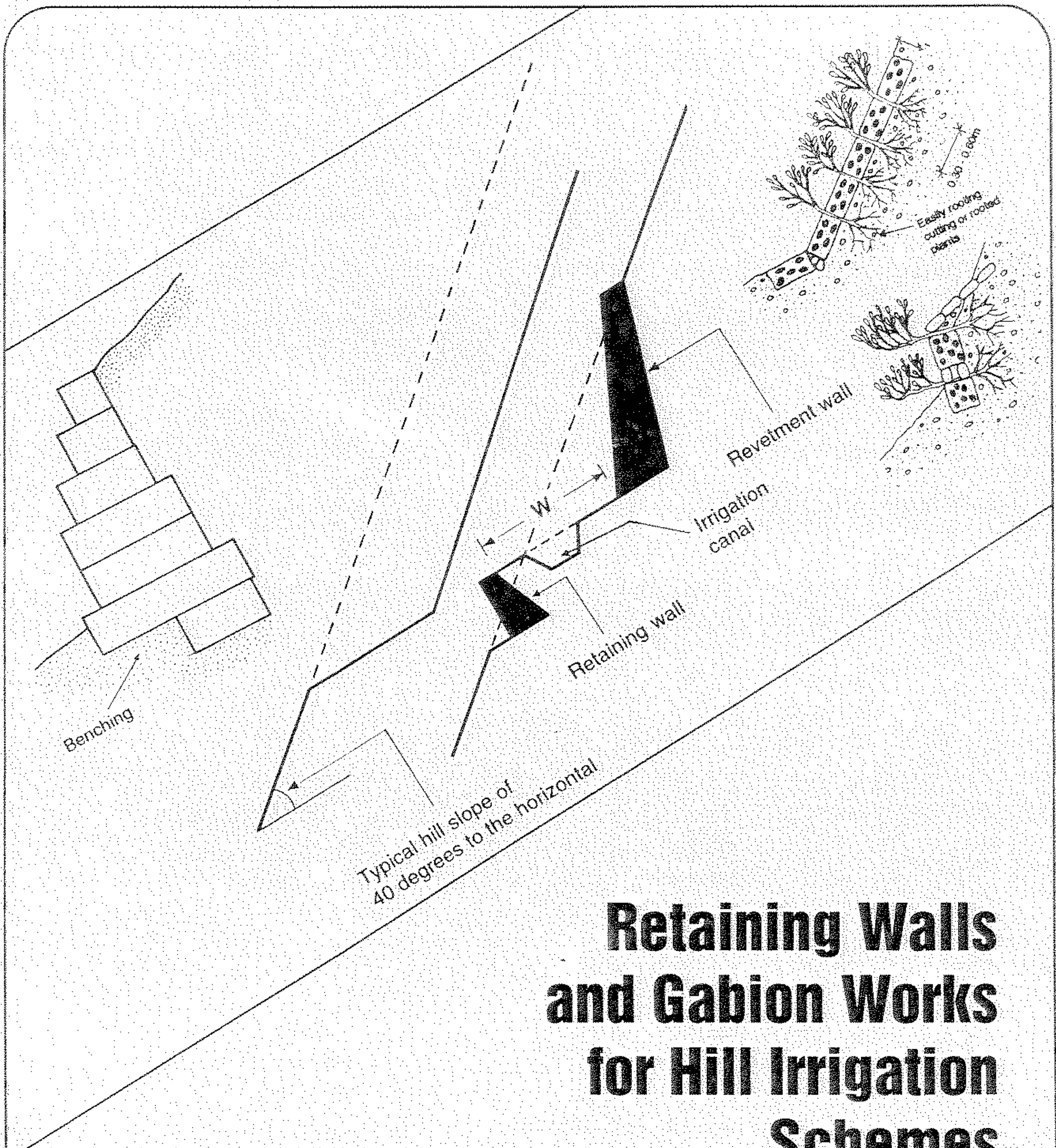
Poverty Alleviation Through Employment Generation in Irrigation Works Programmes

APPROPRIATE DESIGN OF SMALL-SCALE HILL IRRIGATION STRUCTURES



Retaining Walls and Gabion Works for Hill Irrigation Schemes

NEPAL SPECIAL PUBLIC WORKS PROGRAMME
MANUAL NO. 2

Module No 8

RETAINING WALLS AND GABION WORKS FOR HILL IRRIGATION SCHEMES

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Functions of Retaining Walls and Revetment Walls

Retaining walls are mass linear structures to:

- retain backfill,
- withstand earth pressure and surcharge loads.

Revetment walls are also mass linear structures but serve to buttress cut slopes against failure. Revetment walls are sometimes called breast walls.

Retaining walls retain loose or re-compacted earth as opposed to revetment walls which prevent loosening of cut slopes.

In hill irrigation systems retaining walls are normally built below the canal alignment and are used to:

- support canals,
- support backfill material for the construction or support of a canal, see Photograph 8A.
- obtain additional construction width for canals and other structures in steep hill slopes,
- support weak hill slopes and to reduce the risk of landmass failure, see Photograph 8B.

Revetment walls can be built above or below the canal alignment and are used to:

- prevent erosion of cut slopes,
- prevent other minor disturbances leading to progressive failure of cut slopes, see Photograph 8C,
- prevent toe cutting of natural hill slopes, see Photograph 8D.

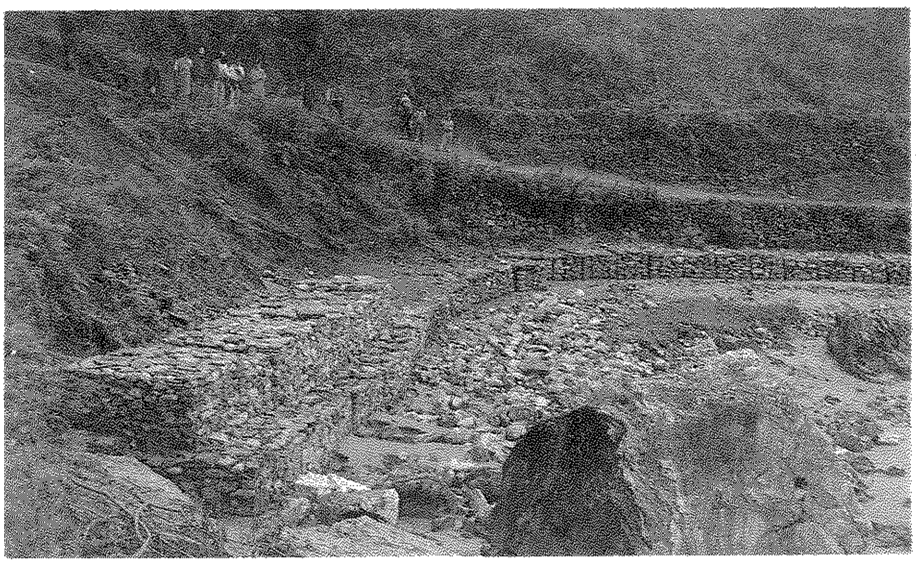
Use of Retaining Walls and Revetment Walls for Minimising Excavation of Steep Hill Slopes

Hill irrigation canals are often built on excavated slopes. Excavation leads to instability of hill slopes. Excavation can be minimised by using retaining walls and revetment walls. Figures 8.1, 8.2 and 8.3 show the use of retaining and revetment walls to minimise the amount of excavation necessary for canal construction.

Photograph 8A
Cement Masonry Retaining Wall to Support a Lined Canal

Photograph 8B
Gabion and Dry-Stone Retaining Walls to Stabilise and Reduce the Risk of Land Mass Failure

Photograph 8C
Dry-Stone Revetment Wall to Stabilise the Cut Slope and Prevent Minor Landslides



Photograph 8D
Gabion Revetment to Prevent Toe Cutting of Hill Slope by River Flow

