CHAPTER 13

RETAINING WALLS

GENERAL

Soils and other materials have a natural angle of repose. To maintain a steeper slope, some type of wall or support is necessary to prevent sloughing. Retaining walls are used widely for this purpose.

Retaining walls can be used:

1. To solve problems of limited right of way and confine ground slopes within practical limits.
2. On road-widening and grade-separation projects.
3. To stabilize steep cut and embankment slopes (but not to stop landslides).
4. To repair breaks in roadway embankment.
5. To prevent shore or bank erosion.
6. As wingwalls for abutments and headwalls.
7. As loading platforms or ramps.
8. For parking areas.
9. For cutoff walls or ditch checks in deep channels.
10. As aircraft splinter protection walls and barricades.
11. Explosion walls in chemical plants.
12. Crusher walls.

Retaining walls must be designed to resist sliding, overturning and settling pressures. Rankine or Coulomb analysis methods are typically used to determine the magnitude, direction and point of application of the soil pressures on a retaining wall. The reader is directed to standard reference works on this subject such as the Canadian Foundation Engineering Manual.

An adequate foundation is necessary for satisfactory performance. The foundation must carry the weight of the retaining wall including the increased pressures due to the overturning moments. Global stability of the entire slope must also be ensured. In seismic zones the additional force effects due to earthquake loads should be considered in the calculations for overturning and sliding.

Backfilling with predominantly clayey soils should be avoided, particularly if seepage exists in the slopes. Pervious granular soils, supplemented with pipe subdrains, ensure the most satisfactory backfill and stability of the wall. Frost susceptible soils should not be used for backfill in locations where frost may penetrate inside or behind the wall.

TYPES OF WALLS

There are several basic types of walls: gravity, reinforced soil, cantilever, buttress, and bulkhead. Bin type walls are either the gravity or bulkhead type with many different variations available.

Bin Type Walls

Bin type walls are a system of closed faced bins, each 3.05 meter long. Sturdy, lightweight steel components are bolted together at the job site. Backfilled with reasonable care, they transform the soil mass into a permanent economical gravity-type retaining wall. Unique design allows bin type walls to flex against minor, unforeseen ground movement that might damage or destroy a rigid wall.

Face of bin type retaining wall.

Bin type retaining wall being assembled.

Steel bin type walls are available in three types. Type I bins, shown schematically in Figure 13.1, have been used to heights of 11 meters. They are not manufactured to a great extent, except for installations requiring extensions or replacement parts. Type II and III bins, as shown in Figures 13.2 and 13.3 respectively, are generally more economical then Type I and have a lot fewer components. The maximum heights for each type include a toe burial depth.

All three types of bins consist of metallic coated, corrugated steel front and rear members (stringers) connected at the bin corners by vertical members. These vertical members (vertical connectors) are U-shaped for Type I walls and T-shaped for Type II and Type III. Bin depth is maintained by using spacers, front to back, between the vertical connectors. Base plates are provided to aid erection and support the vertical connectors during erection but are not to act as footings to develop column loads in the vertical connectors.

DESIGN CONSIDERATIONS

Bin type walls are designed as any gravity wall with the earth and steel box dimensioned to resist overturning and sliding forces imposed by the retained soil and other superimposed loads. The required depth of each wall should be designed individually. Consideration of the loads on the bins (including any surcharge or seismic conditions), the foundation requirements, and the global stability of the entire slope, are all part of a complete analysis.

As stated previously, the gravity wall is actually the confined earth mass. It is important to treat the structure as such at all times. Support for the wall is needed under the earth mass, not under the steel members. On rigid foundations, provisions must be made to allow slight settlement of the vertical corner members. Normal practice is to provide a compressible cushion under the base plates with approximately 200 mm of loose soil.

Sliding forces may or may not be important in a specific installation. Conventional design practices can be employed to check this requirement. As a matter of practice, bin type walls have been placed from 0.5 to 0.9 m below grade to provide sliding resistance.

Where there is a limited or level surcharge, it is conservative practice to specify wall depth (D) Table 13.1, equal to about 45 percent of overall height. With a heavily surcharged wall, depth (D), Table 13.2 should be increased to at least 55 percent of the height.

To increase wall stability, a batter or inclination of 1 to 6 is often used. If the wall is to be installed without batter, additional stability can be obtained by selecting a design with a greater base width.

