TERRACELL®

CELLULAR CONFINEMENT SYSTEM

DESIGN GUIDELINES FOR SLOPE EROSION CONTROL

The TerraCell® Cellular Confinement System is a three-dimensional, "honeycomb" structure made of polyethylene. It is designed to minimize and/or eliminate the effects of the erosive forces of water and wind on exposed soils.

TerraCell® is highly effective in protecting:

**Highway and railroad embankments
Berms, dikes and levees
Landfill slopes and caps
Natural, cut or fill slopes**

Mechanics of Soil Erosion

Slopes are prone to soil erosion. It takes place when the forces of wind or water cause rills to form in the exposed soil. Over time these forces concentrate within the rills which accelerate the erosive process. The principal site parameters that determine the amount of erosion likely to take place are:

1. Angle of the slope
2. Height and length of the slope
3. Type of soil on the surface of the slope
4. Water flowing onto slope from above

Historically, engineers have attempted to minimize the effect of these erosive forces by protecting slopes with vegetation, armor stone, erosion control blankets, etc. Unfortunately, vegetation or blankets are not effective except in mild conditions and armor stone is very costly, highly unattractive, and may create a potential hazard for children and animals.

The **TerraCell** Solution

For many erosion control situations, the **TerraCell Cellular Confinement System** can be substituted for more costly conventional systems such as riprap, revetment mats, and gabions. The cells in TerraCell confine a fill material (soil, sand, aggregate) and protect it from being moved by wind or water.

Each cell acts as a small dam that allows water or wind to pass over the top while holding the fill in place, thereby dissipating erosive forces. The cell walls inhibit formation of rills, thus preventing the erosive process from developing. Also, a grass covered TerraCell slope can be mowed with standard mowing equipment.

In areas subjected to substantial erosive forces (very steep slopes with heavy flows), concrete-filled TerraCell, is the most effective solution. In this particular situation, TerraCell becomes an articulated concrete mat that conforms to possible differential settlement.
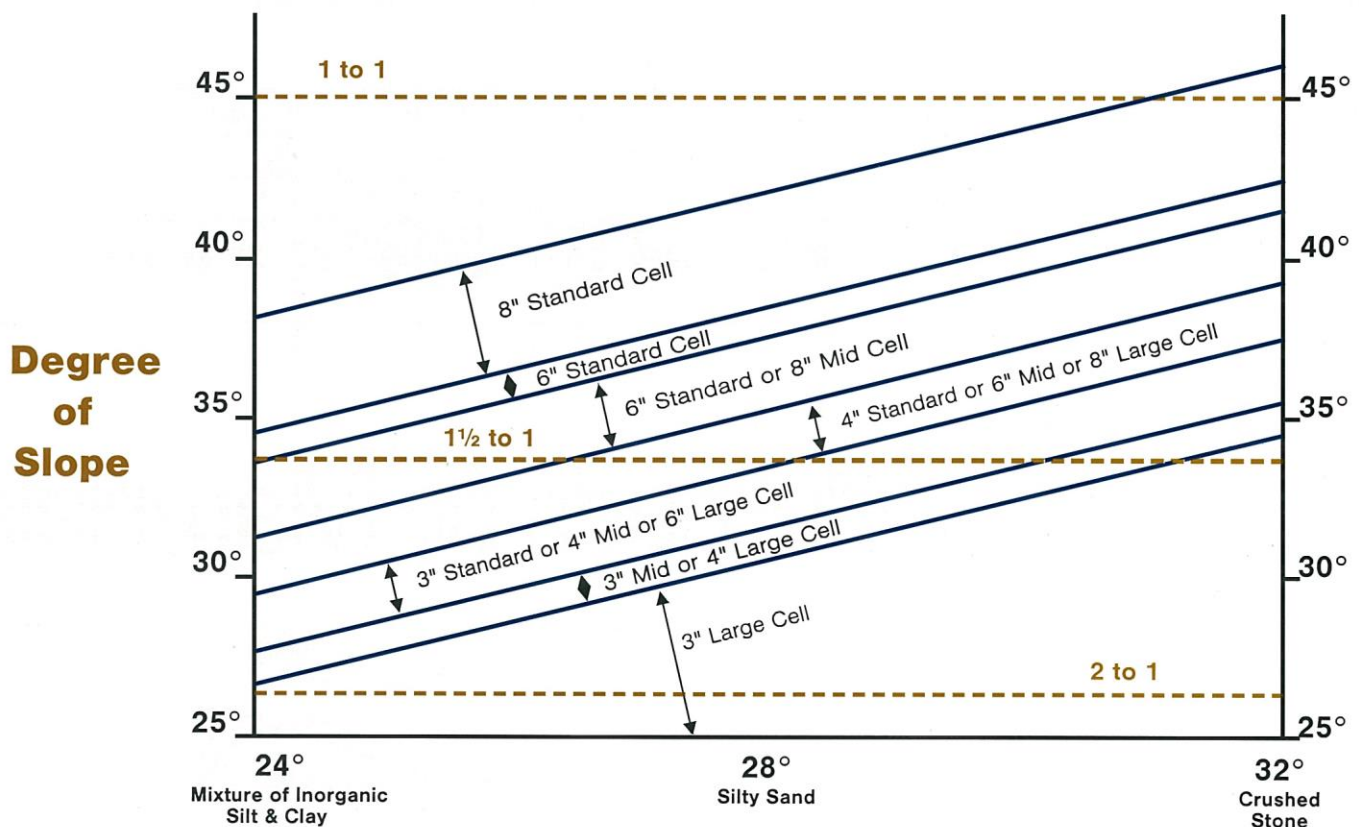
Also, in cases where external weight on the slope is needed to enhance the stability of the slope, TerraCell provides the additional benefit of keeping the fill material in place.

