 inches is equivalent to a pipe with an inner diameter of 4.62 inches.

Utilizing Torecelli's Law, the following eqauation for drainage rate into the Gap can be determined as follows:

$$t = V / (A * \sqrt{}(2 * g * h))$$

Where *t* is time, *V* is the total volume of water on top of a module (constrained to 1/8" due to module frame edge height above glass), *A* is the cross sectional area of the drain "hole" (total area of the gap), *g* is the acceleration due to gravity (32.2 ft/s^2 = 386.4 in/s^2), and *h* is the height of the water. For *h*, we can assume that the height of the water is equal to the height from the soil surface to top of the frame edge (35mm).

$$t_{drain} = (89.685\ in * 44.646\ in * 1/8\ in\ ) / (16.79\ in^2 * \sqrt{}(2 * 386.4\ in/s^2 * 1.378\ in))$$

$$t_{drain} = (500.51\ in^3\ ) / (16.79\ in^2 * \sqrt{}1064.92\ in^3)$$

$$t_{drain} = 0.914349\ seconds$$

If we correlate this drain rate to inches per hour to drain the 1/8-inch-deep water volume in 0.914 seconds, it results in an **effective drain rate of 492.15 in/hr**. Note that this drain rate far exceeds any typical native soil types infiltration rates by a significant amount. Note that the historical maximum inches/hr rainfall for the State of South Carolina is 14.80 inches over 24 hours. This is equavialent to approximately 0.617 in/hr. (https://www.dnr.sc.gov/climate/sco/ClimateData/cli_table_24hr_max_pcpn.php).

"Infiltration" Through ErthCompatible Module Frame Holes

Taking into account that each ErthCompatible module is modified and has eight 13mm holes and eight 9mm holes, we can determine the total cross sectional area of the effective drain hole. Note that four 13mm holes will have a snap-in grommet and mesh cable fitted and will therefore reduce the open area of those holes. This is addressed below.

9mm weep holes:

$$A_{weep} = 8 * \pi r^2$$

$$A_{weep} = 8 * \pi(4.5\ mm)^2$$

$$A_{weep} = 8 * \pi(0.1772\ in)^2$$

$$A_{weep} = 0.789\ in^2$$

13mm (12.7mm) mesh cable holes (no grommet):

$$A_{mesh} = 4 * \pi r^2$$

$$A_{mesh} = 4 * \pi(6.35\ mm)^2$$

$$A_{mesh} = 4 * \pi(0.25\ in)^2$$

$$A_{mesh} = 0.785\ in^2$$

13mm (12.7mm) mesh cable holes (with snap-in grommet):

$$A_{mesh\text{-}modified} = 4 * \pi r^2$$

$$A_{mesh\text{-}modified} = 4 * \pi(4.75\ mm)^2$$

$$A_{mesh\text{-}modified} = 4 * \pi(0.187\ in)^2$$

$$A_{mesh\text{-}modified} = 0.439\ in^2$$

Note, we must subtract out the mesh cable cross section area from the total volume above. This yields an adjusted cross sectional area of 0.3896 in^2.

Total cross section area of holes:

$$A_{hole\text{-}total} = A_{weep} + A_{mesh} + A_{mesh\text{-}modified}$$

$$A_{hole\text{-}total} = 0.789\ in^2 + 0.785\ in^2 + 0.3896\ in^2$$

$$A_{hole\text{-}total} = 1.9636\ in^2$$

Correlating this area to an equivalent pipe size diameter yields the following:

$$A_{pipe} = \pi r^2_{pipe}$$

$$1.9636\ in^2 = \pi r^2_{pipe}$$

$$r_{pipe} = \sqrt{}(1.9636\ in^2 / \pi)$$

$$r_{pipe} = 0.791\ in$$

A pipe radius of 0.791 inches is equivalent to a pipe with an inner diameter of 1.58 inches. Correcting for rounding errors during unit conversion, the effective diameter is 1.49 inches.

Utilizing Torecelli's Law, the following eqauation for drainage rate into the Gap can be determined as follows:

$$t = V / (A * \sqrt{}(2 * g * h))$$

Where *t* is time, *V* is the total volume of water on top of a module (constrained to 1/8" due to module frame edge height above glass), *A* is the cross sectional area of the drain "hole" (total area of the gap), *g* is the acceleration due to gravity ($32.2\ ft/s^2 = 386.4\ in/s^2$), and *h* is the height of the water. For *h*, we can assume that the height of the water is equal to the height from the soil surface to top of the frame edge (35mm).

$$t_{drain} = (89.685\ in * 44.646\ in * 1/8\ in) / (1.9636\ in^2 * \sqrt{}(2 * 386.4\ in/s^2 * 1.378\ in))$$

$$t_{drain} = (500.51\ in^3) / (1.9636\ in^2 * \sqrt{}1064.92\ in^3)$$

$$t_{drain} = 7.8109\ seconds$$

If we correlate this drain rate to inches per hour to drain the 1/8 inch deep water volume in 7.81 seconds, it results in an effective drain rate of 57.61 in/hr. This drain rate far exceeds any typical native soil types infiltration rates by a significant margin. Note again that the maximum inches/hr rainfall for the State of South Carolina is 14.80 inches over 24 hours. This is equavialent to approximately 0.617 in/hr. (https://www.dnr.sc.gov/climate/sco/ClimateData/cli_table_24hr_max_pcpn.php).

In the completely unnatural event that an Erthos site needed to drain the entire maximum rainfall event ever in the state of South Carolina of 14.8 inches, using the same equation for t_{drain} as above, the water would drain into the gaps in approximately 31.6 seconds, further highlighting that the soil beneath the modules – and not the Erthos system – is the constraining factor regarding infiltration and water runoff.