Table 13.1 Loading conditions for retaining walls

Batter	Level	Slight With Superimposed Load	Sloping to 3 x D	Sloping above 3 x D
Wall On 1:6 Batter	H; D; ❶ (R = 0.45)	D; ❷ (R = 0.50)	2; 1; not over 3 x D; D; ❸ (R = 0.55)	2; 1; over 3 x D but not over 100'; D; ❹ (R = 0.60)
Wall Vertical	D; ❸ (R = 0.55)	D; ❹ (R = 0.60)	2; 1; not over 3 x D; D; ❺ (R = 0.65)	2; 1; over 3 x D but not over 100'; D; ❽ (R = 0.70)

*D = R × H

Unit Number	Name	Description
1.	Vertical Connector	Vertical member connecting all other units
2.	Vertical Connector cap	Cover for front vertical connector
3.	Stringer Stiffener	Top flange protector
4.	Stringer	Horizontal longitudinal members in front and rear walls
5.	Connecting Channel	Connector for attaching stringers to vertical connectors
6.	Spacer	Transverse members that separate the front and rear vertical connectors
7.	Bottom Spacer	Special bottom transverse member
8.	Base Plate	Installation plate on which the vertical connector rests
9.	bolts	
10.	nuts	
11.	spring nuts	

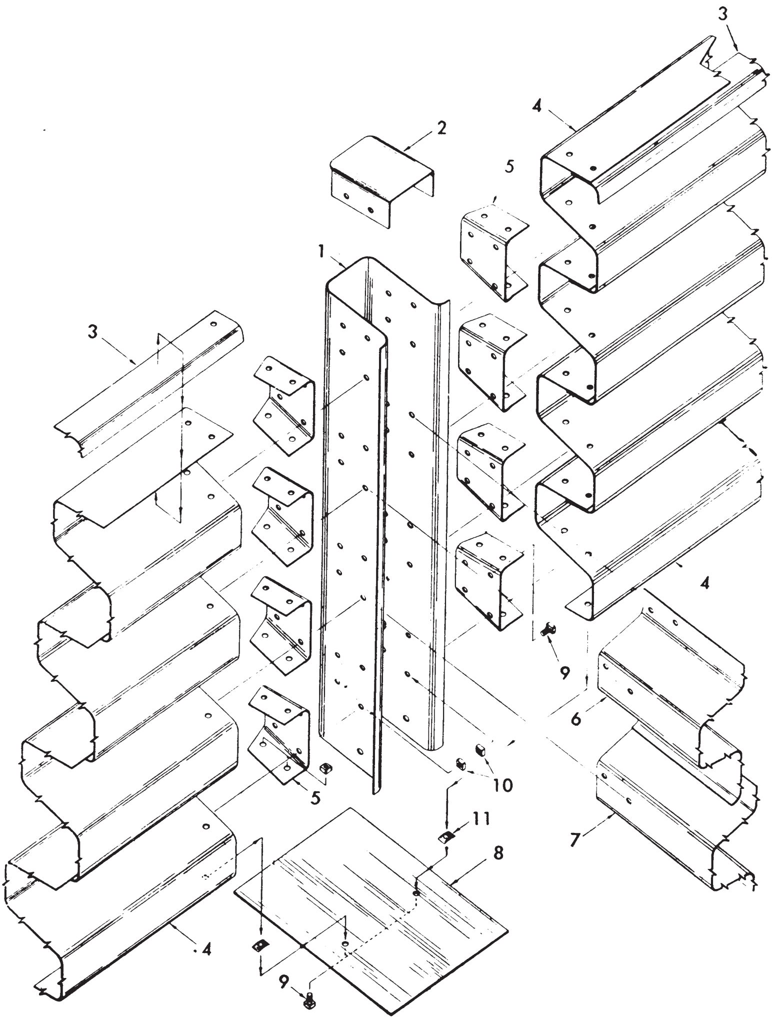

Figure 13.1 Exploded view of front panel joint Type I steel binwall as seen from the inside.

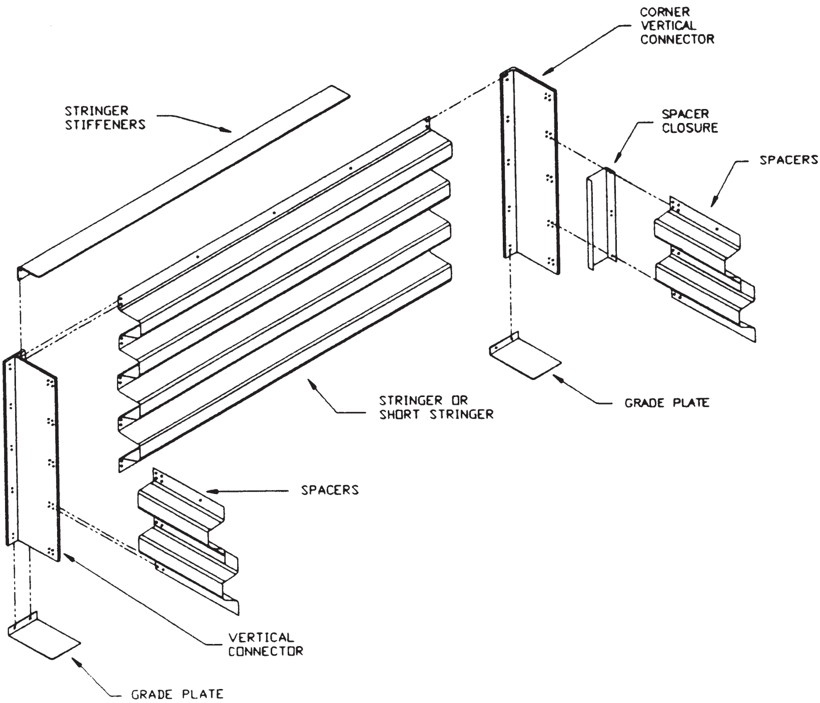

Figure 13.2 Exploded view of front panel joint of Type II steel binwall as seen from the inside.

