Global Synthetics
LEADERS IN GEOSYNTHETICS

Link™ Gabion & Rock Mattresses

Design Manual



Contents

1. Introduction To Link Gabions And Mattresses **2**
1.1 Brief History 2
1.2 Applications 2
1.3 Features Of Woven Mesh Link Gabion And Mattress Structures 2
1.4 Product Characteristics Of Link Gabions And Mattresses 3
2. Link Gabions And Mattresses **4**
2.1 Types Of Link Gabions And Mattresses 4
2.2 General Specification For Link Gabions, Link Mattresses And Link Netting 4
2.3 Standard Sizes Of Link Gabions, Mattresses And Netting 6
2.4 Durability Of Link Gabions, Link Mattresses And Link Netting 7
2.5 Geotextile Filter Specification 7
2.6 Rock Infill Specification 7
2.7 Geogrid Reinforcement 7
3. Link Gabions For Civil Works **9**
3.1 Gravity Retaining Walls 9
3.2 Reinforced Soil Retaining Walls 12
3.3 Landscaping Walls 16
4. Link Gabions And Mattresses For Channel, River And Stream Works **17**
4.1 Bank And Bed Protection 17
4.2 Bridge Abutment And Pier Protection 21
4.3 Culvert Protection 23
4.4 Weir Structure Protection 25
4.5 Low-Level Crossings And Embankment Protection On Flood Plains 26
5. Link Gabions And Mattresses For Coastal And Foreshore Protection Works **28**
5.1 Coastal Revetments 28
5.2 Beach Protection Seawalls 29
6. Link Gabion And Mattress Construction Guidelines **30**
6.1 Delivery And Storage 30
6.2 Labour And Plant Requirements 30
6.3 Assembly 30
7. Bibliography **33**

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Gabion & Rock Mattresses Design Manual

1. Introduction to Link Gabions and Mattresses

1.1 BRIEF HISTORY

The word Gabion is a French word derived from the Italian word "gabbia" meaning cage. The very early use of these products was by the Chinese who made wicker baskets that were rock-filled for protection of structures against river scour. In the latter part of the 16th Century the French and British developed similar structures that were soil-filled for personal protection emplacements in military installations. The word Gabion was adopted by the French to mean "a fortified position".

In the late 19th Century simple wire mesh baskets were being made that could be rock filled and that could provide more permanent solutions to problems of erosion protection in river works and simple earth retaining structures.

Greater levels of sophistication in steel wire coating and manufacturing techniques were employed during the latter part of the 20th Century. This was combined with significant research being undertaken to understand the performance characteristics of the modern day Gabion products. Today, the use of rock-filled Gabion (and the rock Mattress) products are well accepted techniques in earth protection and earth retaining structures around the world.

Link Gabion and Mattress products utilise the latest manufacturing and coating technologies available to produce a highly functional and durable product that Engineers can incorporate into their designs with confidence.

1.2 APPLICATIONS

Link Gabions and Mattresses provide a highly versatile solution of earth retention and erosion protection for designers and contractors in a wide variety of applications.

Link gabions are typically used for earth retention structures although the use of such products is also commonly used in a wide variety of hydraulic structures in conjunction with the Link Mattresses.

When used in a traditional manner, such as earth retention structures, Link Gabions may be designed as gravity structures where resisting forces are generated by the mass of rock infill within the Gabion product, which are laced together to form a monolithic structure. Link Gabion structures, when designed in such a manner, are most commonly used in cut situations.

Soil reinforcement techniques may be used with Link Gabions providing the front face retention system in combination with mesh panels or geogrid reinforcement, laid into compacted reinforced fill material behind the gabion facing. These reinforcements enhance the shear resistance of the structure and increase stability. Such walls are best used in fill situations and it is common for an engineering structure to be constructed above or below the constructed wall. Such techniques allow the efficient use of the Link Gabion facing with the ability to often use "on-site soils" in the reinforced fill zone of the structure.

Link Mattresses are much thinner than the Link Gabion product and are generally used in applications of channel linings and spillways where area coverage is important. The steel wire mesh of the Link Mattresses effectively restrains the movement of the rockfill placed within the mattresses, thereby increasing its shear resistance against hydraulic load. The use of a Link Mattress allows the use of more readily available smaller rock sizes for a given hydraulic situation. When stone is effectively contained within the steel mesh of the Link Mattress the protection and resistance against scour and rock movement is equivalent to rock sizes some 3-4 times the thickness of the Link Mattress being used.

Link Gabions and Mattresses may be used either singly or in combination with each other in the following typical applications.

- Gravity retaining walls,
- Reinforced soil retaining walls,
- River bank and riverbed, stream and channel protection,
- Bridge abutment and pier protection,
- Hydraulic drop structures for abrupt changes in hydraulic grade,
- Culvert structures,
- Weirs and low level creek and river crossings,
- Dam spillways,
- Foreshore protection.

Link Gabions and Mattresses are very flexible, requiring minimal foundation treatment prior to use. The product is extremely simple to erect requiring generally unskilled labour. The product is folded flat for ease of transportation to site.

1.3 FEATURES OF WOVEN MESH LINK GABION AND MATTRESS STRUCTURES

The unique weave construction of Link Gabions and Mattresses results in a flexible structure that enables good load distribution of imposed stresses. The weave is such that isolated breaks in the wire, that may occur from time to time, will not allow unravelling of the mesh. Wire diameters have been selected to provide optimal strength with the mesh openings, allowing a wide range of rock sizes to be retained within the formed mesh product.

The Link Gabion and Mattress shape is easily modified to suit a range of applications by simple cutting and folding. Mesh damage can be overcome by simply wiring onto the damaged section some replacement mesh.

Specific features include:

- Simple design with proven strength, flexibility and free drainage characteristics ensuring there is no build-up of pore water pressures behind the structure.

Gabion & Rock Mattresses Design Manual

- Environmentally compatible with good aesthetic appeal, and the ability to blend into the existing landscape.
- Easily transported in a "flat pack" configuration for quick site assembly.
- Suitable for use in soft ground conditions with minimal foundation treatment required.
- Instant protection provided once erected.
- Low cost with the use of unskilled labour possible.
- Ability to use locally available, smaller sized stone with the Gabions and Mattresses than would normally be possible.

1.4 PRODUCT CHARACTERISTICS OF LINK GABIONS AND MATTRESSES

1.4.1 Durability

Link Gabions and Mattresses are made from either heavily coated zinc or Galfan® steel wire. The Link manufacturing process allows great control over wire quality with the ability to draw the wire "in-house" from selected steel rod and then apply the zinc or Galfan coating. Many of Link's competitors purchase wire from third parties without having complete control of the wire manufacturing process. The use of polymer coatings is used to additionally coat the zinc or Galfan wire for Gabion and Mattress product that is to be used in aggressive environments.

Link Gabions and Mattresses have British Board of Agrément Certification (e.g. BBA, 2000) that demonstrates a design life of up to 120 years. Further information may be sought from Global Synthetics Pty Ltd.

When the polymer coating is applied to the steel wire this whole process is again completed within the Link manufacturing facility, ensuring the most stringent International Standards are met for polymer quality and manufacturing excellence. When polymer coatings are used the colour typically is grey with special formulations that make the coating resistant to ultra-violet (UV) light under Australian conditions. Specific colours can be supplied dependent upon order size.

Link Gabions and Mattresses allow vegetation to become established throughout the structure, further enhancing its stability and aesthetics.

1.4.2 Flexibility

Link Gabions and Mattresses are made from steel wire that is woven by double twisting into a unique hexagonal mesh. The mesh maintains structural integrity under extreme conditions of use, and is not susceptible to unravelling if any individual wires are compromised.

The flexible nature of the Link Gabion and Mattress product ensures that settlement issues associated with foundation ground

movement can generally be accommodated. This quite often means that expensive foundation treatment associated with more rigid and brittle wall types can be avoided. Should post construction settlement occur, retaining structures built with flexible Link Gabions and Mattresses will generally remain serviceable due to the ability of the product to tolerate some deformation, unlike retaining structures built from rigid and brittle concrete materials.

Link Mattresses are often used as channel linings or to protect the toe of Link Gabion walls from potential scour situations. The flexible nature of Link Mattresses ensures they can deform sufficiently to the contour of the developed scour profile, thus ensuring protection from long term undermining.

1.4.3 Permeability

The highly permeable nature of the rock infill used to fill Link Gabion and Mattresses ensures quick dissipation of hydrostatic pressure that can build up behind such structures. The free draining nature of these products overcomes many drainage issues and potential wall failures that may be associated with traditional retaining structures or scour structures. The problem of inadequate drainage behind retaining walls is often a source of major wall failure. The use of Link Gabions and Mattresses helps to ensure that drainage is maintained, but like all retaining structures, a careful assessment of drainage requirements should always be made by the designer.

1.4.4 Hydraulic stability

The rough surface of Link Gabions and Mattresses makes these products particularly effective in dissipating and absorbing hydraulic energy. Additionally, when stone is restrained within Link Gabions or Mattresses, the effective shear capacity of the stone is increased, for a given stone size. This makes the use of smaller, less costly, more available rock, suitable in a wider range of hydraulic applications than would normally be possible.

Where structures are subject to wave attack, such as in coastal environments, there is a significant reduction in wave run-up when using Link Gabions and Mattresses due to their high surface shear characteristics. A careful assessment of the long term durability of the Link Gabion or Mattress solution must be made for these applications.

1.4.5 Link Gabions and Mattresses used in conjunction with geotextile filters

In most instances Link Gabions and Mattresses are used in environments where groundwater and surface water movements occur. In these situations the use of a suitable geotextile filter between the Link Gabions and Mattresses and the soil to be protected should be considered mandatory. The geotextile filter prevents the erosion of the protected soil through the large rock voids in the Link Gabions and Mattresses, while at the same time allowing dissipation of pore water pressures.

Throughout this Design Booklet reference is made to the correct use of geotextile filters with Link Gabions and Mattresses for a range of structural and hydraulic applications. Section 2.5 contains guidance on the specification of a suitable geotextile filter specification to be used with Link Gabions and Mattresses.

Gabion & Rock Mattresses Design Manual

2. Link Gabions and Mattresses

2.1 TYPES OF LINK GABIONS AND MATTRESSES

Link Gabions and Mattresses are manufactured from woven wire mesh. Link Gabions can also be supplied in a welded configuration and additional advice on this topic should be sought from Global Synthetics Pty Ltd. Information provided within this Design Booklet relates to the woven mesh style of product only.

Link Gabions and Mattresses are made into a hexagonal weave pattern that allows good distribution of load points throughout the structure.

Link Gabions and Mattresses are differentiated according to their geometrical shape. Generally, Link Mattresses are "thin" Gabions with a maximum height of 300 mm. In plan area the Mattresses are larger than the Link Gabions and typically produced in a 6 m x 2 m plan area size. Figure 1 shows the fundamental geometric differences between Link Gabions and Link Mattresses.

Link Gabions are manufactured from a hexagonal weave where the distance between the vertical twists of the weave is nominally 80 mm. The wire diameter of the body wire of the Gabion is 2.7 mm. Link Mattresses are also

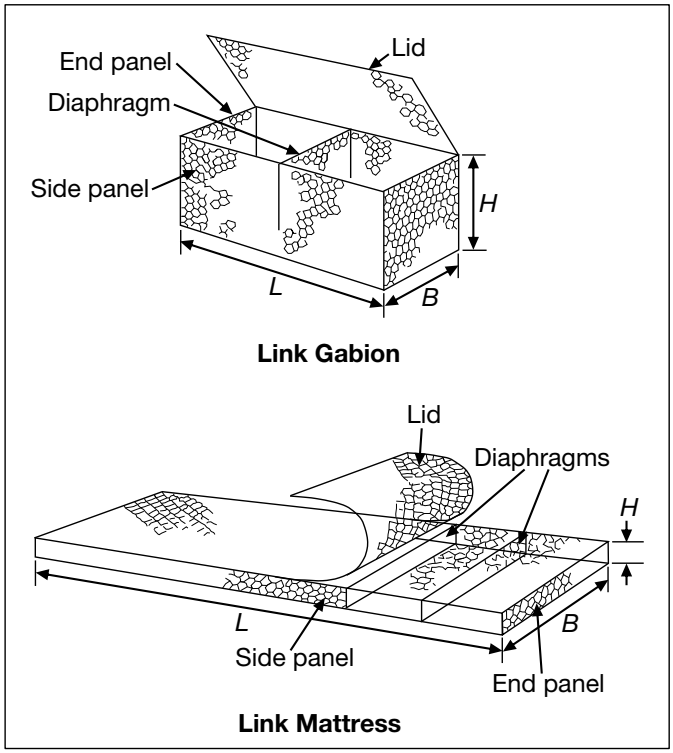


Figure 1- Link Gabions and Mattresses.

manufactured from a hexagonal weave but the distance between the vertical twists of weave is nominally 60 mm. This reduced mesh opening allows for the use of a wider range of rock sizes within the Link Mattress. The wire diameter of the body wire in a Link Mattress is 2.0 mm. The combination of reduced mesh opening size and thinner steel wire diameter provides a mesh strength of the Link Mattress similar to the Link Gabion. The standard sizes of Link Gabions and Mattresses are given in Section 2.3.

Link Gabions and Link Mattresses are manufactured with the following steel wire coating combinations:

- Heavily zinc coated,
- Heavily zinc coated with polymer coating,
- Galfan coated,
- Galfan coated with polymer coating.

Additional specification details are contained within this Design Booklet or can be obtained from Global Synthetics Pty Ltd.

2.2 GENERAL SPECIFICATION FOR LINK GABIONS, LINK MATTRESSES AND LINK NETTING

2.2.1 Introduction

The specification below applies to Link Gabions, Link Mattresses and to Link Netting rolls in general. Where the word "Gabion" appears

in the text, the words "and Mattresses" may be added. Some specific text editing will be required when specifying " Netting" products. If the specification is to apply to Mattresses or Netting only, then deletion of the reference to the other products should be by deletion of text references.

2.2.2 General description

The Gabions shall be flexible woven Gabions as supplied by Global Synthetics Pty Ltd. The Gabions shall be zinc or zinc/ polymer coated, or Galfan or Galfan/polymer coated (delete as required) Gabions of the sizes as stated in the Bill of Quantities and/or on the drawings, fabricated of steel wire mesh of the size and type and selvedged as specified below. Each Gabion shall be divided by diaphragms into cells whose length shall not be greater than the width of the Gabion plus 100 mm, or otherwise as stated in the Bill of Quantities and/or on the drawings.

2.2.3 Steel wire zinc coating

All wire used in the fabrication of the Gabions and in the wiring operations on site shall be zinc coated in accordance with EN 10244-2 : 2023. The minimum mass of the zinc coating shall be in accordance with the values listed in Table 1.

TABLE 1 – MINIMUM MASS OF ZINC COATING.

Diameter of Wire (mm)	Mass of Zinc Coating (g/m^2)
3.4	265
3.0	255
2.7	245
2.4	230
2.2	230
2.0	215

Gabion & Rock Mattresses Design Manual

2.2.4 Galfan Wire Coating

All wire used in the fabrication of the Gabions and in the wiring operations on site shall be Galfan coated in accordance with EN 10244-2 : 2023 Class A. The Galfan shall be supplied from an ingot source complying with ASTM B750-16 to include rare earth metals. The minimum mass of the Galfan coating shall be in accordance with the values listed in Table 2.

TABLE 2 – MINIMUM MASS OF GALFAN COATING.

Diameter of Wire (mm)	Mass of Galfan Coating (g/m^2)
3.4	265
3.0	255
2.7	245
2.4	230
2.2	230
2.0	215

2.2.5 Polymer coating

All wire used in the fabrication and on site wiring operations of Gabions may, if specified, have an additional polymer coating of polyvinyl chloride extruded over either the zinc or Galfan wire. The polyvinyl chloride coating, herein is referred to as the "polymer coating", shall be in accordance with the specification following and shall additionally comply with the requirements of EN 10245-2 : 2011.

The coating shall be 0.5 mm average thickness and nowhere shall be less than 0.4 mm thickness. The polymer coating shall be capable of resisting the deleterious effects of natural weather exposure, immersion in salt water and not show any material differences in the initial characteristics of the polymer coating prior to such exposure.

- Specific gravity shall be ≤ 1.5 g/m3 in accordance with ISO 1183-1 : 2019.
- Durometer Hardness (Shore D) shall be ≥ 38 in accordance with ISO 868 : 2003.
- Tensile strength shall be ≥ 17 MPa in accordance with ISO 527-2 : 2019.
- Elongation shall be ≥ 200% in accordance with ISO 527-2 : 2019. The polymer coating shall be grey in colour.

2.2.6 Mesh body wire, lacing wire and selvedge wire

2.2.6.1 Mesh body wire

The mesh shall be of double twist, hexagonal woven, body wire where the joins are formed by twisting each pair of wires through full turns to make a product with a minimum of three twists at each join. The mesh shall be manufactured to the requirements of EN 10223-3 : 2013. Tolerances on mesh openings shall be +16%,- 4%. Tolerances shall only apply to the mesh openings when measuring the distance centre to centre between parallel twists of the mesh.

For Link Gabions the nominal distance of the mesh opening is 80 mm and for Link Mattresses the nominal distance of the mesh opening shall be 60 mm.

For Gabions, the body wire diameter shall be 2.7 mm or as stated in the Bill of Quantities. For Link Rock Fall Netting, the body wire diameter (core body wire in the case of polymer coated Gabions) shall be 2.7 mm or as stated in the Bill of Quantities.

For Mattresses, the body wire diameter (core body wire in the case of polymer coated Mattresses) shall be 2.0 mm or as stated in the Bill of Quantities.

2.2.6.2 Selvedge Wire

All cut edges of the Link Gabions shall be selvedged with a thicker wire that will minimise ravelling of such ends. All selvedge wire is incorporated into the manufacture of Link Gabions and Mattresses as detailed in Table 3.

Note that the above wire diameters in Table 3 exclude polymer coating thickness. Allow an additional 1 mm for increased diameters of wire when polymer coated. Note that the specification with respect to wire quality and mesh opening of netting rolls for Link Mattresses is the same as applies for Link Mattresses. Specification of netting rolls for rock fall protection with respect to wire quality and mesh opening is the same as for Link Gabions.

TABLE 3 – LINK GABION, MATTRESS AND NETTING BODY AND SELVEDGE WIRE.

