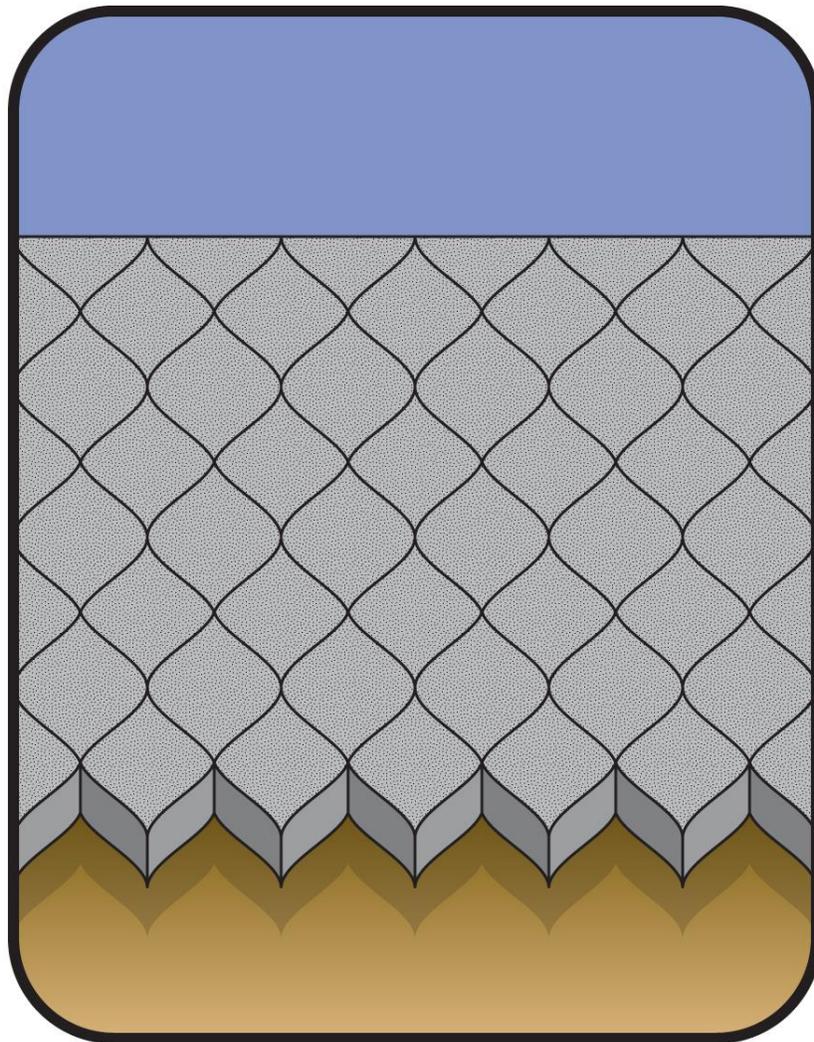**Construction Geosynthetics**

Cellular Confinement Erosion Control Design & Installation Guide

CELLULAR CONFINEMENT

1.0 OVERVIEW

Many variables affect the installation and performance of cellular confinement systems, including:

1) Slope grade
2) Subsurface stability
3) Infill material
4) Rainfall and artificial watering conditions
5) Hydraulic characteristics of ground water flow
6) Sub base anchoring quality

As such, it is difficult to design for specific applications without the input of on-site engineering, design and environmental professionals.

2.0 FILL TYPES AND ADVANTAGES

1) Granular
    a) Reduces hydraulic energy, limiting forces within cells or under cells
    b) Directs flow at the surface of the cell, eliminating flanking and undercutting
    c) Controls individual particle movement caused by gravity and water flow
    d) Results in a flexible and durable system
2) Vegetation
    a) Reduces hydraulic energy, limiting forces within cells or under cells
    b) Increases natural resistance and protects root system
    c) Directs water flow over the top, rather than through the panel
    d) Prevents gutting and rills
    e) Helps reduce moisture loss
3) Concrete
    a) Controls undercutting by allowing cells to conform to sub grade
    b) Acts as a series of expansion joints, providing a flexible form
    c) Allows for vent structures where needed
    d) Provides stability for steep slopes and for continuous flow channels

2.1 CHOOSING A FILL TYPE

1) Topsoil and Vegetation
    a) Steep slopes
    b) Berms
    c) Levees
    d) Chutes
    e) Aprons and spillways
2) Sand and Granular Fill
    a) Gradual slopes
3) Aggregate

a) Channels
b) Slopes (except for severe grades)
c) Moderate sheet flow
4) Structural/Growth Fill
a) Vegetated slopes that experience traffic loads

5) Concrete
a) Bridges
b) Severe slopes
c) High flow rate channels
d) Spillways and chutes

2.2 NOTES ON STRUCTURAL/GROWTH INFILL

The structural/growth infill shall be a blend of an aggregate and growing medium. It shall be pre-blended to achieve a homogenous mixture. The bulked (un-compacted) volume of growing medium shall be 95% – 100% of the void volume within the compacted aggregate.

