LAO PEOPLE'S DEMOCRATIC REPUBLIC

PEACE INDEPENDENCE DEMOCRACY UNITY PROSPERITY

SLOPE MAINTENANCE MANUAL

MINISTRY OF PUBLIC WORKS AND TRANSPORT

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This document has been prepared by Scott Wilson Ltd for its Client, the Department for International Development (DFID) UK, on behalf of the Ministry of Public Works and Transport, Lao PDR.

Definitions of terms

Alluvium	Material, usually fine sand or silt with larger, rounded particles up to boulder size, deposited by a river, having been transported from elsewhere in suspension.
Brush layer	Live cuttings of plants laid into shallow trenches with the tops protruding. They are usually made to form an erosion barrier across the slope.
Colluvium	Angular debris, usually loose and unconsolidated, found on slopes below rock outcrops.
Cutting	Any part of a plant (stem, rhizome or root) that is used for vegetative propagation.
Erosion	The gradual wearing away of soil (or other material) and its loss, particle by particle.
Fascine	Bundles of branches laid along shallow trenches and buried completely. They send up shoots and can be used to form an erosion barrier across the slope
Joints	Cracks in rock masses, formed along a plane of weakness (the joint plane) and where there has been little or no movement, unlike a fault.
Masonry	A structure built of angular rocks bound together with a cement-hardened concrete mortar.
Palisade	The placing of woody cuttings in a line across a slope to form a barrier against soil movement.
Residual soil	Soil formed from the prolonged and intense weathering of rock in its original location, showing no signs of movement and where the original rock structure has disappeared.
Retaining wall	A wall built to support a positive pressure from an unstable soil mass.
Revetment	A wall built to protect the toe of a slope, supported by the slope itself.
Runoff	Surface water flow that occurs when rainfall intensity exceeds infiltration.
Weathering	The physical and chemical alteration of minerals into other minerals by the action of heat, water and air

PREAMBLE

In this Manual, slope maintenance is taken to include the maintenance of all cut, fill, and natural slopes, walls and drainage adjacent to a road.

The concepts and terminology used in this manual have been simplified in order to address the widest possible readership. The manual aims to provide low-cost solutions for low-volume roads.

The instability of slopes and walls adjacent to the hilly and mountain roads of Laos creates a considerable annual problem. During each wet season, failures occur and roads are blocked or sometimes completely severed. This can cause significant disruption to traffic. High annual maintenance costs are incurred to keep the roads open.

In this environment, natural instability is common, and the introduction of a road network into this environment is subjected to the same natural processes. Under these circumstances, it would be totally impractical and, in reality, impossible to attempt to stabilise all the areas of instability affecting the road network.

This *Slope Maintenance Manual* has drawn extensively on road construction and maintenance experience in south-east and south Asia over the past twenty years. The emphasis is on practical guidelines for the prioritisation and maintenance of existing slopes and retaining walls, particularly those that are undergoing or have undergone severe distress or failure. The Manual does not attempt to repeat topics covered in standard textbooks on the design of highways, retaining walls and cut slopes.

The manual is intended mainly for use in the Provincial Departments of the Ministry of Public Works and Transport (MPWT) by field engineers. The accompanying *Slope Maintenance Site Handbook* has been written to provide guidance to field supervisors.

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The following persons are thanked for their assistance in the preparation of this manual:

Ministry of Public Works and Transport

Laokham Sompeth
Chanh Bouphalivanh
Dr Maysy Viengvilay
Sak Dalat
Sengmany Sysouvanthong

Department for International Development/SEACAP

David Salter

The manual was prepared by

Tim Hunt
Gareth Hearn
Xayphone Chonephetsarath
John Howell

1. HOW TO USE THIS MANUAL

If the user of this manual has an instability problem with a slope or a retaining wall:

Section 2 of this manual shows the typical problems that can be expected.

Section 3 gives guidance on what to look for, what further investigations might be necessary, and how to decide how urgently the problem needs to be treated.

Section 4 discusses a number of potential treatment options to remedy the problem and how much they are likely to cost.

Section 5 gives some assistance on how to design the remedial works.

Section 6 discusses a number of issues that may arise during the construction of the remedial works.

Further information is provided in the Appendices.

Appendix A gives some ideas about where further information on slopes and retaining walls can be found.

Appendix B goes through some typical slope stabilisation applications.

Appendix C provides reporting forms for recording landslides and wall problems on site. These can be photocopied for use.