Body Wire		Selvedge wire	
Unit	Dia. (mm)	Unit	Dia. (mm)
Link Gabion	2.7	Link Gabion	3.4
Link Mattress	2.0	Link Mattress	2.4
Netting rolls for Link Mattress lids	2.0	Netting rolls for Link Mattress lids	2.4
Netting rolls for Link rock fall	2.7	Netting rolls for Link rock fall	3.4

2.2.6.3 Lacing Wire

Lacing wire must be supplied with the Link Gabion and Mattress units to perform the necessary wiring and connecting operations that are associated with the installation of these products. Lacing wire shall be supplied at a rate of 5% of the weight of units supplied. Additional wire requirements shall be at the contractors cost. The diameter of lacing wire shall be 2.2 mm for all lacing operations associated with the assembly and construction of Link Gabion and Link Mattress structures.

Pneumatic lacing tools and approved Link lacing clips may be used in lieu of lacing wire. Advice should be sought from Global Synthetics Pty Ltd on correct procedures when using this technique.

Gabion & Rock Mattresses Design Manual

2.2.6.4 Tolerances

Tolerances for wire used in the manufacture of Link mesh products shall comply with the requirements of EN 10223 : 2013. Mesh openings shall be subject to tolerances as detailed in EN10223 : 2013.

Gabion width, length and height shall be subject to a tolerance of +/- 5% from the Gabion size ordered prior to filling. Mattress units shall be subject to a tolerance of +/- 5% for the width and length and a tolerance of +/- 10% for the height of the ordered units prior to filling. Netting rolls shall be subject to a tolerance of +/- 1% of the ordered length with the width of the roll subject to a tolerance of +/- 1 mesh opening (either 60 mm or 80 mm) depending upon mesh type ordered.

2.3 STANDARD SIZES OF LINK GABIONS, MATTRESSES AND NETTING

Tables 4, 5 and 6 contain details of the standard unit sizes of Link Gabions, Mattresses and Netting.

TABLE 4 – STANDARD UNIT SIZES OF LINK GABIONS.

Gabion type*	Unit dimensions (m)			Mesh size (mm)
	Length L	Breadth B	Height H	
2x0.5x0.5	2	0.5	0.5	80 x 100
2x1x0.5	2	1	0.5	80 x 100
4x1x0.5	4	1	0.5	80 x 100
1x1x1	1	1	1	80 x 100
2x1x1	2	1	1	80 x 100
4x1x1	4	1	1	80 x 100
2x1.5x1	2	1.5	1	80 x 100
6x2x0.5	6	2	0.5	80 x 100

*Other sizes available on request.

Coating types:
- heavily galvanised,
- heavily galvanised/polymer coated,
- Galfan coated,
- Galfan coated/polymer coated.

Body wire:
- diameter 2.7 mm plus 1 mm when polymer coated.

Selvedge wire:
- diameter 3.4 mm plus 1 mm when polymer coated.

Lacing wire:
- diameter 2.2 mm plus 1 mm when polymer coated.

TABLE 5 – STANDARD UNIT SIZES OF LINK MATTRESSES.

Mattress type*	Unit dimensions (m)			Mesh size (mm)
	Length L	Breadth B	Height H	
6x2x0.17	6	2	0.17	60 x 80
6x2x0.23	6	2	0.23	60 x 80
6x2x0.30	6	2	0.30	60 x 80

*Other sizes available on request.

Coating types:
- heavily galvanised,
- heavily galvanised/polymer coated,
- Galfan coated,
- Galfan coated/polymer coated.

Body wire:
- diameter 2.0 mm plus 1 mm when polymer coated.

Selvedge wire:
- diameter 2.4 mm plus 1 mm when polymer coated.

Lacing wire:
- diameter 2.2 mm plus 1 mm when polymer coated.

TABLE 6 – STANDARD ROLL SIZES OF LINK NETTING.

Netting sizes*	Unit dimensions (m)	
	Length L	Breadth B
Roll Size	50	2

*Other roll widths and lengths available on request.

Coating types:
- heavily galvanised,
- heavily galvanised/polymer coated,
- Galfan coated,
- Galfan coated/polymer coated.

Mesh size:
- 60 mm x 80 mm for roll Link Mattress Netting,
- 80 mm x 100 mm for Link rock fall Netting.

Body wire:
- diameter 2.0 mm plus 1 mm when polymer coated for Link Mattress Netting,
- diameter 2.7 mm plus 1 mm when polymer coated for Link rock fall Netting.

Selvedge wire:
- diameter 2.4 mm plus 1 mm when polymer coated for Link Mattress Netting,
- diameter 3.4 mm plus 1 mm when polymer coated for Link rock fall Netting,

Lacing wire:
- diameter 2.2 mm plus 1 mm when polymer coated.

Gabion & Rock Mattresses Design Manual

2.4 DURABILITY OF LINK GABIONS, LINK MATTRESSES AND LINK NETTING.

Link woven steel mesh products have a proven history of performance in a wide range of applications. Link mesh products are manufactured to International Standards that describe wire quality, mesh manufacture and coating processes. These products can be supplied in a range of coating types that include zinc, zinc/polymer, Galfan and Galfan/polymer coating.

Link products have certifications from the British Board of Agrément (e.g. BBA, 2000) that attest to a design life for these products of up to 120 years with the use of polymer coatings.

Recent improvements to coating technology by Link, and the licensed use of Galfan coating technology, suggests an improved design life for these products of some 4-5 times longer than that of traditional zinc coating methods alone. (See www.galfan.com for additional details on this coating process.)

Gabions have been used in Australia for over 50 years. Internationally, the use of gabion technology is considerably longer. Polymer coatings have been used with gabions for some 50 years, with many examples of serviceable structures installed around the world that attest to the durability of this coated product in many extreme environmental conditions of use.

Generally, the additional costs associated with the use of polymer coated gabions in applications where long design lives are required, becomes negligible when all fixed costs such as labour, rock cost, transportation and excavation are considered.

2.5 GEOTEXTILE FILTER SPECIFICATION

For Link Gabion and Mattress applications it is important to use a suitable geotextile filter in combination with the Gabions and Mattresses (as shown in Sections 3, 4 and 5). The geotextile filter ensures soil cannot be eroded out through the rockfill in the Gabions and Mattresses, thus protecting the integrity of the structure. The geotextile filter must have specific hydraulic properties that enable it to drain groundwater but prevent soil erosion. Also, the geotextile filter must be robust enough so that it isn't punctured and damaged during the handling and placement of the Gabions and Mattresses.

A generic specification for an appropriate geotextile filter for use beneath Link Gabions and Mattresses is as follows.

The geotextile filter shall be needle-punched nonwoven construction consisting of either polypropylene or polyester fibres and shall exhibit the following mean properties:

CBR puncture resistance (AS 3706.4 : 2012)	Minimum 3,000 N
Trapezoidal tear resistance (AS 3706.3 : 2012)	Minimum 450 N
Drop cone h_{50} (AS 3706.5 : 2014)	Minimum 2,500 mm
G Rating (QMRD)	Minimum 2,500
EOS (AS 3706.7 : 2014)	Maximum 0.20 mm
Water permeability Q_{100} (AS 3706.9 : 2012)	Minimum 50 L/m^2.s
Mass per unit area (AS 3706.1 : 2012)	Minimum 270 g/m^2

A suitable geotextile filter that meets the above requirements and specifications for use beneath Link Gabions and Mattresses is ProFab® AS 801. This geotextile filter is supplied by Global Synthetics Pty Ltd in Australasia.

2.6 ROCK INFILL SPECIFICATION

The rock used to fill Link Gabions and Mattresses shall be hard, dense and durable stone free from fractures or cleavages. It may be quarried or river stone. Stone quality shall be consistent with the proposed design life of the structure.

The dimensions of the stone shall generally be cubic such that the longest axis is not more than three times the shortest axis dimension.

The nominal size of rock used as Link Gabion infill shall be 100 to 250 mm with not more than 5% by mass finer than 75 mm.

The nominal size of rock infill used for Link Mattresses shall be 75 mm to a maximum nominal size of approximately two-thirds the height of the Link Mattress product specified with no more than 5% by mass finer than 75 mm.

2.7 GEOGRID REINFORCEMENT

In Section 3.2 of this Design Booklet a design procedure is presented for reinforced soil walls composed of a Link Gabion facing with geogrid reinforcement. The design of these types of walls requires a specific knowledge of the design strengths of the geogrid reinforcement used as well as its soil bond characteristics and gabion connection capacity. The information given below enables ACEGrid® geogrids to be designed as the geogrid reinforcement with Link Gabion faced reinforced soil walls.

Figure 2 provides the information required to establish the design strengths of ACEGrid geogrid reinforcements using Equation 3 in Section 3.2.4 of this Design Booklet. The ultimate tensile strengths T_u, and the various reduction factors, Φ_{rc}, Φ_{ri} and Φ_{ud} for different ACEGrid grades are listed in Figure 2. For example, the value of Φ_{rc} for 120 yrs design life is found in Item 3 as 0.70.

For granular reinforced fills, the bond coefficient $(f_b)_p$ for ACEGrid geogrids is 0.95 (see Section 3.2.5). This information can be used to determine safe geogrid reinforcement bond lengths.

Gabion & Rock Mattresses Design Manual

1. Governing relationship:

Design strength T_d of geogrid reinforcement is:

$T_d = T_u \Phi_{rc} \Phi_{ri} \Phi_{ud}$

where,

T_d = ultimate tensile strength of geogrid reinforcement,

Φ_{rc} = reduction factor due to creep over required design life,

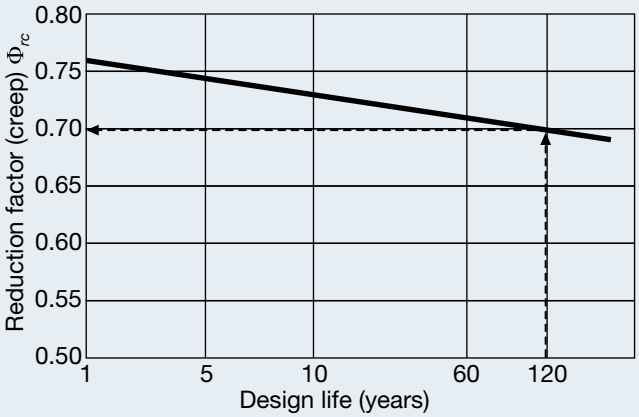
Φ_{ri} = reduction factor to account for installation damage,

Φ_{ud} = uncertainty factor to account for durability over required design life.

2. Values of T_u for ACEGrid geogrids

ACEGrid grade	Units	GG60	GG100	GG150
Ultimate tensile strength AS 3706.2 : 2012	kN/m	70	115	165
Strain at ultimate strength	%	10	10	10

3. Values of Φ_{rc} for ACEGrid geogrids



4. Values of Φ_{ri} for ACEGrid geogrids

SOIL TYPE	GG60	ACEGrid grades GG100	GG150
Sand/silt/clay	0.95	0.96	0.96
Sandy gravel	0.90	0.92	0.94

4. Values of Φ_{ud} for ACEGrid geogrids

For,
design life ≥10 yrs, Φ_{ud} = 1.00,
design life = 60 yrs, Φ_{ud} = 0.95,
design life = 120 yrs, Φ_{ud} = 0.90.

Figure 2 - Design strength components of ACEGrid geogrid reinforcement according to AS 4678 : 2002.

Figure 3 shows the connection capacities between ACEGrid geogrids and Link Gabions, presented in the form described in Section 3.2.6. This information can be used to determine safe ACEGrid connection capacities with Link Gabions.

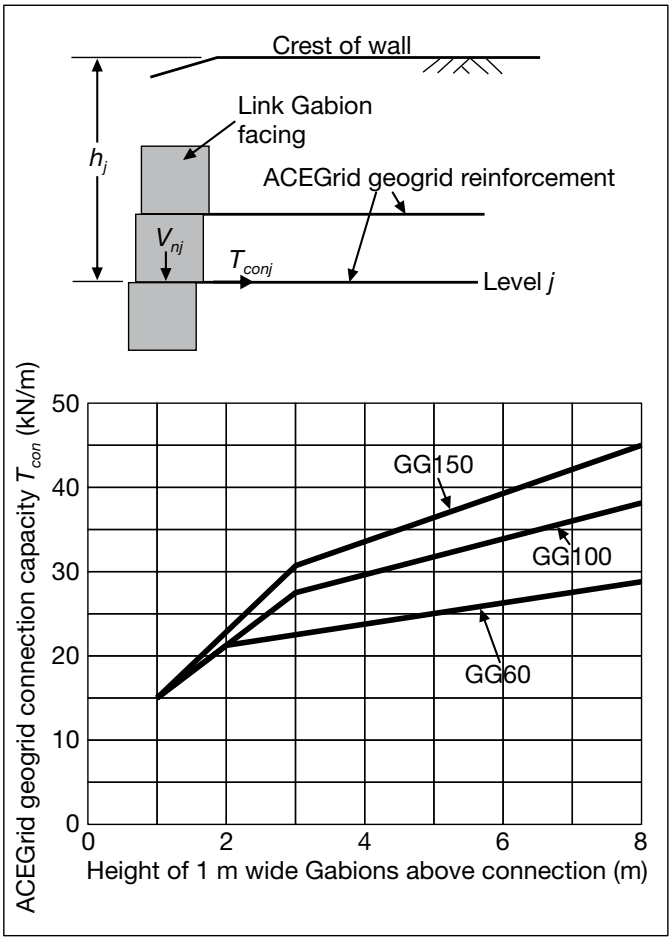


Figure 3 - ACEGrid geogrid connection capacity with 1 m wide Link Gabions.

Gabion & Rock Mattresses Design Manual

3. Link Gabions for Civil Works

Link Gabions are used for a wide variety of retaining wall structures. Their versatile size allows the design of many different wall sections to suit the architectural demands of a project as well as its engineering requirements.

Link Gabions may be used for gravity retaining walls, reinforced soil retaining walls and low-height landscaping walls. The design procedures for gravity and reinforced soil retaining walls are described below.

3.1 GRAVITY RETAINING WALLS

Link Gabions are an efficient method of gravity retaining wall construction offering low cost, easy installation and generally requiring a minimum of foundation preparation and drainage. They may take many shapes and forms depending upon the particular use, soil and foundation characteristics, surface slope of backfill and any superimposed loadings. While the external shapes and forms may vary, the internal structure of these gravity walls is made up of one of two types – front sloped walls and rear sloped walls. These two types are shown in Figure 4. To enhance stability, it is common practice to incline the angle of the walls 6° to 10° towards the backfill, especially with rear sloped walls.

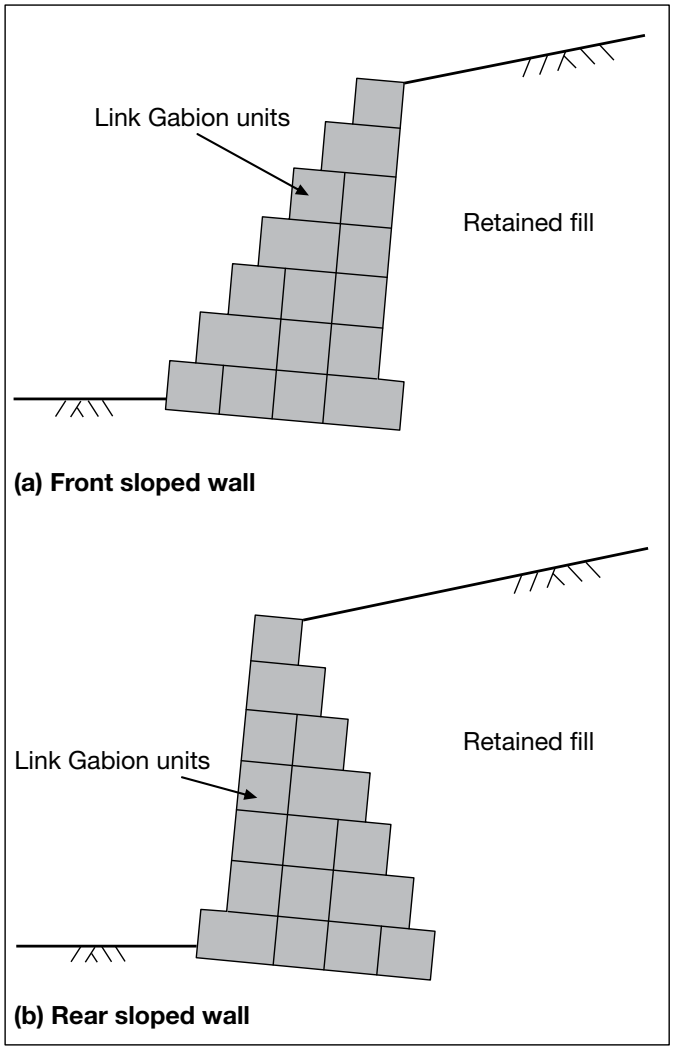


Figure 4 - Two types of Link Gabion gravity walls.

Link Gabion gravity retaining walls are designed as mass gravity structures, where the weight of the gabion wall retains the backfill material in a stable manner. For the wall to remain stable it must be designed to meet a number of limit states (i.e. potential failure modes). For Link

Gabion gravity walls there are four limit states – overturning, sliding, bearing capacity and overall stability. These are shown in Figure 5 and described in detail below.

3.1.1 Stability against overturning failure

The weight of the Link Gabion wall provides the stability to the structure. The weight per metre run can be calculated from the following relationship:

$$W = (1\text{-}v)\ \gamma_s\ A \qquad (1)$$

where, W = the weight of the wall per metre run, v = the void ratio of the wall rock infill (approximately 0.35), γ_s = the unit weight of the wall rock infill (see Table 7), A = the cross sectional area of the wall.

TABLE 7- UNIT WEIGHT OF GABION ROCK INFILL.

Type of rock infill	Unit weight γ_s (kN/m^3)
Basalt	27
Granite	26
Hard limestone	26
Calcareous pebbles	23
Sandstone	23
Soft limestone	22
Tuff	17

Figure 6 sets out the procedure used to determine the stability against overturning. Moments are summed around the front toe of the wall to arrive at a suitable level of safety.

The location of the centre of gravity (CG in Figures 6 and 8) through which the wall weight acts is obtained by taking moments of the wall components about the toe of the retaining wall structure.