1) The structural/growth infill shall meet the following requirements:
a) Aggregate
   i) The aggregate shall be durable, with 95+% of its fascia split or broken.
   ii) The aggregate shall meet the following gradation and void ratio requirements:

EGA 20	Cell Depth	Particle Range	D_{50}	Void Ratio
	4 Inch	0.5 – 1.25 inches	0.75 – 1 inches	≥ 30%
	6 Inch	0.5 – 2 inches	0.75 – 1.25 inches	≥ 30%
	8 Inch	0.5 – 2 inches	0.75 – 1.25 inches	≥ 30%
EGA 30	6 Inch	0.5 – 2 inches	0.75 – 1.25 inches	≥ 30%
	8 Inch	0.5 – 2 inches	0.75 – 1.25 inches	≥ 30%

b) Growing Medium
   i) The growing medium shall be suitable to support the specified vegetation.
   ii) The growing medium shall be well-drained, allowing water to pass through to an underlying drainage layer or a well-drained subgrade layer.
   iii) The growing medium shall be screened to remove sticks, soil clods and other deleterious materials.
c) Infill Placement

i) The placed infill material shall be compacted to a minimum of 95% Standard Proctor Density or per the Engineer's requirements.
ii) Blended infill should slightly overfill the cellular confinement product.
   (1) 0.5 – 0.75 inch overfill is typical for 4 inch deep cells.
   (2) 0.75 to 1.5 inch overfill is typical for 6 inch and 8 inch deep cells.
   (3) Compaction shall result in the Infill being level with or slightly above the cell walls of the cellular confinement product.
   (4) Operation of compaction equipment directly on the cellular confinement is prohibited.

3.0 APPLICATIONS

3.1 SLOPES

1) Design of cellular confinement systems for slopes requires analysis of several site characteristics. These include:
   a) The length, height and angle of the slope
   b) The failure angle of existing fill
   c) Minor factors include snow load and the weight of the fill material
2) Cellular confinement improves the performance of vegetated slopes by reinforcing root systems and directing hydraulic flows over the top of cells. The cells act as a series of check dams preventing formation of rills and gullies.
3) Cellular Confinement improves the performance of granular filled slopes by controlling the migration of fills by hydraulic and gravitational forces. The cellular confinement dissipates hydraulic energy throughout and underneath the cells and confines the fill materials within cells.

3.2 CHANNELS

1) Where minimal to severe erosive forces are at work on channel bottoms and slopes, cellular confinement allows for the use of various types of infill, including:
   a) Soil with Vegetation
      i) Confined vegetative soil performs exceptionally well in applications with low to moderate flows.
      ii) Cellular confinement increases the shear resistance of the fill on vegetated slopes by reinforcing root systems and directing hydraulic flows over the top of cells.
   b) Soil infill with Grass Cover
      i) Peak flow velocity less than 6 m/s (20 fps) and duration of peak flow less than 24 hours
      ii) Peak flow velocity less than 4.5 m/s (15 fps) and duration of peak flow less than 48 hours
      iii) Side of channel slopes above high water level
   c) Aggregate
      i) Cellular confinement confines and improves the performance of smaller diameter, less costly aggregate and allows use of different sizes to deal with variances in flow

velocities from site to site. This provides an aesthetically pleasing and cost effective alternative to large rip rap or hard armoring.

    ii) Peak flow velocities with stone infill and recommended sizes:

      (1) <1 m/s (3.3 fps): Graded stone

      (2) 1-2 m/s (3.3-6.6 fps): 1.5 inch median stone size

      (3) 2-3 m/s (6.6-11.5 fps): 5 inch median stone size

      (4) >3 m/s (11.5 fps): Stone infill not recommended

d) Concrete

    i) Cost effective alternative to traditional concrete lined channels

    ii) Flexible nature

      (1) Permits conformance with subgrade movement

      (2) Eliminates possible cracking and undermining associated with poured-in-place concrete slabs

    iii) Installation costs dramatically reduced

      (1) Elimination of costly forms

      (2) Elimination of traditional concrete channel construction techniques

    iv) Can perform as retaining wall if space is limited

      (1) Use of vegetative, granular or concrete fills in the outer cells

      (2) Create steeper slopes

      (3) Increase resistance to higher flow rates

    v) Peak flow velocities and recommended cell depths:

      (1) 1.8-6 m/s (6-20 fps): 3 inch depth

      (2) 6-7 m/s (20-23 fps): 4 inch depth

      (3) >7 m/s (23 fps): 8 inch depth

e) Combination of the Above

4.0 SUITABLE CELL DEPTHS & CELL OPENINGS

In most erosion control applications, load bearing is not a major consideration. Therefore, the depth of the cell is generally determined by:

1) Slope grade
2) Size and weight of infill
3) Environmental factors
4) Economics
5) Required root zone for vegetation

EGA 20: 44.8 inch Nominal Expanded Cell Area
EGA 30: 71.3 inch Nominal Expanded Cell Area
EGA 40: 187 inch Nominal Expanded Cell Area

4.1 RECOMMENDED CELL SIZE AND DEPTH FOR VARIOUS SLOPE CONDITIONS

Below is a table used to determine the recommended cell depth and cell size for different slope scenarios. Please contact US Fabrics Inc for any final recommendations based on specific project parameters.

Slope / Degree

Slope	Degree	14°	16°	18°	20°	22°	24°	26°	28°	30°	32°	34°	36°	38°	40°	EGA
0.5 to 1	60°	6"	6"	6"	6"	6"	6"	6"	6"	6"	6"	6"	6"	6"	6"	EGA 20
1 to 1.5	55°	6"	6"	6"	6"	6"	6"	6"	6"	4"	4"	4"	4"	4"	4"	
1 to 1	45°	6"	6"	6"	6"	6"	6"	6"	6"	6"	6"	6"	4"	4"	4"	EGA 30
1.5 to 1	35°	6"	6"	6"	6"	6"	4"	4"	4"	4"	4"	4"	3"	3"	3"	
2 to 1	25°	6"	4"	4"	4"	4"	4"	4"	3"	3"	3"	3"	3"	3"	3"	
3 to 1	20°	4"	4"	4"	4"	4"	4"	3"	3"	3"	3"	3"	3"	3"	3"	
4 to 1	15°	6"	6"	4"	4"	4"	4"	4"	4"	3"	3"	3"	3"	3"	3"	EGA 40
5 to 1	10°	6"	4"	4"	4"	4"	4"	4"	3"	3"	3"	3"	3"	3"	3"	
		14°	16°	18°	20°	22°	24°	26°	28°	30°	32°	34°	36°	38°	40°	
		Wet Clay, Water-filled Sand	Silty Clay		Clay	Mixture of Inorganic Silt & Clay			Silty Sand		Crushed Stone, Dry Sand		Decomposed Granite, Limestone		Wet Sand	

Lowest Angle of Repose φ for infill material

*Metric Conversions: 6" = 150mm, 4" = 100mm, 3" = 75mm

5.0 GEOTEXTILE SEPARATOR

1) Optional
   a) Infill material is different from the sub-base material
   b) Subgrade is very soft or wet
   c) Protecting the subgrade under the cellular confinement
   d) Typically a nonwoven
      i) US 160NW (6oz) is a common option
2) Benefits Vs Disadvantages
   a) Can significantly reduce the friction along the plane at the bottom of the cellular confinement
      i) Increases the net sliding force
      ii) Decision to use a geotextile should be made after evaluating the advantages, disadvantages and costs.

6.0 ANCHORING CELLULAR CONFINEMENT

1) Proper anchoring of the cellular confinement to the slope is critical to performance.
2) Anchors are left in place after installation. The number and type of anchors is determined by:
   a) Subgrade density
   b) Weight and type of infill
   c) Slope length
   d) Slope grade
   e) Environmental conditions such as snow
   f) Angle of internal friction (ϕ) of the fill material and slope soil (the smaller of the two is used)
   g) Cellular confinement height
   h) Presence of geomembrane liner
   i) Presence of non-woven geotextile
   j) Factors of safety