Appendix D provides a detailed procedure for the inspection of large and complex landslides, and a check list for assessing the severity of the problems.

Appendix E comprises a number of drawings showing typical details that might be considered or adapted for stabilisation construction works

2. SLOPE INSTABILITY PROBLEMS

2.1 Geographical setting

The geology of Laos is complex and includes a wide variety of rock types, of a range of igneous, sedimentary and metamorphic origins. Many rock masses exposed in road cuttings and in the natural slopes are highly disturbed and jointed due to tectonic processes, and so are vulnerable to instability. Furthermore, weathering under the tropical climate has led to the weakening of rock masses and has also resulted in the development of deep residual soils in places that are also prone to erosion and landsliding, especially during the wet season.

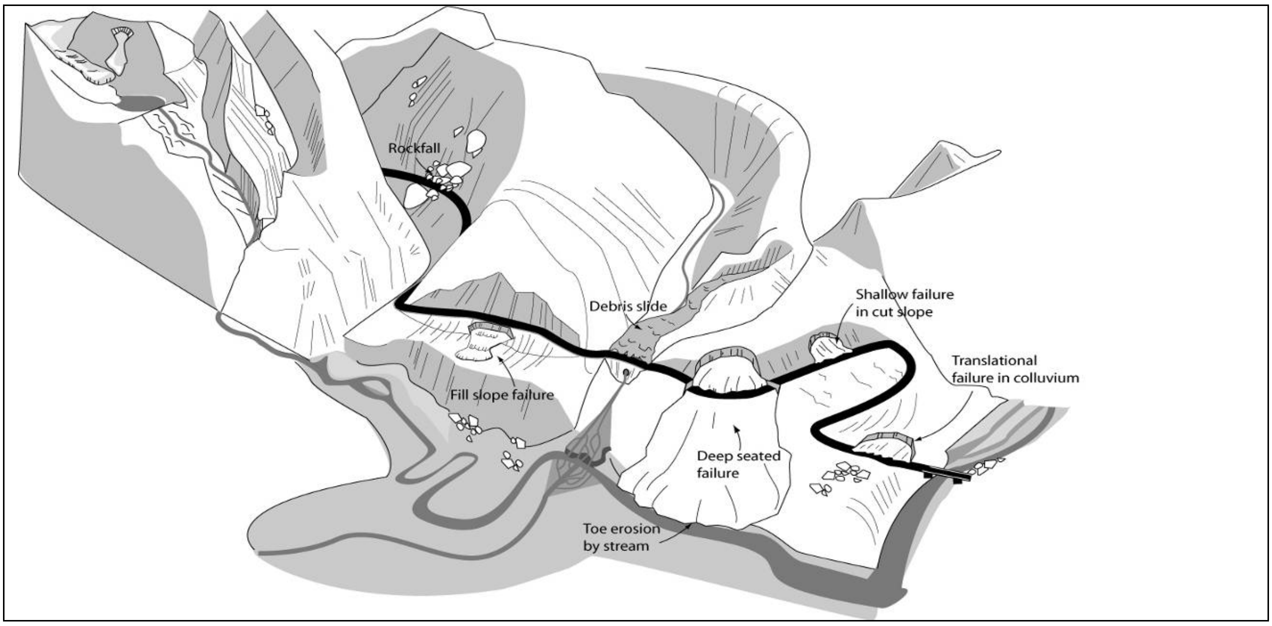
Rainfall patterns in Laos are dominated by the south-west monsoon and the relief of the country. Annual rainfalls of 3000mm and 4000mm are not uncommon and rainstorms can yield intense rainfall, with 100mm in 24 hours being common. This rainfall can lead to the development of high groundwater in slopes, as well as flooding in streams and rivers that give rise to erosion.

This underlying geology and hydrology, combined with the steep topography found in the vicinity of approximately 50% of the national road network, creates conditions in which landslides are common. These range from large and deep failures through to shallow and localised landslides in roadside cuttings and adjacent slopes, the latter being far the most common along the national road network.

2.1 Soil/weathered rock slopes

Typical soil or weathered rock slope maintenance problems affecting the road network can conveniently be subdivided into four categories: slope instability above the road, below the road, through the entire road bench; and erosion. These are illustrated schematically in Figures 2-1 and 2-2.