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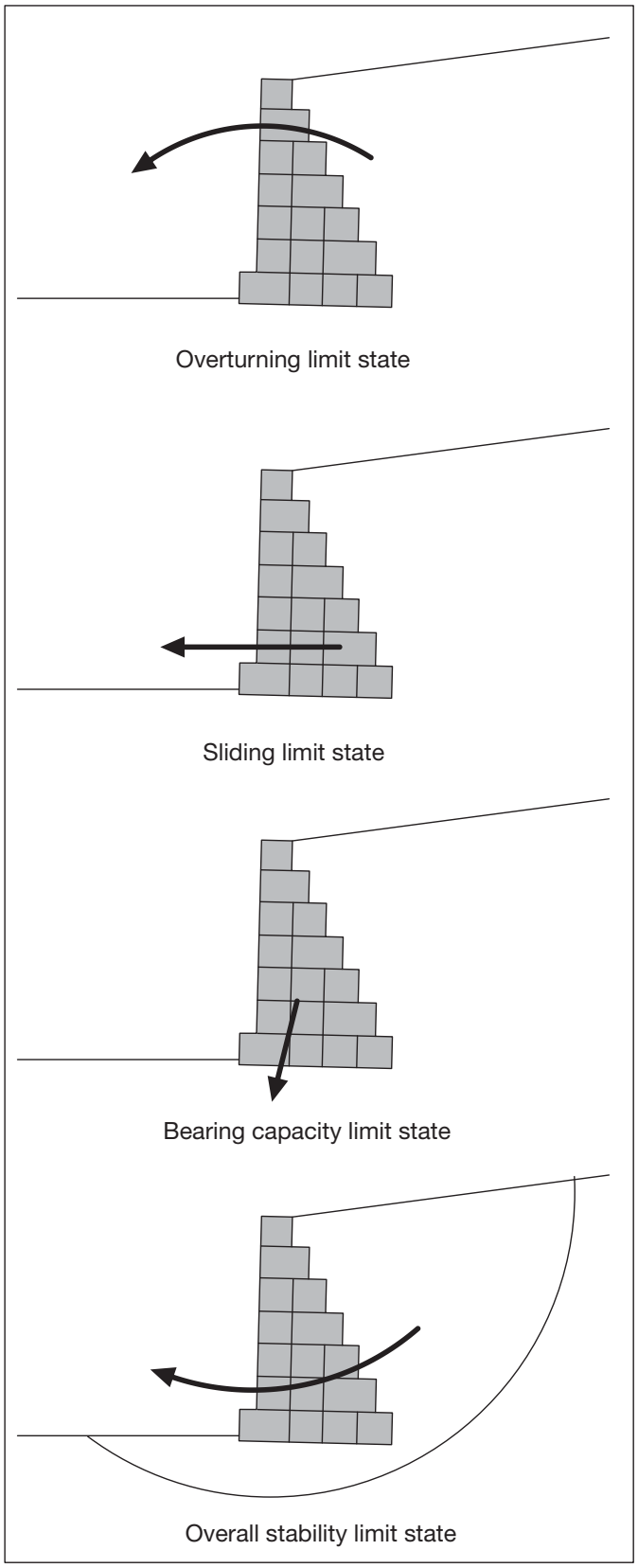
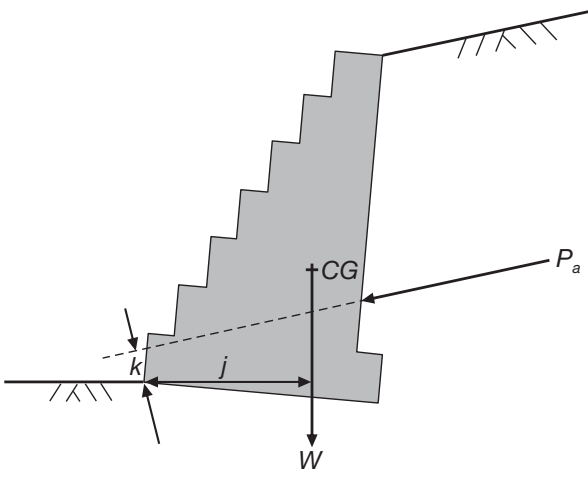


Figure 5 - Design limit states for Link Gabion gravity retaining walls.

Normally, if the resultant force R, shown in Figure 9, acts through the middle third of the base of the wall, then overturning stability is not a limiting state.

The magnitude of the earth force acting at the rear of the wall is dependent on the type of soil in the retained fill, the height of the wall,



Taking moments around the front toe of the wall,

$M_r \geq F_{so} M_o$

where,

$M_r = W.j$ = restoring moment due to weight of the wall,

$M_o = P_a.k$ = overturning moment due to active earth pressure acting on the wall,

F_{so} = factor of safety with regard to overturning (= 1.5).

Figure 6 - Stability against overturning.

whether there are any surcharge or line or point loads above, or behind, the wall, if any groundwater is present in the retained fill and if the wall is subject to any seismic loadings. The relationships presented in Figure 7 account only for the type of soil in the retained fill and the height of the wall with a uniform surcharge applied above the wall. The procedures listed in a variety of soil mechanics text books can be used to account for the other loading components. Normally, the Designer assesses a range of potential loading cases in order to determine the worst possible loading condition for each limit state.

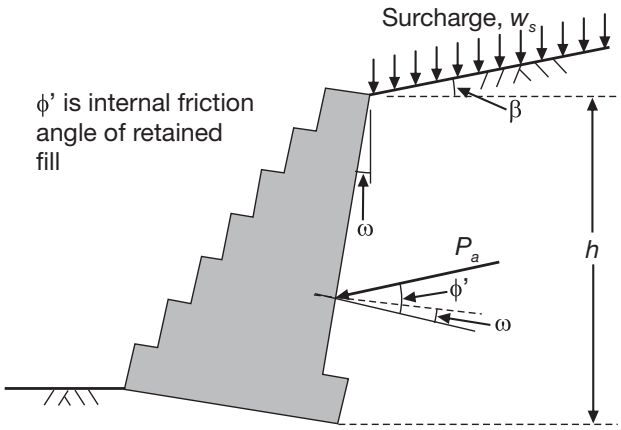
3.1.2 Stability against sliding failure

Figure 8 sets out the procedure used to determine the stability against sliding. The component of the resultant force normal to the base of the wall has to counteract the component of the resultant force parallel to the base of the wall.

3.1.3 Stability against bearing failure

Figure 9 sets out the procedure used to determine the stability against bearing failure. The resultant force at the base of the wall ***R*** acts eccentrically resulting in a trapezoidal pressure distribution across the base of the wall. The maximum bearing stress acting on the foundation σ_1 has to be less than or equal to

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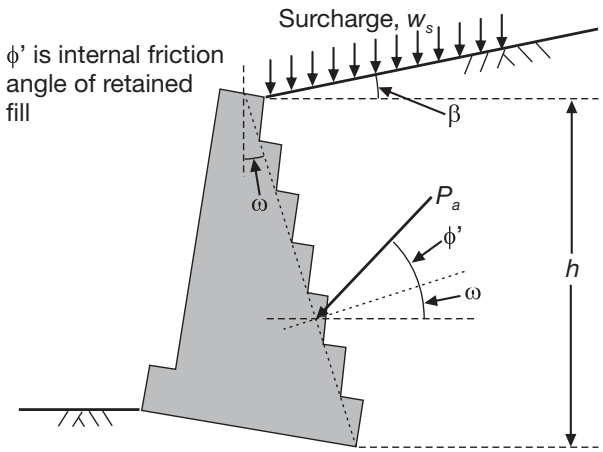


$$P_a = 0.5K_a(\gamma h + 2w_s)h$$

where,

$$K_a = \frac{\cos^2(\phi' + \omega)}{\cos^2\omega\cos(\omega - \phi')\left[1 + \sqrt{\frac{\sin 2\phi' \sin(\phi' - \beta)}{\cos(\omega - \phi')\cos(\omega + \beta)}}\right]^2}$$

Front sloped wall



$$P_a = 0.5K_a(\gamma h + 2w_s)h$$

where,

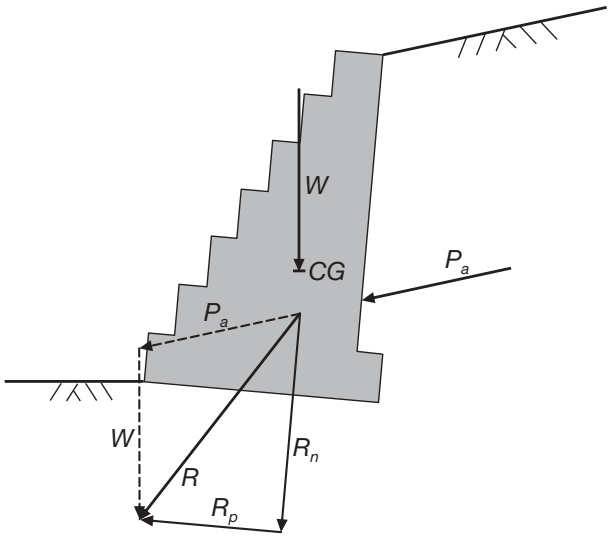
$$K_a = \frac{\cos^2(\phi' - \omega)}{\cos^2\omega\cos(\omega + \phi')\left[1 + \sqrt{\frac{\sin 2\phi' \sin(\phi' - \beta)}{\cos(\omega + \phi')\cos(\omega - \beta)}}\right]^2}$$

Rear sloped wall

Figure 7 - Calculation of coefficient of active thrust on rear of Link Gabion gravity walls.

the ultimate bearing capacity of the foundation divided by a suitable factor of safety.

Where possible, the ultimate bearing capacity of the foundation should be analysed by engineering means. Account should be taken of the vertical and horizontal applied loads, the presence of groundwater, the geometry of the foundation surface in the vicinity of the toe of the wall, as well as the base width of the proposed retaining wall. It should be noted that before the onset of ultimate bearing



Summing vertical and horizontal forces normal to and parallel to the base of the wall,

$R_n f \geq F_{ss} R_p$

where,

R_n = component of the resultant force R normal to the base of the wall,

f = coefficient of friction at the base of the wall (= tan ϕ', where ϕ' = friction angle of foundation soil),

R_p = component of the resultant force R parallel to the base of the wall,

F_{ss} = factor of safety with regard to sliding (=1.5).

Figure 8 - Stability against sliding.

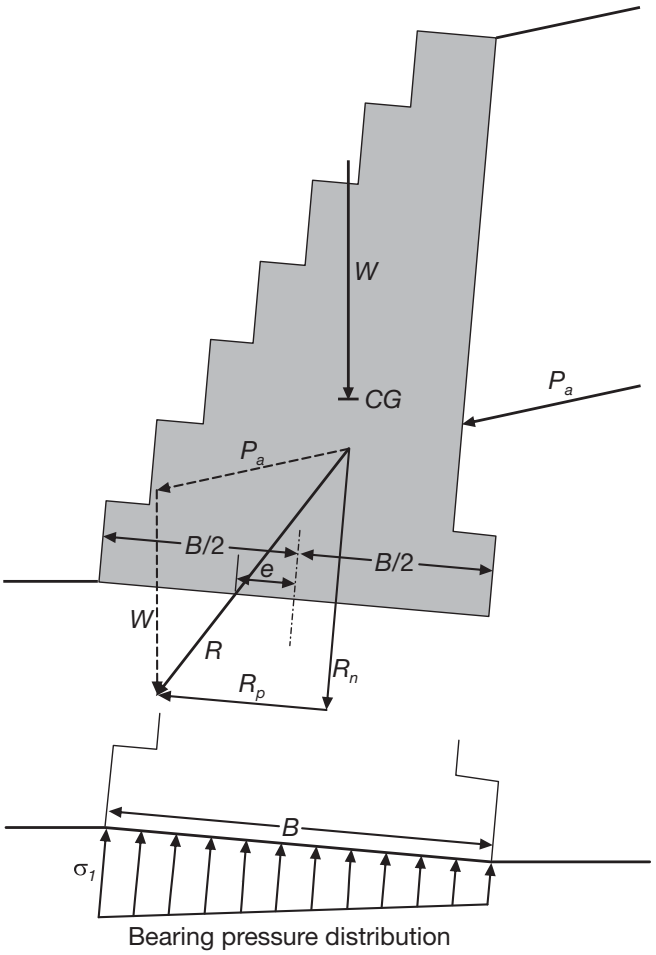
resistance the foundation soil undergoes considerable deformation. This deformation may be incompatible with the serviceability requirements of the gravity wall. To reduce the effects of deformation a large value for F_{sb} in Figure 9 has been adopted (= 2.5). In certain instances where wall movements are critical it may be necessary to increase this factor of safety to 3.0.

3.1.4 Stability against overall failure

Overall stability (see Figure 5) of the gravity wall should be assessed in detail in the following situations;

- where there is doubt concerning the stability of the foundation,
- where the foundation surface in the vicinity of the toe of the wall slopes downwards from the wall,
- where the back-slope angle (β in Figure 7) is significant,
- where line and/or point loads occur in the vicinity behind the wall,
- where weak strata layers occur within the vicinity of the wall,

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Bearing pressure distribution

To ensure no bearing failure,

$$\frac{q_u}{F_{sb}} \geq \sigma_1 = \frac{R_n(B+6e)}{B^2}$$

where,
q_u = ultimate bearing capacity of foundation,
F_{sb} = factor of safety against bearing failure (= 2.5),
σ_1 = maximum bearing stress on foundation,
R_n = resultant force normal to base of wall,
B = width of base of wall,
e = eccentricity of resultant force R.

Figure 9 - Stability against bearing failure.

- where the presence of groundwater is likely to affect the overall stability of the wall.

In assessing the stability of the gravity wall the Designer should consider both short term and long term conditions.

Detailed design procedures for gravity retaining structures may be referred to in various Codes of Practice - AS 4678 : 2002, BS 8002 : 2014 and ISE (1951).

3.2 REINFORCED SOIL RETAINING WALLS

Reinforced soil retaining walls are cost effective retaining structures that can be constructed to a wide range of heights. Here, Link Gabions can be used as the retaining wall facing. A typical layout is shown in Figure 10. For this structure,

the Link Gabion facing provides local stability to the face of the wall, with the reinforced fill in combination with the geogrid reinforcement providing the required shear resistance for internal stability purposes.

The combination of geogrid reinforcement with a Link Gabion facing provides an economical retaining wall system with a durable and permeable outer facing that can be constructed often with on site materials. Walls can be constructed that are either temporary in nature, or are permanent.

For the detailed design/analysis of reinforced soil retaining walls the reader should consult AS 4678 : 2002 and/or BS 8006 : 2010. A summarised approach is provided below pertaining specifically to Link Gabion faced reinforced soil walls that are reinforced with geogrid reinforcement.

For the reinforced soil wall to remain stable it must be designed to meet a number of limit states (i.e. potential failure modes). For Link Gabion faced reinforced soil walls there are six limit states – sliding resistance, bearing resistance, overall stability, geogrid strength, geogrid bond and geogrid/gabion connection capacity. These limit states are shown in Figure 11 and described in detail below.

3.2.1 External stability – sliding resistance

The external stability of reinforced soil retaining walls is assessed in an identical manner to

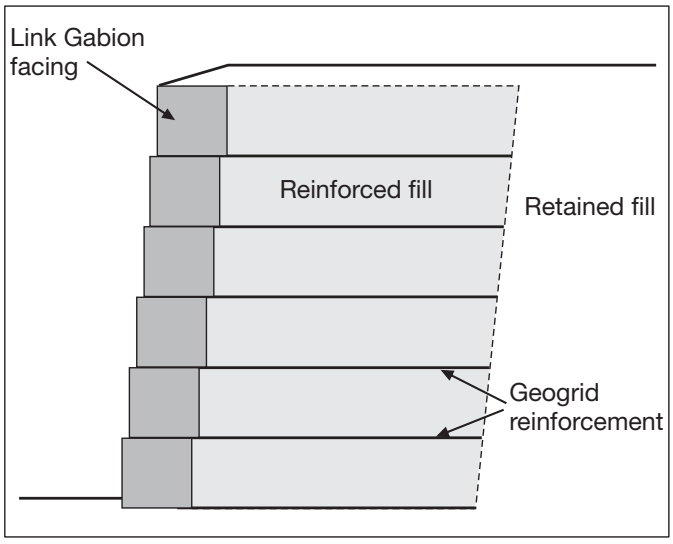


Figure 10 - Typical layout showing the components of a Link Gabion reinforced soil wall.