Economics

Slope protection using heavy armor stone tends to be very costly in terms of materials and the time consumed in installation, especially if the rock must be transported from off-site. Slope protection using TerraCell filled with locally available soils, aggregate, or concrete can be more effective than expensive alternatives and is usually less costly to maintain.

Designing with **TerraCell**

Once it has been determined that TerraCell is the most appropriate solution to a slope erosion control problem, it becomes necessary to select the proper size TerraCell and the most suitable fill material. This is accomplished by first determining the degree of the slope being protected and the conditions affecting the slope. Using this information, one can then select the most appropriate cell height, cell size, and fill material needed for the particular situation.

Degree of Slope (vertical axis): 25°, 30°, 35°, 40°, 45°

Dashed reference lines: 1 to 1 (at 45°), 1½ to 1 (at ~33°), 2 to 1 (at ~25°)

Band labels (bottom to top): 3" Large Cell; 3" Mid or 4" Large Cell; 3" Standard or 4" Mid or 6" Large Cell; 4" Standard or 6" Mid or 8" Large Cell; 6" Standard or 8" Mid Cell; 6" Standard Cell; 8" Standard Cell

Horizontal axis — **Angle of Internal Friction, Ø, of infill**: 24° Mixture of Inorganic Silt & Clay; 28° Silty Sand; 32° Crushed Stone

The above chart can be used to select the cell height and size in moderate situations. The three different cell areas are: Standard (9.6" x 8"), Mid (13.7" x 12") and Large Cell (19.2" x 16"), nominal dimensions. Moderate situations are characterized by modest precipitation, some water flow from beyond the crest of the slope, and no expectation that a good ground cover will become established before the rainy season or a major storm event. If the actual situation is more severe, or less severe, the selection of the height and width of cell should reflect this. The maximum size of individual pieces of infill should be no larger than 1/3 the height of the cell. This is a factor in selecting the height of cell.

Anchoring the TerraCell

Proper anchoring of TerraCell to a slope is critical to how well the product performs. No matter which anchoring materials are selected, they must be left in place throughout the life of the project. The following factors must be considered when deciding what anchoring materials will perform best:

1. Degree of slope
2. Length of slope
3. External loads, such as snow
4. Angle of internal friction (Ø) of the fill material and of the slope soil (only the smaller of the two will be used)
5. Unit weight of the material used as fill
6. Height of TerraCell
7. Presence of a geomembrane on the slope

Before selecting an anchoring method, it is first necessary to calculate the net sliding force (NSF) or the force which would have to be overcome to keep TerraCell from sliding down the slope. If the NSF is negative, then the friction force between TerraCell and the slope is sufficient to hold the system in place. Table 1 shows examples of calculating NSF.

