

Filing Category: DESIGN—Masonry

LOCK+LOAD RETAINING WALL SYSTEMS

LOCK+LOAD RETAINING WALLS LTD.

#400—1681 CHESTNUT STREET
VANCOUVER, BRITISH COLUMBIA V6J 4M6
CANADA

CONCRETAS PREFORZADOS S.A. de C.V.
CARRATERA A SAN FILIPE NO. 733
MEXICALI, BAJA CALIFORNIA
MEXICO

1.0 SUBJECT

LOCK+LOAD Retaining Wall Systems.

2.0 DESCRIPTION

2.1 General:

The LOCK+LOAD Retaining Wall Systems utilize non-stacking, modular reinforced concrete segmental retaining wall (SRW) units and optional geosynthetic material reinforcement for construction of reinforced soil segmental retaining walls. The modular steel- and polyfiber-reinforced concrete units consist of a facing panel and an anchoring/reinforcing component known as a Counterfort, mechanically joined together during wall assembly to form an integral unit. The LOCK+LOAD retaining wall structures are gravity retaining walls having an increased mass created by the Counterfort-reinforced soil mass or the Counterfort and geosynthetic reinforced-soil mass located behind the facing panels to resist the destabilizing forces generated by the retained soil and any surcharge or seismic loadings. Geosynthetic reinforcement is used to increase the retaining wall height beyond the maximum height limit of the reinforced-soil wall created by the Counterforts alone. The wall systems are shown in Figure 1.

2.2 Materials:

2.2.1 Modular Reinforced Concrete Segmental Retaining Wall (SRW) Units: The SRW units consist of 15³/₄-inch-by- 31¹/₂-inch (400 mm by 800 mm) facing panels and 5.3-inch-wide-by-26-inch-long (135 mm by 660 mm) Counterforts. The height of the Counterfort is 8 inches (204 mm) at the face, tapering to 4 inches (100 mm) at the tail end. The facing panel and Counterfort weigh approximately 110 pounds (50 kg) and 55 pounds (25 kg), respectively. Dimensional drawings of the SRW units are shown in Figure 2.

A galvanized plain steel bar formed into a hoop is embedded into each facing panel during casting, for connection to the Counterfort during wall assembly. The hot-dip galvanized steel has a diameter of ³/₈ inch (10 mm).

Galvanizing shall be in accordance with ASTM A 767 to a minimum of 2 ounces per square foot (610 g/m²) of surface area. The Counterfort is reinforced with a ³/₈-inch-diameter (10 mm), No. 3 deformed steel hook as shown in Figure 2. All reinforcing steel must conform to ASTM A 615 Grade 60, or ASTM A 706.

The SRW units have a maximum water absorption of 8 percent, and contain alkali-resistant polyfibers consisting of approximately 1-inch-long-by-0.015-inch-thick (25 mm by 0.38 mm) filaments, manufactured by 3M Company, added into the concrete mix having a minimum 28-day compressive strength of 5,500 psi (40 MPa). Concrete must comply with Chapter 19 of the 1997 *Uniform Building Code*™ (UBC) and the manufacturer's specifications. Unit tolerances must comply with UBC Standard 21-4, recommendations specified in the National Concrete Masonry Association's (NCMA) publication titled *TEK 2-4 Specification for Segmental Retaining Wall Units*, or the manufacturer's specifications, whichever is most restrictive.

2.2.2 Geosynthetic Material: Geosynthetic materials are high-tensile-strength polymeric woven or knitted sheet materials commonly referred to as geogrids, and considered extendable reinforcement. When installed in accordance with this report, the geogrids extend through the space between the Counterforts and into the soil to create a composite gravity mass structure. Geogrids must be stored at temperatures not lower than -10EF (-23EC), and must not be in contact with wet cement, epoxy or other adhesives. To prevent ultraviolet (UV) light degradation, the geogrids must not be subjected to prolonged exposure to sunlight. Compatible geogrid products described in Table 1 include the following:

- Mirafi Miragrid 5XT, 8XT, 10XT
- Strata Stratagrid 300, 500

2.2.3 Backfill Soil: Backfill soil used in the reinforced soil mass must consist of site-specific materials placed in compacted lifts. The backfill soil properties, lift thickness and degree of compaction must be determined by the geotechnical engineer. A drainage aggregate layer and drain tile must be installed into the system to prevent hydrostatic pressure buildup behind the wall, with the drainage provisions determined by the geotechnical engineer and approved by the building official.