TYPE III WALL COMPONENTS

A	VERTICAL CONNECTOR	Connects stringers and spacers.
B	UPPER VERTICAL CONNECTOR	Connects stringers and spacers above vertical connector splice.
C	SPLIT VERTICAL CONNECTOR, TYPE A	Connects stringers and spacers at end wall corners.
D	SPLIT VERTICAL CONNECTOR, TYPE B	Connects rear stringers to spacer at change in bin depth.
E	STANDARD STRINGER	Forms front and rear walls.
F	SPACER	Forms transverse and end walls.
G	STRINGER STIFFENER	Stiffens top stringer (front wall).
H	SPACER CLOSURE	Retains bin fill at end walls.
I	GRADE PLATE	Assists in bin construction layout.
J	TIE ROD	Reinforces spacers in end bin.
K	15.9mm (5/8") ø A325 BOLT	Fastens all components.

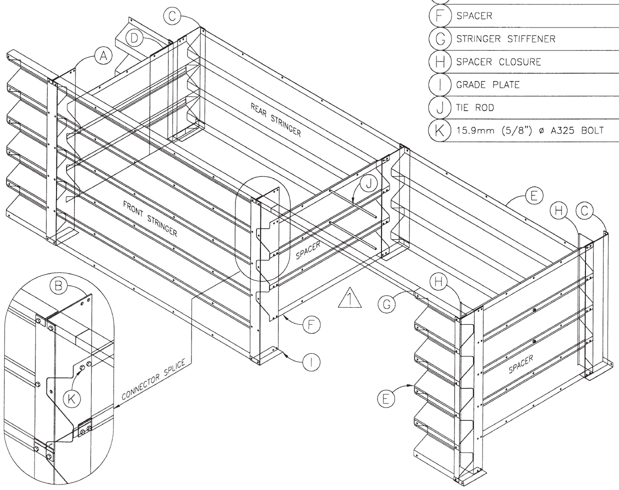

Figure 13.3 Isometric view of Type III steel bin type wall

Design Depths and Heights

In both Type I and Type II bins, six basic bin depths are available and in Type III, there are 11 bin depths available. Bin depths increase to provide additional support as heights increase, but are approximately one-half the wall height. (Wall height is measured overall, not just ground level to top of wall.)

Battered walls (1:6) are recommended. When vertical walls are designed, a small batter should be provided in installation to account for slight settlement of the toe.

Changes in Elevation

Stringers may be erected on a horizontal plane and stepped in multiples of 406 mm to meet a change in grade. Where a change in wall height requires a change in the base width, a split vertical connector is attached to the transverse spacers at an intermediate joint.

Curved Walls

Bin type steel retaining walls can be built to almost any degree of curvature or with sharp change of direction tangentially. See the manufacturers literature for suggested details for curves and special corners.

Special Treatment

Normally bin type walls are furnished in a galvanized finish. For particularly corrosive conditions, additional protective coatings are available.

When special aesthetic treatment is required, it can be achieved through the use of vegetation, plantings or stepped bins. With Type II and Type III bins, precast concrete face panels, often with special textured surfaces may be used.

Bridge pier uses bin type retaining wall components.

INSTALLATION CONSIDERATIONS

Retaining walls are more effective and less susceptible to failure if used near the top of a slope rather than at the bottom. Soundings or borings should be made to determine the subsoil, ground water and foundation conditions. A uniform foundation is best.

By trenching only for the walls of the bins, earth inside the bins need not be disturbed.

The baseplates under the vertical connectors must not be founded on rock or concrete. A 200 mm thick layer of backfill material (lightly composted and then scarified to provide a loose surface) should be placed under the baseplate in these cases. The wall is intended to be flexible. It depends on the whole system settling uniformly to avoid concentrated loads which can cause local deformations on the wall components.

Backfill inside the bin is a key part of the finished wall performance. No mass dumping of the fill inside can be tolerated. It must be placed and compacted in 150 to 200 mm lifts to 90% standard Proctor density. Ideal bins contain well graded, granular materials with maximum particle sizes not exceeding the 25 mm range and with no more than 10% passing the 100 sieve size. The manufacturer should be consulted if other backfills are to be used.

Backfill behind the wall must also be properly controlled and compacted to limit the active soil pressure on the wall and surface settlements behind the wall.

Proper drainage of the backfill is critical to any retaining wall. The load on the wall and the foundation can be excessive if ground water is not removed. Every wall should be well drained either by the use of highly permeable backfill and base material, or by proper subdrainage systems.