Figure 8.1
Use of Revetment Wall for Minimising Excavation

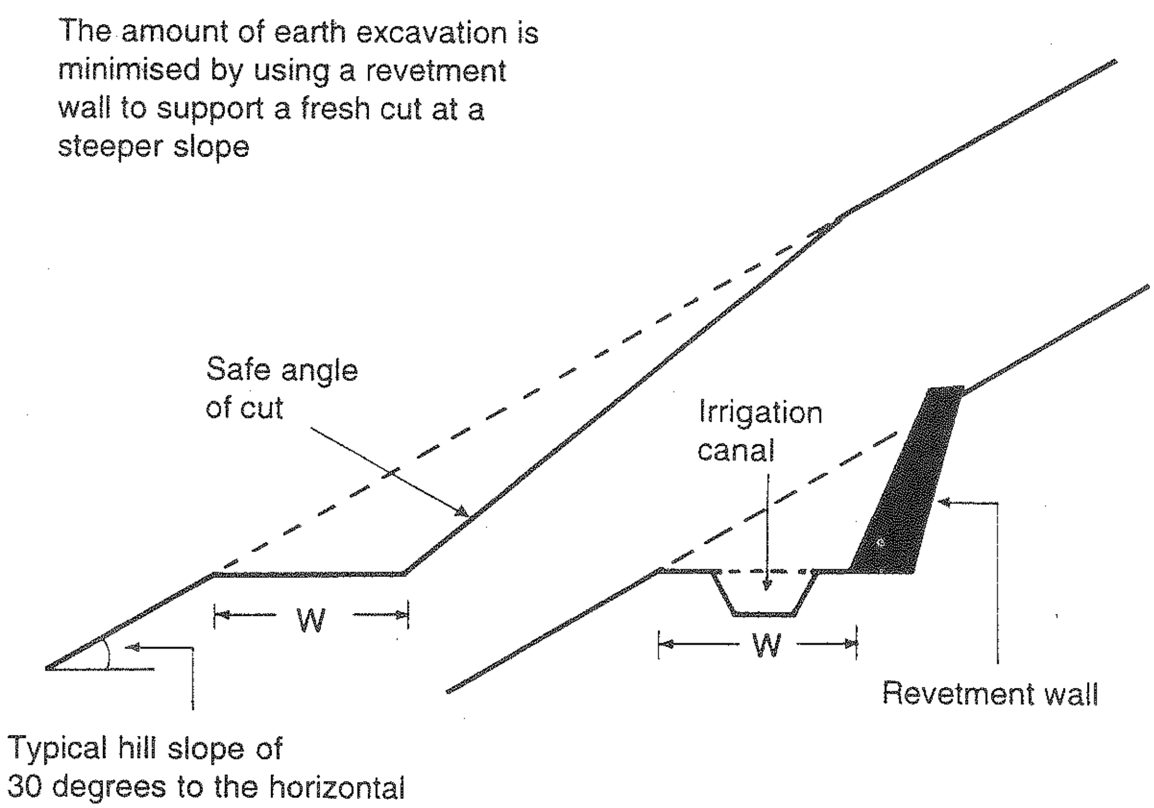


Figure 8.2
Use of Retaining Wall for Minimising Excavation

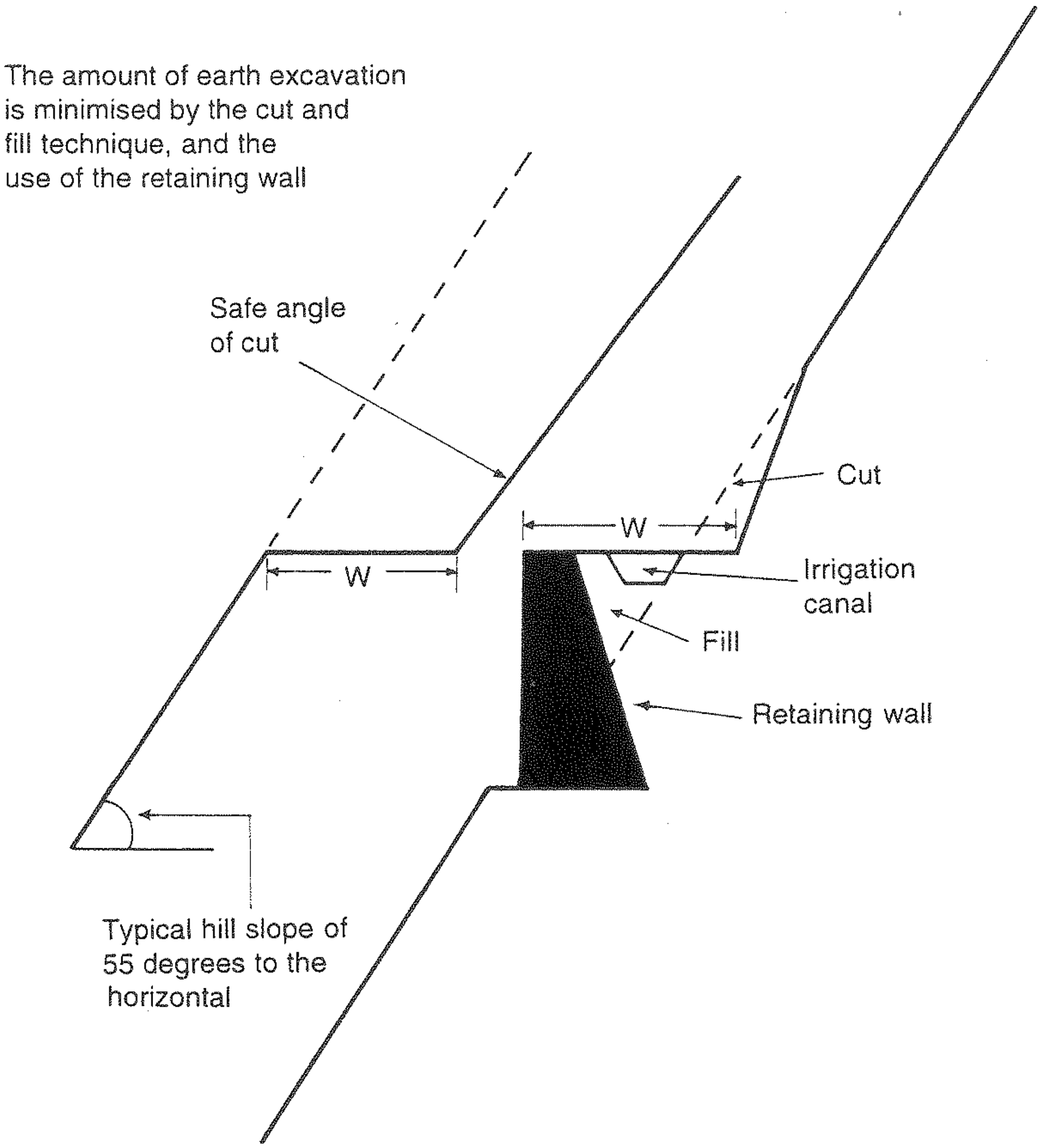
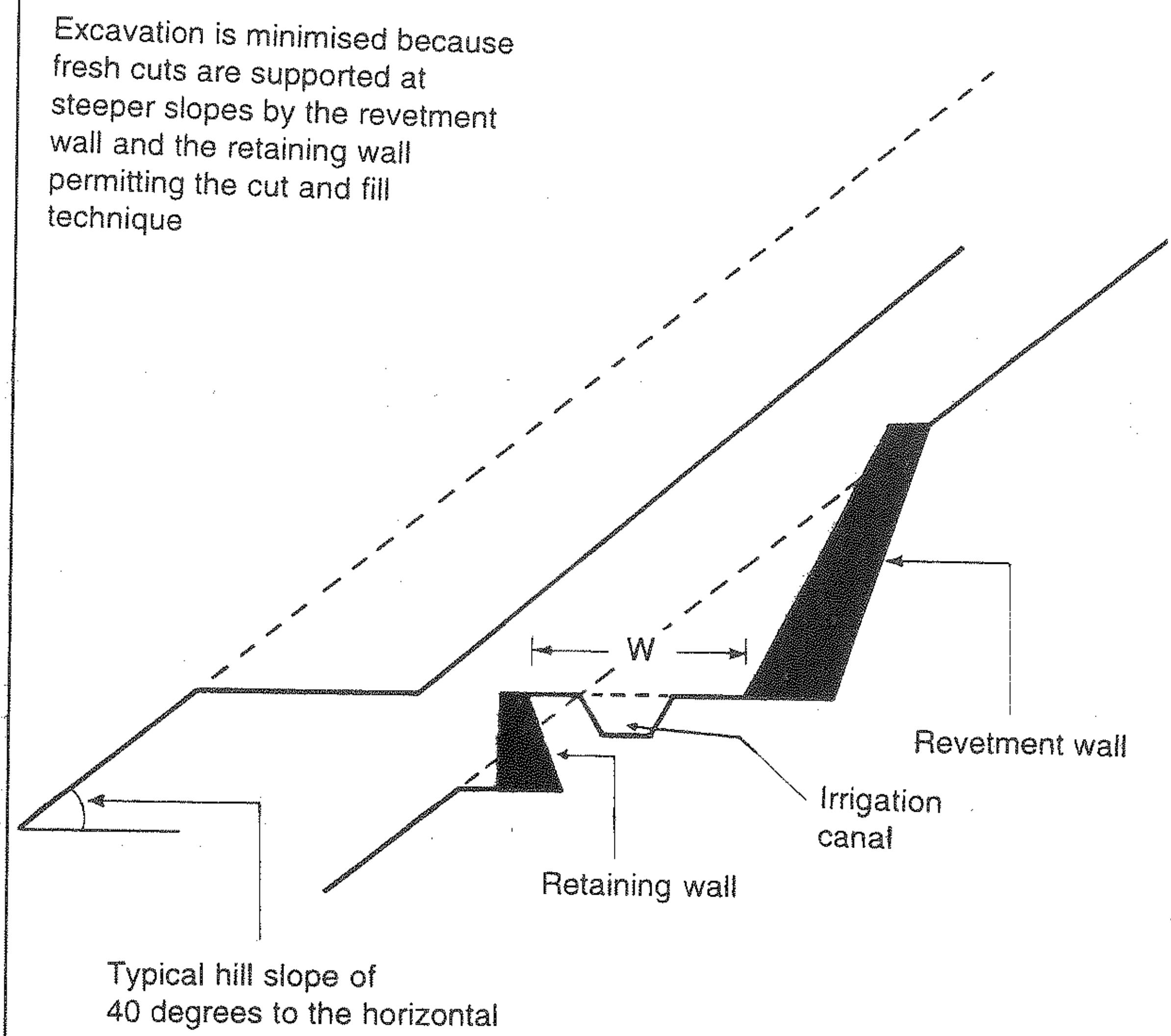


Figure 8.3
Combined Use of Retaining and Revetment Walls for Minimising Excavation



Cut Slopes and Revetment Walls

Revetment walls give stability to cut slopes even at steep angles.

Cut Slope Stability

Stability of cut slopes depends on several factors, including:

- degree of moisture in the soil,
- soil type, and
- height of cut.

Figure 8.4 shows how the safe height and slope of a cut are affected by soil type during low water conditions.

Figure 8.5 shows the same for high water conditions. The general conclusions that can be made by comparing Figures 8.4 and 8.5 are:

For any given soil type:

- cut slope angles must be made flatter as the cut height increases,
- cut slope angles must be flatter for high water conditions.

For all practical purposes, high water conditions (Figure 8.6) should be assumed for determining safe angles and heights of cut slopes.