Figure 2-1: Typical slope failures in the mountain landscape



It is possible to find a whole range of existing instability in the landscape. Large deep-seated failures in the past have created curved cliff-like features (known as back scarps) and extensive deposits of slipped material comprising soil and rock (known as colluvium). Some of these failures may have occurred very rapidly in response to extreme rainfall, floods and earthquakes. Others may have been progressive or comprised of multiple smaller failures. The most common occurrences of slope instability affecting the road network are shallow translational or planar (i.e. with a slip surface more or less parallel to the slope) debris slides in colluvium, weathered rock and residual soil, as shown in Figure 2-2 and in relation to valley slide slope profiles in Figure 2-3.

2.1.1 Instability above the road

Failures in colluvium

These are reactivations of earlier landslide deposits and are usually triggered by local and temporarily perched water tables in the colluvium. Usually as a result of the wet season rains, the slopes become increasingly saturated. These slopes frequently have a factor of safety little above unity. These unstable areas typically comprise a jumbled mass of colluvial soils and boulders. They can often be recognised by the presence of loose colluvial debris in cuttings and the irregular hummocky nature of the slope surface. During the monsoon, seepages are often prevalent. On a larger scale these unstable areas can frequently be recognised by the presence of curved steeper topography above and the presence of very large boulders immediately below, representing the earlier back and side scarps at the periphery of the original failure (see Figure 2-1).

Shallow planar debris slides are the most frequent type of instability encountered along the road network. They are usually between 1m - 2m deep (though occasionally up to 5m and deeper) with a failure surface sometimes defined by the weathered rock head level or where colluvium continues to slide over an underlying bedrock surface. Failure usually occurs as a result of extended periods of heavy rainfall. Water enters the potentially unstable area as rainfall, as groundwater, and often via a drainage course at its head. The overlying colluvium becomes saturated, a perched water table may be formed, the factor of safety drops below unity and failure occurs.