2.3 Design:

2.3.1 General: Design of the reinforced-soil segmental retaining wall structures must be based on the guidelines in the U.S. Department of Transportation Federal Highway Administration's *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines*, Publication FHWA-SA-96-071, dated June 1999; the NC

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MA's *Design Manual for Segmental Retaining Walls*, 2nd edition, dated 1997; and LOCK+LOAD Retaining Walls Ltd.'s *Design Overview of Internal and External Stability*, V. 2, dated December 9, 2001. A copy of each manual must be made available to the building official upon request.

Slope stability analysis must be performed and the design must consider external stability, internal stability, local facing stability and global/overall stability of the retaining wall structure. Consideration must also be given to external loads generated by surcharges and seismic forces. Lateral earth pressures are determined using Coulomb or Rankine earth pressure theories.

Structural calculations must be submitted to the building official for each retaining wall structure. Minimum external stability safety factors under service load conditions are 1.5 for base sliding, 2.0 for overturning, 2.5 for bearing capacity, and 1.5 for global stability. Required seismic safety factors shall be no less than 75 percent of these minimum allowable static safety factors.

2.3.2 Seismic Loading: Seismic loads on the LOCK+LOAD system are determined in accordance with Section 4.2h of the FHWA publication. To increase resistance, the LOCK+LOAD system may be enhanced by installing an additional Counterfort connected to the primary Counterfort by a GEO-CLIP or by installing geogrid, soil anchors or other means approved by the building official, the retaining wall designer and LOCK+LOAD Retaining Walls Ltd. The GEO-CLIP is formed from $\frac{3}{8}$ -inch-diameter (9.5 mm), plain, galvanized steel bar complying with ASTM A 82 and ASTM A 641. The GEO-CLIP forms a continuous hoop butt welded at the ends, and measures $5\frac{3}{8}$ inches (136 mm) long by $32\frac{3}{4}$ inches (830 mm) long.

2.3.3 External Stability: External stability design must consider three failure modes, described as follows:

1. Base sliding: Outward movement along the base of the reinforced soil mass due to insufficient shear resistance in the weakest soil at or near the base of the wall. For design details, refer to Section 4.2e of the FHWA publication or Section 5.5.2 of the NCMA design manual, and Chapter 3 of the LOCK+LOAD Retaining Walls design manual.
2. Overturning: Rotation of the reinforced soil mass about the toe of the wall, which must be countered by resisting moments due to the weight of the reinforced soil zone and any dead load surcharge acting over the reinforced zone. For design details, refer to Section 4.2g of the FHWA publication or Section 5.5.3 of the NCMA design manual, and Chapter 3 of the LOCK+LOAD Retaining Walls design manual.
3. Bearing capacity: Shear failure or unacceptable deformation of the foundation soils due to excessive foundation pressures, which must be countered with sufficient width of reinforced soil mass to prevent overstressing of the foundation soils. For design details, refer to Section 4.2f of the FHWA publication or Section 5.5.4 of the NCMA design manual, and Chapter 3 of the LOCK+LOAD Retaining Walls design manual.

2.3.4 Internal Stability: Internal stability design must be carried out to evaluate the integrity of the reinforced soil zone as a monolithic composite mass comprised of the reinforcements (Counterforts and/or geogrids), compacted soil, and the facing panels. Tensile forces to be resisted by

the horizontal reinforcement layers must be calculated using Coulomb or Rankine lateral earth pressure theory. The following failure modes must be examined:

1. Tensile overstress: The applied force in any Counterfort must not exceed the tensile strength of that Counterfort for walls without geogrids. For design details, refer to Section 4.3b of the FHWA publication, Section 5.6.2 of the NCMA design manual and Chapter 3 of the LOCK+LOAD Retaining Walls design manual. For walls with geogrids, the applied force in any geogrids must not exceed the allowable working stress level, T_a , for the proprietary geogrids specified in Tables 2A and 3A of this report, or the tensile strength of the Counterforts, whichever is less. The strength design tensile capacity of the Counterfort is 8,370 pounds (36 kN).
2. Pullout:
 - a. Without geogrid: For walls without geogrids, the applied tensile force in the Counterforts must be transferred to the soil through the development of the pullout resistance of the Counterforts and tension capacity between the facing panels and Counterforts. The strength design connection tension capacity between the panel and Counterforts is 6,000 pounds (26.8 kN) using a friction angle coefficient, ϕ , of 0.65. For design details, refer to Section 4.3c of the FHWA publication or Section 5.6.3 of NCMA's design manual, and Chapter 3 of the LOCK+LOAD Retaining Walls design manual.
 - b. With geogrids: For geogrid-reinforced walls, the applied tensile force must not exceed the lowest of the following:
 - C The anchorage capacity (A_{c_n}) of the geogrids, which is related to the coefficient of interaction (C_i) for pullout resistance of the geogrids from the reinforced soil zone. Refer to Tables 2B and 3B for typical allowable values for C_i for each proprietary geogrid referenced in this report.
 - C The pullout resistance of the Counterforts from the surrounding backfill soil, which must be assessed individually and as a group. For calculations for the pullout resistance of the Counterforts, refer to Chapter 3 of the LOCK+LOAD Retaining Walls design manual.
 - C The strength design connection capacity between the facing panel and Counterfort of 6,000 pounds (26.8 kN).
3. Internal sliding: Internal sliding occurs when horizontal movement occurs between courses of LOCK+LOAD units or geogrids, due to lack of adequate shear resistance between the soil and units or geogrid. Section 4.3a of the FHWA publication, Section 5.6.4 of the NCMA design manual and Chapter 3 of the LOCK+LOAD Retaining Walls design manual contain design details.

2.3.5 Local Stability: Three local stability failure modes must be examined:

2.3.5.1 Facing Connection Strength:

- a. Connection strength: The strength design tension connection capacity between panel and counterfort is 6,000 pounds (26.8 kN). Counterfort tensile strength is 8,370 pounds (36 kN).

- b. Counterfort pullout resistance: Friction of the soil on the Counterfort provides pullout resistance. This resistance is detailed in Section 2.3.4.2a of this report. The pullout factor of safety is analyzed for each Counterfort under active earth pressures.

For an SRW unit at any level, the applied or driven tension force T_s (lbs or N) is given by:

$$T_s = K_a \gamma Z A_p$$

where:

K_a = Active earth pressure coefficient for backfill material.

γ = Unit weight (gamma) of the backfill material (pcf or kg/m³).

Z = Average depth of the modular concrete unit (ft or m).

A_p = Facing area of modular concrete panel (ft² or m²)
= 3.44 ft² (0.32 m²).

The equation then is reduced to:

$$T_s = 3.44 K_a \gamma Z \text{ (pound-inch units).}$$

$$T_s = 0.32 K_a \gamma Z \text{ (metric units).}$$

Internal resistance R_s (lbs or N) is calculated as:

$$R_s = 2A_f \gamma Z N \tan \phi + 2 K_o \gamma Z N A_s$$

where:

A_f = The surface area of the bottom of the modular concrete Counterfort footing (ft² or m²).
= 1 ft² (0.093 m²).

γ = The unit weight (gamma) of the backfill material (pcf or kg/m³).

ZN = The average depth of the modular concrete Counterfort element (ft or m).

ϕ = The friction angle of the backfill material.

K_o = The at-rest earth coefficient of the backfill material.

A_s = The surface area of one side of the modular concrete counterfort footing (ft² or m²).
= 0.72 ft² (0.067m²).

Since the modular concrete Counterfort is a standard size, the above expression can be reduced to:

$$R_s = 1.9\gamma ZN \tan \phi + 1.7 K_o \gamma ZN \text{ (pound-inch units).}$$

$$R_s = 0.18 AN \tan \phi + 0.10 K_o \gamma ZN \text{ (metric units).}$$

The minimum allowable factor of safety against pullout is $R_s/T_s = 1.5$.