When to Use Revetment Walls

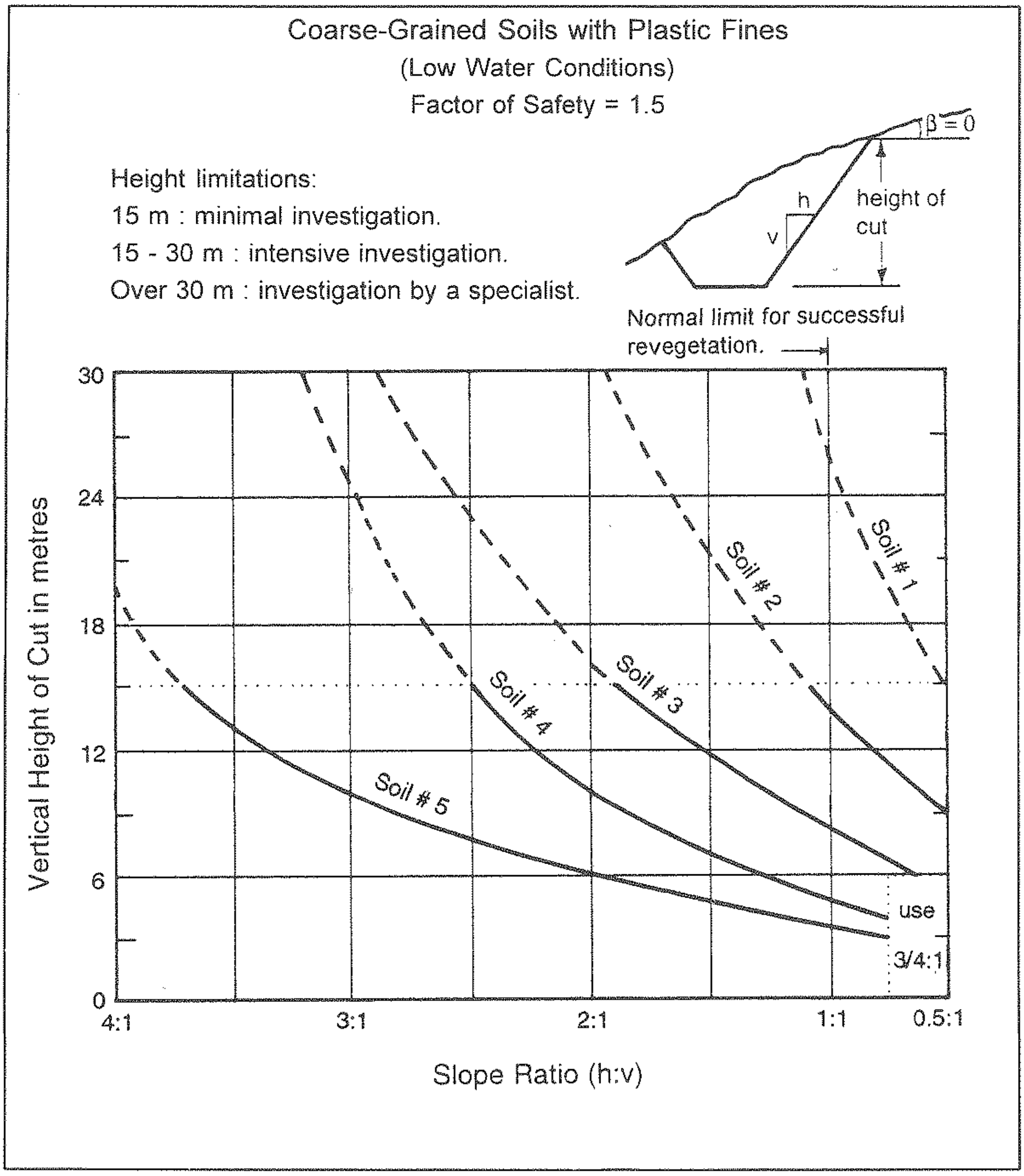
When excavating hill slopes for the construction of canals it is desirable to trim cut slopes to safe angles. Revetment walls may not be necessary if cut slopes can be trimmed to safe angles.

However, in hill situations, trimming to flatter slopes may be difficult or impossible for the following reasons:

- extensive earthworks are expensive and pose difficulties in spoil disposal,
- loss of valuable farm land,
- loss of fertile soil (if top soil is not reused correctly),
- large areas of barren slopes become exposed leading to more soil erosion.

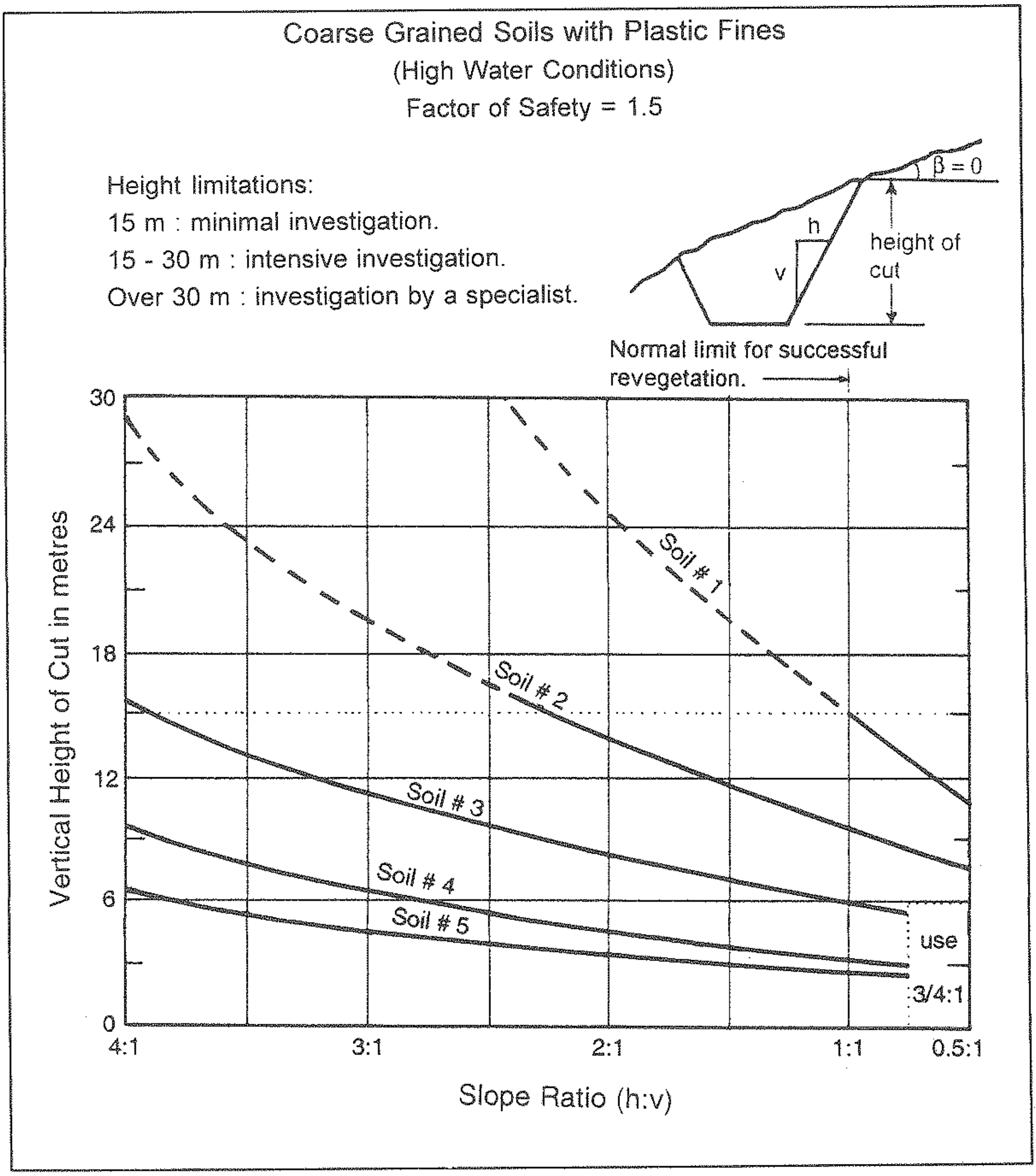
In such cases cut slope profiles will be unavoidably steep and will require revetments to stabilise and protect them from surface erosion.

Figure 8.4
Maximum Unsupported Height of Steepest Slope of Cuts for Low Water Conditions



Source: TRB 1980

Figure 8.5
Maximum Unsupported Height of Steepest Slope of Cuts for High Water Conditions

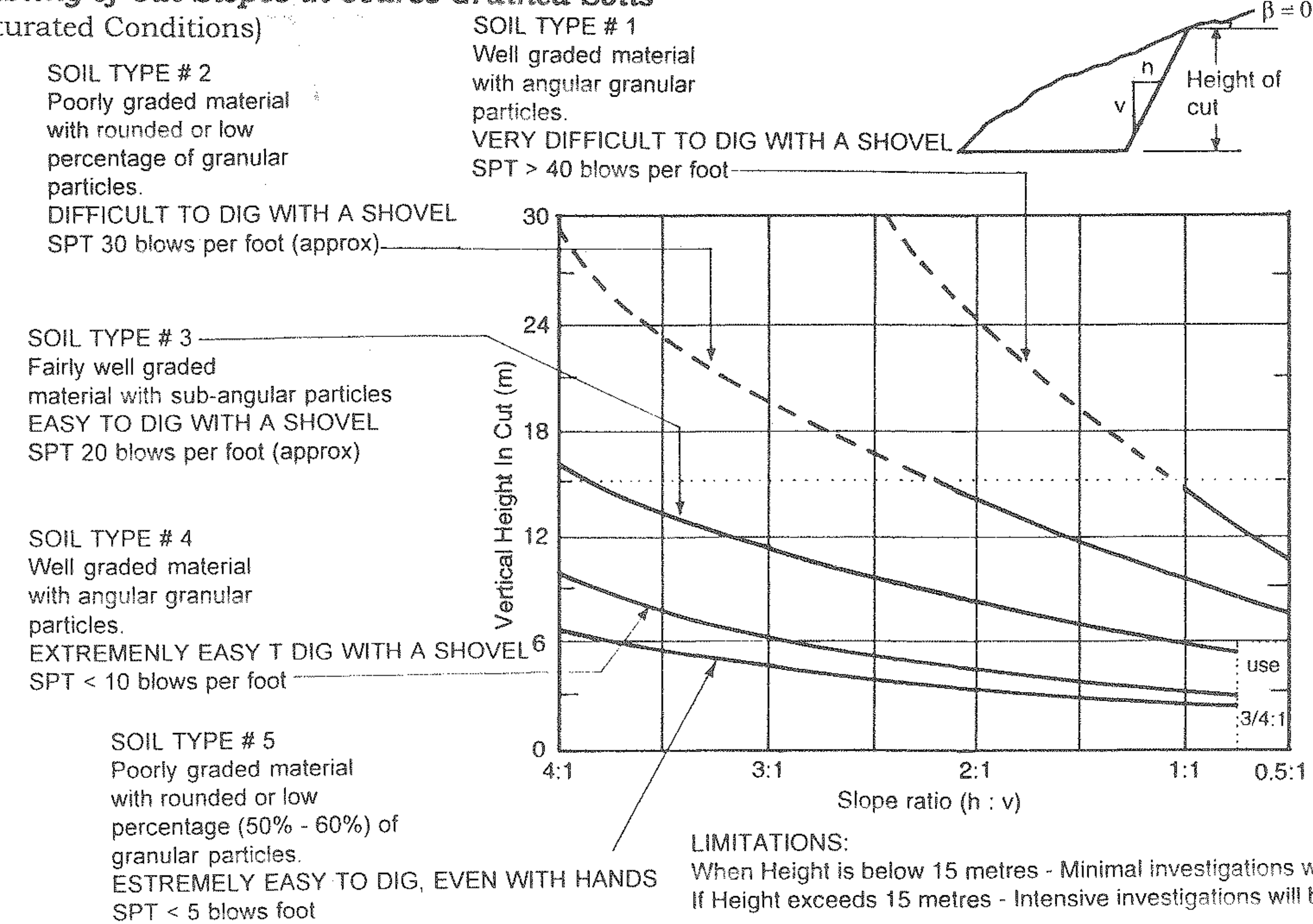


Source: TRB 1980

Figure 8.6

Stability of Cut Slopes in Coarse Grained Soils

(Saturated Conditions)



LIMITATIONS:
When Height is below 15 metres - Minimal investigations will be required.
If Height exceeds 15 metres - Intensive investigations will be required.