Figure 2-2: Soil/weathered rock slopes: typical slope instability

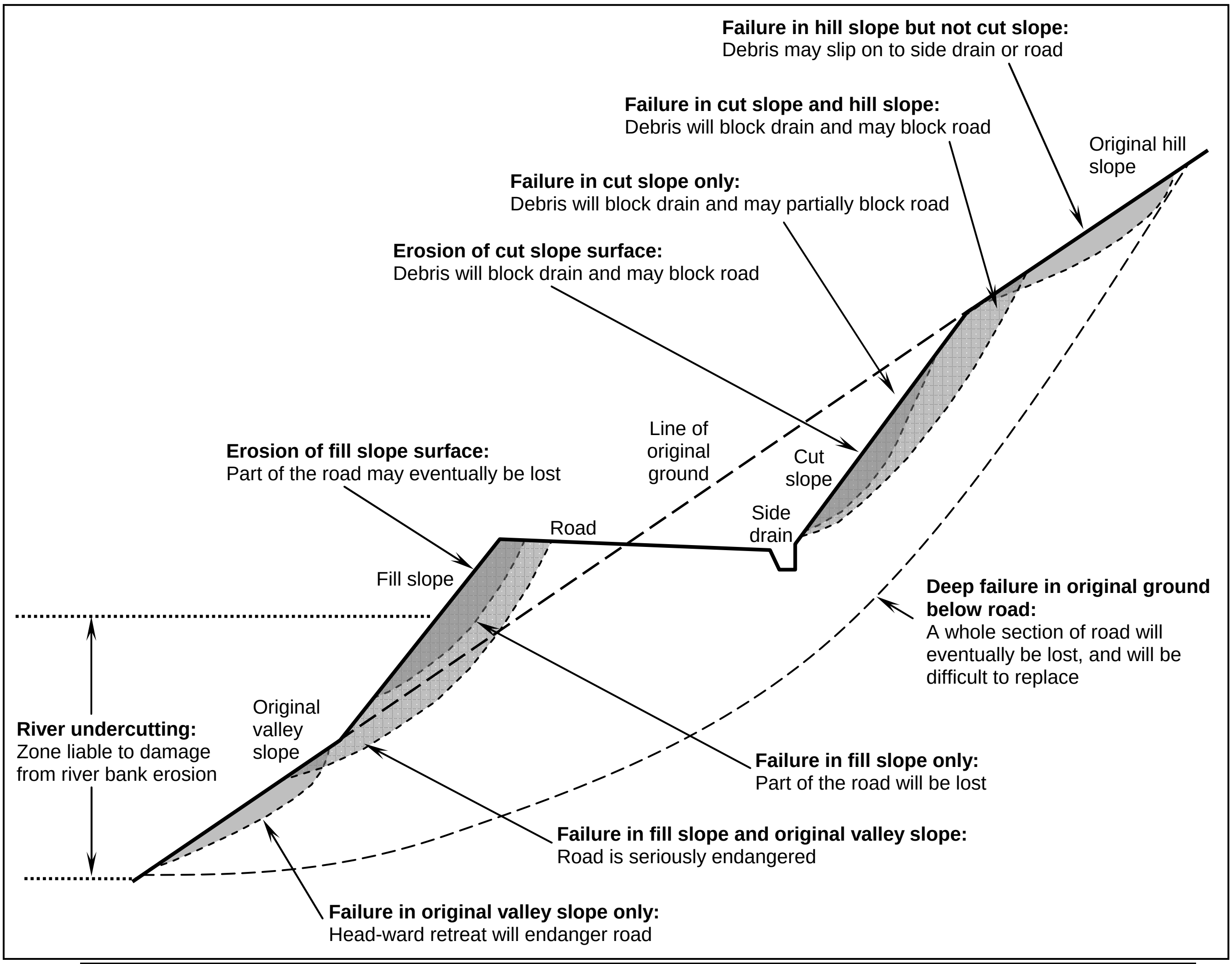


Figure 2-3: Shallow translational failure in colluvium

Failures in residual soils

Many failures occur in slopes that have been steeply cut into residual soil (i.e. soil that has formed in-place over a geological timescale) and weathered rock (see Figure 2-4).

This type of failure is usually of limited consequence and is therefore given a low priority during clearance operations. Nonetheless, it creates continuing problems of roadside drainage maintenance by causing blockages, and if allowed to continue unchecked, can sometimes lead to progressive instability upslope.

Partly due to the steep topography traversed by sections of the road network, and partly due to inappropriate use of construction equipment to cut the slopes, the formed slopes in residual soil or weathered rock are often cut at very steep slope angles. Whilst this may minimise the amount of cut (and the amount of spoil to be disposed) and immediate construction cost, it does frequently create long-term instability that leads to continuing maintenance and environmental problems.

Figure 2-4: Failure of an over-steep cut slope

2.1.2 Instability below the road

Instability confined to slopes below the road is mainly related to three main causes; oversteep or poorly compacted fill slopes, natural landslides and soil erosion (see 2.1.5).

The original construction of many roads in side-sloping ground is usually in cut, since this minimises the need for road support retaining walls and requires little or no compaction of the earthworks or the use of specialist compaction equipment. However, this form of construction obviously produces a considerable quantity of spoil, and the easiest way to dispose of this spoil is to dump it alongside and over the edge of the newly-formed road onto the valley slopes below. The same is also often true for landslide clearance operations on existing roads.