- c. Geogrid pullout: The interface between the synthetic geogrid material and the reinforced soil mass must have sufficient connection strength and stiffness such that the geogrid does not pull through the soil mass or rupture. The connection capacity of the geogrid is determined as the pullout resistance of the section of geogrid located between the panel and the back of the Counterfort. The length of geogrid is therefore equal to the length of the Counterfort (2.17 ft. or 0.67 m). The frictional resistance of the geogrid $T_{grid-pullout}$ (lb/ft or N/m) is normally taken as:

$$T_{grid-pullout} = 2C_i \gamma ZN \tan \delta$$

where:

C_i = The coefficient of interaction between the geogrid and the soil (Tables 2B and 3B).

γ = The unit weight of the backfill soil (pcf or kg/m³).

ZN = The effective depth of the geogrid below the ground surface (ft or m).

δ = The coefficient of friction between the geogrid and the soil (radian).

The average tension in the geogrid, T_w (lbs/ft or N/m), for level backfills:

$$T_w = \frac{K_a h^2}{2N_g}$$

where:

h = Distance from ground surface to bottom of wedge (ft or m).

N_g = Numbered grid layers in wedge.

The minimum allowable factor of safety against grid pullout is the ratio:

$$T_{grid-pullout} / T_w = 1.5$$

For determining connection strength between geogrid and SRW units, Equations 5-59 and 5-60 of the NCMA Design Manual for Segmental Retaining Walls are modified to:

$$T_{cs} = W_r \tan \phi$$

where:

W_r = Weight of reinforced zone (lbs or kg).

ϕ = friction angle of soil material.

$T_{cs} / 1.5$ must be less than T_a , described in Tables 2A and 3A.

2.3.5.2 Bulging: The vertical spacing of the geogrid layers must be restricted to prevent shear deformations of units between grids. Maximum spacing is three SRW unit rows or 1200 mm (48 inches) between grid layers. There must be sufficient shear resistance available from the Counterforts behind the active zone to restrain the group of Counterforts between the grids. Design must consider individual or group pullout of Counterforts between geogrid reinforcement layers.

Design details are described in Section 5.7.2 of the NCMA design manual.

2.3.5.3 Maximum Unreinforced Height: For vertical walls, the LOCK+LOAD SRW units are limited to a 4-foot (1219 mm) maximum height without geogrid. Similarly, the LOCK+LOAD SRW units above the highest geogrid placement must be examined to ensure they will perform as a freestanding retaining wall. This distance also is 4 feet (1219 mm), maximum. Design details are described in Section 5.7.3 of the NCMA design manual and Chapter 3 of the LOCK+LOAD Retaining Walls design manual.

2.3.6 Global/Overall Stability: The general mass movement of the entire reinforced soil structure, including soil adjacent to the structure, must be considered. Design details are described in Section 5.2.7 of the NCMA design

manual and Chapter 3 of LOCK+LOAD Retaining Walls design manual.

2.4 Installation:

2.4.1 Without Geogrid: The modular concrete units must be supported on an approved foundation subgrade that is level, and that consists of at least 6 inches (152 mm) of granular fill compacted to at least 95 percent of the soil's maximum dry density as determined by ASTM D 698. Specific foundation requirements for each site must be determined by the foundation investigation complying with Section 1804 of the UBC and approved by the building official.

The maximum height for vertical walls with Counterforts alone is 4 feet (1219 mm). Higher walls require the use of geosynthetic (geogrid) reinforcement. Typical construction details are shown in Figure 3.

The SRW units are assembled by hooking the Counterfort into the connecting loop embedded into the facing panel. The unit is then rotated into its standard orientation with the base of the Counterfort horizontal. The back bottom edge of the facing panel is placed on line, with the necessary adjustments to the backfill grade underneath the Counterfort to bring the panel into alignment with the previously placed units below. The rabbet joint at the base of each facing panel is set directly behind the back face of the panel below to prevent direct bearing between the panels as soil consolidation occurs. Panels are level from side to side with the back face vertical, creating an overall vertical to horizontal wall batter of 10:1 to the face of the retaining wall, with the Counterfort base being horizontal. The backfill soil is placed over the assembled units, compacted to 95 percent in accordance with ASTM D 698, and graded level with the top of the panel. Compaction occurs over the Counterfort tail first, and continues away from the wall face. Light hand compactors are required immediately adjacent to the panels.