6.1 CALCULATE NET SLIDING FORCE (NSF)

1) Before selecting an anchoring method, you must calculate the net sliding force (NSF) of the cellular confinement to insure it does not slide down the slope.
   a) If the NSF is negative, the friction force between the cellular confinement and the slope is sufficient to hold it in place.
   b) If it is positive, earth anchors are required. The following table shows some examples of NSF calculation:

$$NSF = [(H \times L \times \gamma) + (L \times S)] \times [\sin W - (\cos W \times \tan\phi)]$$

NSF kN/m*	H (mm)	L (m)	γ kN/m3	S kN/ m2	W Slope	ϕ DEGREES
0.8	100	6.1	19.6	1.9	1.75 to 1 (29.7⁰)	28⁰ (silty sand)
5.5	150	33.0	19.6	1.9	1.75 to 1 (29.7⁰)	28⁰ (silty sand)
−13.1**	100	30.5	19.6	1.9	2.00 to 1 (26.6⁰)	32⁰ (crushed stone)

NSF– Net Sliding Force   H– Height of Cell   L– Length of Slope
γ– Unit Weight of Fill   S– Snow Load   W– Slope Inclination (H to V)
ϕ– Lowest Angle of Internal Friction of Soil

* Pounds per foot measured parallel to top of slope
** Negative number indicates no special anchoring is required

6.2 DETERMINE ANCHORING BASED ON NSF

1) **NSF = 0.8 kN/m** (Reference above table)

a) Toe in cellular confinement (anchor trench)
   i) Determine anchor trench dimensions
      (1) The following equation can be used to calculate the required length and height of the trench to resist the sliding force:

$$\left((d-a)a + \frac{(d-a)^2}{2}\right) * \gamma = NSF^a * FS$$

d = Depth of Trench
a = Diameter of Anchoring Pipe
γ = Unit weight of the backfill material in the trench
NSFa = Net Sliding force per m
FS = Factor of Safety with respect to Sliding

b) Stake cellular confinement to the slope with anchor pins (J-Hooks)
   i) No geomembrane underneath
   ii) Soil has adequate strength to retain the anchor pins
   iii) Base material is not rock
   iv) J-Hooks (steel rebar bars bent into a candy cane shape) are preferred pin type
   v) Typical length of J-Hook is three times the cell height
      (1) Number of J-Hooks
         (a) Typical Number of J-Hooks
            (i) One J-Hook per square yard of cellular confinement
            (ii) Standard drawings of pin locations are available
      (2) Specific Number of J-Hooks
         (a) Determine Factor of Safety
            (i) Using a Net Sliding Force of 0.8 kN/m and a 2.56 meter width cellular confinement panel:
               1. 0.8 x 2.56 = 2.0 kN Factor of Safety
         (b) Determine Number of J-Hooks
            (i) Using a Factor of Safety of 2.0 and a Stake Pull-out Capacity of 0.27 kN*:
               1. 2.0 x 2.0 / 0.27 = 14.8 J-Hooks per 2.56 meters
                  a. Use 15 J-Hooks per 2.56 meters of panel width.
                  b. If tendons are to be tied to each of the J-Hooks, use an additional factor safety of 1.25.
                  c. *Stake Pull-out Capacity depends upon several factors, including the weakest on-site soil conditions and how the stakes are driven into the soil. A local engineer is best suited to determine this value.

2) **NSF = 5.5 kN/m**:
  a) Use anchor trench with earth anchors (anchor pipe) and tendons (high strength polyester webbing or cord)
   i) Use on steep slopes where additional support is needed
   ii) Use where use of J-Hooks are not an option

       iii) Use if more than one section of cellular confinement is required to cover the slope from top to bottom

       iv) Important tendon characteristics

          (1) Strength

          (2) Durability

          (3) Resistance to creep

                i. Design load and spacing of tendons is determined by the force to be supported. At the lowest section of cellular confinement the tendons can be tied to a J-Hook to avoid stress concentrations.

                    1. Number of Tendons

                       a. Should be determined by the project engineer.

                          i. Please contact US Fabrics if assistance is needed.

                       b. Specific Number of Tendons

                         i. Determine Factor of Safety

                             1. Using a Net Sliding Force of 5.5 kN/m and a 2.56 meter width cellular confinement panel:

                                 a. 5.5 x 2.56 = 14.1 kN Factor of Safety

                        ii. Determine Number of Tendons

                             1. Using a Factor of Safety of 3.0 and a Pull-out Capacity of 13.00 kN*:

                                 a. 13.0 x 3.0 / 13.00 = 3.25 tendons

                                     i. Use 4 tendons per 2.56 m 13.00 meters of panel width

7.0 PACKAGING

Cellular Confinement sections are shipped to the jobsite in collapsed form, measuring 12 foot x 5 inch x the cell height (3-8 inches).