Several problems can then arise. The additional weight of loose spoil on the valley slope can “overload” the underlying slope, particularly if the spoil later becomes saturated, creating a failure in the underlying ground. Even if the underlying ground has sufficient strength to support the additional weight, the uncompacted and over-steep fill slope will often fail internally.

As a result of these failures, or as a result of poor or blocked roadside drainage, erosion can then develop, creating erosion scars on the hillside and further instability.

The smothering of the underlying natural vegetation can in itself create a preferred future failure surface, and the surface of the fill will usually take many years to re-vegetate.

Figure 2-5: Fill slope failure

Slope instability below the road is often very difficult to detect in the absence of a detailed walkover survey. The most common sign of a potential problem is the presence of a curved depression or cracking in the road surface along the valley side edge of the road, by which time the need for remedial works may be very urgent.

2.1.3 Instability affecting the entire road bench

Occasionally, deeper failure surfaces may extend beneath and cut through the entire road bench. These “sinking areas” along the road network can be up to several hundreds of metres wide and can experience movements of many metres (Figure 2-6).

Figure 2-6: Failure through entire road bench on Road 13N

In Laos, this type of failure is most frequently associated with landslides in deep colluvium or landslides controlled by adverse joint planes slides in the underlying rock. Usually, a major factor in the initiation and acceleration of these movements is the presence of large quantities of water, either due to man-made causes (e.g. crop irrigation) or natural causes (e.g. groundwater and stream course inflow). In many cases, the presence of a stream or river at the base of a failure extending below the road provides the mechanism for spoil removal, and the consequent continuation of the gradual downslope movement of the failure.