Adapted from: Risk Engingeering in the Hindu Kush-Himalaya. ICIMOD.
SPT = Standard Penetration Test

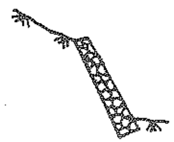
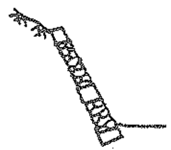
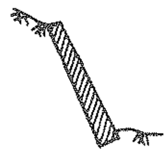
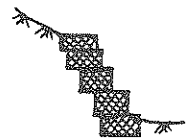
Revetment Walls Can Be Built Using a Variety of Construction Materials such as:

- dry-stone,
- dry-stone inside cement masonry panels,
- cement masonry,
- gabions, and
- used oil drums filled with earth.

Figure 8.7 shows the different types of revetment walls and their applications in hill irrigation construction.

Figure 8.7

Types of Revetment Walls and Their Applications in Hill Irrigation Projects

	Type	Revetment Walls/Breast Walls						
		Dry-Stone			Handed Dry-Stone Masonry	Cement Masonry	Gabion	Horizontal Drum Walls
	Diagramatric cross-section							
Construction notes	Top width	0.5			0.5	0.5	2	1
	Base width	0.29H	0.3H	0.33H		0.23H	2	1
	Batter	3:1	4:1	5:1	3:1	3:1	3 to 5:1	3:1
	Inward dip of foundation	1:3	1:4	1:5	1:3	1:3	1:5	1:3
	Foundation depth below bench cut	0.5m	0.5m	0.5m	0.5m	0.5m	0.5-1m	0.25m
	Range of height	6m	4m	3m	3-8m	1-10m	1-8m	2.2m
	Hill slope angle		35 - 60⁰		35 - 60⁰	35 - 70⁰	35 - 60⁰	35⁰
	General	Pack stone along foundation bed. Use bond stones. Specify minimum stone size.			Cement masonry (1:6) bands of 0.5m thickness at 3m c/c.	Weep holes 15x15 cm at 1.5-2m c/c and grade 1:10. Cement sand mortar (1:6)	Step in front face 20-50 cm wide. Otherwise as for retaining walls.	Use vertical single drum for 0.7m height. Anchor drum walls on side. Fill debris material.
		Revetment walls have uniform section of 0.5m/0.75m thickness for batter of 2:1 or more. Section shaped to suit variation and overbreak in rock cut slope.						
	Remarks	More economical in the hills. Farmers can repair/rebuild in case of damage.			Not very common in the hills. Particulary suitable for deep cuts. Little more expensive than dry-stone revetment.	More durable but more costly. To be used only when other less expensive alternatives are structurally inadequate.	Very flexible structure. Adjacent gabion boxes need to be well tied together for the structure to act as one mass.	Not very common in the hills. Most ecomonical and appropriate solution when oil drums can be easily transported or are available in the village.

Adapted from: Risk Engineering in the Hindu Kush - Himalaya, ICIMOD.

Fill Slopes, Hill Slopes and Retaining Walls

Fill Slopes and Retaining Walls

Earth fills can be used in hill irrigation projects to make more construction space available for building irrigation canals along steep hillsides. Building irrigation canals on earth fill is generally not recommended but in some exceptional situations may be the only feasible solution.

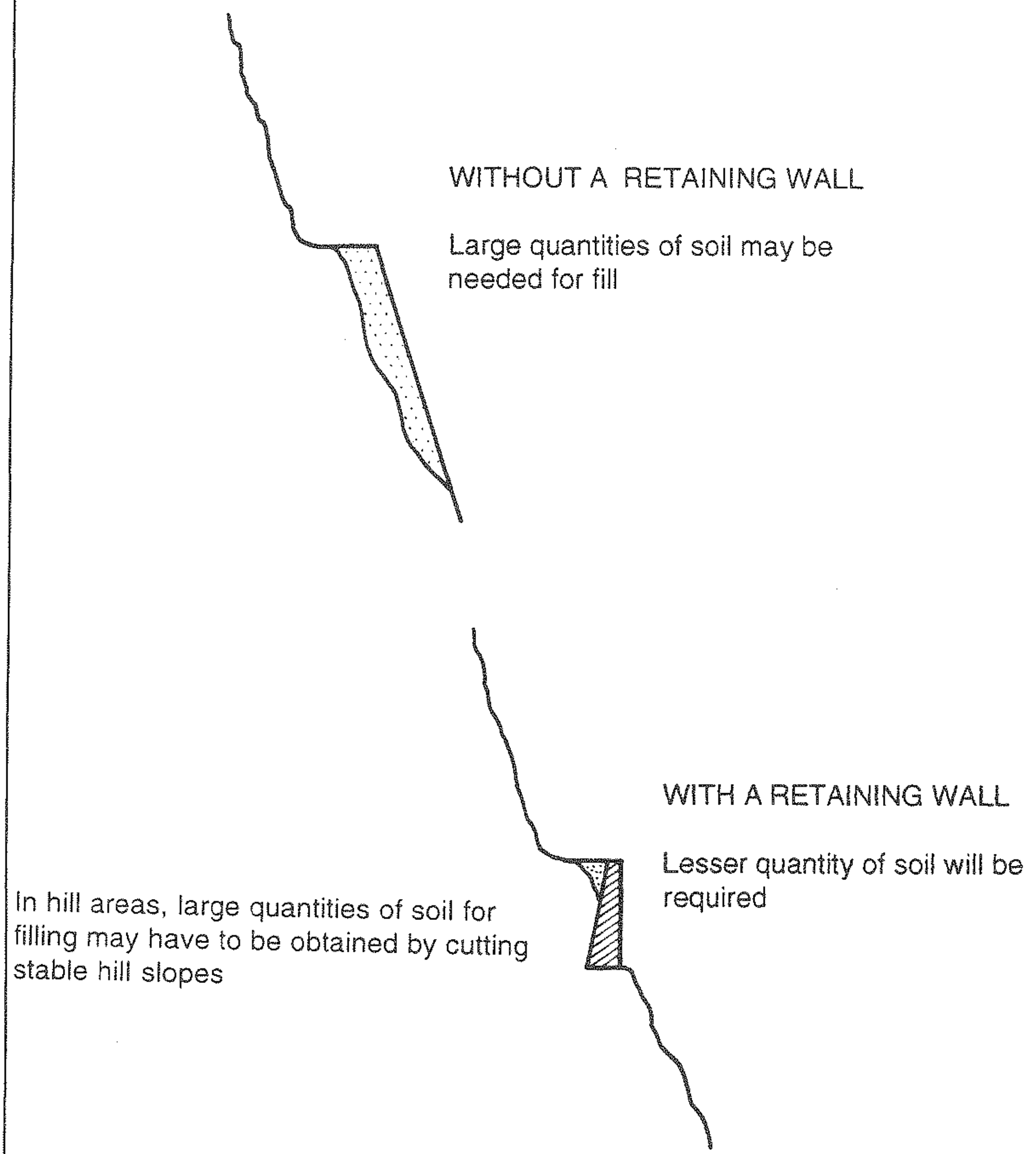
Covered canals, preferably HDP pipes, should be used in these areas to reduce the risk of canal water leakage or overtopping causing slope failure.

Fill slopes can stand on their own if clay earth is used and the layers are well compacted.

Fill slopes need to be flatter than natural hill slopes because the soil structure is destroyed and the cohesive strength of soil decreased during cut and recompaction.

Making earth fills with flat profiles requires more earth. In hill areas this may mean extra cutting of stable hill slopes. The use of retaining walls can reduce the amount of earth required for backfilling, see Figure 8.8.

Figure 8.8
Use of Retaining Walls for Reducing the Quantity of Soil Required for Filling



Hill Slopes and Retaining Walls

Retaining walls and revetment walls can be used to stabilise weak hill slopes and to reduce the risk of landslips. However, retaining walls and revetment walls alone cannot stabilise unstable hill slopes.

Depending on what is causing the instability of the hill slope other appropriate measures, such as surface and underground drains, toe protection and vegetative hill slope stabilisation techniques, etc., must be employed together with retaining/revetment walls for maximum effectiveness.

Appropriate Materials for Retaining Walls

As with revetment walls:

- dry-stone,
- cement masonry,
- gabions, and
- used oil drums filled with earth

are all appropriate materials for the construction of retaining walls in remote hill areas. When tall, heavy and strong retaining walls are necessary to support a large mass of earth, cement masonry or gabions can be used. For short walls, dry-stone or oil drums are more economical.