2.4.2 With Geogrid: Geogrids, when used, are placed at the elevations and orientation specified on the approved building plans. The backfill first proceeds to the 8-inch (200 mm) mid-height of the facing panels, and is compacted. The geogrid in the design strength direction must be one continuous piece of material. The geogrid is placed against the back of the facing panel at the specified location with the strong axis perpendicular to the wall face, and is pulled taut, freed of wrinkles, and secured. The remaining backfill material is placed and compacted up to the panel top.

Adjacent geogrid pieces are butted against each other, without lapping. Geogrids can be either mechanically attached (usually in high seismic areas) or unattached to the facing panels, depending on design.

The concrete units may be assembled with an inside or outside curved layout. Minimum radius for the inside or outside curved layout is 6 feet (1800 mm).

2.5 Special Inspection:

Special inspection is required in accordance with Section 1701.5.7.1 of the UBC. The inspector's responsibilities include verifying the following:

1. The modular concrete unit dimensions.
2. Concrete unit identification compliance.
3. Foundation preparation.
4. Concrete unit placement, including alignment and inclination.

5. Geosynthetic reinforcement type and placement.
6. Backfill placement and compaction.
7. Drainage provisions.

2.6 Identification:

A label affixed to each shipping pallet of the modular concrete units (facing panels and Counterforts) includes the name and address of LOCK+LOAD Retaining Walls Ltd., the manufacturer's name (Concretos Preforzados S.A. de C.V.) and address, the product name (LOCK+LOAD Retaining Wall Systems), the ICBO ES evaluation report number (ICBO ES ER-5893) and the name of the quality control agency (Smith-Emery Company). The geosynthetic reinforcement material (geogrid) is identified by labels that include the manufacturer name, product designation, and strong direction.

3.0 EVIDENCE SUBMITTED

Descriptive literature, calculations and test reports.

4.0 FINDINGS

The LOCK+LOAD Retaining Wall Systems comply with the 1997 *Uniform Building Code*™ (UBC), subject to the following conditions:

- 4.1 **The systems are designed and installed in accordance with this evaluation report; the manufacturer's published instructions; the National Concrete Masonry Association's (NCMA) *Design Manual for Segmental Retaining Walls* (2nd edition), dated 1997; the U.S. Department of Transportation Federal Highway Administration's *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines*, Publication FHWA-SA-96-071; and LOCK+LOAD Retaining Walls Ltd.'s *Design Overview of Internal and External Stability, V. 2*, dated December 9, 2001. Copies of these manuals must be supplied to the building official upon request.**
- 4.2 **Special inspection is provided in accordance with Section 2.5 of this report.**
- 4.3 **A foundation investigation in accordance with Section 1804 of the UBC must be provided for each project site.**
- 4.4 **Details in this report are limited to areas outside of groundwater. For applications where free-flowing groundwater is encountered, or where wall systems are submerged, the installation and design of such systems shall comply with the appropriate sections of the NCMA *Design Manual for Segmental Retaining Walls* (2nd edition, 1997) and the recommendations of the geotechnical engineer, and must be approved by the building official.**
- 4.5 **The facing panels and counterforts are produced by Concretos Preforzados S.A. de C.V., at Carretera a San Filipe No. 273, Mexicali, Baja California, Mexico, with inspections by Smith-Emery Company (AA-554).**

This report is subject to re-examination in one year.

TABLE 1—GEOGRID MATERIAL GRADES

LIGHT GRADE	MEDIUM GRADE	HEAVY GRADE
Mirafi 5T	Mirafi 8T	Mirafi 10T
N/A	STRATA 300	STRATA 500

TABLE 2A—STRATAGRID PROPERTIES

GRADE	THICKNESS (inch)	WEIGHT (oz./yd. ²)	T _a , ALLOWABLE WORKING STRESS TENSION LOAD, MD (plf) ¹
STRATAGRID 300	0.052	10	730
STRATAGRID 500	0.05	12.5	1,100

For SI: 1 inch = 25.4 mm, 1 plf = 14.59 N/m, 1 oz./yd.² = 33.9 g/m².

¹MD = Machine direction pullout.