2.1.4 Drainage

Slope instability in Laos is nearly always initiated by water. Rainfall infiltrates the slope surface and runoff will be concentrated along natural and artificial watercourses. Excess water may increase the height of the groundwater table, decrease pore suction in the underlying soil, increase seepage from the base of the slope, and create erosion of the slope surface or base. Drainage and the maintenance of drainage is of the utmost importance to ensure that this excess water can be intercepted and conveyed at all times to a safe location where it will not create further instability problems.

The maintenance of roadside drainage is therefore an important requirement during the wet season. Even the most minor slip is capable of blocking the side drains and causing water to flow uncontrollably over to the valley side of the road. When this occurs during periods of prolonged and heavy rainfall, slopes below the road can be at risk, and it is clear that this has been the cause of some below-road failures in the past. There is no easy solution to this problem other than to clear above-road slips at the earliest opportunity, or to take further measures to prevent them occurring in the first place and to protect the slopes below and control runoff.

2.1.5 Erosion

Large-scale erosion problems are uncommon in Laos although erosion of the surface soils adjacent to the road does occur, often with the potential of creating larger scale instability (Figure 2-7).

Erosion adjacent to the road most commonly comprises:

- erosion of cut slopes above the road, usually as a result of the original slope being cut at too steep an angle in the first place, and often associated with minor instability.
- gully erosion, particularly below culverts and drainage turn-outs.
- erosion of fill slopes below the road, usually as a result of the original fill being placed uncompacted and at too steep an angle.

Erosion below the road is often caused by blocked roadside drains and uncontrolled runoff (see 2.1.4).

Figure 2-7: Typical slope erosion

However, more serious problems can arise due to toe erosion of slopes below the road caused by the action of rivers and streams, particularly when these are in flood after periods of prolonged and heavy rainfall (Figure 2-1). This aspect is partly covered in 2.1.3 and Appendix B (B.3), but the issue relates primarily to river training, rather than slope stabilisation. Unless the base of the slope can be protected from the erosive action of the stream or river, then all other stability measures undertaken will be compromised.

2.2 Rock Slopes

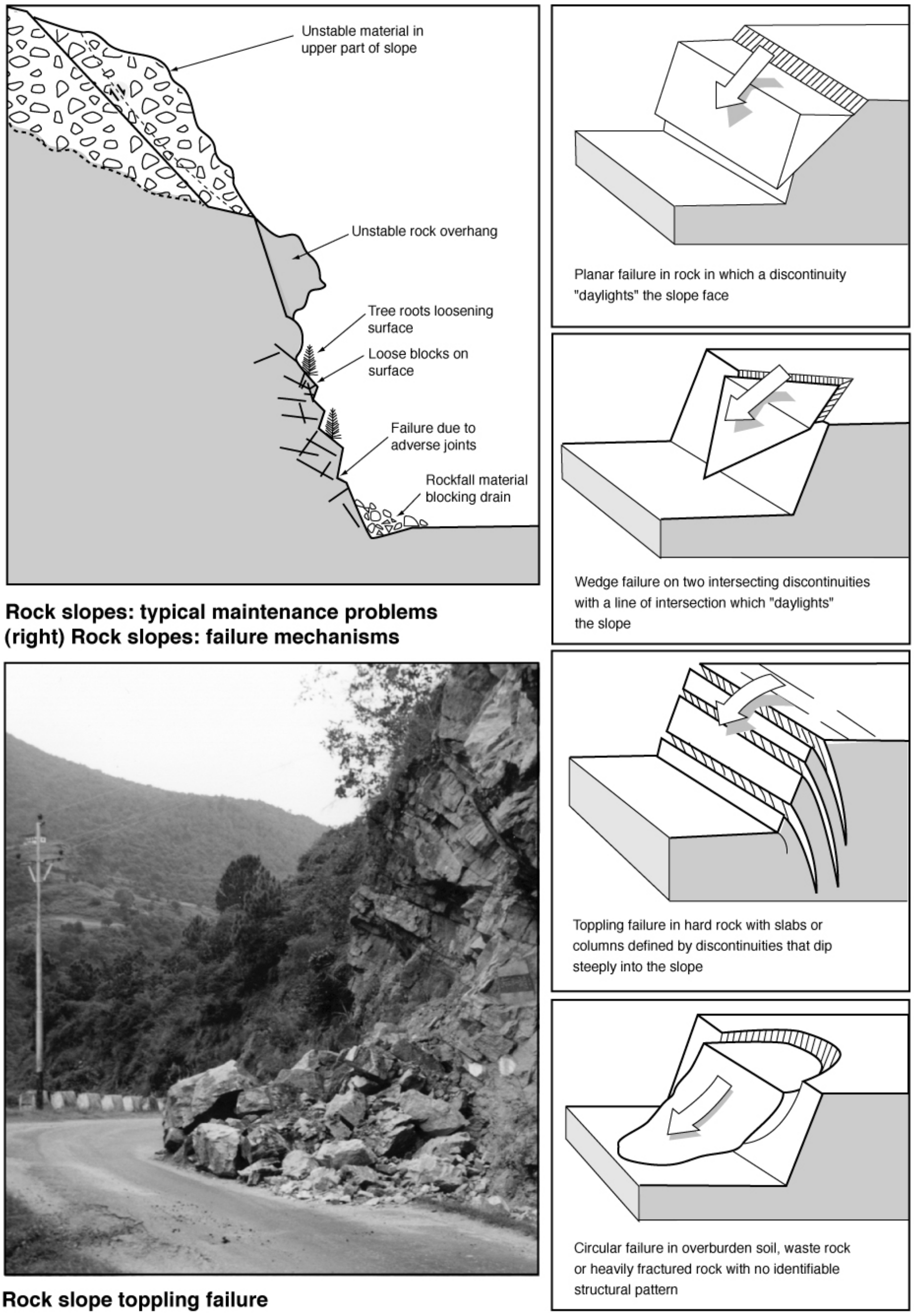
Typical rock slope instability is shown on Figure 2-9. In Laos, rockfalls occasionally occur and sometimes involve a significant amount of material (see Figure 2-8).