WELDED WIRE WALLS

A welded wire wall is essentially a gravity type retaining wall composed of a “block” of reinforced soil. The reinforcement of this soil mass is achieved by laying welded wire mats horizontally in regularly spaced lifts as the soil is being compacted. The welded wire reinforcement along with the compaction of the granular fill allows this soil block to act monolithically to resist lateral earth forces.

The proper design of both the soil and the reinforcing mesh is crucial to the stability of the welded wire wall. The soil must be a free draining granular material placed and compacted as specified by the wall designer. The welded wire reinforcement must be of an adequate size to resist the stresses within the soil mass.

The facing material for a welded wire wall is typically a welded wire mesh or precast concrete panels. The facing material is attached to the soil reinforcement mats as the wall is constructed. The wall face can be vertical or battered. If the wall face is battered as much as 1:1, a lighter wire mesh reinforcing can be used. This sloped wall system is generally referred to as a welded wire steepened slope and is illustrated in the photos that follow.

Welded Wire Wall Specifications

The welded wire mesh is shop fabricated of cold drawn steel wire conforming to the minimum requirements of CSA-G30.3-M1983. The wire mesh is welded into the finished mesh fabric in accordance with CSAG30.5-M1983. All wire materials including the soil reinforcements, facing materials, connection pins and other related

Welded wire wall.

Construction of welded wire wall.

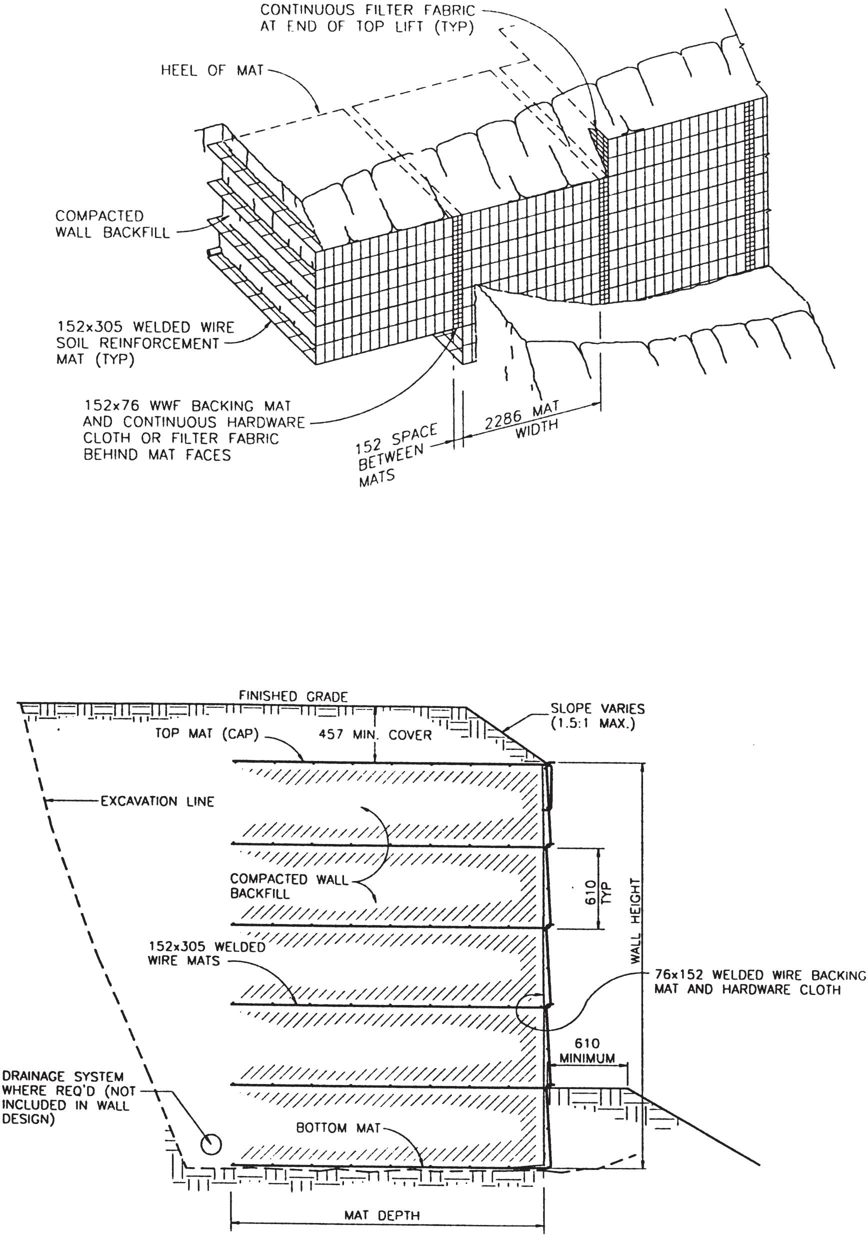

Figure 13.4 Welded wire wall.

hardware are hot-dip galvanized with 610 g/m^2 zinc coating as per CAN/CSA-G164-M92. Any damage done to the galvanizing prior to installation should be repaired in an acceptable manner and provide a galvanized coating comparable to that provided by CAN/CSA-G164-M92. Typical welded wire mesh spacing is 152 mm or 305 mm for the longitudinal wires (normal to the wall face) and 305mm, 610 mm or 914 mm for the transverse wires (parallel to the wall face).