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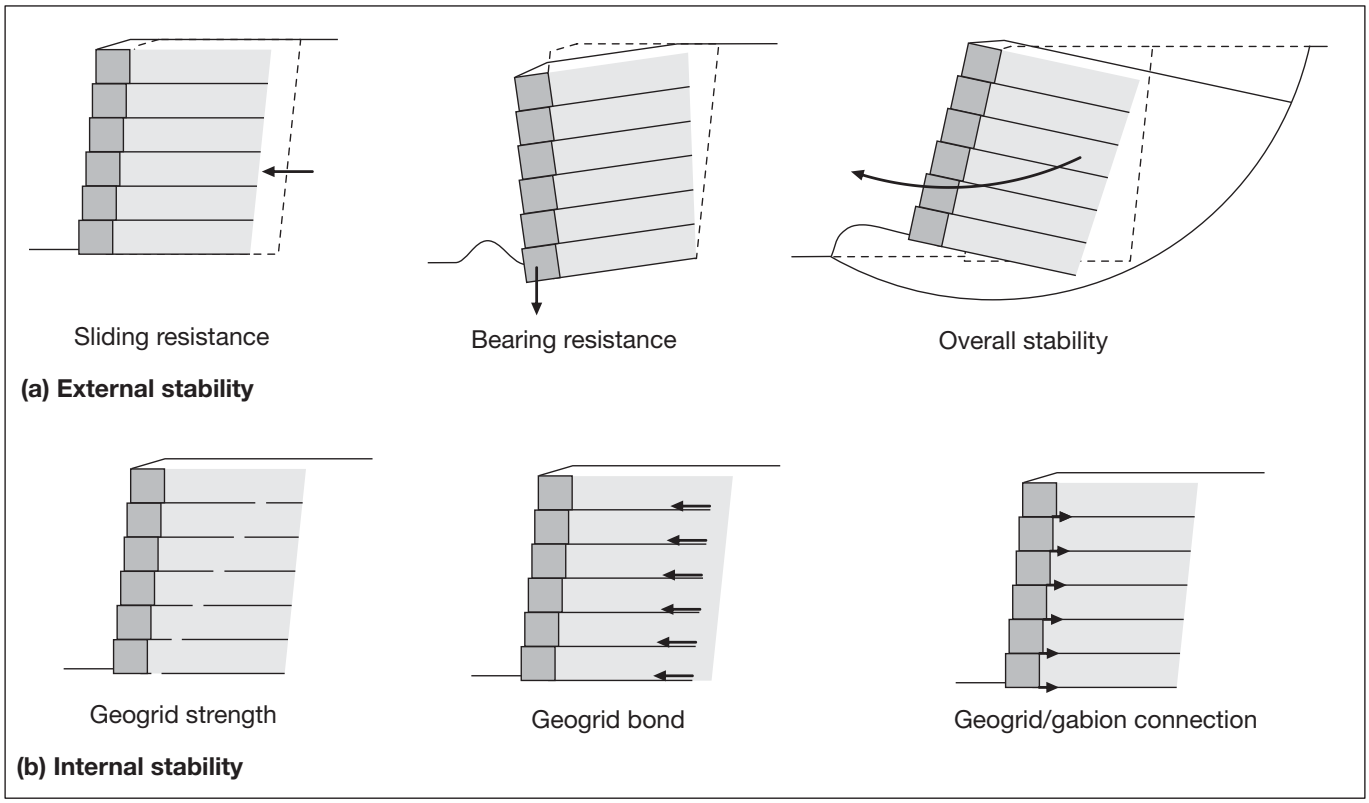
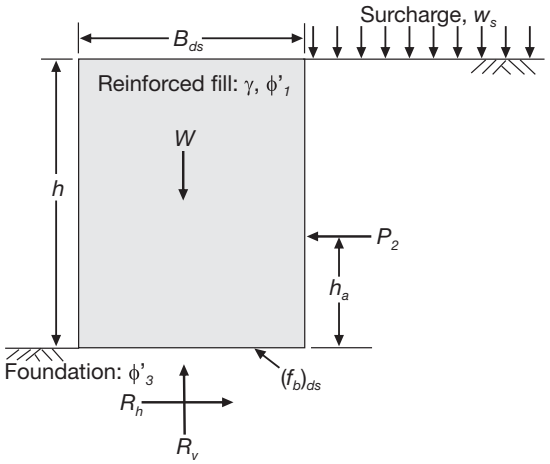


Figure 11 - Design limit states for Link Gabion faced reinforced soil walls.

gravity retaining walls. The combination of Link Gabion facing, reinforced fill and geogrid reinforcement is considered to act as a gravity structure.



Summing vertical and horizontal forces at base of wall gives:

$$W (f_b)_{ds} \tan\phi'_3 \geq F_{ss} P_2$$

where,
W = weight of the reinforced soil mass,
$(f_b)_{ds}$ = bond coefficient between foundation soil and base of wall,
ϕ'_3 = internal angle of friction of foundation soil,
P_2 = horizontal force causing sliding,
F_{ss} = factor of safety against sliding (= 1.5).

Figure 12 - Stability against sliding.

Figure 12 sets out the procedure used to determine the stability against sliding. Here, the weight of the reinforced fill in the wall counteracts the horizontal active force behind the reinforced fill zone. Using the procedure in Figure 12 a safe value of Bds is determined such that forward sliding of the reinforced soil wall cannot occur.

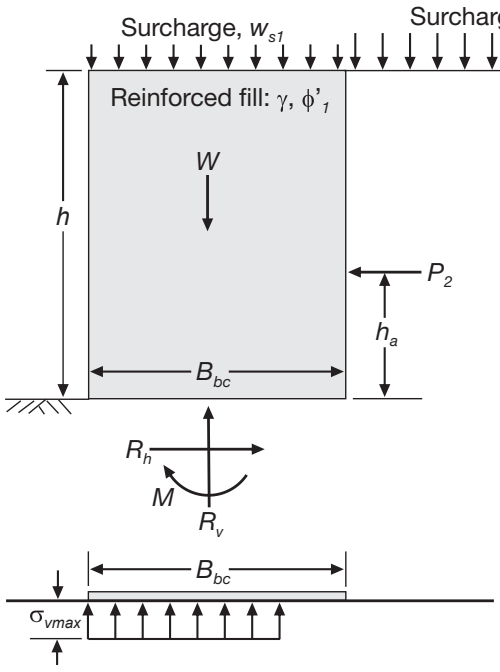
3.2.2 External stability – bearing resistance

Figure 13 sets out the procedure used to determine the stability against bearing failure. Here, the combination of vertical force due to wall weight and horizontal force due to active thrust causes an uneven stress distribution on the foundation beneath the reinforced soil wall. The assumed uneven stress distribution shown in Figure 13 is that described by Meyerhof (1953), and is commonly used for the bearing resistance design of reinforced soil walls. Using the procedure in Figure 13 a safe value of Bbc is determined such that bearing failure of the reinforced soil wall foundation cannot occur.

3.2.3 External stability – overall stability

Overall stability (see Figure 11) of the Link Gabion reinforced soil wall should be assessed in detail where the same situations as listed in Section 3.1.4 exist.

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To ensure no bearing failure,

$$\frac{q_u}{F_{sb}} \geq \sigma_{v\,max} = \frac{R_v}{\left(B_{bc} - \frac{2M}{R_v}\right)}$$

where,

q_u = ultimate bearing capacity of foundation,

F_{sb} = factor of safety against bearing failure (= 2.5),

σ_{vmax} = maximum vertical stress on foundation.

Figure 13 - Stability against bearing failure.

In situations where overall stability may be critical, and where the critical slip surface passes close to the heel of the reinforced fill zone, improvement in stability can be attained by increasing the extent of the reinforced fill zone, thus forcing the critical slip surface deeper into the retained fill zone.

3.2.4 Internal stability – geogrid strength

The layers of geogrid reinforcement placed in the reinforced fill (see Figure 10) provide the additional shear resistance that is required to achieve internal stability for the reinforced soil wall. This additional shear resistance is achieved by the layers of geogrid reinforcement absorbing the out-of-balance internal stresses in the reinforced fill.

Figure 14 sets out the procedure used to determine these out-of-balance stresses, and then determine the required design strengths of the geogrid reinforcement layers in the wall. The horizontal component of the active earth thrust P_{ah} creates an out-of-balance stress distribution behind the gabion face. This must be resisted by the geogrid reinforcement layers. In Figure 14, the out-of-balance stress distribution due to reinforced fill self weight and uniform surcharge w_s is shown. In many practical situations the out-of-balance stresses due to line and point loads above the wall may also have to be taken into account when determining the total out of balance stress distribution within the wall. Readers should consult AS 4678 : 2002 and BS 8006 : 1995 for details concerning these external load cases.

The magnitude of the horizontal restraining stresses σ_{aj} due to the presence of the geogrid reinforcement is dependent upon the design strength of the geogrid reinforcement and the vertical spacing between layers, Figure 14. Link Gabions are either 0.5 m or 1 m in height, and thus the geogrid layers, which have to conform to the gabion heights, will have vertical spacings of either 0.5 m or 1 m.

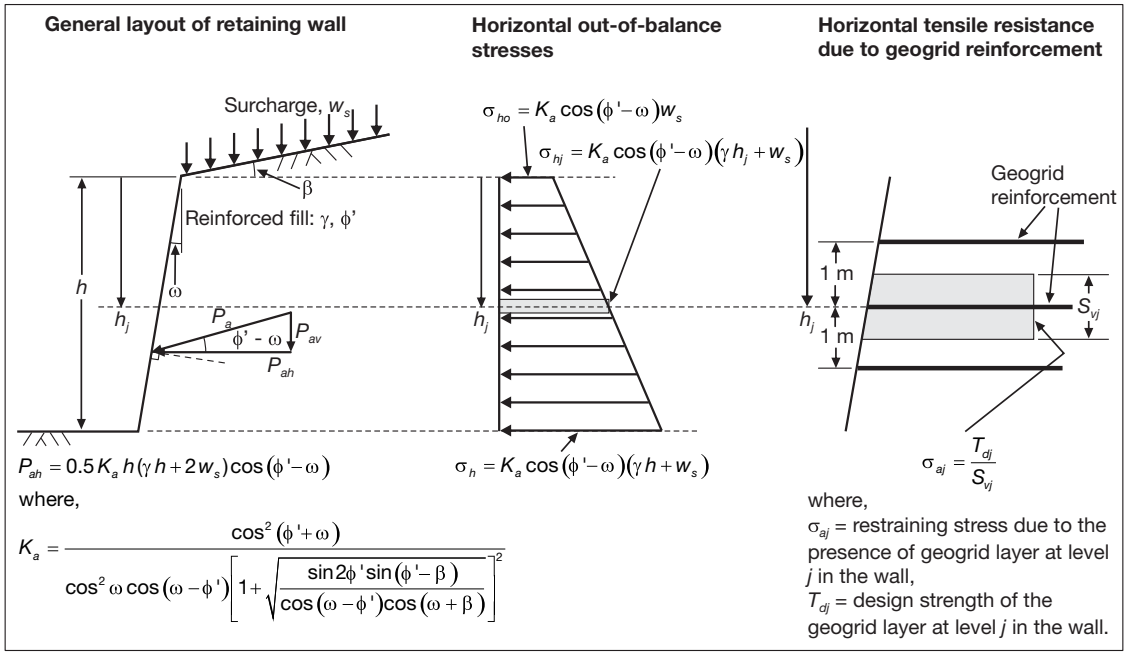


Figure 14 - Determination of required geogrid reinforcement design strengths in a Link Gabion faced reinforced soil wall.

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The horizontal restraining stresses due to the presence of the geogrid layers within the wall σ_{aj} are related to the horizontal out-of-balance stresses σ_{hj} at all levels in the wall by,

$$\sigma_{aj} \geq F_{st}\,\sigma_{hj} \qquad (2)$$

where, F_{st} = factor of safety against tensile rupture of the geogrid reinforcement. It is common practice to use a value of 1.5 for F_{st}.

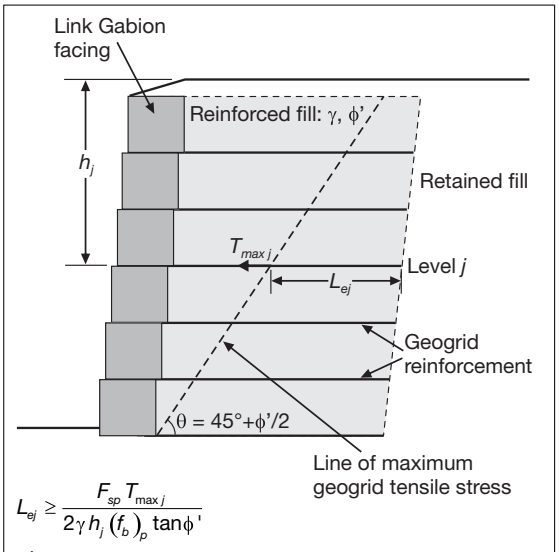
To determine the horizontal restraining stresses due to the presence of the geogrid layers σ_{aj} the design strength of the geogrid layer T_{dj} must be known, Figure 14.

The design strength of geogrid reinforcement is dependent upon its ultimate tensile strength, the environment in which it is installed, and the design life over which it is required to perform. AS 4678 : 2002 provides a formalised procedure to assess the design strengths of geogrid reinforcement. The fundamental relationship is,

$$T_d = T_u \Phi_{rc} \Phi_{ri} \Phi_{ud} \qquad (3)$$

where, T_d = the design strength of the geogrid reinforcement, T_u = the ultimate tensile strength of the geogrid reinforcement, Φ_{rc} = a reduction factor to account for creep over the required design life, Φ_{ri} = a reduction factor to account for installation damage, and Φ_{ud} = an uncertainty factor to account for reinforcement durability over the required design life.

The values of the reduction factors in Equation 3 are specific to the type of geogrid reinforcement being used in the reinforced soil wall. In Section 2.7 of this Design Booklet ultimate tensile strengths and reduction factors are given for ACEGrid geogrids to enable the determination of safe design strengths for these materials.



$$L_{ej} \geq \frac{F_{sp}\,T_{max\,j}}{2\gamma h_j (f_b)_p \tan\phi'}$$

where,
$T_{max\,j}$ = maximum tension generated in the geogrid layer at level j in the wall,
F_{sp} = factor of safety for geogrid bond resistance (= 1.5),
$(f_b)_p$ = bond coefficient for pull-out resistance between geogrid and reinforced fill.

Figure 15 - Required geogrid reinforcement bond length.

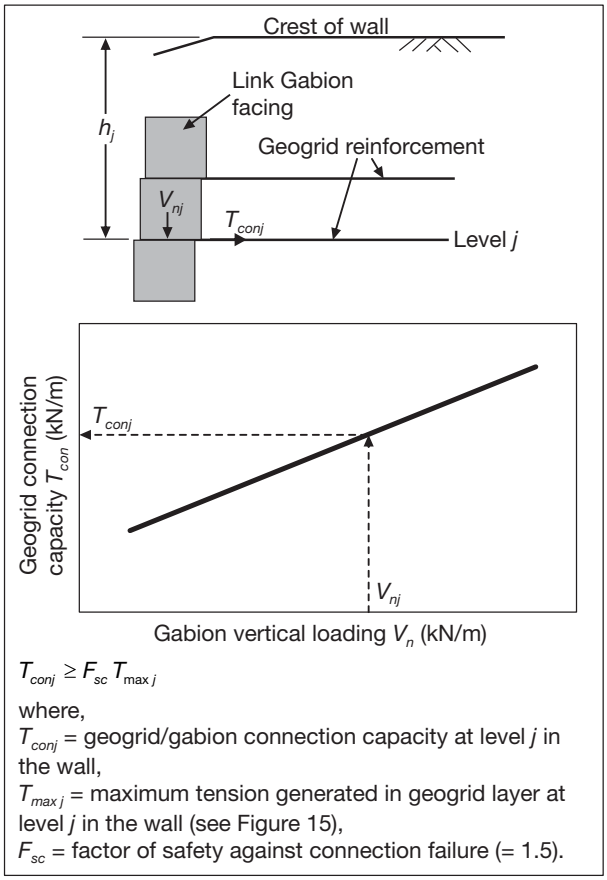
3.2.5 Internal stability – geogrid bond length

The layers of geogrid reinforcement placed within the reinforced fill have to be long enough in order to dissipate the generated tensile stresses and ensure they don't pull-out of the reinforced fill. Figure 15 shows the method used to determine the required bond length to prevent pull-out failure at different levels in the wall.

3.2.6 Internal stability – geogrid/gabion

connection capacity The layers of geogrid reinforcement are connected to the Link Gabion facing at the horizontal joins of the facing. Adequate connection can be made by simply continuing the geogrid layer through to the outer face of the Gabion facing. This creates a frictional connection at the gabion facing. Other means of connecting the geogrid to the gabion facing may also be undertaken.

Figure 16 shows the procedure used to assess connection capacity at various levels in the reinforced soil wall.



$$T_{conj} \geq F_{sc}\,T_{max\,j}$$

where,
T_{conj} = geogrid/gabion connection capacity at level j in the wall,
$T_{max\,j}$ = maximum tension generated in geogrid layer at level j in the wall (see Figure 15),
F_{sc} = factor of safety against connection failure (= 1.5).

Figure 16 - Geogrid connection capacity determination with Link Gabion facing.

3.2.7 Link Gabion faced reinforced soil walls

construction details The reinforced fill used behind the Link Gabion facing should be granular in nature and be free of organic matter and other deleterious material. The material should be capable of being compacted to form a stable mass.

Gabion & Rock Mattresses Design Manual

A geotextile filter meeting the specification requirements listed in Section 2.5 should be installed behind the Link Gabion facing units prior to placement of the reinforced fill.

Where the wall may be exposed to groundwater flows and surface water adequate protection measures should be provided. To intercept groundwater flows a subsurface drainage blanket should be provided across the base of the wall and extending up the rear of the reinforced fill (see Figure 17). The drainage blanket may consist of drainage aggregate wrapped in a suitable geotextile filter or a geocomposite sheet drain (for the rear of the wall only). To protect against surface water an impermeable capping layer should be provided above the reinforced fill (see Figure 17), along

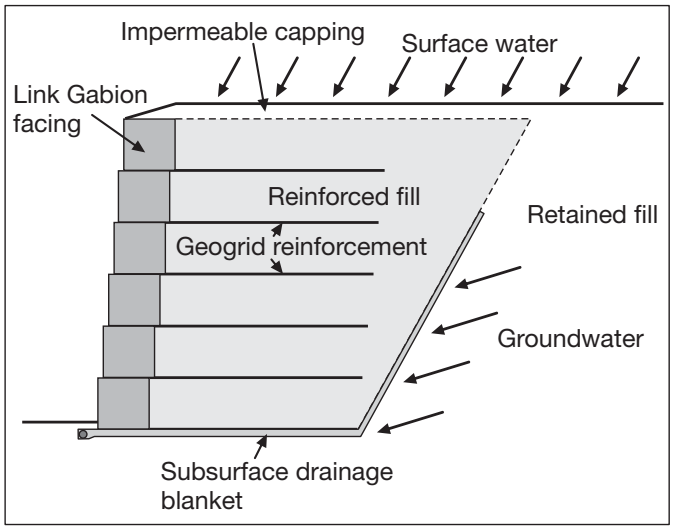


Figure 17 - Protection of reinforced soil wall from surface water and groundwater flows.

with adequate surface drainage measures to ensure the surface water is transported away from the structure in a controlled manner.

Placement and compaction of the reinforced fill should be carried out in a direction parallel to the face of the wall and should be completed in stages to closely follow the installation of the Link Gabion facing units and geogrid reinforcement.

Placement and installation of Link Gabion facing units should follow the guidelines given in Section 6 of this Design Booklet.

The geogrid reinforcement should be installed at the correct lines and levels as shown on construction drawings. The geogrid reinforcement should be fixed between two layers of Link Gabion facing courses by lacing through the two adjacent Link Gabion units as described in Section 6.3 ensuring that the lacing ties together both the Link Gabion units and the geogrid layer in between. Two rows of lacing parallel with the wall face should be completed for every one lineal metre of Link Gabion facing units installed.

The geogrid reinforcement should be properly oriented with the roll direction (primary strength direction) laid perpendicular to the wall face. The geogrids should be tensioned by hand until taut and free from wrinkles and secured by pins, stakes or similar prior to placement of the next layer of reinforced fill.