TABLE 1

$$\text{Net Sliding Force} = [(H \times L \times \gamma) + (L \times SL)] \times [\sin w - (\cos w \tan Ø)]$$

| NSF NET SLIDING FORCE	H Height of Cell	L Length of Slope	γ Unit Weight of Fill	SL Snow Load	W Slope Inclination (H to V)	Ø Lowest Angle of Internal Friction of Soil
LBS/FT*	INCHES	FEET	LBS/FT³	LBS/FT²	SLOPE	DEGREES
56	4	20	125	40	1.75 to 1 (29.7°)	28° (silty sand)
353	6	100	125	40	1.75 to 1 (29.7°)	28° (silty sand)
-912 **	4	100	125	40	2.00 to 1 (26.6°)	32° (crushed stone)

* Pounds per foot measured parallel to top of slope.   ** Indicates no special anchoring is required.

Anchoring Methods or Materials

Anchor Trench

The upper edge of the TerraCell should be buried in an anchor trench to prevent flow underneath. This also serves to anchor the TerraCell to the top of the slope. This method takes advantage of the weight of the soil on top of the buried cells. The following equation can be used to calculate the required length and height of the trench to resist the sliding force:
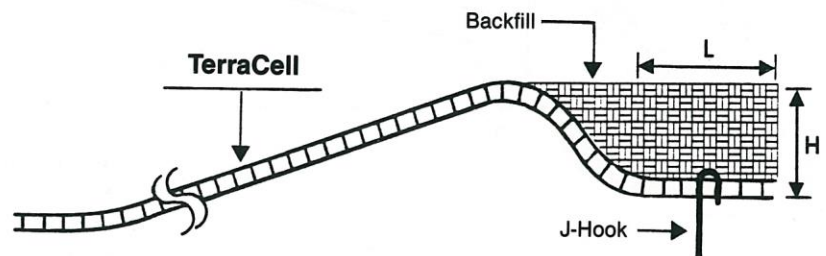
$$L \times H = \frac{\text{net sliding force} \times \text{factor of safety}}{\text{unit weight of soil} \times \tan Ø}$$

Where Ø is the angle of internal friction of the fill, or of the surface soil, whichever is lower.

If the slope is longer than the panel length, lower panels must also be toed in or attached to the upper panel, or anchored using another appropriate method.

Anchor Pins

Staking or pinning TerraCell to a slope is the common anchoring method used if there is no geomembrane present and if the soil has adequate strength to retain the anchor pins. Steel reinforcing bars bent into "candy cane" shapes called J-Hooks are the preferred type of pin. *(**Caution:** If the surface of the slope is covered with vegetation that will be mowed, anchor pins other than J-Hooks, such as wooden or plastic stakes, should be considered.)*