The select backfill material used within the welded wire wall must be free draining, well graded and free from deleterious materials. The material must exhibit an internal friction angle of no less than 34 degrees and must contain no particles larger than the smallest mesh size opening in the wire soil reinforcements. The soil must meet electrochemical requirements in terms of conductivity, pH, sulphate and chloride content to avoid accelerated corrosion of the soil reinforcement mats.

Welded Wire Wall Design Considerations

A welded wire retaining wall is designed externally as any gravity system is. The length that the welded wire mats must extend into the soil from the wall face is determined by the depth required to satisfy sliding and overturning criteria. The minimum length for the welded wire soil reinforcement is the larger of 70% of the wall face height or 2438 mm.

The internal pressures within the reinforced soil mass must be calculated in order to determine the gauges of wire required for the reinforcing mesh. The longitudinal wire are sized to withstand the tensile stresses transferred from the soil to the wire mesh while the transverse wires are sized to ensure adequate pullout capacity of the mesh.

Special Treatment

The facing material of the welded wire wall can be made from welded wire mesh or precast concrete panels. The concrete panels can be manufactured to achieve virtually any finish desired. The welded wire mesh can be covered with precast tilt-up panels, a cast in place fascia, or virtually any treatment of wood, concrete or stone. A welded wire wall can easily adapt to convex and concave bends in the profile of the wall face.

Welded Wire Wall Construction

Generally, the only preparation required for the installation of a welded wire wall is the placement, compaction and levelling of a minimal depth of granular fill below the bottom lift of welded wire. However, any unsuitable base material must be removed and replaced with a suitable granular material. If precast panel facing is used, a cast-in-place levelling pad may be used to facilitate the level installation of the bottom row of panels. A minimum of 610 mm of face should be buried to provide protection from frost.

The engineered fill must be protected from water during construction. Any backfill which has become wet should be removed and replaced with dry material.

The engineered backfill must be placed in lifts to a maximum of 305 mm per lift. Compaction equipment specifications should be checked to ensure that 95% of Standard Proctor Density can be achieved with a lift height of 305 mm. Care should be taken to avoid running any equipment directly on the welded wire mesh. Compaction of the soil within 1000 mm of the face should be done with hand equipment to avoid distorting the facing material.

Gabions provide protection.

Construction of gabion wall.

Proper drainage must be supplied to ensure that water does not enter the engineered backfill zone. The presence of water could introduce hydrostatic pressures on the wall not considered during design and could also wash fine soil particles out of the engineered backfill zone.

GABIONS

A gabion is a heavy duty, galvanized steel welded wire or twisted wire mesh basket, in the shape of a box, that is divided by wire diaphragms into cells. Filled with heavy material (typically rocks, or broken concrete) that cannot escape through the mesh openings, it generally is used as a construction block, becoming part of a larger unit of several gabions tied together to form a structure. Main features of the gabion as a construction material are:

- Strength
- Flexibility
- Durability
- Aesthetics
- Permeability
- Practical Installation
- Low Cost
- Low Environmental Impact

Sack gabions, sheets of mesh stitched around the fill material, provide small, cylindrical units typically used without interconnection for emergency situations.

Introduced to the construction industry during the last century, the unique combination of these features make gabions an economical material for constructing many earth retention, soil erosion control and river training structures.

Materials

Type I Welded Wire Gabions

Welded wire gabions are made to the requirements of ASTM A974 from metallic-coated steel wire fastened together to form rectangles or squares by a process that employs the principle of fusion combined with pressure. The welded wire fabric conforms to ASTM A641, A853, A856/A856M, or A809. (An additional PVC coating is also available.) It is supplied in a diameter of 2.2 mm (Standard US wire 13.5 Gauge). The nominal mesh opening is 76 x 76 mm.

Type II Twisted Wire Gabions

Twisted wire gabions are made to the requirements of ASTM A975 of twisted metallic-coated steel wire mesh. For proper performance, the mesh must be non-raveling (i.e., does not pull apart when one of its wires is cut) and provide a maximum nominal mesh opening of 114 mm. The wire, used to manufacture the mesh as well as to assemble and install the gabion, must meet ASTM A 641 or A856/A856M requirements with a minimum nominal diameter of 2.2 mm (standard U.S. wire gauge 13.5).

Additional PVC or epoxy coatings have high mechanical and chemical resistances and are used when additional protective coatings are desirable.