3.3 LANDSCAPING WALLS

Rock infilled Link Gabions with their natural appearance have good aesthetics. This aspect may be utilised effectively for slope landscaping applications. Link Gabions may be used to provide stepped slopes in parks and gardens or used to stabilise unstable slopes in an environmentally sensitive area. A typical example of the use of Link Gabions in landscaping is shown in Figure 18.

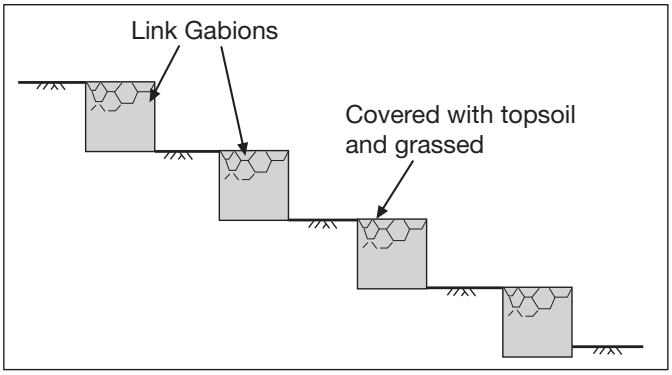


Figure 18 - using Link Gabions for landscaping slopes.

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4. Link Gabions and Mattresses for Channel, River and Stream Works

Channels, rivers and streams are dynamic energy systems performing the functions of erosion, transportation, and deposition of sediments.

Water, because of its relatively high viscosity and density, has the ability to transport particles at much slower velocity than it requires to pick them up (unlike wind). Once lifted into suspension, therefore, soil particles will travel considerable distances before being deposited. In addition, water has the ability to move stones and pebbles by rolling them. This rolling velocity is very much lower than the lifting/ carrying velocity. Table 8 shows the threshold water velocity at which various soil types will erode (soils will remain in suspension at lower velocities). In many instances the water flow rates in channels, rivers and streams can be significantly greater than those depicted in Table 8 thus, erosion protection becomes a major issue.

TABLE 8 - EROSION SUSCEPTIBILITY OF DIFFERENT SOIL TYPES (AFTER KUENEN, 1950).

Bed material	Threshold water velocity (m/sec)
Clay (non-dispersive) (up to 0.002 mm dia)	1.5
Silt (0.002 – 0.06 mm dia)	0.6
Sand (0.06 – 2.0 mm dia)	0.2
Gravel (2.0 – 20 mm dia)	1.0
Cobbles (20 – 100 mm dia)	3

For design purposes, when calculating the flow in a channel or river, use is commonly made of Manning's equation:

$$V_{avg} = \frac{R^{2/3} S^{1/2}}{n} \quad (4)$$

where, V_{avg} = the average water velocity (in m/ sec), R = the hydraulic radius of the channel or river (in m), S = the slope of the water surface, n = Manning's roughness coefficient.

Manning's roughness coefficient describes the shear resistance at the bank and bed interface with the water. Where Link Gabions and Mattresses are used for bank and bed protection, values of Manning's roughness coefficient may be taken as 0.0222 where no vegetation is present through the Gabions and Mattresses, or 0.0272 where vegetation is present through the Gabions and Mattresses.

Local scour can occur in channels, rivers and streams where water velocities and turbulence cause the erosion and removal of soil. This normally occurs at the following locations.

- Within channels, rivers and streams subject to high water flows, and at bends. These normally require bank and bed protection works.
- At bridge abutments and piers.
- At sluice gates and rectangular culverts.
- At circular and square culverts.
- At weirs and drop structures.
- At low-level crossings, and embankments crossing flood plains.

These structures are discussed in further detail below.

4.1 BANK AND BED PROTECTION

Link Gabions and Mattresses can be used to provide bank and bed erosion protection. These normally take the form of revetments, groynes or training walls.

4.1.1 Revetment protection

Link Mattresses are used to provide revetment protection for rivers, channels and streams. The common layout is shown in Figure 19. The Mattresses are placed down the side-slope, beginning above the design high water level, and extending a distance L across the base of the channel or river. This distance L should be at least 2 times the maximum predicted scour depth at the base of the channel or river.

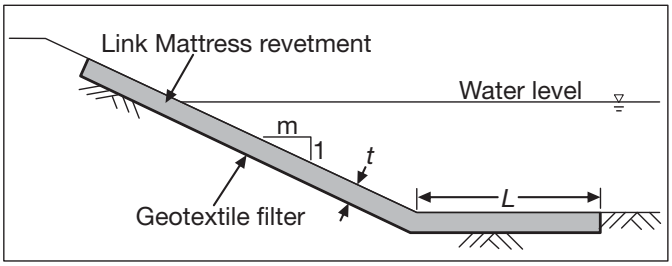


Figure 19 - Link Mattresses used for revetment protection.

A suitable geotextile filter should be placed beneath the Link Mattresses to ensure the retained soil cannot be eroded out through the rock infill in the mattresses, see Section 2.5.

The erosion protection provided by a Link Mattress revetment is dependent on the Mattress thickness being able to resist the erosive water flows in the channel or river. A number of methods have been proposed to determine the required mattress thickness to resist a specific water flow rate, the most commonly used is that of Maynord (1995), and this is detailed in Figure 20.

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Maynord's governing relationship is dependent on a number of coefficients dealing with stability, water velocity distribution and sideslope angle; the depth of the revetment toe below water level; the mass density of the rockfill in the mattresses; and the depthaveraged water velocity at the revetment surface. For rock infill stability, the governing relationship shown in Figure 20 assumes that the maximum rock infill diameter in the mattress is around 50% of the thickness of the mattress, and that instability occurs at the onset of rock infill movement within the mattress (and not the movement of the mattress itself). The water velocity that induces rock infill movement within the mattress is commonly referred to as the "critical velocity".

The depth-averaged water velocity can vary within a channel or river. For straight channels and rivers the depth-averaged water velocity V_s will approximate that of the average flow velocity V_{avg} (see item 4, Figure 20). However, where curves and bends occur in channels, rivers and streams the depth-averaged water velocity close to the side-slope revetment may be considerably greater than that of the average flow velocity. Consequently, this needs to be taken into account when determining mattress stability in these locations – see item 4, Figure 20.

In many instances, the relationship between the maximum average flow velocity and the required Link Mattress thickness for stability are the two fundamental parameters for design. Using Maynord's relationship contained in Figure 20 the critical (i.e. maximum allowable) average flow velocity for the various Link Mattress thicknesses assuming a straight river or channel

1. Governing relationship:
The required Link Mattress thickness t is:

$$t \geq 2 F_s C_s C_v d \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{0.5} \frac{V_s}{\sqrt{g d K_1}} \right]^{2.5}$$

where,
F_s = safety factor (F_s =1.1),
C_s = stability coefficient of the rock mattress (C_s = 0.1),
C_v = velocity distribution coefficient (see item 3 below),
V_s = depth-averaged velocity between water level and toe of the side-slope (normally at 20% above revetment toe),
K_1 = side-slope correction factor (see item 2 below),
g = acceleration due to gravity,
d = flow depth at V_s (normally 80% of revetment toe depth),
γ_w = unit mass of water (kg/m^3),
γ_s = unit mass of stone (kg/m^3).

2. Determination of K_1

Side-slope	K_1
1*V*:1*H*	0.46
1*V*:1.5*H*	0.71
1*V*:2*H*	0.88
1*V*:3*H*	0.98
1*V*:4*H* or flatter	1.00

3. Determination of C_v
For $r/w < 25$, $C_v = 1.283 - 0.2 \log (r/w)$
For $r/w \geq 25$, $C_v = 1.0$.
C_v = 1.25 immediately downstream of concrete channels.

where,
r = centreline bend radius of the channel,
w = water surface width.

4. Approximation of V_s
For straight rivers and channels, $V_s = V_{avg}$, the average flow velocity. Where there are curves and bends V_s is greater than V_{avg}, and may be approximated using the following diagram.

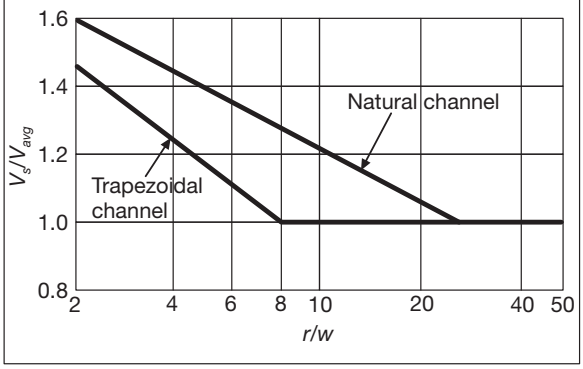


Figure 20 - Determination of Link Mattress thickness requirements for water flows in rivers, channels and streams (After Maynord, 1995).

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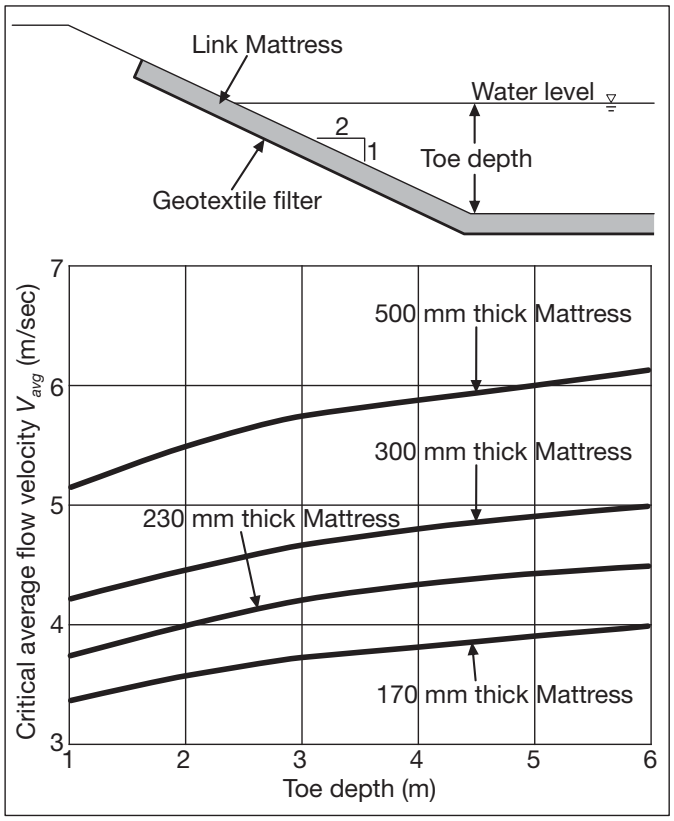


Figure 21 - Critical average flow velocities for different thickness Link Mattresses laid at slope 1V:2H in a straight, natural channel where Froude number ≤ 1.5.

and a 1V:2H side-slope has been plotted in Figure 21. Flatter side-slopes show a slightly increased maximum allowable flow rate, while steeper side-slopes show a slightly decreased maximum allowable flow rate. The curves in Figure 21 can be used to quickly determine the Link Mattress thickness required to provide stable erosion protection in a straight river or channel having a specific average flow velocity.

When designing Link Mattresses for bank and bed revetment protection, detailing is an important factor. The Link Mattresses should be placed up (or down) the slope of the bank. When placing them in the bed, they should be aligned parallel to the direction of flow. This is shown schematically in Figure 22.

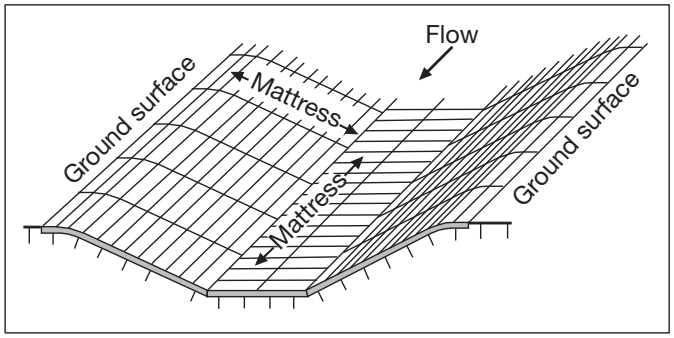


Figure 22 - Arrangement of Link mattresses in rivers, channels and streams.

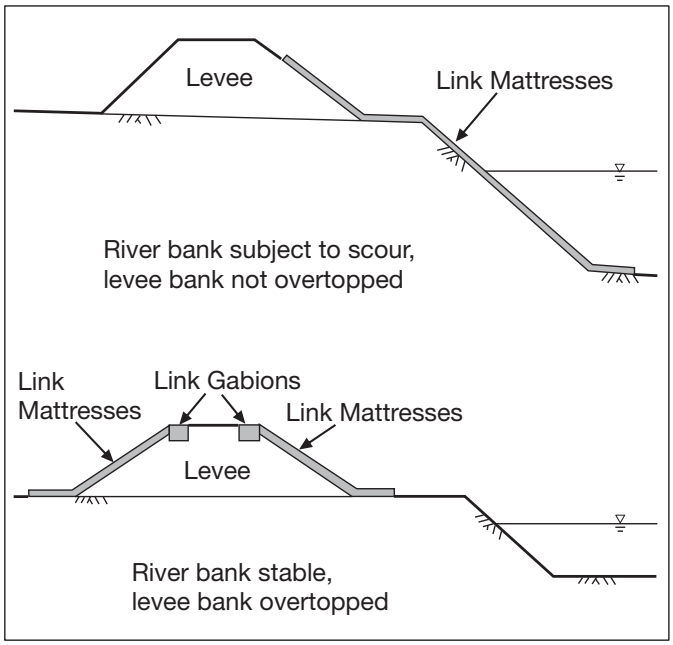


Figure 23 - Use of Link Mattresses to protect levees.

Where the banks of rivers, channels and streams have to be raised to accommodate high water flows, levees (or dykes) are constructed along the banks to contain the water flows. Levees consist of compacted earth. Where it is necessary to protect the levees from erosion during periods of flooding Link Mattress revetments have been used extensively. Examples of levee protection are shown in Figure 23.

The maximum recommended slope for a Link Mattress is 1V:1.5H. Link Mattresses laid at steeper slopes can be difficult to construct, and will require additional mechanical fixing to maintain the in-place stability on steeper slopes. For these steeper slopes it is best to use Link Gabions.

Failure of a revetment is often the result of inadequate protection against scour at the toe of the revetment. Rigid revetments have the disadvantage that they are easily undermined by scour. Link Mattresses and Gabions on the other hand are flexible and can deform in a controlled manner at the onset of scour and maintain the protection of the channel edge.

Estimating the likely depth of scour is difficult to do with any accuracy, and there is no substitute for local knowledge or field measurements. However, it should be noted that large scour holes formed in floods can be filled in by sediment deposition during the flood recession, so accurate physical data can be hard to come by. The Engineer should ensure that formulae used for scour depth estimates are appropriate for the bed material considered. May et al. (2002) provide guidelines for the estimation of local scour depths for a variety of hydraulic structures. As stated previously, the extent of the Link Mattress protection should be at least twice the estimated maximum scour depth.

Gabion & Rock Mattresses Design Manual

4.1.2 Groyne protection

Groynes deflect or guide water flows away from vulnerable river and canal banks. They can therefore be used both for bank protection and to help maintain a navigational channel.

Groynes cannot be spaced too far apart otherwise the river will attack the bank in between. Furthermore, groynes by their nature obstruct the flow and will generate turbulence and consequential local scour. Groynes therefore require careful detailing to ensure that they are not outflanked, or undermined, in floods.

Figure 24a can be used to determine the typical dimensions and spacings of groynes. The aim of groyne spacing is to ensure that eddy currents occurring between adjacent groynes do not cause erosion of the river banks. Because of their direct obstruction to flows, groynes must be designed with considerable local scour protection measures. Figure 24b shows an extensive Mattress apron applied across the base of the groyne to prevent scour at the base.

4.1.3 River training wall protection

Where a river or stream bank is unstable and where insufficient space is available to allow the construction of a revetment a retaining wall may be constructed. Typical examples of training walls are shown in Figure 25.

The major advantage of using flexible Link Gabions for river walls is that excavation in the bed can be kept to a minimum. The wall itself must be designed and checked for stability as a retaining structure, but to prevent undermining the structure must either;

a) have a foundation at least 0.5 m below the expected depth of scour, or

b) incorporate a flexible Link Mattress apron. The effectiveness and economy of construction of a flexible Link Mattress apron has been demonstrated many times over and is a particular feature of gabion work that has been exploited to advantage by many Engineers.

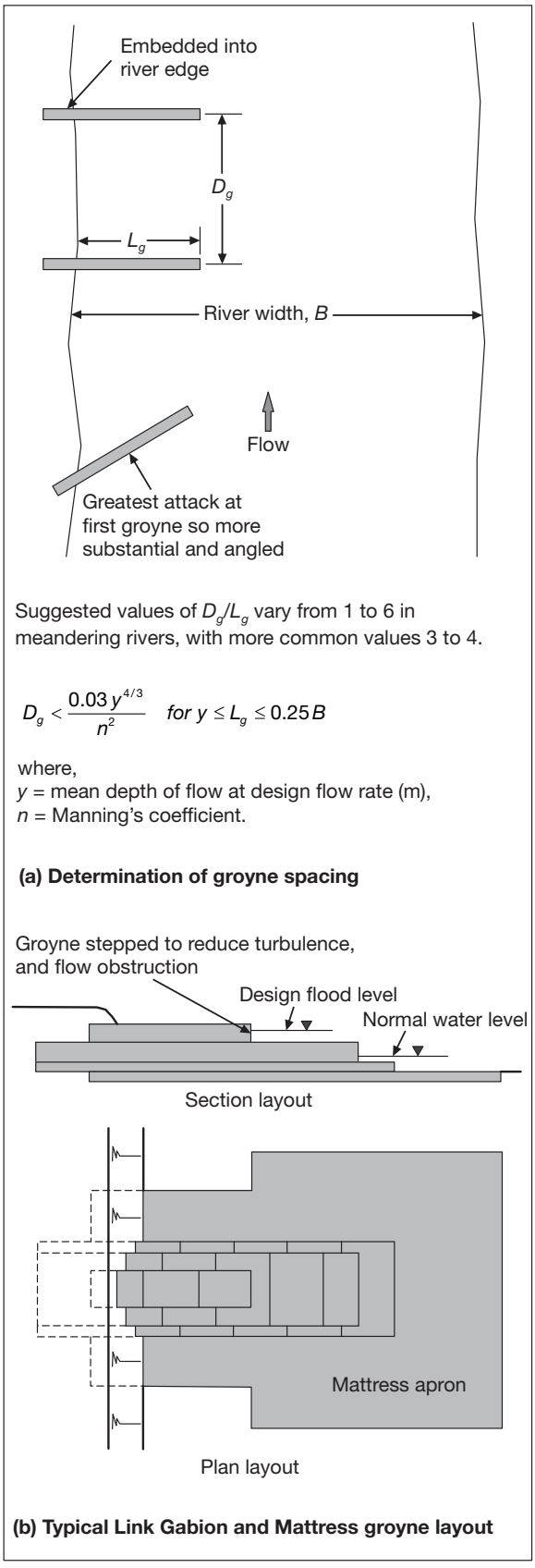


Figure 24 - Dimensions of river groynes using Link Gabions and Matresses (derived from CIRIA, 2007).