J-Hooks

**Typical
Pinning Pattern**

As a general rule, the length of the pin should be three times the cell height. A typical pinning pattern is shown in the above drawing.
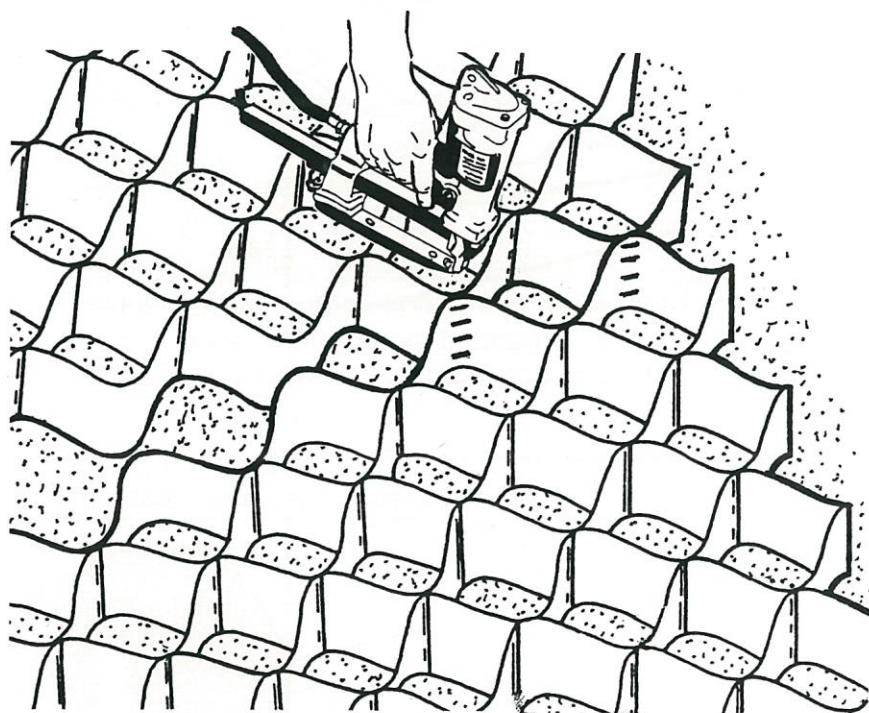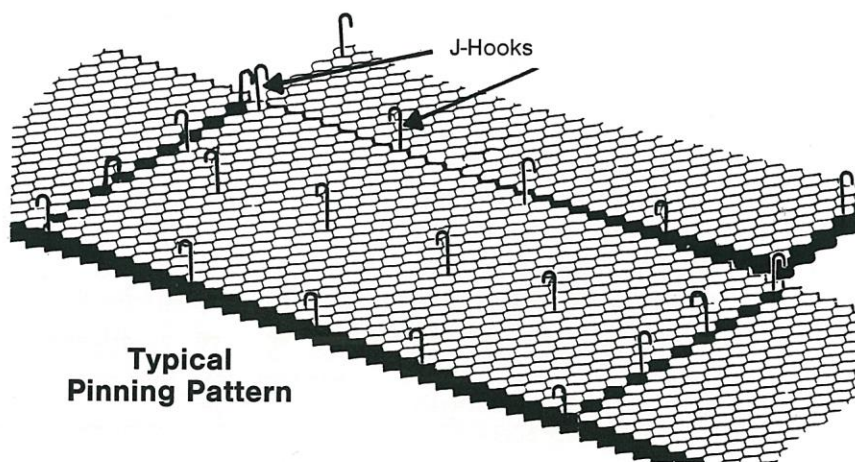
Staples and Rings

If conditions require that adjacent sections of the TerraCell be joined together rather than butted against each other, staples or hog rings can be used. Staples are normally attached using a pneumatic staple gun with industrial grade staples. The staples or rings are attached through each set of adjoining cells. Stainless steel staples are recommended for long-term performance. Adjacent TerraCell panels may also be tied together with tendons.

Tendons and Restraint Pins

Tendons and restraint pins are employed on steep slopes where additional support is needed, or where use of pins is prohibited (rock base, geomembrane underliner). They are also commonly used when more than one section of TerraCell is needed to cover the slope from top to bottom.

The three important characteristics of tendons are strength, durability and resistance to creep. Tendons usually consist of high strength polyester webbing or cord. The design load and spacing of the tendons is determined by the force to be supported. A large number of lighter tendons is preferable to a smaller number of heavier tendons. Batten strips or large washers at the bottom of the lowest section of TerraCell are essential to avoid stress concentrations.

Installation Using Tendons

If the TerraCell does not already have holes for the tendons, drill the holes before expanding the TerraCell sections. Measure and cut tendons to desired lengths. Tie the tendons to a supporting structure beyond the crest of the slope. This supporting structure may be a length of high-strength PVC pipe, a concrete beam, or set of concrete blocks placed in an anchor trench. An alternative system may consist of harpoon-like earth anchors.

Whether or not tendons are utilized, TerraCell should be placed beyond the crest of the slope to prevent surface water from undermining the TerraCell.

At the top of the slope, thread tendons through the holes in the unexpanded TerraCell sections. Measure and mark the perimeter of the area to be covered by the first section to be installed. If allowable, place anchor pins around the perimeter to hold the expanded section into place. Expand and place the section, taking care that the tendons do not come out of the holes. Repeat this procedure for remaining sections.