8.0 INSTALLATION PROCEDURES

8.1 PREPARE SITE

1) Remove all vegetative cover, debris and any unacceptable soils form the area.
2) Replace removed soils with acceptable materials and complete all earthwork.
3) Excavate anchor trenches (if required) or prepare anchoring locations.

8.2 PLACE GEOTEXTILE (IF REQUIRED)

1) Place the geotextile directly on the prepared subgrade.
1) Orient the geotextile with the roll direction parallel to the direction of water flow.

a) For stream bank and channel protection: Typically parallel to the stream or channel.

b) For erosion control runoff and wave action: Typically parallel to the slope.

2) Roll it out flat in the roll direction, minimizing folds and creases.

3) Use key trenches or aprons at the crest and toe of the slope to anchor the ends of the geotextile.

a) 18" anchoring pins may be an acceptable option to expedite construction.

4) Soil CBR will determine if overlapping or sewing is the correct option. AASHTO offers these general guidelines for sewing versus overlapping:

a) Soil CBR > 3 Minimum overlaps of 1 – 1.5 feet

b) Soil CBR 1-3 Minimum overlaps of 2 – 3.25 feet

c) Soil CBR < 0.5 Must be sewn

5) In cases where wave action or multidirectional flow is anticipated, all adjoining sheets perpendicular to the direction of flow should be sewn.

8.3 GEOMEMBRANE (IF REQUIRED)

Make sure that the geomembrane has been installed per manufacturer's instructions.

8.4 MEASURE SLOPE LENGTH

1) Measure the length down the slope to be covered.

a) Calculate how many cells will be required to cover the entire length.
    The chart below will help in this calculation:

EXPANDED CELL AND PANEL SIZES				
All Standard Panels are 2.56 m(8.4') Wide and 29 Cells Long				
Product	**Cells per Width**	**Cell Width**	**Cell Length**	**Panel Length**
EGA 20	10	0.26m (0.85')	0.22m (0.74')	6.52 m (21.4')
EGA 30	8	0.32m (1.05')	0.29m (0.95')	8.35 m (27.4')
EGA 40	5	0.51m (1.67')	0.48m (1.56')	13.72 m (45')

i) If the length to be covered is less than a single standard panel length:

(1) Cut off the extra cells or

(2) Keep the additional cells collapsed

ii) If the length to be covered is more than a single standard panel length:

(1) Multiple panels will need to be joined together using staples or Envirolocks.

(a) For example: If the slope is 100' long, and you are using EGA30 Panels, you will need 3 full panels (3 x 27.4' = 82.2'), plus 19 cells of an additional panel ((100' – 82.2') 0.95' = 18.7 $cells$ [round up to 19 cells]).

(b) Join or staple the panels together BEFORE expanding the panel down the slope.

(c) STAPLING PROCEDURE

(i) Staples are attached through each set of adjoining cells using a pneumatic staple gun with industrial grade staples.

(ii) The number of recommended staples per various cell heights is listed in the table below:

Number Of Staples Required	
Cell Height	# of Staples
3 inches (76 mm)	3
4 inches (102 mm)	3
6 inches (152 mm)	4
58 inches (203 mm)	5

(d) ENVIROLOCKS PROCEDURE
Fin to Fin (2 Slots, 6" & 8" material)

(i) Align slots on Fins of Adjacent Panels
(ii) Pull EnviroLock tongue through bottom slot of both cell walls
(iii) Pull EnviroLock tongue up and back through the top slot of both cell walls.
(iv) Close EnviroLock by placing the tongue into the head and pulling tight
(v) Repeat for adjacent cells until all cells are attached.

Cell to Cell (2 Slots, 6" & 8" material)

(i) Align slots on cells of Adjacent Panels
(ii) Pull EnviroLock tongue through bottom slot of both cell walls
(iii) Pull EnviroLock tongue up and back through the top slot of both cell walls.
(iv) Close EnviroLock by placing the tongue into the head and pulling tight.
(v) Repeat for adjacent cells until all cells are attached.