Gabion fill material must have suitable compressive strength and be durable to resist the loads on the gabion, as well as the effects of water and weathering. The size of fill material is limited to the 75 mm to 300 mm range. A well graded fill increases the gabions density.

Table 13.2 Standard sizes box gabions

Sizes			No. of Diaphragms	Capacity, m^3
Length, m	Width, m	Depth, m		
1	1	1	0	1
2	1	1	1	2
3	1	1	2	3
4	1	1	3	4
2	1	0.5	1	1
3	1	0.5	2	1.5
4	1	0.5	3	2
2	1	0.3	1	0.6
3	1	0.3	2	0.9
4	1	0.3	3	1.2
3	2	1	2	6
4	2	1	3	8

Table 13.3 Standard sizes sack gabions

Length, m	Diameter, m	Capacity, m^3
2	0.6	0.57
3	0.6	0.85
2	1	1.57
3	1	2.35

Gabion Sizes

Gabions come in a range of modular sizes to facilitate construction of larger units. For standard sizes, see Table 13.2 and 13.3.

Applications

Gabions are used in a variety of applications to provide aesthetic, low cost solutions to construction and design problems.

Principle uses include:

- Channel linings and bank protection
- Retaining walls
- Bridge abutments and bridge abutment protection
- Culverts (headwalls and outlet protection)
- Weirs and drop structures
- Groins
- Low water crossings
- Lake and coastal protection
- Earth dam; detention and retention basin revetments
- Emergency works - sack gabions

A review of a few typical uses does not cover the complete range of gabion applications, but helps to demonstrate the adaptability and flexibility of gabions in aiding or providing the solution of several typical design problems.

Gabions form free draining vertical, stepped or battered retaining structures that often do not require a special foundation. The flexibility of gabion walls allows them to withstand foundation movements and differential settlements.

These features are especially advantageous in constructing a range of retaining walls for general earth retention, bridge abutments (for short or light duty bridges), as well as wing walls and end protection for culvert structures. Examples of some design applications are shown in Figures 13.5 and 13.6.

Wall design typically follows gravity retaining wall methods or reinforced soil structure methods. For the latter (Figure 13.12), layers of the same mesh used for gabion fabrication provide the reinforcement.

Gabions are ideal for many hydraulic flow control applications because of their mass, flexibility and permeability. They are used to construct weirs, where their modularity makes it easy and economical to change crest levels, as well as for groins and low level water crossings. Gabions resist stream flow and flood forces, follow changing foundation configurations without cracking or breaking and allow free drainage of the foundation soil after flow levels subside.

These same features - mass, flexibility and permeability - also make gabions ideal for a variety of erosion protection applications. They are widely used to line stream channels, protect road embankments and the upstream forces of dams and detention basin revetments. When the gabion fill is treated with a sand asphaltic mastic, which penetrates the voids making the unit impermeable, gabions may economically replace the impervious core of the earth dam.

Gabions resist wave action and erosion due to runoff. They are easily adaptable to almost any channel shape, cross section or embankment slope. A typical channel lining application demonstrates a variety of erosion control functions.

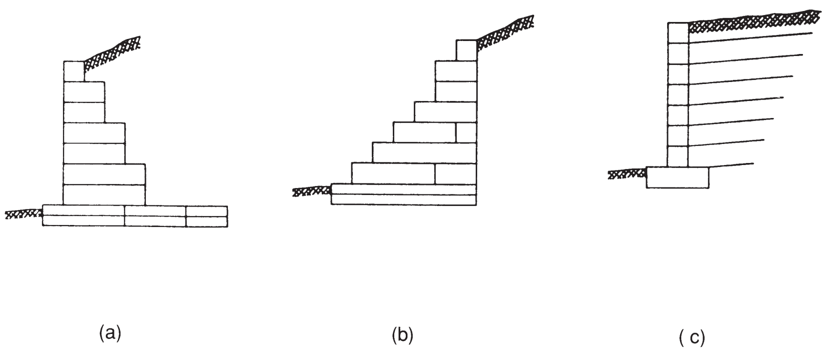

Figure 13.5 Typical cross sections for a) gravity gabion wall (stepped); b) semi-gravity gabion wall; and c) reinforced soil gabion wall.

Design

Gabion design and engineering considerations vary with application and site conditions. Detailed information can be obtained from the manufacturer.