The tendon must be tied, in tension, to a restraint pin or batten strip on the downhill side of the last cell wall (see diagram). The use of washers or plates helps to relieve point stresses. The use of restraint pins, batten strips, washers and plates helps to transfer the load from TerraCell to the tendons. Restraint pins, batten strips, washers and plates should be made from corrosion-resistant materials such as galvanized steel, high-strength plastic, etc.
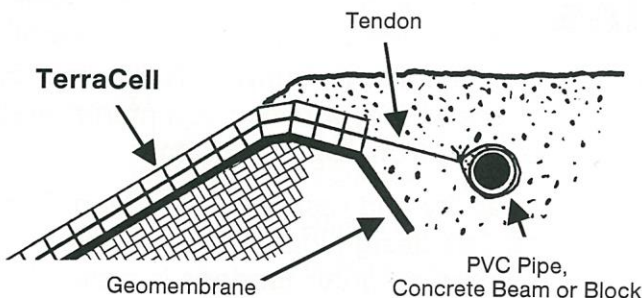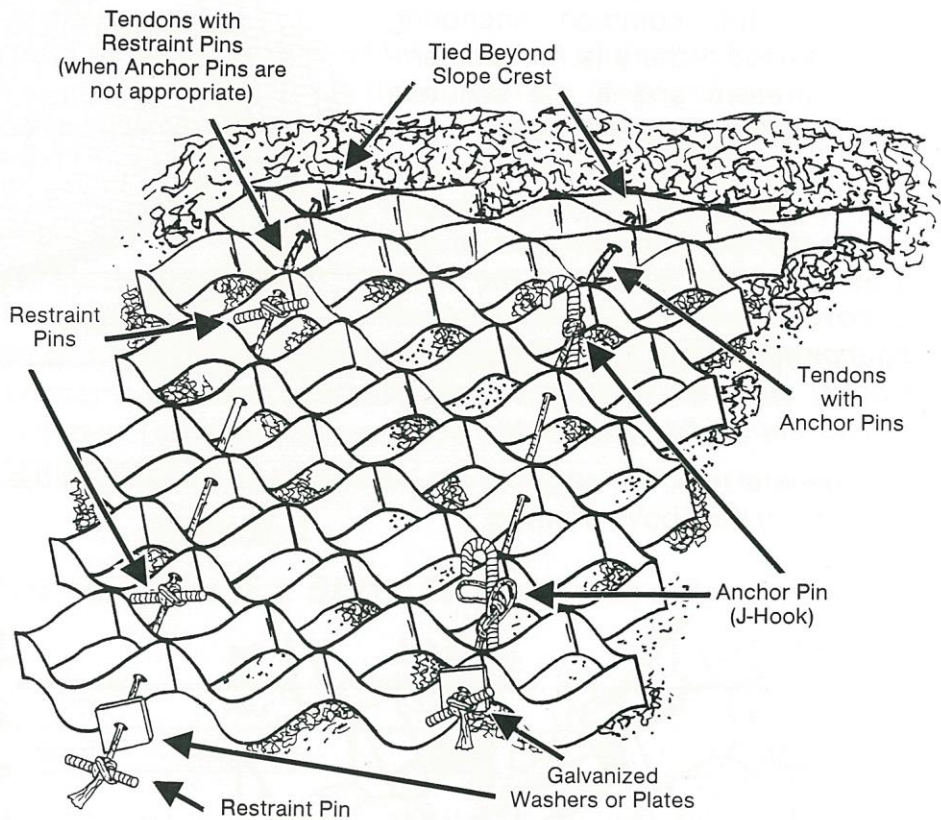
Supporting Structure: Dead Man System
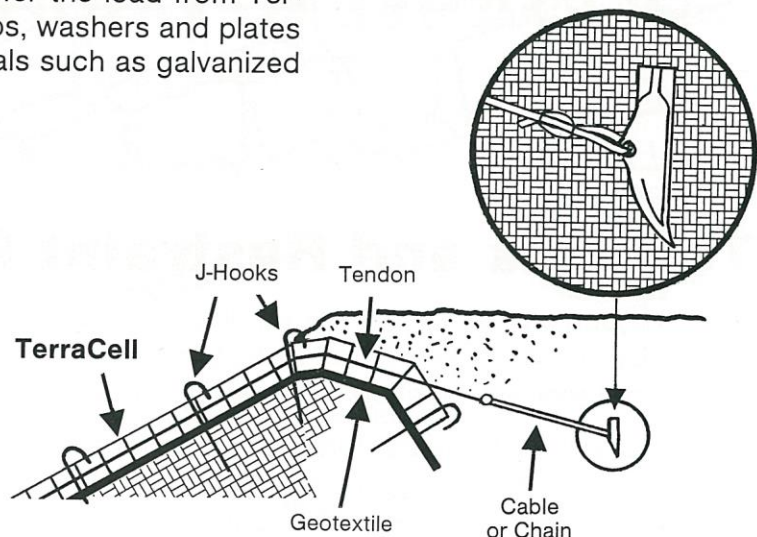
Supporting Structure: Harpoon-like System

Which Anchoring Method?