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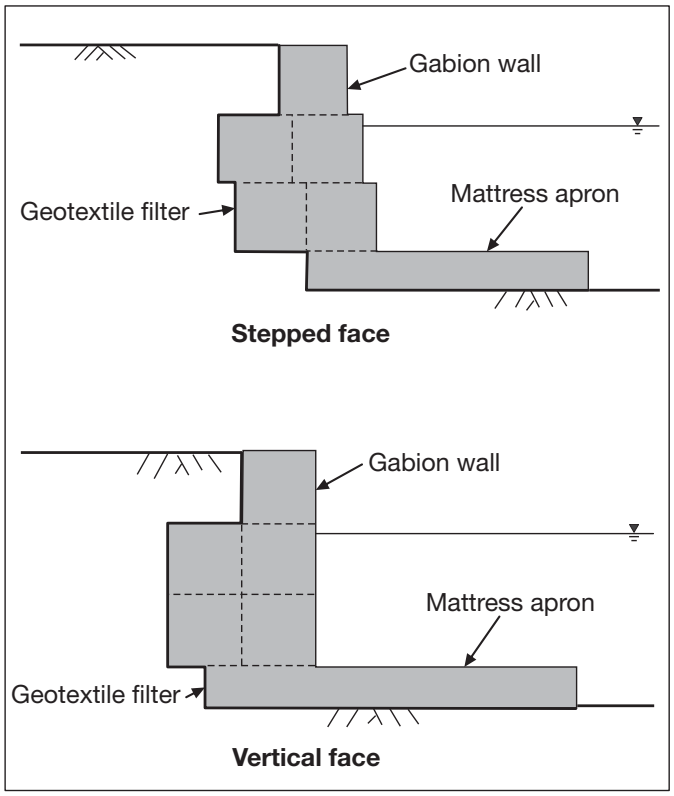


Figure 25 - Typical river and stream training walls.

To prevent erosion of the retained soil a suitable geotextile filter should be installed behind the Gabions and beneath the Mattress apron – see Section 2.5.

4.2 BRIDGE ABUTMENT AND PIER PROTECTION

The occurrence of bridges invariably causes constrictions to the water flow in rivers and streams. Depending on the nature of the water flow, the area in the vicinity of the bridge structure can be subject to a high degree of local scour (especially during periods of flooding). May et al. (2002) provide methods for estimating the maximum amount of local scour at bridge abutments and pier footings. To prevent scour, the abutments and the pier footings of bridges have to be protected and in certain cases the river or stream bed also has to be protected.

At bridge abutment constrictions it has been observed that the local depth-averaged flow velocity (V_s in Figure 20) may be twice the average flow velocity (V_{avg} in Equation 4) upstream of the bridge structure. This increase in local water flow velocity needs to be taken into account when designing protection works at bridge abutments and piers.

4.2.1 Bridge abutment protection

For the protection of bridge abutments, Link Mattresses can best be used on slopes less than 1V:1.5H. While it is possible to use Mattresses at steeper slopes (up to 1:1), special care needs to be taken to ensure stability. For steeper slopes Link Gabions should be used and the structure designed as a retaining structure. The required Link Mattress thickness may be determined using Figure 20, taking due account of the local depth-averaged flow velocity V_s at the abutment constriction.

For best performance Link Mattress placement and edge detailing is very important. Link Mattress placement should be such that their long axis is directed down the slope of the abutment (see Figure 22). If bed protection is also provided, then the toe of the abutment Mattresses should be tied adequately to the bed Mattresses. The toe apron mattresses should extend a minimum distance of twice the estimated maximum local scour depth, as shown in Figure 26a.

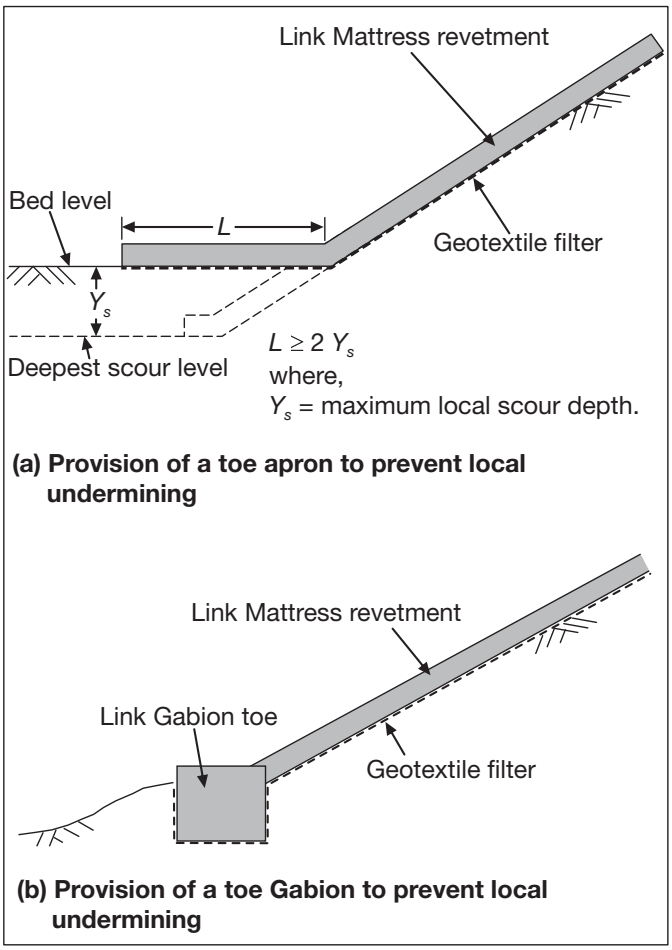


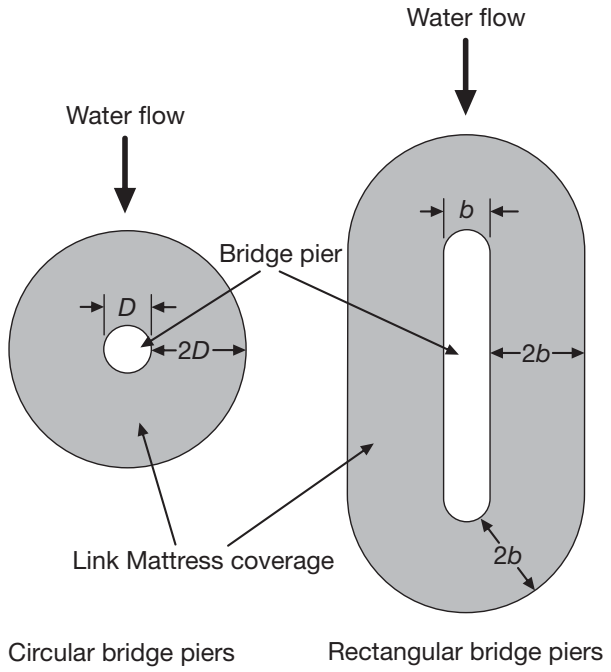
Figure 26 - Toe detailing for abutment protection using Link Mattresses.

If protection of the stream bed is not required then it is good practice to provide a Link Gabion toe at the base of the abutment to prevent local undermining of the Link Mattress layer, as shown in Figure 26b.

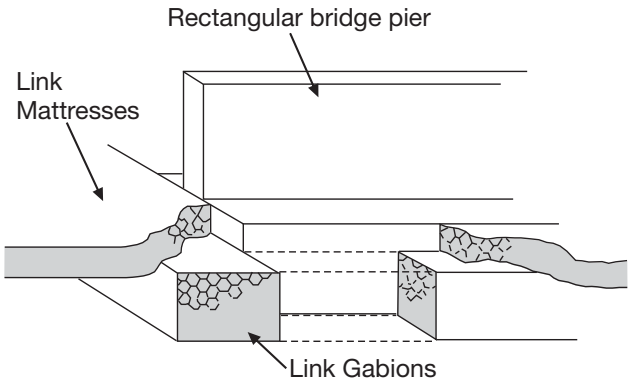
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4.2.2 Bridge pier protection

Scour protection is necessary around bridge piers if the predicted local scour depth exceeds what is permissible for structural or other reasons. Where the spacing between adjacent bridge piers is significant and where the river or channel is open and wide, then the protection of individual piers (only) is warranted. Here, the coverage of the Mattress and Gabion protection has to ensure that local scour does not undermine the bridge piers. Figure 27a provides recommendations for the extent of Mattress and Gabion coverage at individual bridge piers. The required Mattress thickness may be determined using Figure 20 taking due account of the local depth-averaged flow velocity V_s in the vicinity of the piers.



(a) Recommended bridge pier protection coverage



(b) Recommended Link Gabion and Mattress layout around a bridge pier with shallow footing (After Argue, 1981)

Figure 27 - Link Mattress and Gabion protection around bridge piers.

If the footings of bridge piers are deep and extend well below the predicted local scour depth, then protection can be provided by the use of Link Mattresses directly abutting the footings. However, if the footings are shallow, Link Gabions should be provided around the foundation with Link Mattresses on top. This is shown schematically in Figure 27b. The underlying Link Gabion should not extend deeper than the base of the footing.

For bridge pier footing protection the Link Mattresses and/or Gabions should be welltied together to enable the protection layer to perform as a monolithic structure.

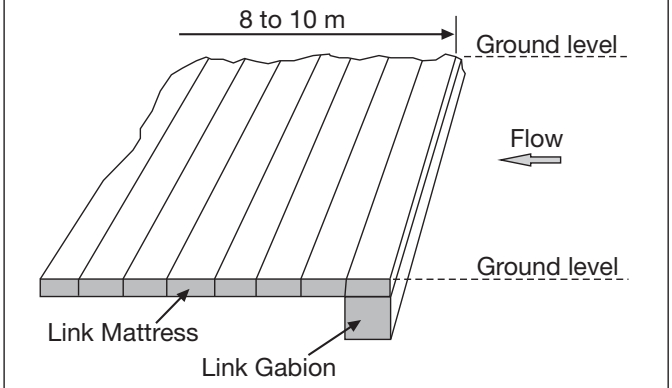
In Australia, many bridge structures are relatively small and bridge piers lie fairly close to each other. Further, during periods of flooding, scour can occur across the base of the stream bed in this constricted location and consequently, it may be warranted to completely protect the stream bed here. The protection detailing depends on the location and placement of the Link Mattresses when placed across the stream bed.

1) Upstream protection: For upstream protection Link Mattresses should be used. It is important that the maximum top elevation of the Link Mattresses be no higher than the surrounding natural ground level. To protect against undermining of the upstream extremity of the Link Mattress layer, either a Link Gabion toe should be provided (see Figure 28a) or the Link Mattress layer extremity should be angled into the river or stream bed (see Figure 28b).

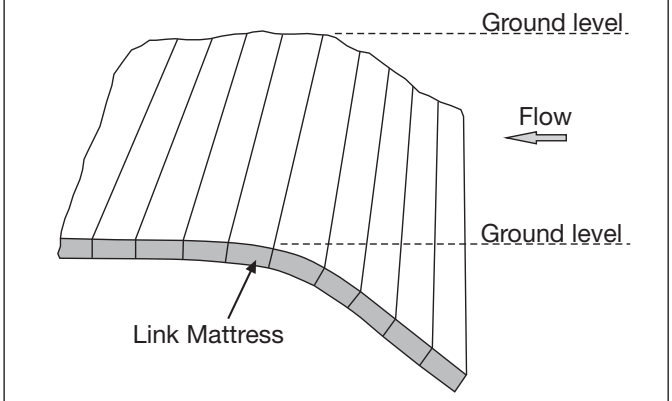
2. Downstream protection: For downstream protection the Link Mattress layer should extend 8 to 10 m downstream of the bridge. If scour is anticipated as being a problem at the downstream extremity of the Link Mattress layer, the Link Mattresses should he angled into the foundation soil in a manner similar to that shown in Figure 28c.

In all applications where Link Mattresses or Gabions are used to prevent scour around bridges it is important that a geotextile filter be used beneath the Link Mattresses or Gabions - see Section 2.5.

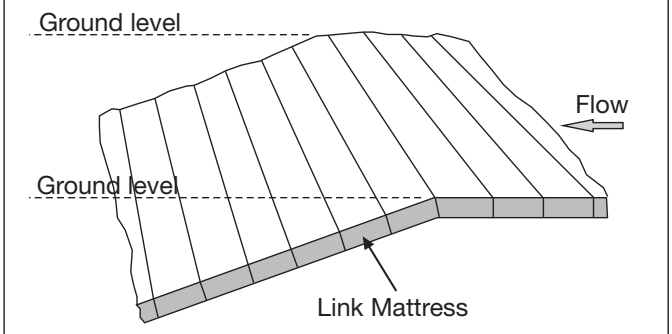
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(a) Embedded Gabion at upstream extremity



(b) Angled Mattress at upstream extremity



(c) Angled Mattress at downstream extremity

Figure 28 - Extremity details for stream bed protection.

4.3 CULVERT PROTECTION

Culvert structures enable the passage of surface water through embankments. The flow rate of water through the culvert will depend on the diameter and slope and whether or not the culvert flows full. Culverts may be circular, square, rectangular or curvilinear in nature. To assess the relative flow rates of these different shapes of structures it is best to equate their cross-sectional area to a comparative diameter and analyse them on the basis of circular culvert flow.

Table 9 indicates the likely flow conditions in a circular culvert given the outlet condition, inlet condition and culvert length. If the culvert flows full then the system can be analysed on the basis of pipe flow. If the culvert flows partially full then the system is analysed as open channel flow.

TABLE 9 – WATER FLOW CONDITIONS IN CIRCULAR CULVERTS (AFTER VALLENTINE ET AL., 1961).

Outlet condition	Inlet condition	Culvert length	Flow condition
Submerged	h > D	Any length	Full
Free	h > 2D	L > 30D	Full
Free	2D < h < 3D	L < 20D	Part full
Free	h < 2D	Any length	Part full

where, D = the culvert diameter, h = the inlet water head above the culvert invert, and L = the culvert length.

To prevent the inlets and outlets of culverts from collapse due to local scour, protection has to be provided. Protection is provided in the form of aprons, wingwalls and headwalls, depending on the height of water adjacent to the inlet and/or outlet.

Headwalls are provided around the upstream and downstream ends of culverts if it is anticipated that water levels will rise above the obvert level the culvert. Wingwalls also should be provided where the entrance and/or exit of culverts are set into the earth embankment. If the headwall and wingwall slopes are to be greater than 1:1 (45°) then Link Gabions should used. If the headwall and wingwall slopes are less than 45° then Link Mattresses can be used. Figure 29 shows a combined vertical Link Gabion headwall and wingwalls at a culvert exit, along with a Mattress apron.

For the use of Link Gabions and/or Mattresses for headwall and wingwall design, checks should be carried out to ensure that water velocities at the extremities of the Link Gabion (or Mattress) wingwalls do not cause local scour. Also, it is important to ensure that the Link Gabions (or Mattresses) are anchored to the culvert. Large Link Gabion wingwalls can be analysed on the basis of gravity retaining structures (see Section 3.1). If Link Mattresses are used then Figure 20 can be consulted to determine the required thickness.

Gabion & Rock Mattresses Design Manual

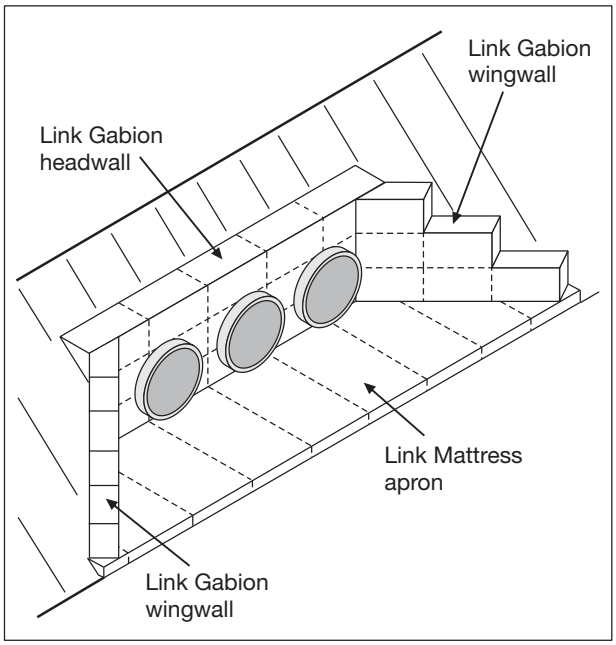


Figure 29 - Typical use of Link Gabions and Mattresses at culvert exits.

Link Mattress aprons at the upstream and downstream ends of culverts can prevent local scour of the base of the structure. The basic design at the upstream end of the culvert is similar to that described in Section 4.2.2 for the protection of river beds upstream of bridges.bThe detailing of upstream apron protection for culverts are shown in Figure 30.

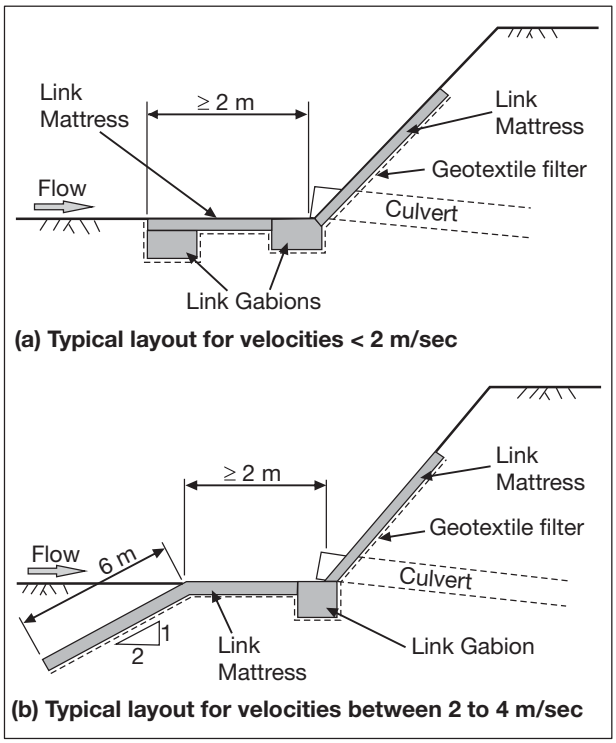


Figure 30 - Link Mattress apron details for local scour protection at entrance to culverts.