Front-Battered or Back-Battered

When using dry-stone or cement masonry for the construction of retaining walls, it is possible to construct either a:

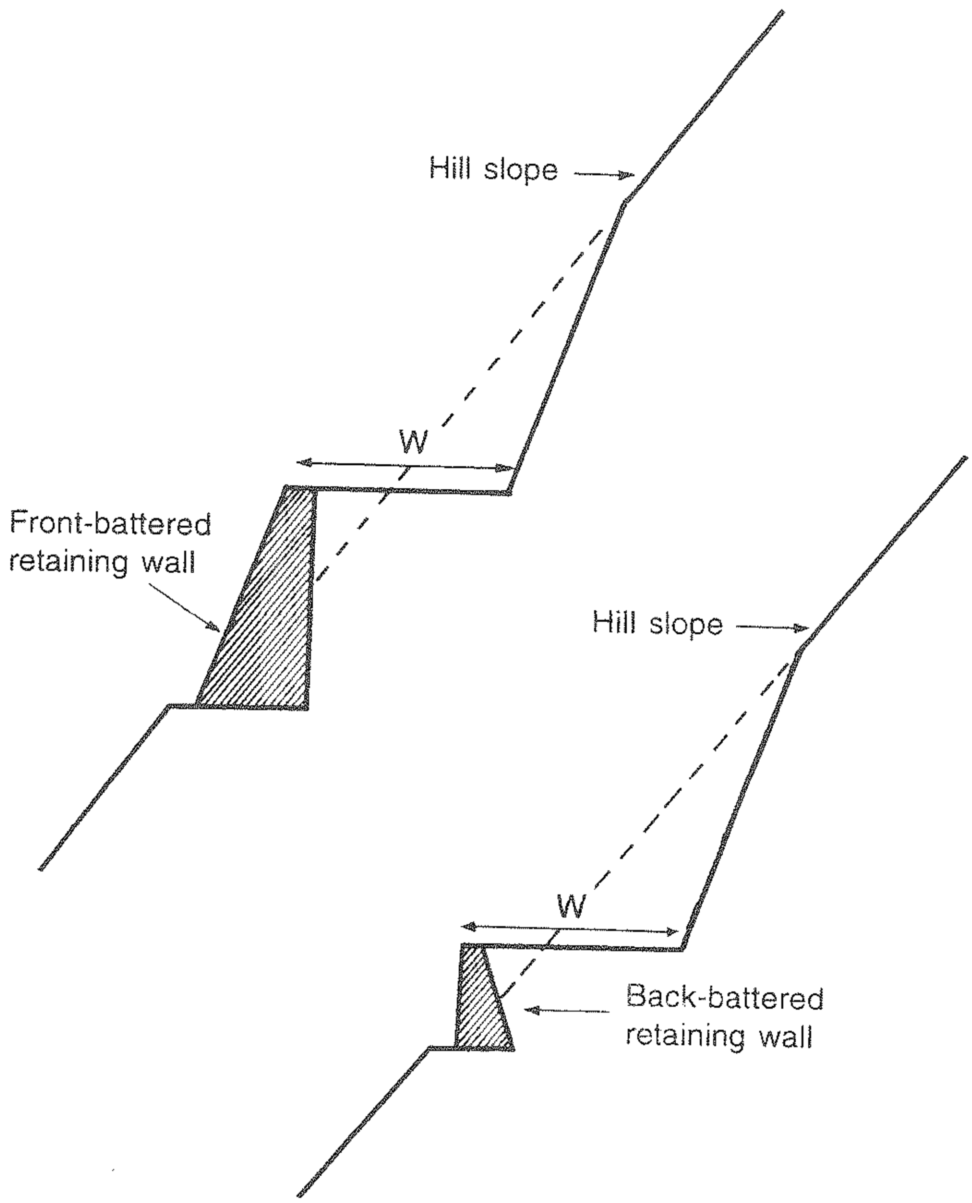
- front-battered, or a
- back-battered retaining wall.

A front-battered retaining wall has a sloping exposed face and a vertical buried face.

A back-battered retaining wall has a vertical exposed face and a sloping buried face.

Front-battered retaining walls are many times more expensive than back-battered walls because the weight of the backfill contributes towards the forces stabilising the wall. Figure 8.9 illustrates this point.

Figure 8.9
Back-Battered versus Front-Battered Retaining Walls



A back-battered retaining wall is more economical than a front-battered retaining wall.
Typically, for platform width (W) varying between 1.5m to 2m the back-battered wall section will be 2 to 3 times smaller than the front-battered section.

Design of Retaining Wall Cross-Sections

Standard tables or charts for wall cross-sections are available in several design manuals. The user must exercise good judgement when using standard tables and charts for the design of retaining walls. In particular he must make certain that the situation for which the retaining wall is needed is represented in the design chart that he is about to use. If the actual situation is not represented in the standard table or chart, he should use the cross-section obtained from the table or chart only as a guide for more rigorous calculations.

'Rule of Thumb' Design for Masonry Retaining Walls

Masonry retaining walls up to 3 metres in height may be designed using the following rule of thumb:

Top Width = 0.50 to 0.60 metres
Base Width = 0.55 to 0.65 times the height of the wall.

Common Causes of Retaining Wall Failure

Retaining walls can fail due to:

- inadequate design, or
- poor construction.

Inadequate Design

Inadequate design can result when the site conditions and loads are not correctly estimated. Inadequate design can also result if standard design tables and charts are used without proper care.

Poor Construction

Poor construction and inadequate supervision during construction can result in wall failure due to:

- uneven settlement of masonry walls during rainy season,
- poor bonding and wrong bedding of stones in masonry walls, see Figure 8.10,
- roots of big trees pushing the wall from behind,
- unstable boulders not cleared from the foundation,
- design cross-section not fully constructed,
- poor backfilling resulting in high seepage water pressure,
- blocked weep holes in cement masonry walls, and
- lack of toe protection for walls, see Figure 8.11.

Some Construction Techniques for Increasing Stability of Masonry Retaining Walls

Techniques for increasing overall stability of masonry retaining walls include:

- tilting,
- benching,
- packing of stones in layers that dip into hill slope (for dry-stone walls),
- bond stones (for dry-stone walls),
- circular or arch type walls in plan.

Tilting

Tilting the wall towards the hill slope increases the stability of the wall and its effectiveness. Typically, walls may be tilted by 6 to 10 degrees, see Figure 8.12.

Benching

Benching the foundations as indicated in Figure 8.13 can add to the stability of the wall by providing more anchorage between the wall and the soil.

Sloping Stone Layers

Stones can be prevented from coming loose by packing the stone layers of a masonry wall so that the layers dip into the slope, as in Figure 8.14.

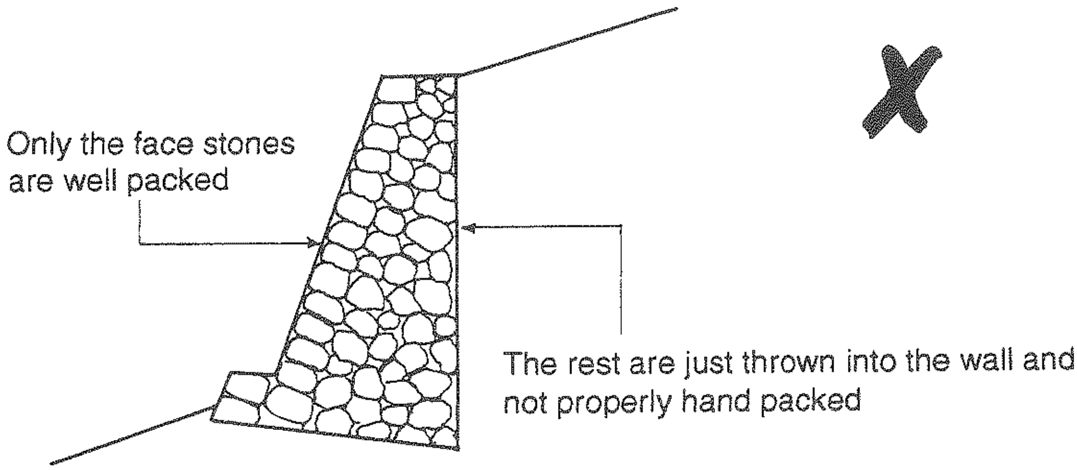
Bond Stones

Long, flat stones extending well into the soil slope and placed at regular intervals in the wall can increase the bond between the dry-stone wall and the soil slope.

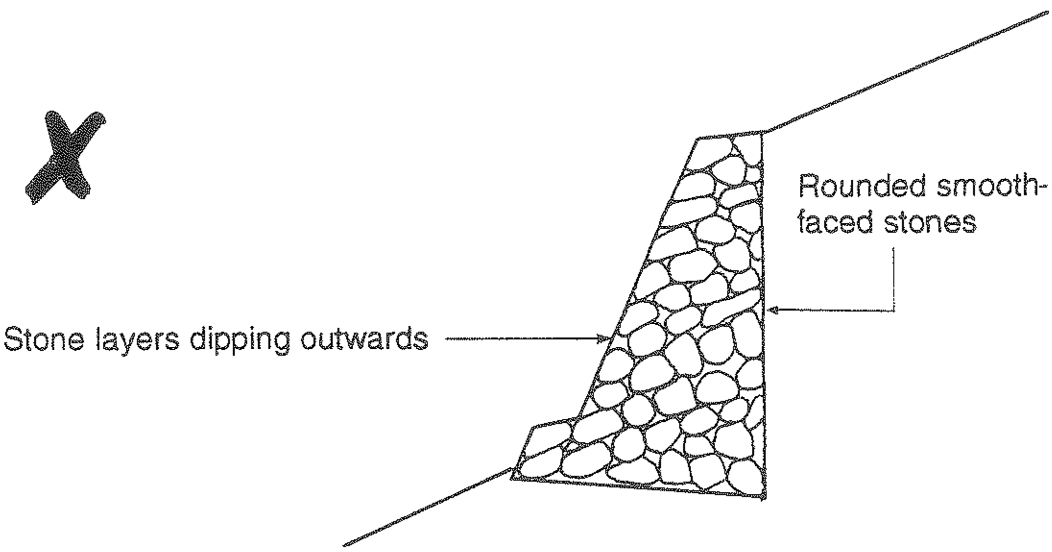
Circular or Arch Type Construction (in plan)

Retaining walls that, in plan, are constructed in a way similar to arch type dams (see Figure 8.15 and top of Photograph 8B) are stronger than linear walls. Drainage gullies along irrigation canals are examples of suitable locations for such types of arch retaining walls.