Fin to Fin (1 Slot, 3" & 4" material)

(i) Align single slot on Fins of Adjacent Panels
(ii) Push EnviroLock tongue through the slot of both cell walls
(iii) Wrap EnviroLock tongue under the bottom of both cell walls
(iv) Push EnviroLock tongue again through the slot of both cell walls
(v) Close EnviroLock by placing the tongue into the head and pulling tight.
(vi) Repeat for adjacent cells until all cells are attached.

Cell to Cell (1 Slot, 3" & 4" material)

(i) Align single slot on cells of Adjacent Panels
(ii) Pull EnviroLock tongue under bottom of both cell walls
(iii) Wrap EnviroLock tongue back around the top of both cell walls
(iv) Close EnviroLock by placing the tongue into the head and pulling tight
(v) Repeat for adjacent cells until all cells are attached.

8.5 DO NOT EXPAND CELLULAR CONFINEMENT DOWN SLOPE AT THIS TIME

8.6 INSTALL TENDONS (IF REQUIRED OR SKIP TO PLACE CELLULAR CONFINEMENT)

1) If the cellular confinement does not already have slots for tendons:

a) Drill a 5/8 to 1 inch hole through all the cell walls of the unexpanded cellular confinement.
2) Measure and cut tendons to desired length for the first 2-3 panel widths.
    a) Include slope length, horizontal component on top of slope, and depth of anchor trench.
    b) Add 15% for tying around restraint pins and anchor pipe.
3) A single tendon should run the entire length of the slope including multiple panels of cellular confinement.
4) Temporarily tie the tendons to a supporting structure beyond the crest of the slope. Options include, but are not limited to:
    a) A length of high-strength PVC pipe
    b) A concrete beam
    c) A set of concrete blocks placed in anchor trench
    d) Harpoon like earth anchors
5) Thread tendons through the slots in the unexpanded cellular confinement sections at the crest of the slope.
6) Expand the panels of cellular confinement down the slope.
    a) Watch that the tendons do not come out of the holes.
7) Sections should be stretched past the desired length then allowed to settle back.
8) Tie the tendons, in tension, to a J-Hook, restraint pin, or the cell wall on the downhill side of the last cell.
    a) Restraining devices help transfer the load from the cell to the tendons.
    b) They should be made from corrosion resistant materials such as galvanized steel, high strength plastic, etc.
    c) Tying instructions:
        i) STEP 1: Make 2 loops in the tendon.
        ii) STEP 2: Pull loop 1 partially through loop 2.
        iii) STEP 3: Insert the specified J-Hook anchor through loop 1 and drive J-hook into the ground until the top of hook is level with the top of the cellular confinement section.
        iv) STEP 4: Pull both ends of tendon to close the loop and drive the J-hook until the top of it is flush with ground surface.
9) Move 1 meter up the slope along the tendon and repeat step 8, continuing until you reach the crest of the slope.
10) Remove excess slack and permanently tie the tendon to the supporting structure detailed in step 4.
11) Adjust the length of tendon used based on the first 2-3 panels and repeat steps 2-10 until installation of tendons throughout the system is complete.

8.7 PLACE CELLULAR CONFINEMENT

10) Place unexpanded cells at the top of slope.
    a) Cellular confinement should always be installed beyond the crest of the slope with the leading edge toed in or place in an anchor trench to prevent surface water from undermining it.
11) A string or chalk line may be used to align staking locations and borders.
12) Place initial cell in anchor trench.

13) Expand cellular confinement down the slope.

14) Place J-Hooks in cells where needed to hold shape for filling.

    a)   Do not use J-Hooks with geomembranes.

15) Adjoining sections must be level and flush with each other.

16) Overlap the sides of the sections and butt the ends together.

17) Secure adjoining sections to each other using a pneumatic stapler or Envirolocks (see "MEASURE SLOPE LENGTH").

18) Install the balance of the J- hooks (if required).

    a)   The amount of anchoring required will vary by job site conditions and many other factors.

    b)   See "DETERMINE ANCHORING BASED ON NSF" for more information.

19) Fill the cellular confinement.

    a)   To prevent possible damage, limit the drop height to no more than 40 inches.

    b)   Infill should be delivered from the top of the slope to the base using a front-end loader, backhoe, bucket excavator or conveyor.

    c)   When using sand, granular or topsoil fills, overfill the sections by 1 to 2 inches to allow for settling and compaction.

    d)   Sand and granular fills should then be blade compacted to the top of the cells.

    e)   Topsoil fills should be compacted with the loader, backhoe bucket or a tamper plate.

    f)   Concrete fills should be manually raked and machine finished.