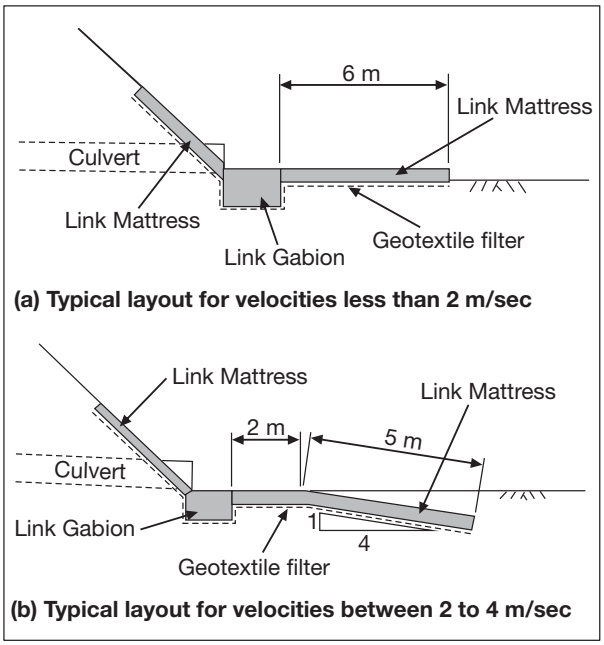


Figure 31 - Link Mattress apron details for local scour protection at culvert outlets.

Generally, the highest water velocities (and hence maximum local scour) occur in the vicinity of the downstream culvert outlet. Therefore, it is important to ensure that the downstream Link Mattress apron layer is designed properly in terms of both thickness and extent. The thickness of this Mattress layer can be determined using Figure 20. Vallentine et al. (1961) recommends downstream Link Mattress apron lengths to ensure that local scour does not occur in the vicinity of the culvert. These recommendations are listed in Table 10. Typical downstream apron detailing is shown in Figure 31.

TABLE 10 – RECOMMENDED DOWNSTREAM LINK MATTRESS APRON LENGTHS FOR CULVERT PROTECTION.

Tailwater depth[1]	Headwater depth[2]	Link Mattress apron length[3]
0.25*D*	1.5*D*	2.5 – 3.0*D*
	1.5 – 2.5*D*	3.0 – 3.5*D*
0.25 – 0.5*D*	2.0*D*	2.5*D*
	2.0 – 2.5*D*	3.0*D*
0.5 – 1.0*D*	1.0 – 2.5*D*	2.5*D*

Notes:
[1]Tailwater depth is height of water above culvert exit invert;
[2]Headwater depth is height of water above culvert entrance invert;
[3]Link Mattress apron length is length downstream of culvert;
D = culvert diameter.

When detailing the layout of Link Mattress protection at culverts it is simpler to utilise the standard Mattress dimensions of 6 m long by 2 m wide. Using multiples of these dimensions where possible will minimise cutting and wastage of Link Mattress units.

Gabion & Rock Mattresses Design Manual

When using Link Gabions and/or Mattresses to protect culverts from local scour, it is recommended that a geotextile filter always be used beneath or behind the Link Gabions and Mattresses. A specification for a suitable geotextile filter is listed in Section 2.5.

4.4 WEIR STRUCTURE PROTECTION

Weirs are usually designed for the raising of upstream water levels to facilitate the formation of reservoirs, canal takeoffs, pump intakes, protection of upstream bridge foundations, reduction of river and streambed erosion, and the formation of silt traps. A special form of weir, the spillway and energy dissipater, allows the release of excess water heads without accompanying erosion immediately downstream of the weir.

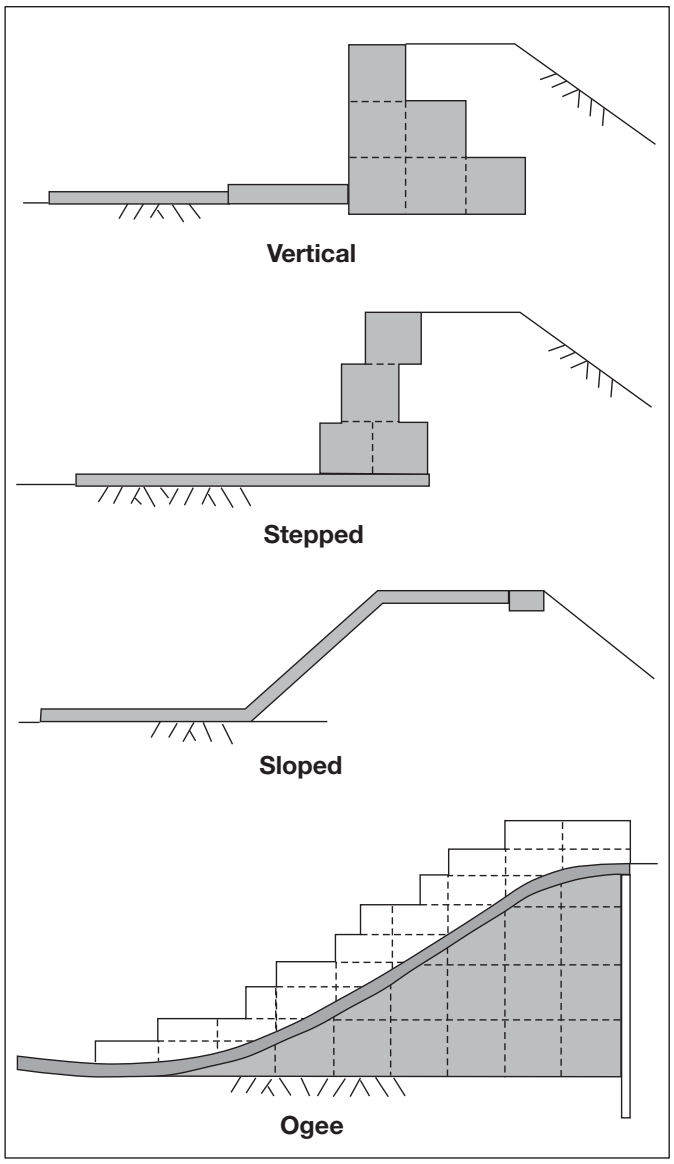


Figure 32 - Weir types using Link Gabions and Mattresses

Local scour can occur downstream of weir structures where a plunging water jet from the weir or drop structure discharges on to an unprotected erodible soil bed. To raise upstream water levels and control downstream erosion, four weir types are commonly used - the vertical, the stepped, the sloped and the Ogee weir. These are shown in Figure 32. Weirs designed using Link Gabions and Mattresses should follow closely those designed using more conventional materials (e.g. concrete).

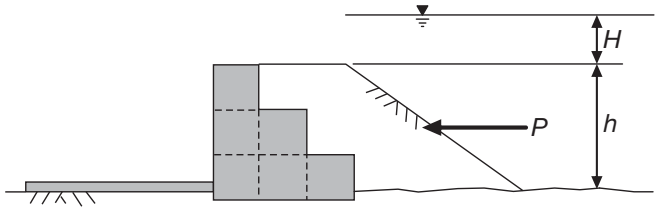
To determine the discharge capacity of a vertical faced weir, use may be made of the following relationship:

$$q = 1.8H^{1.5} \quad (5)$$

where, q = the discharge over the top of the weir in m^3/sec per m width of weir, and H = the head of water (in m) above the top of the weir. For stepped, sloped and Ogee type weirs, the designer should consult relevant technical manuals to determine design discharge capacities.

The weir must be stable against overturning and sliding. For overturning resistance, the restraining moment must be greater than or equal to a safety factor multiplied by the overturning moment (e.g. see Section 3.1). For sliding resistance, the weight of the weir multiplied by the coefficient of friction at the weir - foundation interface must be greater than the horizontal force component of the upstream water head multiplied by a suitable safety factor. The horizontal water force acting on the upstream face of the weir may be calculated using the relationship shown in Figure 33. This relationship only applies to weirs and to drop structures whose sills are level with the upstream bed.

The area immediately downstream of the weir is required to dissipate the energy generated by the water plunging over the weir crest. This dissipation of energy can lead to severe local scour problems if the downstream side of the weir is not adequately protected. It is common to use Link Mattresses (and/or Gabions) to provide the downstream protection for weirs.



$$P = 0.5\gamma_w h(2H + h)$$

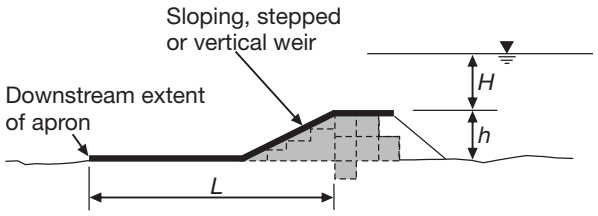
where,
P = water force acting on upstream face of the weir per unit width,
γ_w = density of water,
h = height of weir crest above bed level,
H = head of water above weir crest.

Figure 33 - Horizontal water force acting on upstream face of weirs.

Gabion & Rock Mattresses Design Manual

Where a vertical weir is constructed, the vertical drop on the downstream side of the weir should be minimised to alleviate hydraulic impact forces.

For downstream protection the Link Mattress and/or Gabion layer should be thick enough to prevent scour at the underside of the protection layer. To help in this it is essential that a suitable geotextile filter be placed at the underside of the Link Mattress layer (see Section 2.5). The Link Mattress apron layer should also be extended a distance downstream to ensure local scour of the bed does not occur. The distance downstream susceptible to scour depends on



$L = K\,(2H + h)$

Bed material	Factor K
Hard clay	1.00
Soft clay	2.50
Medium gravel	1.75
Fine gravel	2.00
Coarse sand	2.50
Medium sand	3.00
Fine sand	2.50
Fine sand and silt	4.50
Cobbles	1.50

Figure 34 - Link Mattress extent requirements downstream of weirs.

the height of the water head above the weir crest and the type of material in the bed. Figure 34 provides the required downstream apron length given the water head conditions and type of downstream bed material. The relationship in Figure 34 only applies to conditions where the maximum water height over the weir (H) is less than 3 m. Where greater heads are anticipated a more detailed analysis should be carried out and an energy dissipater and stilling basin incorporated in the design.

Other factors, such as seepage under the weir, and upstream and downstream bank protection also need to be considered when designing weirs. To prevent seepage under the Link Gabion weir a cut-off wall or impermeable geomembrane may have to be considered. To prevent leaching of soil through the Link Gabions a geotextile filter should be used. To protect the banks from erosion upstream and downstream of the weir, Link Mattresses and Gabions can be used in a similar manner to that discussed in Section 4.1.

Other factors may also have to be considered when designing Link Gabion weirs. These are the possibility of corrosion of the wire and breakage, or abrasion, of the wire. Where the water is likely to attack galvanised wire, polymer coated mesh or Galfan or Galfan/polymer coated mesh must be used.

Where wire breakage and abrasion due to impact of rocks and tree branches carried by rivers are anticipated, the horizontal Link Gabion and Mattress surfaces should be protected. Such protection can be afforded by timber, precast concrete slabs, asphalt or steel plate attached to the wire mesh.

4.5 LOW-LEVEL CROSSINGS AND EMBANKMENT PROTECTION ON FLOOD PLAINS

Low cost water crossings may be designed using Link Gabions as the protection and support for fill material during periods of flooding. An example of such a use is shown in Figure 35. The design procedure should follow the guidelines recommended above.

Embankments or causeways, which are subject to overtopping during periods of flooding, are susceptible to erosion on the downstream side if adequate protection is not provided. The use of Link Mattresses and Gabions on both the upstream and downstream sides has provided an economic means of protecting embankments and causeways from failure due to overtopping.

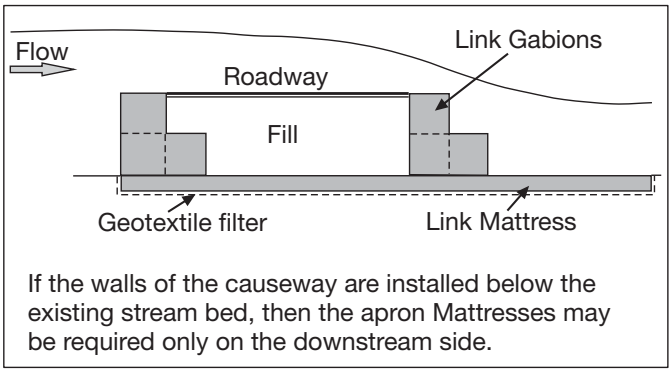


Figure 35 - Low cost design using Link Gabions for low level crossings.

For downstream protection, the design procedure adopted using Link Mattresses and Gabions should follow closely that for sloped weirs. The Link Gabions (or Mattresses) should begin at the crest of the embankment (or causeway) and extend such a distance downstream so as to prevent erosion occurring in the vicinity of the embankment. Use can be made of Figure 34 to determine the required extent of the downstream Link Mattress protection.

For these types of structures, edge detailing of the Link Gabions and Mattresses is important to ensure failure of ancillary structures adjacent to the edges of the protection layer do not occur. If the embankment supports a structure on its crest (such as a road pavement or railway track) then the upper extremity of the protection layer should abut the edge

Gabion & Rock Mattresses Design Manual

of the crest structure (road pavement or railway track). For example, one Australian railway authority has found that a Link Gabion placed at the downstream edge of the railway ballast layer prevents the washing out of the ballast during periods of flooding. This principle is shown in Figure 36. The edge detailing of the protection layer at the downstream extremity is also important to ensure undermining does not occur. Either a Link Gabion should he used here (see Figure 36) or the Link Mattress layer should be sloped into the wadi bed (see Figures 28c and 31).

To ensure satisfactory performance, the Link Gabions and Mattresses should be constructed in accordance with the manufacturer's specification (see Section 6), particularly with regard to the rock grading used in the baskets. The top of Link Gabion ballast protection units should be a minimum of 100 mm above the adjacent rail level (see Figure 36). (A larger Link Gabion, 1.0 m x 1.0 m, may be required, depending on depth of the ballast/track structure and condition of the formation, in order to obtain this minimum clearance.) The extent of protection downstream of the toe of the embankment depends upon individual circumstances.

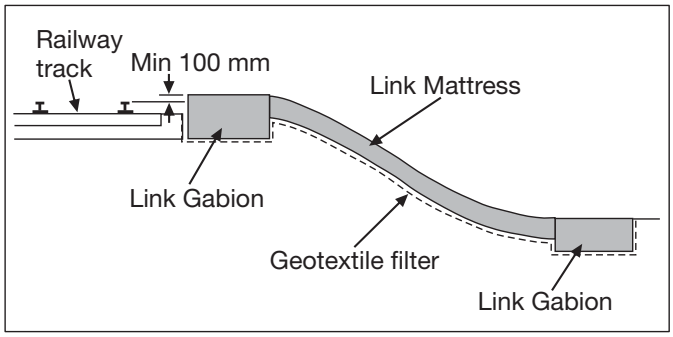


Figure 36 - Detail showing railway embankment protection on downstream face when designed for overtopping by medium to high flows.

It is recommended that in all applications where Link Gabions and Mattresses are used to provide protection to embankments and causeways subject to overtopping, a suitable geotextile filter be placed beneath the Link Gabions and Mattresses – see Section 2.5. If properly designed, Link Mattresses and Gabions provide very effective protection to embankments and causeways subject to overtopping.

Gabion & Rock Mattresses Design Manual

5. Link Gabions and Mattresses for Coastal and Foreshore Protection Works

Water forces acting on structures in coastal and foreshore environments are complex. They normally consist of a combination of wave, tidal and current forces. Wave forces may be due to coastal waves, ship waves and/or storm waves depending on the location of the structure.

The use of Link Gabions and Mattresses in the coastal and foreshore environments has proved very successful because they combine monolithic and flexible mass, coupled with high permeability and a rough surface. The high permeability and rough surface of Link Gabion and Mattress revetments make them very effective in dissipating and absorbing wave energy, thus reducing the extent of wave run-up and overtopping.

It is imperative that only zinc/polymer coated or Galfan/polymer coated Link Gabions and Mattresses be used in a coastal environment. The polymer coating protects the wire from corrosion due to the concentration of salt in the water.

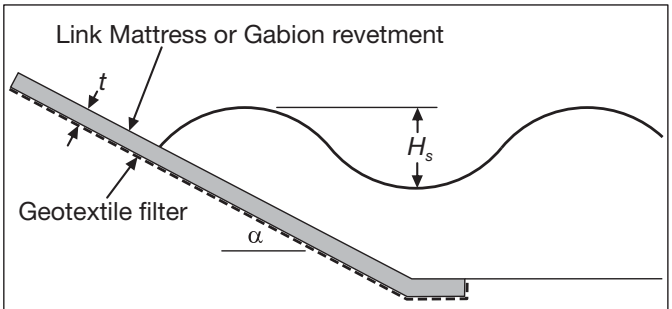
It is also imperative that a suitable geotextile filter be used beneath the Link Gabions and Mattresses in all coastal and foreshore engineering applications – see Section 2.5.

5.1 COASTAL REVETMENTS

Link Gabion and Mattress revetments are effective in preventing scour and erosion of slopes provided the wave action is not extreme. The revetment should be adequately anchored at the top to prevent it sliding or being dragged out of alignment by wave drawdown forces. The toe of the revetment should be protected from undermining by a Mattress apron or Gabion foundation below the lowest expected scour depth.

The thickness of the Link Mattress or Gabion revetment should be designed to prevent uplift and sliding due to wave action. Brown (1978a & b) formulated a relationship to determine the required Link Gabion or Mattress thickness to resist wave forces. This is shown in Figure 37. Figure 37 also contains a chart to quickly determine the required Link Mattress thickness given a significant wave height and revetment slope angle.