Figure 8.10
Examples of Poor Construction that can Lead to Failure of Masonry Retaining Walls

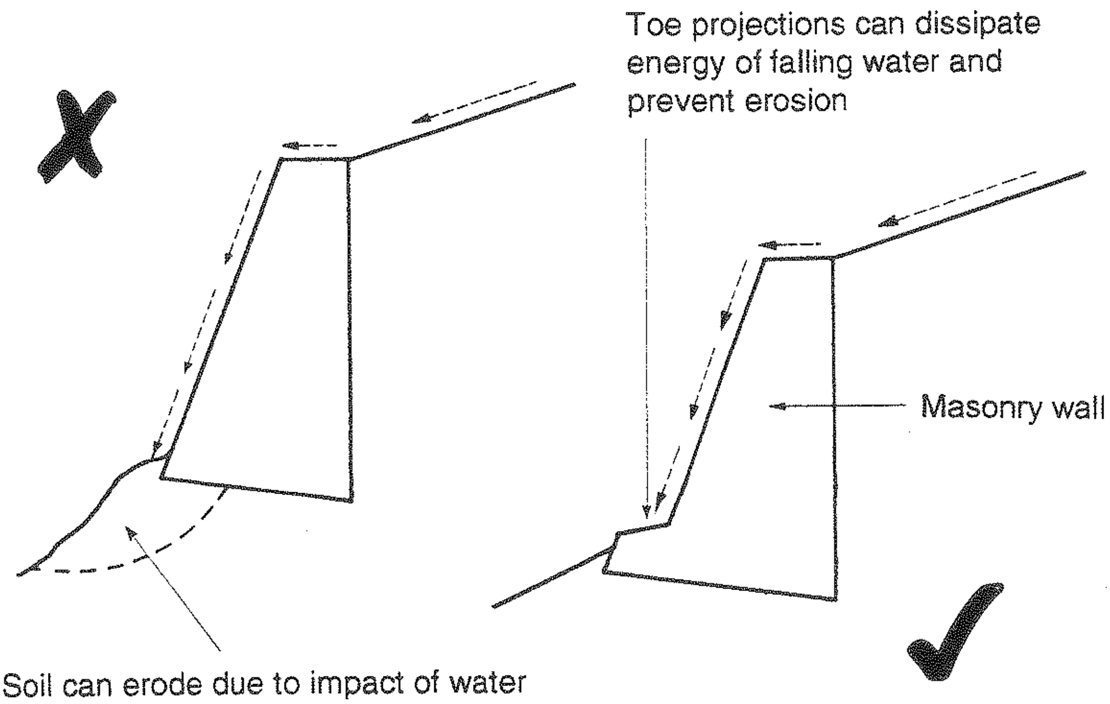


Retaining Wall of Very Little Strength



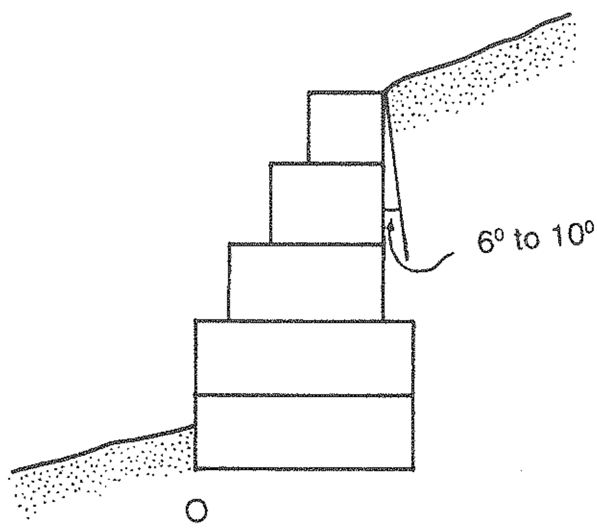
Retaining Wall of Poor Strength
(Layers can slide out of the wall)

Figure 8.11
Toe Projections for Retaining Walls and Their Use



Large quantities of overland flow due to heavy rainfall on hill slopes can undermine foundations of retaining walls. Toe projections can reduce undermining.

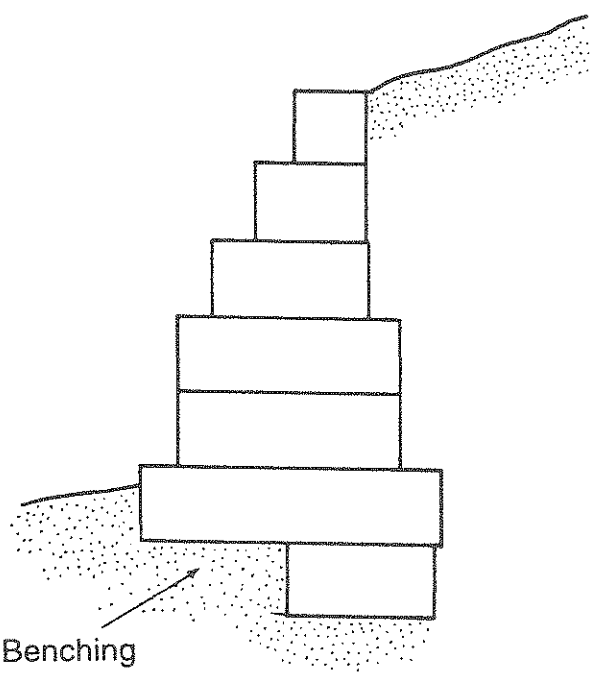
Figure 8.12
Tilting of Retaining Walls for Increasing Stablity



Tilting retaining walls towards the hill slope increases the stability of the wall by increasing the magnitude of the restoring moment about the toe point (O) of the wall.

A tilt angle between 6° and 10° to the vertical is generally recommended.

Figure 8.13
Benching the Foundations of Retaining Walls for Increasing Stablity



Inward sloping benches can make retaining walls more stable by helping to increase the bond between the foundation soil and the wall.

Figure 8.14
Sloping Stone Layers in Retaining Walls Increase Stability

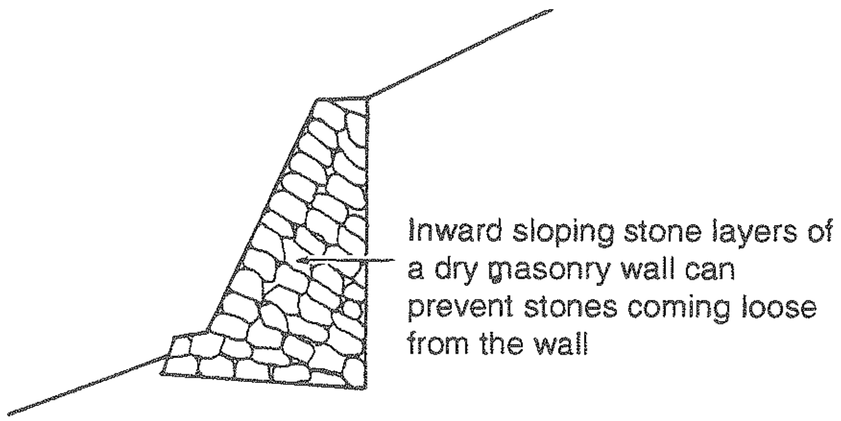
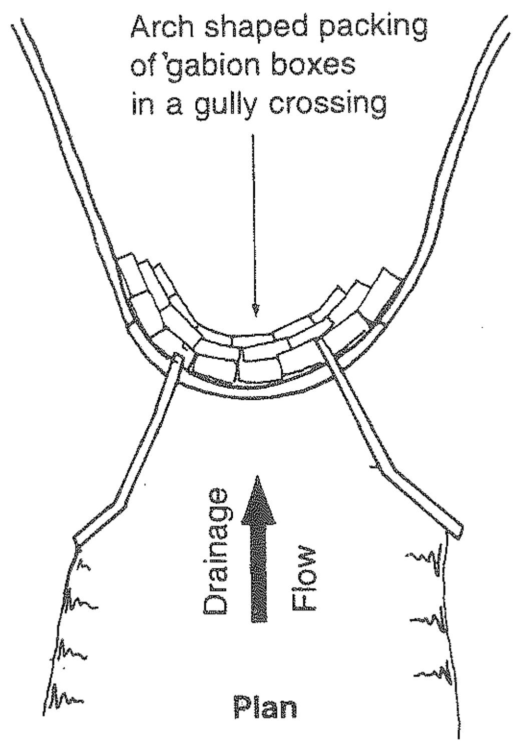


Figure 8.15
Curved Construction of Retaining Wall



Circular arch type construction of a retaining wall, wherever possible, increases the strength of the overall structure

Gabions - and their Advantage in Hill Areas for Use in Retaining Walls

In remote hill districts where there is a shortage of:

- skilled craftsmen for making good masonry for retaining walls, and
- appropriate stones for making dry-stone walls,

gabion cages can be used to advantage.

When stones are well-packed and caged inside a gabion they behave as big heavy blocks.

Special Qualities of Gabions which make them Suitable for Constructing Revetment and Retaining Walls

Gabion construction has the following inherent properties that make gabion work suitable for the construction of retaining and revetment walls in remote hill districts:

- flexibility,
- permeability,
- speed of construction and flexible construction scheduling,
- relatively low cost,
- ease of combining with bio-engineering methods.

Flexibility

Gabion structures are inherently flexible. When correctly built they can deform or bend without loss of strength to conform to changes in the ground or adjacent surfaces. Retaining walls, foundation support structures, river bank erosion protection and river diversion structures will all undergo deformations of their foundation layers, particularly during the initial period following construction.

Although the flexibility of gabions can be a very useful factor, enabling them to undergo a certain amount of deformation with little loss of strength, it can also present a danger to the safety of a gabion structure if it is not controlled by good design and construction technique.

If a gabion structure is too flexible it will not serve its intended use.

Permeability

Gabion structures are highly permeable and need no special pressure relief arrangements to prevent build-up of water pressure behind them. However, gabions can be made impermeable if necessary by laying them on impervious membranes or by grouting them after filling with stones. Their permeability is particularly useful in retaining wall construction because smaller and more economic cross-sections can be used.

In some other cases however, such as structures on river banks or river beds, this property can be very harmful to the safety of the structure. High permeability can cause rapid erosion of the soil underneath the gabion which will lead to failure. In such cases, the gabion structure must be built on special graded filter layers or on a hard impermeable surface.

Speed of Construction

Assembly and construction of gabions is fast. The gabion wire baskets are light and easy to handle. Gabions can be laid on running water and there is no need for removal or diversion of water to ensure foundations are dry. The gabion structure is ready for use immediately on completion, see Table 8.1.