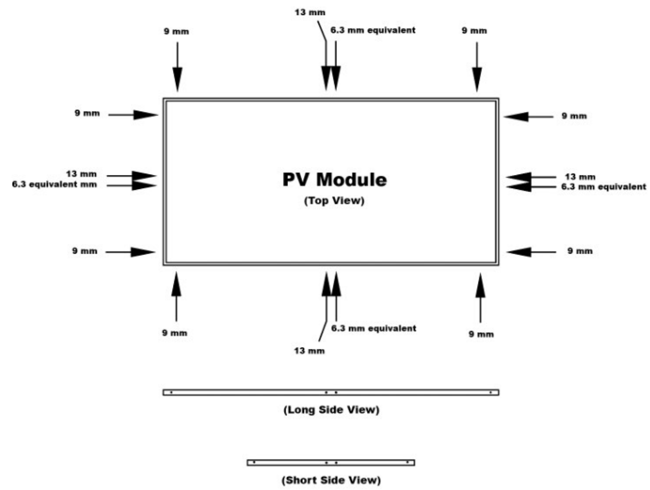

Figure 5 – Typical ErthCompatible Module with Frame Hole Callouts

Analyzing the results above, it becomes clear that the solar modules are permeable, and in fact, are more permeable than any soil conditions one might encounter anywhere in the United States. Recognizing that the module gaps and the ErthCompatible frame holes do no impede the ability of water to permeate and make it's way to the soil underneath Erthos solar systems, the limiting factor with regards to infiltration and subsequate runoff is the soil underneath the solar system.

Runoff Storage Underneath Erthos Solar Array

Considering the standard Erthos 2MWac Block attributes, Erthos "Islands" enable a timed release storage feature. Looking at the standard Erthos Island, each island is bounded by concrete Perimeter Blocks that are ~35mm tall (equivalent to the module frame). There is a 5/8" gap between each Perimeter Block around all four sides of the Island. Additionally, each Island has a typical dimension of 225' x 202'.

With this information, we can determine the following:

Maximum Storage Potential

$$V_{store\text{-}max} = l * w * h$$

$$V_{store\text{-}max} = 225\ ft * 202\ ft * 35\ mm$$

$$V_{store\text{-}max} = 225\ ft * 202\ ft * 0.115\ ft$$

$$V_{store\text{-}max} = 5226.75\ ft^3$$

Correlating this to real world applications and utilizing the Erthos array infiltration values as calculated above, at 0 in/hr soil infiltration a typical Erthos Island has a storage potential with a depth of 1.378 inches for a total of 5226 ft^3. At 225' x 202', each island is approximately 1.04 acres. Meaning that for every Erthos island, that island inherently has a storage capacity of 0.119 ac-ft. On a typical 2MWac Block, the total storage capacity of the solar system is 0.478 ac-ft.

Baffling Effect of Erthos Array via Module Frame Edges

Similar to baffles that are often specified and installed in flow channels on development sites, the Erthos system boasts a highly robust system of baffles that are inherent in nature to the aluminum module frames being in contact with the surface of the Earth. On the short side edge, baffles have a maximum spacing of 3.5 ft. On the long side edge, baffles have a maximum spacing of 7.5 ft. This system feature creates a condition in which the dirt benath Erthos sytems cannot be subjected to erosive velocities and helps to increase the time that water can undergo infiltration into the subsoil beneath Erthos systems.

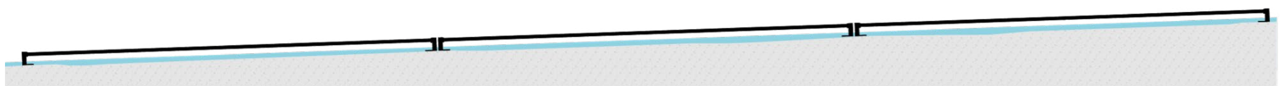

Figure 6 – Typical ErthCompatible Module Frames in Contact with Surface

Summary

Erthos solar arrays have the lowest land requirement in the industry. With Erthos, for the same AC energy output, a site only requires one-half to one-third the acreage of land. In this way, Erthos technology is a perfect example or cluster development, whereby land disturbance is significantly reduced and adjacent land that would otherwise be needed to meet the same energy production requirement can be preserved for open space.

Erthos solar arrays are permeable and allow water to flow directly to the natural grade, allowing infiltration to occur at the source of the potential runoff. Similar to permeable pavements, an Erthos array has impermeable material that is perforated with open holes for drainage and open gaps between each solar module. This provides an effective permeability of 1% – meaning that of the total area of each solar module in an array, 1% of that area is 100% permeable. This allows for water flows that far exceed the rate of infiltration of the underlying soil. This means that the solar array does not contribute to water flowing away from the source of runoff. Instead, that is impacted by the rate of infiltration of the soil.

Additionally, Erthos arrays slow down conveyance of runoff and allow for gradual infiltration at the source, helping to reduce peak flow discharges. This is because each solar module has a >1” water detention area underneath the glass, providing runoff storage, and an aluminum frame that contacts the soil. The aluminum frame acts as a water baffle, allowing more time for infiltration.

Erthos arrays thus accomplish four major objectives that aid in low-impact development:

1. Limit the amount of land disturbed (cluster development).
2. Utilize permeable equipment (perforated solar module frames and gaps between modules).
3. Provide runoff storage (detention area under each solar module).
4. Slow down conveyance (module frame creates a water baffle).