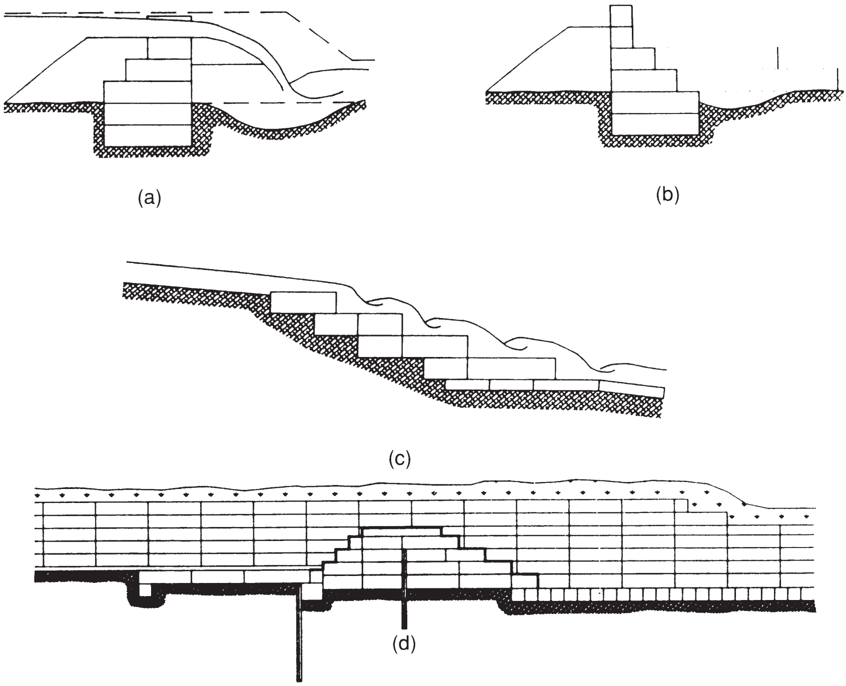

Figure 13.6 Typical gabion weir cross sections: a) vertical face; b) stepped face; c) long stepped; and d) sloped.

Installation

Gabion installation is relatively simple and requires little skilled labor. They can be installed underwater and in adverse conditions. Basic installation is completed by following these steps:

1. *Foundation Preparation* - Since gabions typically do not require special foundation preparation, it is generally only necessary to excavate to proper grade and alignment through an area slightly wider than the base of the structure.

2. *Preassembly* - Preassemble gabion baskets prior to installation by rotating lateral panels, end panels and diaphragms into position and joining their vertical edges together with the manufacturer recommended assembly system. See Figures 13.7 and 13.8.

3. *Basket Installation* - Each layer of empty gabion baskets should be placed in position and filled according to the requirements of the project. Join the contacting edges of adjacent, empty baskets in the same layer, by the recommended lacing or spiraling system, vertically along the sides and horizontally along the top.

4. *Basket Filling* - Use care when filling the gabions to avoid damage to the wire coating, prevent bulging, minimize voids and maintain alignment. Whenever

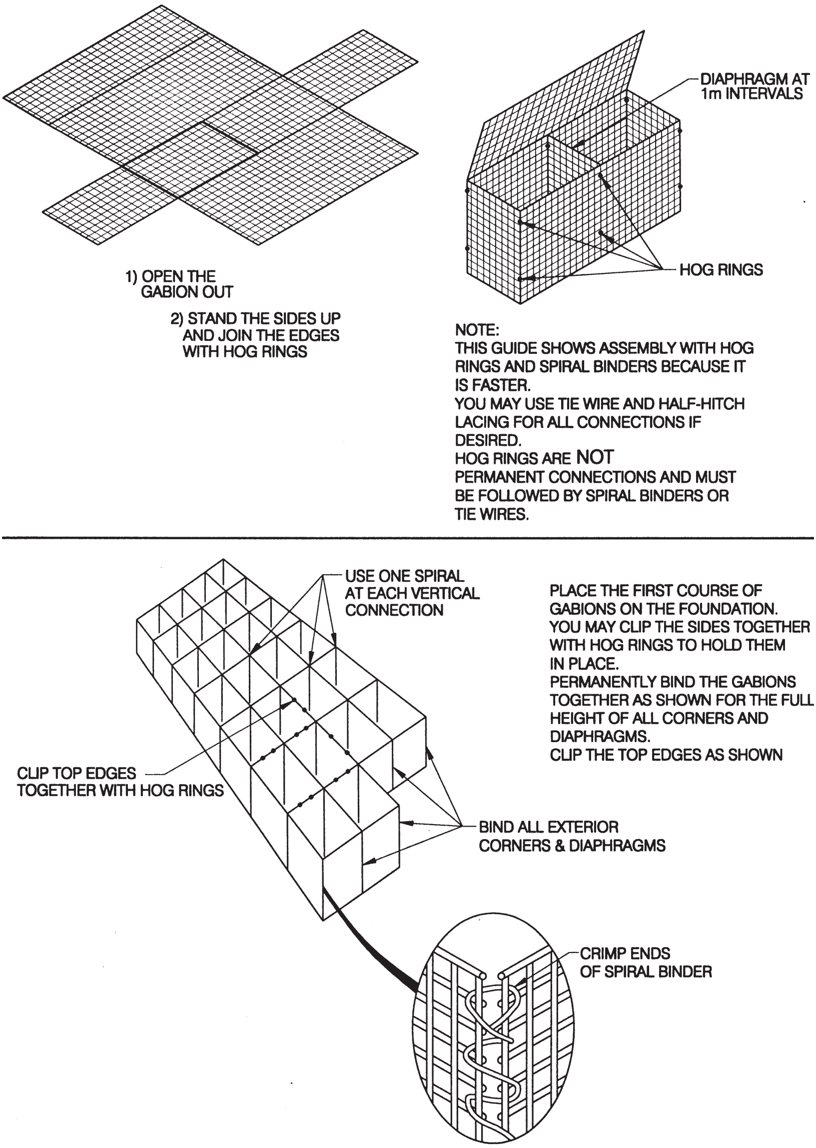

Figure 13.7 Welded wire gabions preassembly.