Figure 2-8: Rockfall on Road 18b

In the past, construction of some of the road network involved the use of bulk-blasting methods when encountering massive rock, rather than any form of pre-splitting, with the result that the final exposed rock face is highly fractured and weakened. This weakened face then has a high potential for ravelling and failure, particularly if the parent rock contains adverse joint orientations. Failure is most likely to occur during and immediately after periods of heavy rain, when the joints can be subjected to high water pressures.

In Laos the consequences of sporadic rock-fall type failures are usually relatively small; the small volume of rock usually being insufficient to cause total blockage of the road. Nonetheless, injury and death to the travelling public will always be a potential risk unless these slopes are cut back to stable angles or otherwise stabilised or protected.

Figure 2-9: Typical rock slope instability



Source: Hoek & Bray 1981

2.3 Walls

Typical wall stability problems are shown in Figure 2-10.

Figure 2-10: Walls: typical stability problems

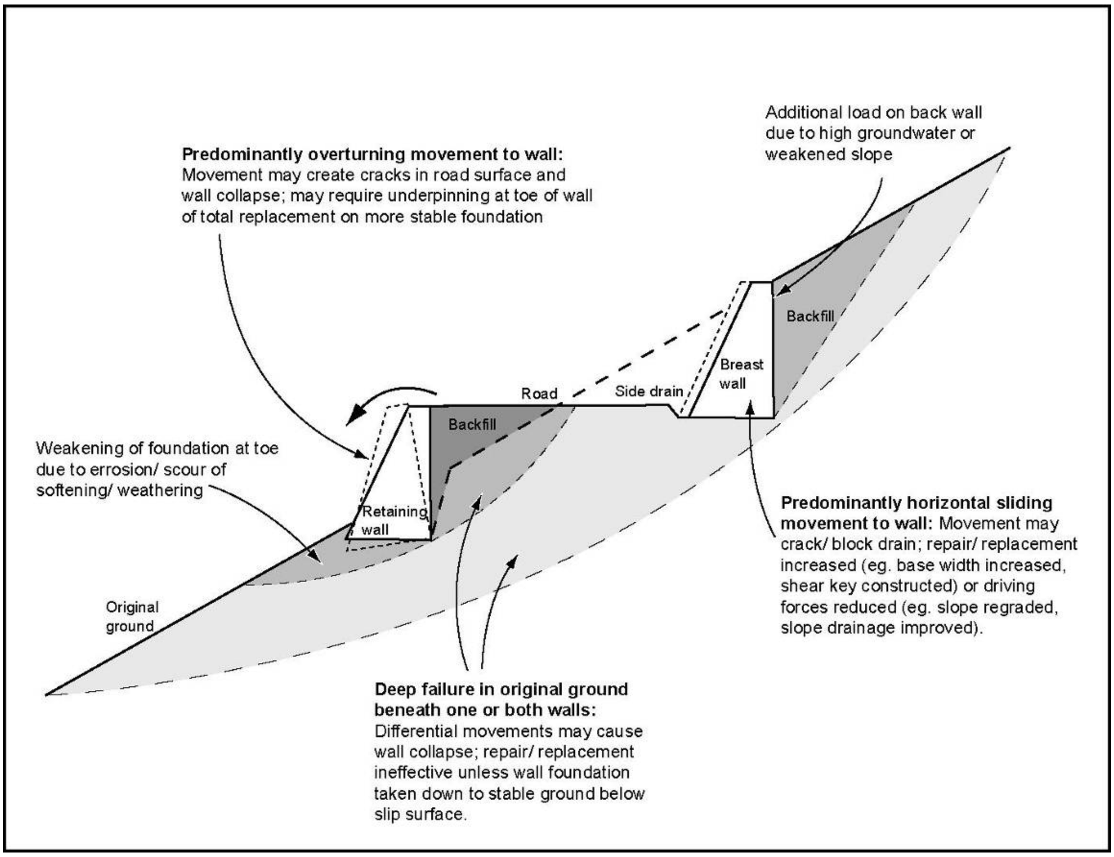


Figure 2-11: Failure of mortared masonry wall due to large scale slope movement

Most retaining walls in Laos that experience distress or failure, do so as a result of larger-scale slope movements rather than a structural deficiency of the walls themselves (see Figure 2-11). However, walls can also fail due to sliding and overturning, although these failure modes are more likely to occur to walls supporting the road than those located above, probably as a result of poor founding conditions (see Figure 2-12).

Figure 2-12: Gabion wall failure due to poor foundation[1]

Figure 2-13: Masonry wall failure due to scour[1]

Failure of road supporting retaining walls can also occur due to erosion taking place immediately at the toe of the wall, undermining the foundation (see Figure 2-13).

In situations where roads run close to rivers, road supporting retaining walls can fail after high flooding. This is caused by the soaking of the backfill during the high flood stage of the river. When the river level falls quickly, the excess hydrostatic pressure behind the wall due to the soaked backfill can cause the walls to fail in sliding and overturning (see Figure 2-14).

Figure 2-14: Failure following river flooding in front of wall[1]

[1] Illustration not from Laos

3. INSPECTION AND INVESTIGATION

3.1 Factors affecting slope and wall stability

Factors that need to be taken into account when undertaking road, slope and wall inspections and investigations are likely to include many of the following:

Topographical
- the steepness and shape of the slope
- the location of tension cracks and other signs of movement

Hydrological
- the presence of a river or stream at the base of the slope, particularly if this could cause toe erosion during periods of flood or high flow
- the presence of a drainage course at or above the crest of the slope
- any indications of a high or temporarily perched water table within the slope, e.g. seepages and springs.
- the effectiveness and condition of the existing drainage measures

Rainfall
- the pattern of rainfall in the immediate locality, particularly periods of prolonged and/or intense rainfall that could lead to saturation of the slope

Geological (particularly for rock slopes)
- rock type, weathering grade, jointing and fracture patterns
- presence of faults or shear zones
- the direction and angle of dip and joints in underlying bedrock compared to the angle and orientation to the slope, particularly if bedrock is exposed or is at a shallow depth beneath the surface, the persistence of the joints, the presence of clay filling
- the sequence of the underlying strata, particularly if this includes weak or impermeable layers

Geomorphological
- soil types and depths
- the presence of pre-existing landslides, the distribution of colluvial deposits and unstable/erodible soils

Land Use
- forest clearance and the extent and type of cultivation, particularly wet padi
- the presence of irrigation channels, ditches and water pipes
- excavations and fill slopes associated with commercial and residential developments adjacent to the road

3.2 Routine Inspections of Roadside Slopes and Structures

Inspections of slopes and off-road structures are additional to inspections of the road itself.

Slope problems are most likely to occur after periods of prolonged and heavy rainfall, and these are most likely to happen during the wet season between July and the end of September. Nonetheless, severe and localised rainfall can occur outside this period.