TABLE 2B—STRATAGRID SHEAR PULLOUT COEFFICIENTS

SOIL CLASS	C _i AND C _{ds} COEFFICIENTS
GW and GM	0.90
SW and SM	0.80
SC and ML	0.70
CL	0.60

TABLE 3A—MIRAGRID PROPERTIES

GRADE	WARP/FILL THICKNESS (mils)	WEIGHT (oz./yd. ²)	LONG-TERM ALLOWABLE WORKING STRESS TENSION LOAD, MD (plf) ¹
5XT	55/35	6	750
8XT	75/45	9.5	1,320
10XT	85/45	11.5	1,840

For SI: 1 mil = 0.254 mm, 1 plf = 14.59 N/m, 1 oz./yd.² = 33.9 g/m².

¹MD = Machine direction.

TABLE 3B—MIRAGRID SHEAR PULLOUT COEFFICIENTS

SOIL CLASS	C _i AND C _{ds} COEFFICIENTS
GW and GM	0.90
SW and SP	0.80
MH	0.60

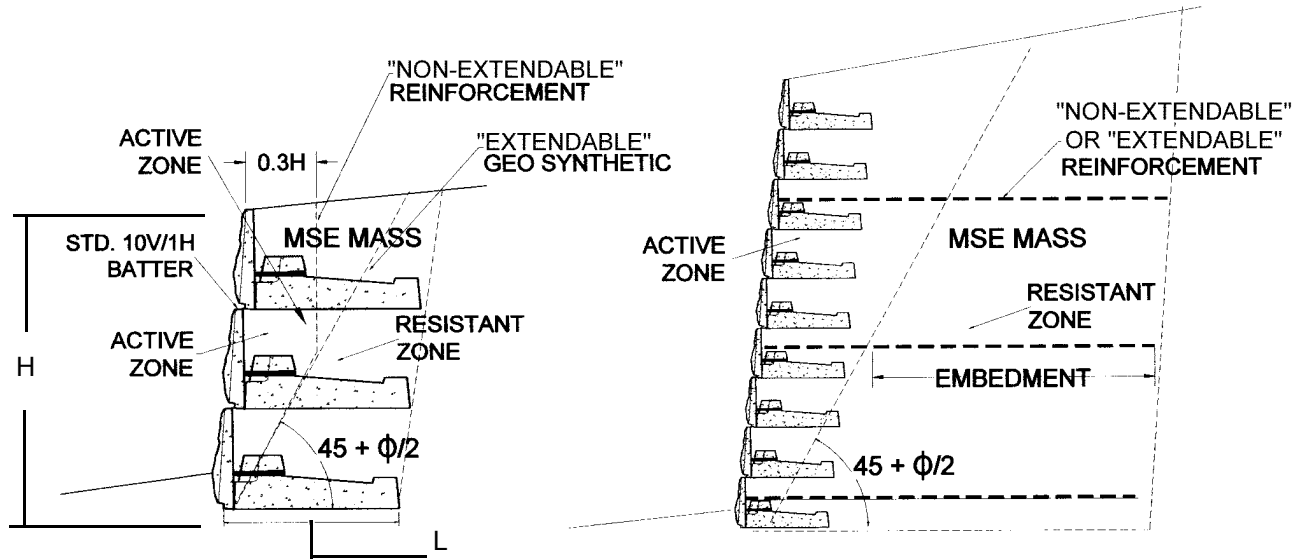