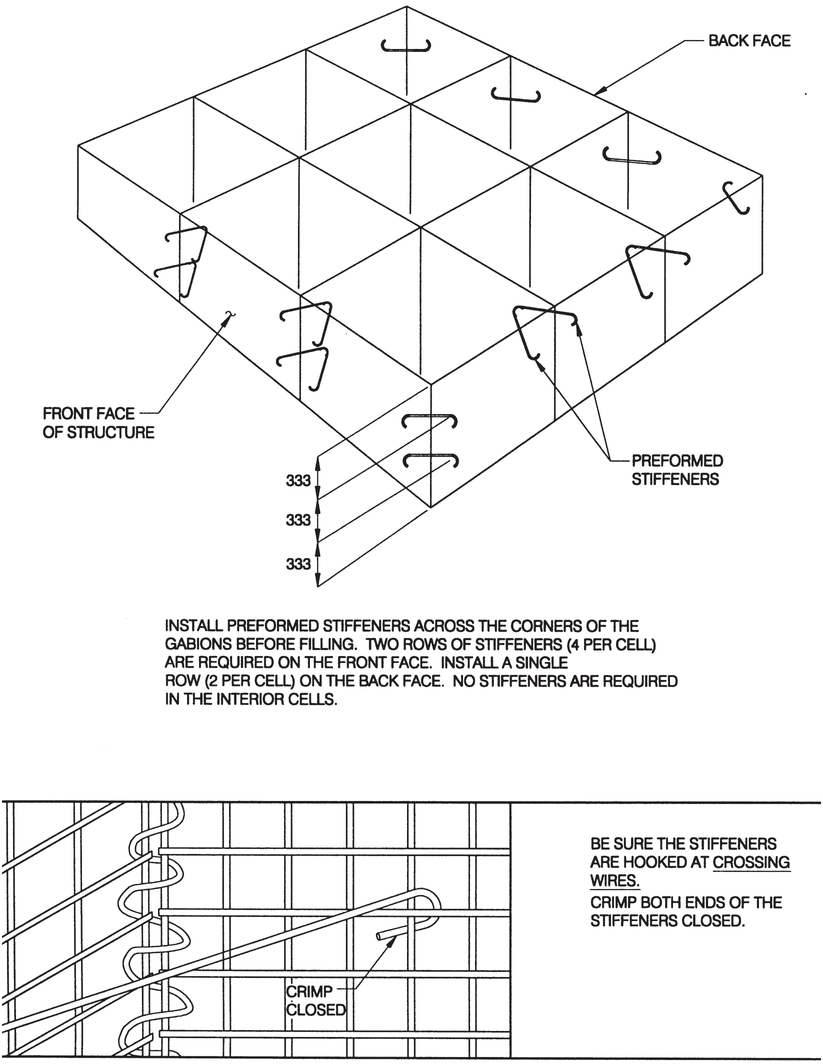

Figure 13.8 Welded wire gabions preassembly.

possible, all the cells in a layer should be filled at the same time. In no case should a cell in a layer be filled to a level more than 300 mm higher than the level of an adjacent cell. Prevent bulging of vertical faces by inserting horizontal, internal connecting wires or corner stiffeners approximately every 300 mm between layers of fill as recommended by the manufacturer. These reinforcements connect the front panel with the back panel of the same cell. To counter any future reduction in volume, due to settlement of the filling material, gabions typically are uniformly overfilled to a level 25 - 50 mm above the top of the basket.

5. *Lid Closing* - Stretch the lid tight over the fill material. Use crowbars or manufacturer approved lid closing tools if necessary. Join the top edges of front, end panels and diaphragms to the lid using a recommended assembly system.

6. *Layer Connection* - Where multiple layers are used, each is placed in position over the already filled and closed layer. First, the empty gabions in the new layer should be connected to one another as described in point 3. Then the gabions are securely attached as before to the already filled and closed lower layer along their contacting perimeters.

7. *Backfilling* - Backfill the area behind the gabion structure simultaneously with the cell filling operation. Unless otherwise required by project specifications, place the backfill material at or near optimum moisture content in 200 mm lifts and compact to a minimum of 95% Standard Proctor Density. Where filter fabric is specified to control soil migration, the seams should be overlapped a minimum of 300 mm.

For detailed gabion characteristics and installation procedures, request specifications and instructions directly from manufacturers.

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