Flexible Construction Scheduling

Gabion construction can be interrupted, at least for short periods, without any serious risk to the solidity of the finished structure.

However, when gabion structures are required in critical areas where immediate protection is needed, interruption can result in damage to the partly finished gabion structure as well as to the area being protected.

Cost

If stones are available nearby, gabions compare favourably with other materials in cost.

Other Special Considerations for Using Gabions

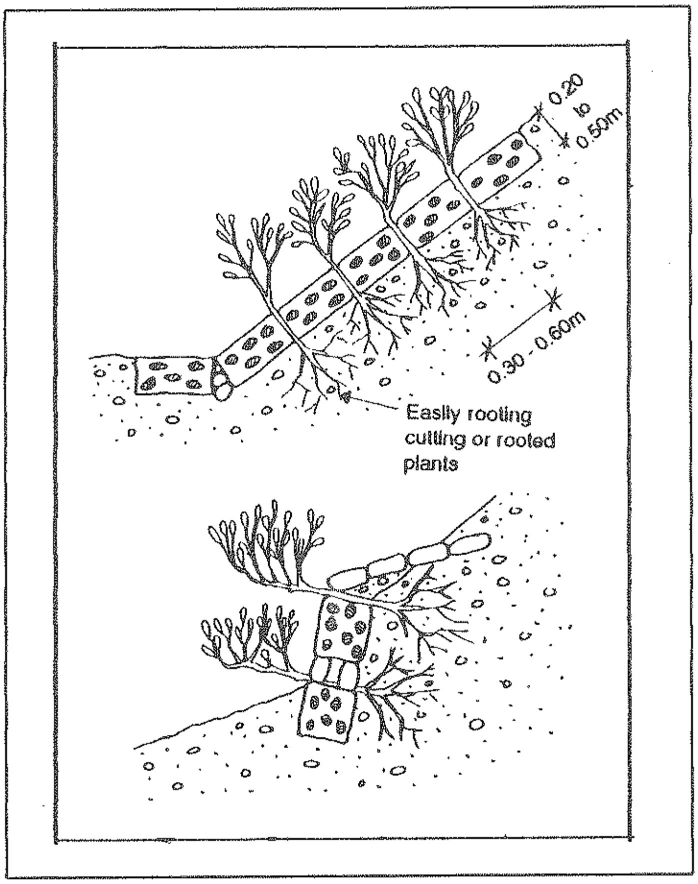
Gabion construction is labour-intensive and often creates many unskilled labour days; the income generated from these labour days can be particularly useful in poor remote villages.

Gabions can be combined easily with bio-engineering techniques, see Figure 8.16. When combined with bio-engineering, gabions can ensure the initial safety of a hill or river bank slope until the bio-engineering measures take effect. By the time the gabion cages eventually rust away, the bio-engineering measures will have taken over completely.

Table 8.1
Speed of Construction of Gabion Works

Gabion Bank Protection Structures	Concrete or Masonry Bank Protection Structures
● No foundation excavation needed. (In most cases.)	● Foundation excavation needed. (In most cases.)
● No removal or diversion of water needed.	● Removal or diversion of water needed.
● No formwork or falsework needed.	● Formwork or falsework needed.
● No delay waiting for layers of structure to harden before removing formwork or continuing with work.	● Delays before formwork can be removed or construction continued.
● Work can proceed smoothly and rapidly, even simultaneously at several locations.	● More machinery and equipment needed to work simultaneously at several locations.
● Stage-wise construction is easier hence work schedules can be easily modified to suit labour availability.	● Stage-wise construction difficult, hence work schedules are tied up with resource availability.
● Constant supervision not necessary.	● Constant supervision needed when concreting.
● Structure ready for immediate use.	● Structure needs 'Curing' before becoming operational.

Figure 8.16
Vegetated Gabion



Combining gabions with vegetation gives long-lasting protection to unstable hill slopes.

Design Considerations For Gabion Structures

Gabion structures are designed as "mass" structures. In other words, they depend on their "mass" or "bulk" to perform the desired functions such as retaining and protecting earth slopes and banks in river bank protection works and resisting forces due to river currents in groins and spurs.

The mass of the structure must be put to maximum use by:

- tilting the structure suitably, or
- using heavy fill material, or
- both.

Gabions Can Take:	Gabions Cannot Take:
• Compression forces	• Excessive forces due to vibration
• Limited shear forces	• Abrasive forces

Design Considerations For Compression Forces

When gabions have to withstand compression loads, the fill material must be strong and densely packed so that the load is distributed uniformly.

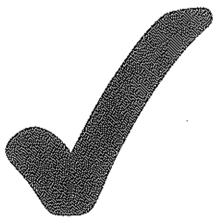
Design Considerations For Shear Forces

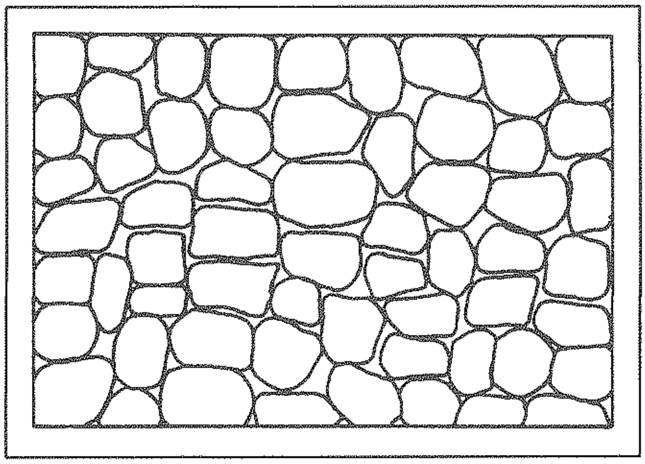
Gabions can withstand only limited shear forces.

- If shear forces are in operation then stones of the correct size, shape and surface roughness must be carefully hand packed in the gabion cage, see Figure 8.17.
- Shear forces are resisted entirely by the fill material. The gabion wire is considered to be a safety factor only.
- Deflection or deformation of gabion boxes by shear forces can be reduced by using horizontal wire trusses, or diaphragms, as in Figure 8.18.

Figure 8.17
Effect of Stone Size, Shape, Surface Roughness and Packing on Gabion Construction

This gabion box can resist shear stress.

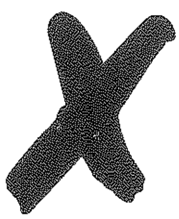


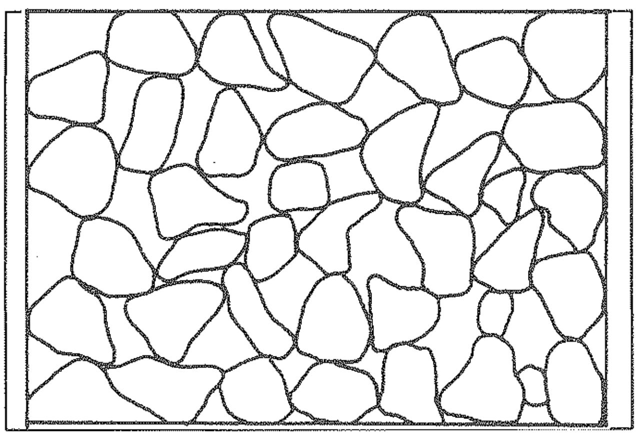


Correctly-Filled Gabion

- correct size stones
- correct shape stones
- correct surface roughness
- hand placed

This gabion box cannot resist shear stress.

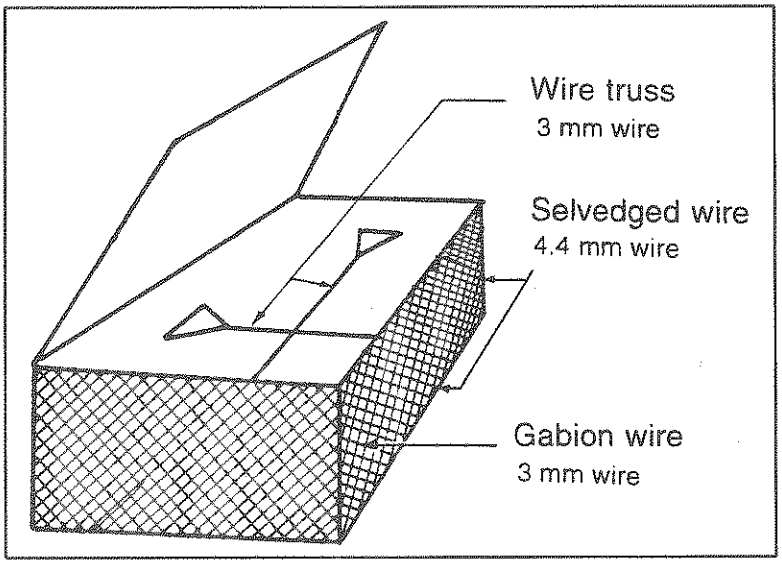




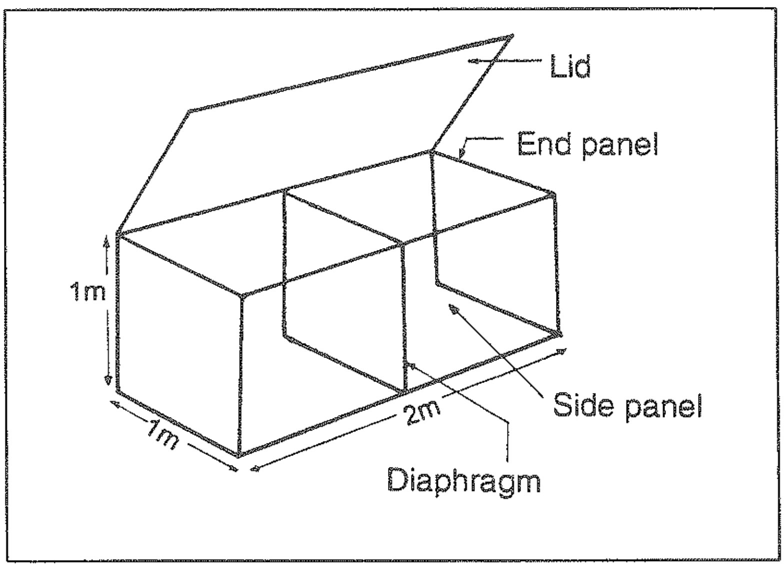
Wrongly-Filled Gabion

- wrong size stones
- wrong shape stones
- inadequate surface roughness
- not hand placed

Figure 8.18
Gabion Box



... with Horizontal Wire Trusses



... with Diaphragm

Design Considerations For Vibration Loads

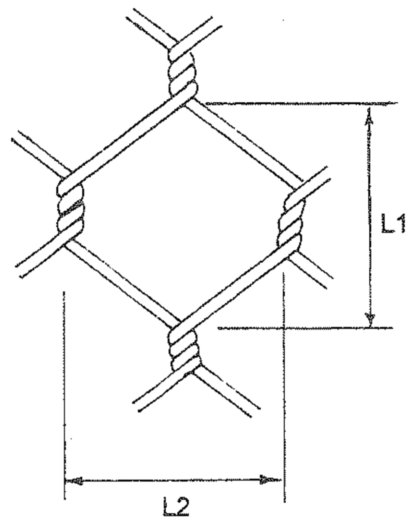
When gabions are used for river bank protection and river training works they are subjected to vibrational forces.