FIGURE 1—LOCK+LOAD RETAINING WALL SYSTEMS

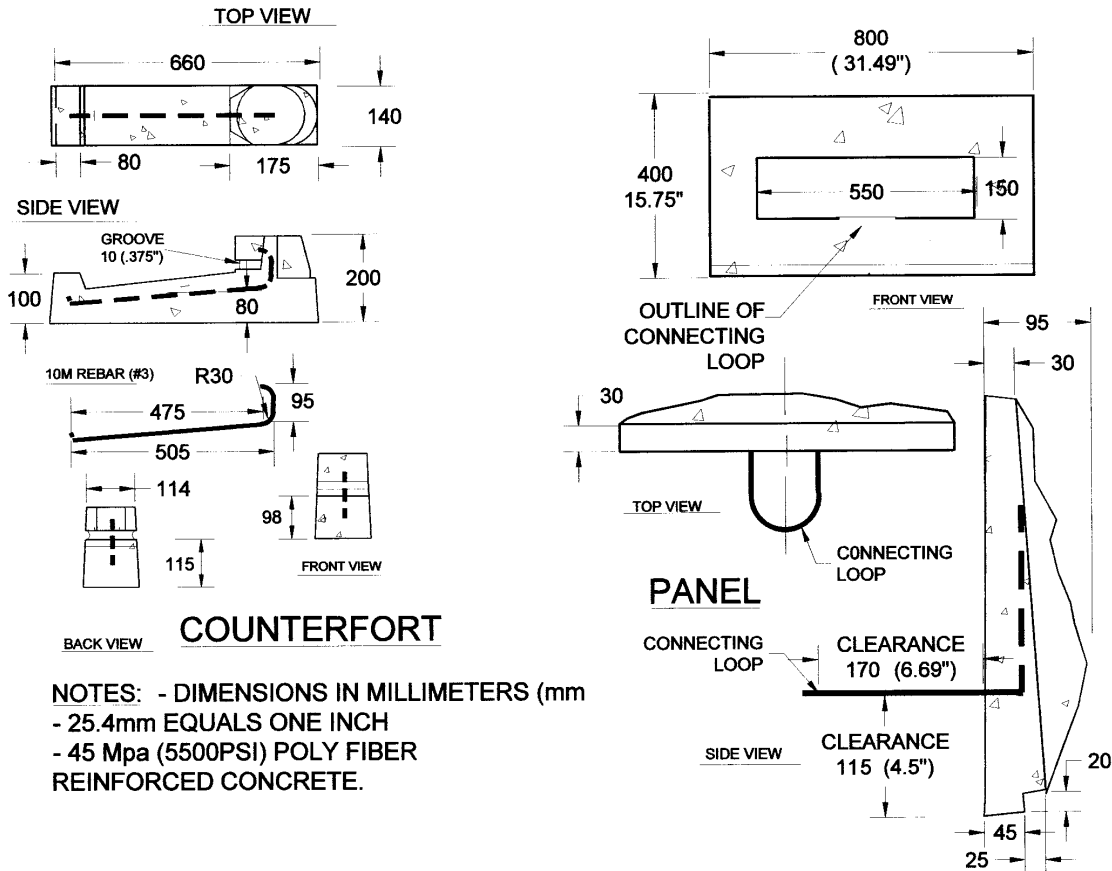
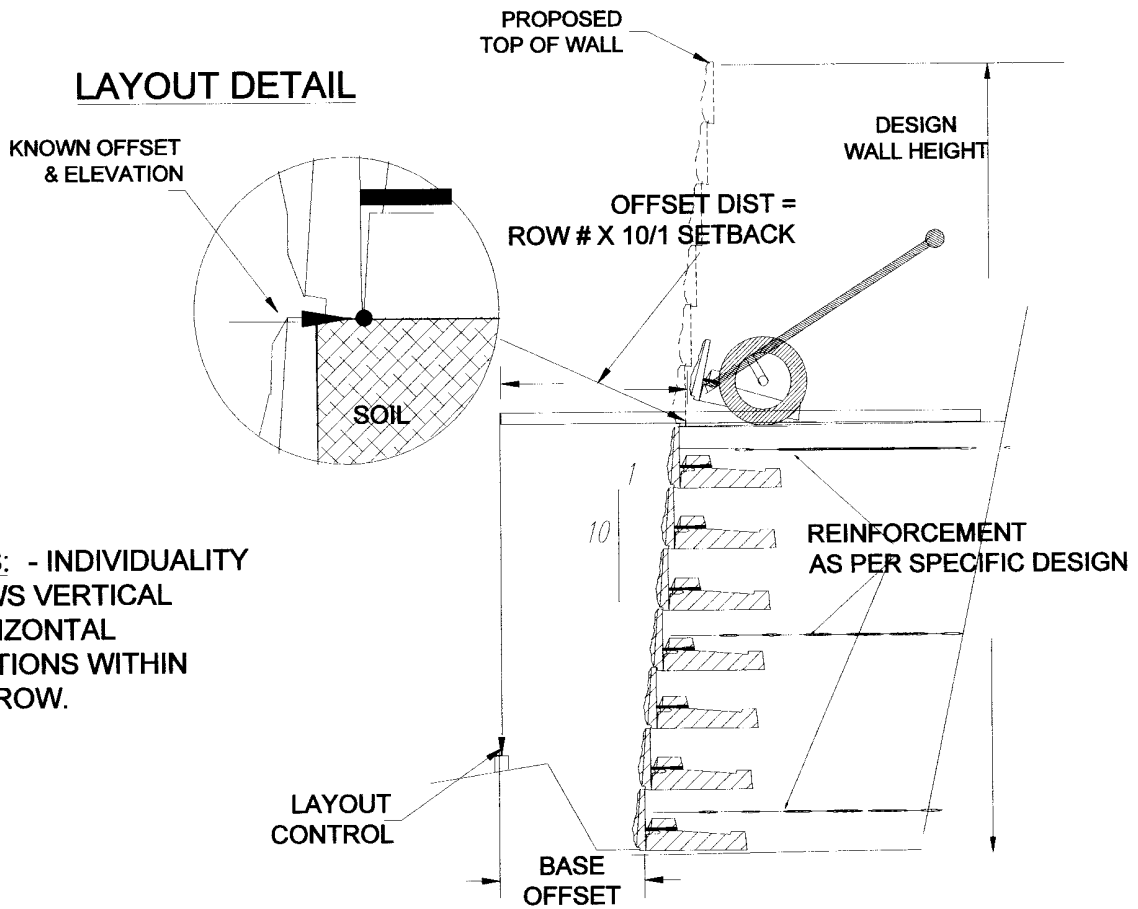
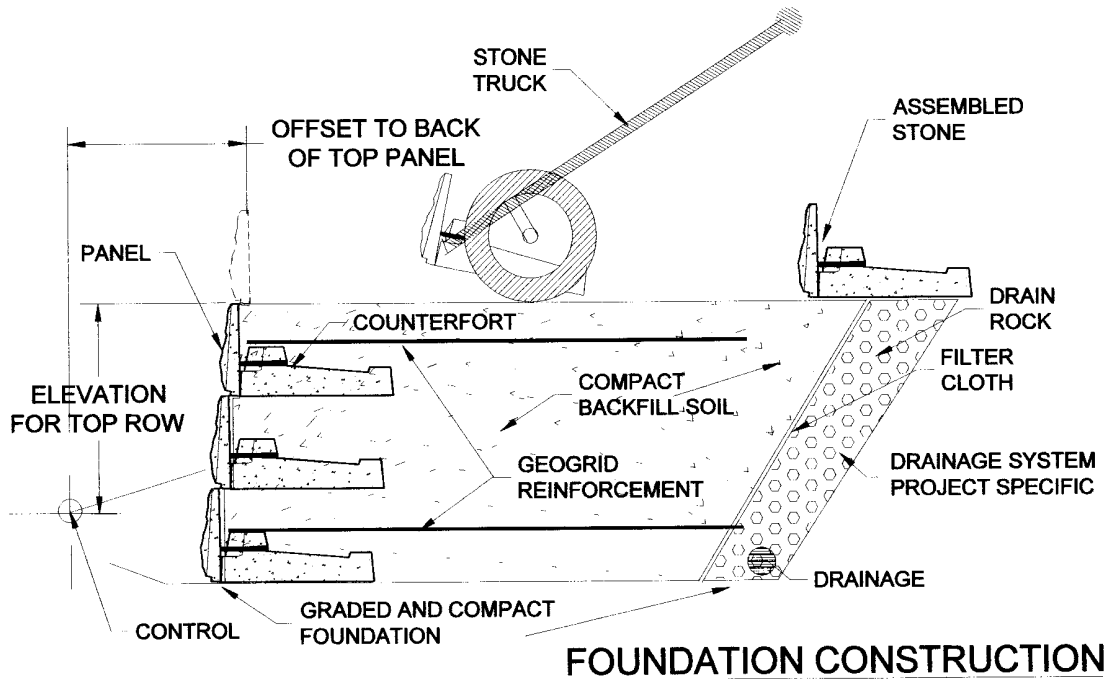


FIGURE 2—SRW CONCRETE UNITS



NOTES: - INDIVIDUALITY
 ALLOWS VERTICAL
 & HORIZONTAL
 VARIATIONS WITHIN
 EACH ROW.

FIGURE 3—TYPICAL CONSTRUCTION DETAILS