Where revetment slopes are less than 45° either Link Mattresses or Gabions may be used depending on their thickness requirements. For slopes greater than 45°, Link Gabions should be used and the structure should be analysed on the basis of both design wave height and gravity retaining structure (see Section 3.1). Where Link Gabions are used on slopes of 45° or greater, a Link Mattress apron should always be provided to prevent undermining of the base of the Link Gabion wall.



Governing relationship:

The required thickness t of the Link Gabion or Mattress is:

$$t \geq \frac{F_{sw} H_s}{C_B (G_s - 1)(1 - \nu)(\cot \alpha)^{1/3}}$$

where,

F_{sw} = factor of safety (= 1.5),

H_s = significant wave height (= $0.67 H_{max}$),

C_B = damage coefficient for Gabions and Mattresses ($C_B \approx 4.3$),

G_s = specific gravity of rock in Gabions and Mattresses,

ν = void ratio of the Gabions and Mattresses (= 0.35),

α = revetment slope angle.

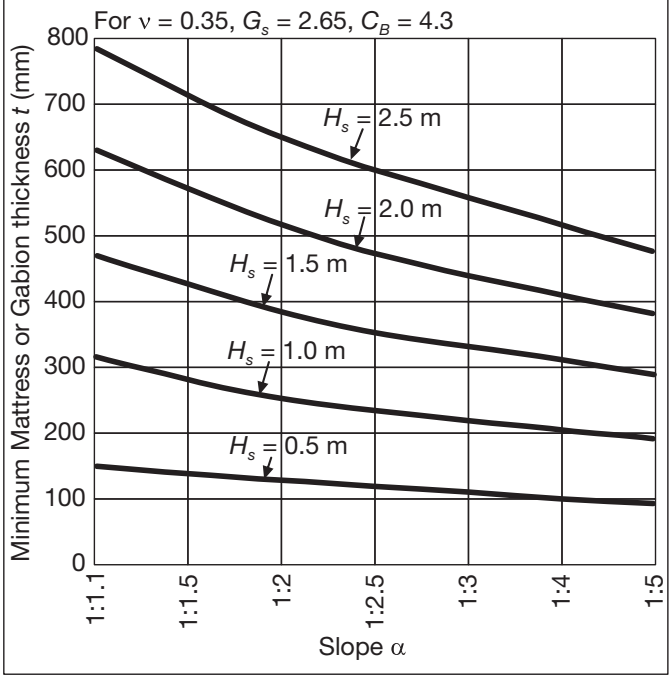


Figure 37 - Link Gabion and Mattress thickness requirements for revetment stability due to waves (After Brown, 1978).

Gabion & Rock Mattresses Design Manual

5.2 BEACH PROTECTION SEAWALLS

The usual purpose of seawalls is to prevent erosion and flooding and to retain a sea frontage. The major advantages of Link Gabion seawalls over other forms of seawall construction are their relatively low cost, their flexibility, the ease with which they can be added to, and their ability to blend in with the local surroundings over a period of time. Another advantage is their high permeability which allows the natural outflow of groundwater through the Gabion wall.

The following factors are critical to design. First, the foundation for the seawall should be adequately protected against local scour and undermining. Second, the seawall footing should be placed below the lowest level to which the foreshore is likely to drop. Third, an anti-scour apron should be constructed to further protect the toe of the seawall.

Link Gabions and Mattresses have found extensive use for beach protection seawall applications because their rough surface accelerates a build up of sand (more so than smooth faced structures). Typical layouts for beach protection seawalls are shown in Figure 38.

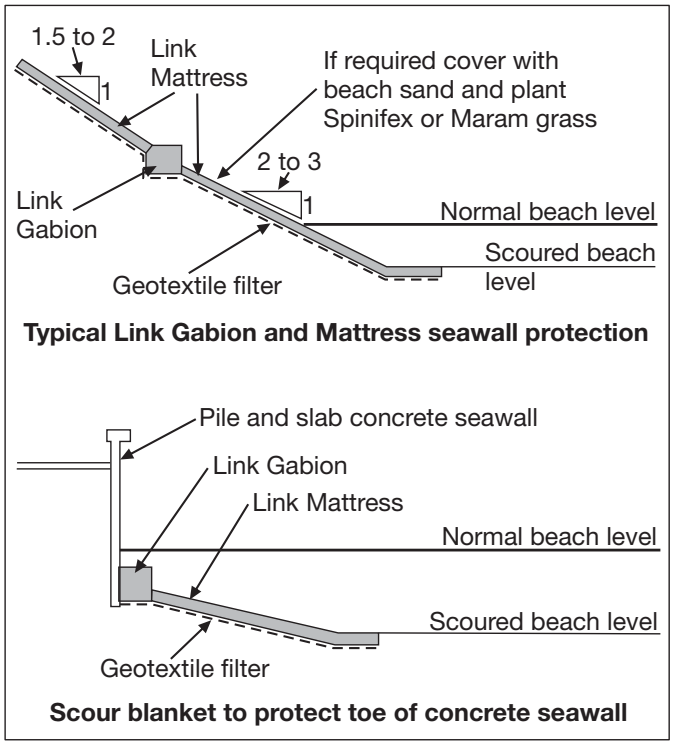


Figure 38 - Typical layouts of Link Gabions and Mattresses for beach protection seawall works.

Gabion & Rock Mattresses Design Manual

Link Gabion and Mattress Construction Guidelines

6.1 DELIVERY AND STORAGE

Link Gabions and Mattresses are delivered to site in a flat packed form for ease of delivery and storage. Each bundle of units supplied will contain a varying number of units dependent upon the type of units purchased. Typically, the bundle size will contain between 20-50 units of the product when significant product quantities are purchased. For smaller purchases, the bundle may contain mixed quantities of product. Full bundle sizes will be labelled with the product size, product type and coating type for ease of identification. Additionally, bundles are colour coded to enable product identification in cases where the labels are lost. Full bundles are identified with unique bundle references such that product can be traced to manufacture under the Link ISO 9001 Quality Assurance Scheme.

6.2 LABOUR AND PLANT REQUIREMENTS

Each project requires an assessment of the total manning levels appropriate for the works. Depending on the complexity and size of the project this will vary. Generally, for these types of construction activities it is best to have crew sizes limited to about 4 personnel (1 leading hand and 3 labourers) with an additional excavator operator working between crews. Plant requirements, such as excavators, are best limited to medium-to-small sizes for ease of manoeuvrability.

As an indication of manpower requirements, using relatively experienced personnel the following man hours may be applied for the activities of prefabrication, filling and closing.

- Gabions 1 m x 1 m cross section: Approximately 2 man hours/m^3.
- Mattresses (assume 0.23 m thickness): Approximately 0.5 man hours/m^2.

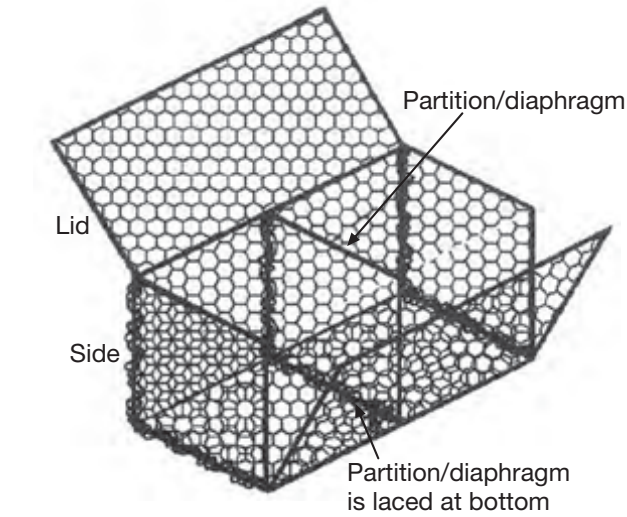
Additional allowances should be made for excavation works as necessary, including backfilling operations and all other ancillary activities that may be associated with the works. Further allowances for manning levels should be made, particularly when smaller sized gabions are used or an extremely high standard of gabion face finish is required. The above estimates are not reflective of projects that are relatively small in size. To assist in filling and finishing of the works to a high standard careful supervision of rock quality and grading limits should be monitored.

6.3 ASSEMBLY

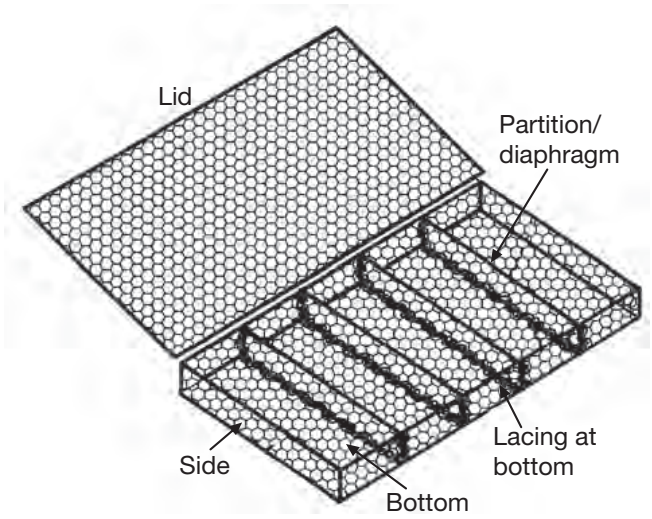
6.3.1 Fabrication

All Link Gabion and Mattress bundles are compressed under load at the time of manufacture. Each bundle is strapped and should only be opened with sufficient care to avoid injury.

Link Gabion baskets are supplied complete with an integral lid whilst the Link Mattresses are supplied with a base unit and a separate lid (see Figure 39).



a) Link Gabion components



b) Link Mattress components

Figure 39 - Link Gabion and Mattress components.

Gabion & Rock Mattresses Design Manual

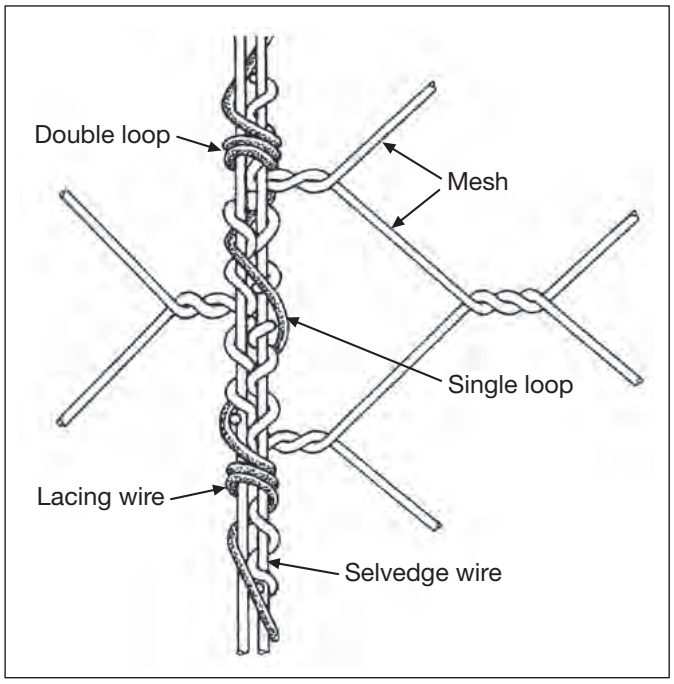


Figure 40 - Link Gabion and Mattress lacing technique.

Link Gabion and Mattress units should be unfolded on level ground and any unwanted fold creases removed. Corners should initially be joined ensuring that the box shape remains as square and as regular in shape as possible. Next, join all sides of the Link Gabion or Mattress unit together and each partition within the cage to the sides of the cage (see Figure 39). The partitions or diaphragms are factory connected to the base of the cage at the appropriate position not more than 1 m apart (see Figure 39). The joining/connection should be conducted as described below.

6.3.2 Joining/connection techniques

Where a connection is to be made, the traditional manner is to take a piece of tie wire and lace it in and out of the mesh openings at approximately 150 mm centres in a continuous manner, alternating between a single loop and a double loop around the selvedge wire (see Figure 40).

An alternative method of making a suitable connection is by using Global Synthetics Pty Ltd's "C" rings. The "C" ring begins as an open steel clip, positioned over the mesh wires to be connected, and is closed by the compressive action of a pneumatic closing tool. Additional advice on the pneumatic closing tool can be supplied by Global Synthetics Pty Ltd. The "C" rings can be supplied with the Gabion or Mattress supply at an additional cost. Stainless steel rings are used for polymer coated product whilst Galfan coated rings are used for either zinc or Galfan supplied product.



Figure 41 - Pneumatic closing tool for installing "C" ring connectors.

6.3.3 Placement and filling

Prepare the site where the Link Gabions or Link Mattresses are to be installed. The ground should be prepared to the correct grade lines and be reasonably smooth and flat. Generally, a geotextile filter should be installed first under and behind Gabions and beneath Mattresses. Recommendations have been made in Section 2.5 on an appropriate specification for a geotextile filter. The fabricated cages are then placed in the desired position on site. Adjacent cages should be joined together using the connection techniques described in Section 6.3.2 to form one monolithic structure. It may be advisable that where additional Gabion or Mattress units need to adjoin a previous section of work that has already been rock-infilled, that the last Gabion or Mattress compartment is left empty of rock to assist in lacing the new section to the existing section.

Link Gabion units should be positioned as required and adjacent units connected as described above. Once in position, Gabion units should be stretched taught to provide a neat, straight alignment and where a high standard of rock facing is required to the Gabions, additional temporary formwork may be used on the face of the cage to provide a straight neat finish.

The lid of the Gabion that remains open during the filling process should be folded back out of the way whilst filling. Rock should be machine placed into the Gabion cage to about one third height of a typical 1 m high cage. In the case of 34 0.5 m high units the cage should be half filled. Labour should then hand position the rock against the front face of the cage to ensure a neat, tightly packed finish is achieved (see Figure 42a). Once the rock at this layer is neatly faced, two bracing wires should be installed from the front face to the back face of the cage to prevent localised bulging of the face (see Figure 42b). This process is repeated for the next one third metre of Gabion height increment and completed with lid

Gabion & Rock Mattresses Design Manual

losure. For Gabions of 0.5 m height one internal set of bracing wires at the mid height is sufficient.

All Gabions should be slightly overfilled to allow for potential settlement of rock over time. The top of the Gabion should be relatively level and flat to ensure a sound base is available for the stacking of Gabions for taller structures. Lastly, the lid is pulled over into position on top of the rock and is laced closed to the perimeter of the Gabion cage and to each of the vertical partitions within the Gabion cage (see Figure 39a). Lacing should be performed in the approved manner, as described in Section 6.3.2.

Link Mattresses are placed into position and laced in the same manner as described for Link Gabions. The orientation of the Mattresses normally ensures that the partitions of the units are at right angles to the water flow direction in channels and beds. When Mattresses are placed on slopes it is best to orient them with the partitions running across the slope. This procedure ensures that the likelihood of movement of rock within the Mattress is minimised. The maximum spacing distance between partitions is 1 m whilst the width across the Mattress is 2 m.

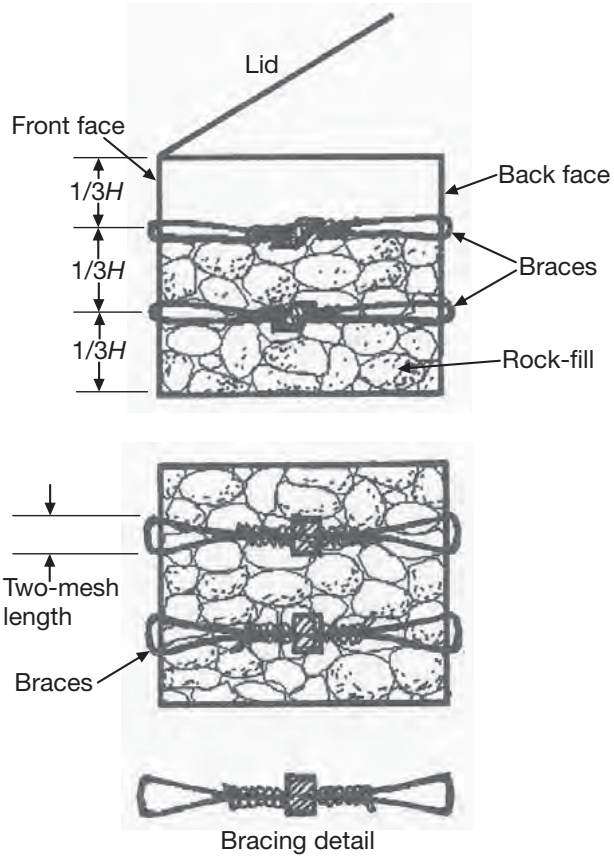
When Link Mattresses are placed on slopes steeper than 1V:1.5H it is advisable to anchor the top edge of the Mattress structure with star pickets at approximately 1.5 m centres to enhance sliding resistance. Rock infill is machine placed into the Mattress base unit and filling continues until the cages are approximately 10% overfilled. During machine placement of rock, care should be taken to ensure that the internal partitions are not damaged or displaced. Over filling allows for potential settlement of the rock with time. Manual labour may be required to neatly pack the rock into the cage and level the top surface in preparation for the Mattress lid to be placed and joined to the base unit. The Link Mattress lid is laced closed to the perimeter of each unit as well as to the standard five partitions over the length of the 6 m mattress cage. All lacing should be carried out in the approved manner, as described in Section 6.3.2. The use of "C" rings and the pneumatic lacing tool is allowed, provided appropriate ring types are used and that the maximum ring spacing of 150 mm is maintained.

It is important that strict controls are placed on the specification and delivery of rock infill for Mattress work. Particular attention should be paid to the preferred grading limits.

It may be necessary to shorten, or provide unique irregular shapes, for some Mattress units to be installed. The cutting of Mattresses into specific shapes can be carried out on site. Specific advice may be obtained from Global Synthetics Pty Ltd.



a) Hand positioning of rock against face of Gabion cages



b) Gabion filling and bracing placement

Figure 42 - Filling of Link Gabions.

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Get in Touch

AUSTRALIA

Website
globalsynthetics.com.au

Email
info@globalsynthetics.com.au

New South Wales
(02) 9725 4321

North Qld
(04) 5921 1692

Victoria/Tasmania
(03) 9791 1772

Queensland
(07) 3865 7000

South Australia
(08) 8384 8894

Western Australia
(08) 9459 4300

NEW ZEALAND

Website
globalsynthetics.co.nz

Email
info@globalsynthetics.co.nz

Auckland
0800 510 120

Christchurch
0800 510 120



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