- Fast moving water causes the stones inside the gabion boxes to vibrate. Particularly, lightweight and flat stones near the surface of the gabion vibrate leading to 'fatigue' failure of the gabion wire. Lightweight and flat stones should therefore be avoided near the exposed faces of the gabion.
- Gabion boxes should be densely packed and rigidly bound, leaving no room for vibration.
- The stronger double twist hexagonal mesh should be preferred for gabion structures in fast moving water, see Figure 8.19.

Design Considerations For Abrasive Forces

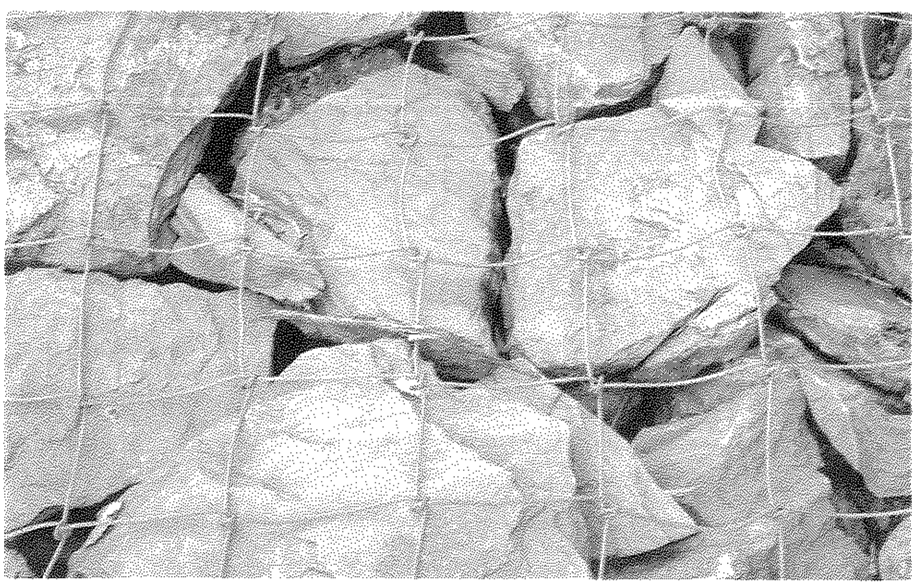
- Fast moving water carrying boulders and pebbles can damage the exposed mesh wire by impact or abrasive action. In such situations the exposed mesh needs additional protection. Rock armour, heavy wooden planks and concrete lining are possible solutions.

Figure 8.19
Two Types of Gabion Wire Mesh



... Hexagonal Mesh

Stronger double twist hexagonal wire mesh should be used for gabions on river banks and river control or training works.



... Square Mesh

Less strong double twist square wire mesh may be used for small retaining structures. Large retaining structures will require the double twist hexagonal wire mesh.

Other Design Considerations:

- mesh wire size,
- mesh type and mesh opening,
- characteristics of fill material.

Mesh Wire Size

The size or thickness of galvanised wire is measured using many gauges. SWG, (Imperial Standard Wire Gauge) is popularly used in Nepal.

The table below shows the combination of wire sizes used in Nepal for weaving hexagonal mesh with double knots.

Boxes made using thicker wire are obviously stronger but are also more expensive.

Table 8.2
Recommended Combination of Wire Sizes for Making Gabion Boxes

Gauge Number	6	7	8	9	10	11	12	13
Diameter (mm)	4.88	4.47	4.06	3.66	3.25	2.95	2.64	2.34
Use Mesh Wire = M Selvedge = S Binding = B	S1	S2	S3	M1	M2	M3 B1	B2	B3

For economical reasons thick wire is used to weave large mesh and thin wire to weave small mesh.

The wire's durability is dependent on the thickness of the zinc coating and the ability of the coating to withstand localised cracks at or near knots or sharp bends.

Mesh Type and Opening

The most commonly used mesh types in Nepal are:

- Double twist hexagonal mesh, also known as double knot hexagonal mesh.
- Double twist square mesh, also known as double knot square mesh.

The double twist hexagonal mesh is stronger than the double twist square mesh. The double twist square mesh is only recommended for constructing low stress structures. In some cases a fair economic compromise can be achieved by incorporating square mesh gabions in large works built with hexagonal mesh gabions.

In Nepal the following types of mesh are used:

Hexagonal Mesh	80 x 100 mm,	100 x 120 mm
Square Mesh	100 x 100 mm,	150 x 150 mm

It is always more economical to use large size mesh gabions (hexagonal 100 x 120) with large stones.

Characteristics of Fill Material

The characteristics of the fill material play an important role in the performance of the gabion structure.

The ideal fill material should be:

- non-porous,
- sufficiently hard and heavy, and
- large and suitably shaped.

Porosity reduces self-weight of the structure. The reduction is even more evident when gabion structures are submerged in water.

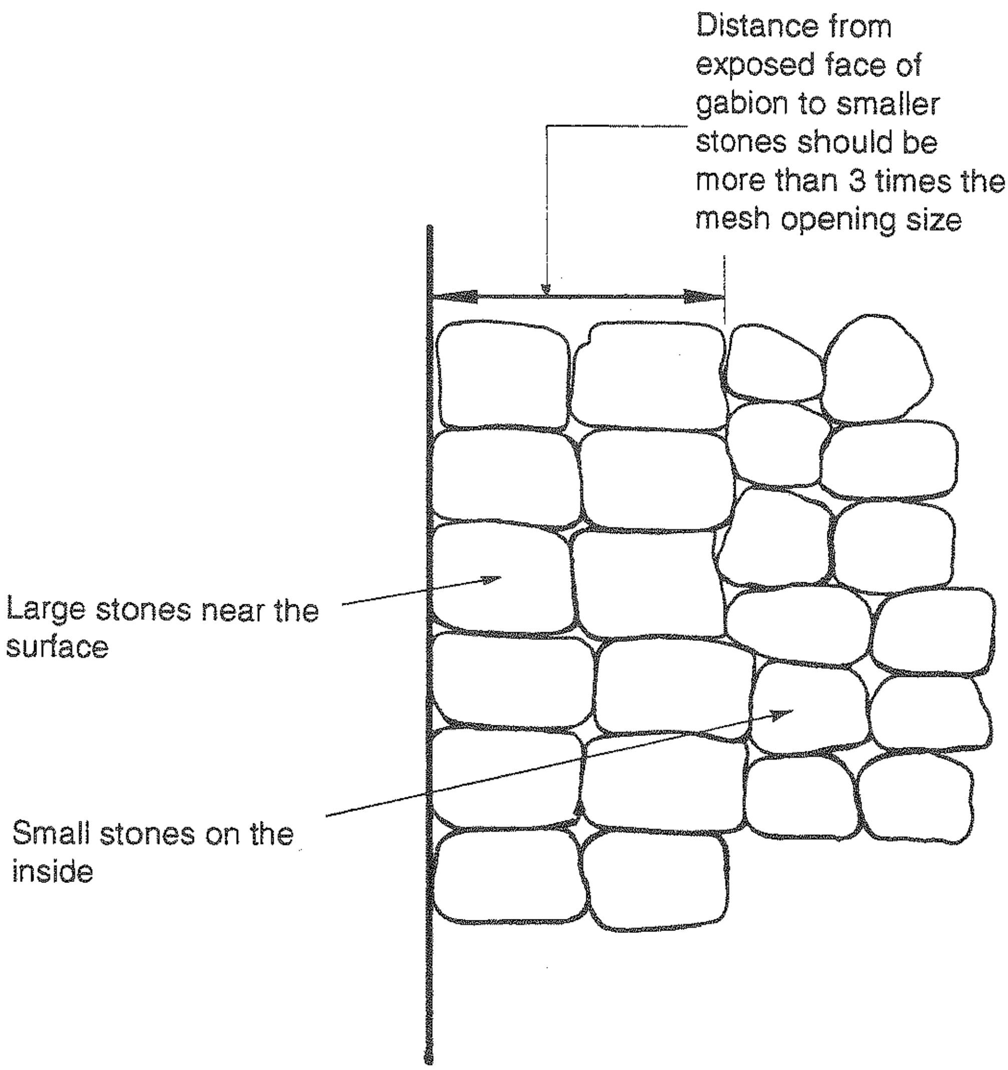
The heavier the material the more economic the structure.

When calculating self-weight it is usual to allow for 30 to 40 percent empty space. The self-weight of a gabion box filled with granite is not 2700 kg/cu m but 0.6 times 2700, that is 1620 kg/cu m.

Large stones are more economical and should always be preferred.

If large stones are not available in sufficient quantity then smaller stones may also be used provided they are placed a distance of at least 3 times the size of the wire mesh inside from the gabion face, see Figure 8.20.

Figure 8.20
Using a Combination of Small and Large Stones When Large Stones are Not Available in Sufficient Quantity



Fill stones with suitable interlocking shapes are desirable for most gabion work. They:

- help transfer the load uniformly,
- do not slip excessively under loading thus causing gabion boxes to bulge.

In some cases, especially for footing aprons or mattresses of river bank protection measures where launching of gabions is required, round smooth stones are preferred. Smooth stones allow movement and enable the footing gabion to mould itself to the form of the ground, see Figure 8.21.

Figure 8.21
Flexible Apron