Given the resulting net sliding force (NSF) for two of the cases in Table 1, the next step is to decide how to anchor the TerraCell. For the situation where NSF = 56 lbs./ft., two common methods of anchoring the TerraCell are to toe it in or to stake it to the slope. For the situation where NSF = 353 lbs./ft., the TerraCell could be supported by earth anchors with tendons.

ANCHOR TRENCH: *Using the appropriate equation (given in Table 1 on page 4):*

$$L \times H = \frac{56 \times 1.25}{125 \times \tan 28°} = 1.1 \text{ sq. ft.}$$

*A practical combination would be to bury the top edge of the TerraCell 1 foot deep and 1.1 foot back. Another practical combination would be to let **L** be 2.2 feet and let **H** be 0.5 feet.*

STAKES: *56 lbs./ft. is equivalent to 56 × 8 = 448 lbs. for the 8-foot wide panel. Using a factor of safety of 1.25 and a stake pull-out capacity of 60 lbs:*

$$\frac{448 \times 1.25}{60} = 9.33 \text{ J-Hooks, use 10 stakes per 8-foot width}$$

TENDONS: *353 lbs./ft. is equivalent to 353 × 8 = 2824 lbs. for the 8-foot wide panel. Using a factor of safety of 1.25 and a tendon tensile strength of 700 lbs:*

$$\frac{2824 \times 1.25}{700} = 5.04 \text{ Tendons, use 5 tendons per 8-foot panel width}$$

If the tendons are tied to earth anchors, using the same number of anchors as tendons, an additional factor of safety of 1.25 to account for uncertainties in the subgrade soil:
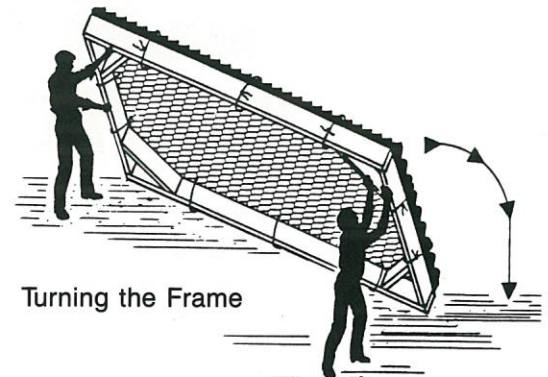
$$\frac{2824 \times 1.25 \times 1.25}{5} = 883, \text{ use anchors with a minimum pull-out capacity of 900 lbs/anchor}$$

Installation Frame

Sometimes it is necessary to pre-stretch and open the TerraCell prior to placing it on a slope. This is especially true if part or all of a section were going under water. In most cases, an installation frame can be built from common lumber (or PVC) and rebar.
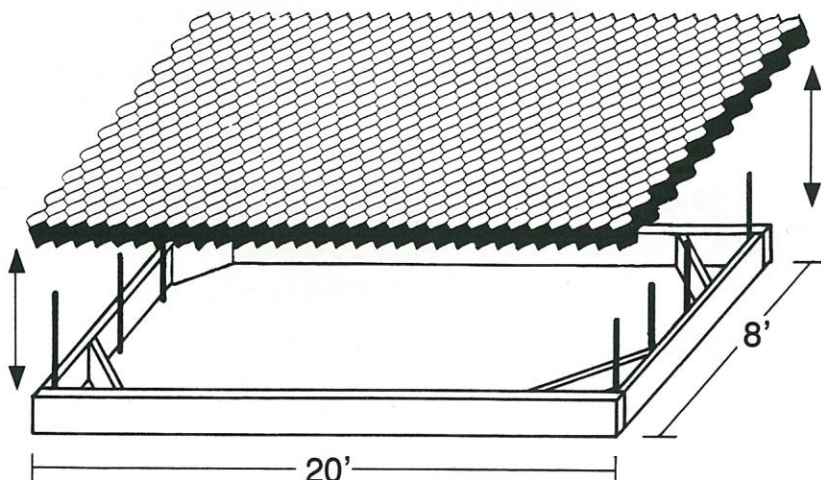
Turning the Frame

Placing **TerraCell** on Frame

Installed

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