Routine inspections of roadside slopes, and stabilisation and drainage structures, should be carried out at least three times a year:
- shortly before the onset of the wet season, to check that any dry season’s repairs have been completed satisfactorily and that all high-risk locations have been tackled;
- during the wet season, to check that appropriate clearance and emergency stabilisation measures are being carried out; and
- immediately after the wet season, to ascertain the extent of damage and movement and to plan a programme of remedial work for the forthcoming dry season.

Emergency inspections must also be made as soon as landslides or road failures are reported.

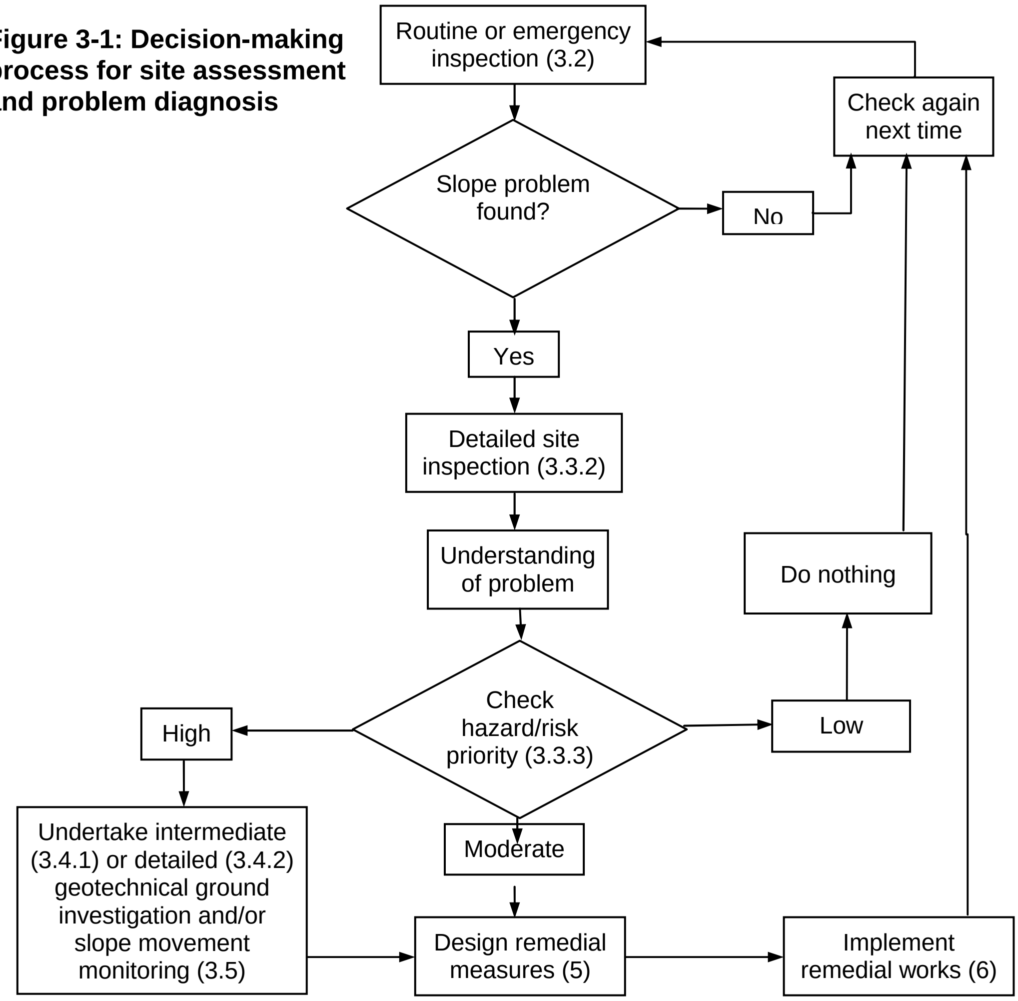
Routine inspections are usually undertaken by driving slowly along the road and stopping whenever potential problems are reached, although complete walkover inspections are preferred. These should concentrate on the following.

- Locations where slope problems have been reported.
- Locations where slope works have been undertaken recently.
- Anywhere there is any sign of disturbance or change to the roadside slopes or structures.

Inspections should also include off-road structures that cannot be easily seen from a vehicle, such as culvert outfalls and below the road retaining walls.

If an instability problem is detected, then a detailed site inspection must be undertaken. The process for this is covered in section 3.3. The decision-making process is given in Figure 3-1.

Figure 3-1: Decision-making process for site assessment and problem diagnosis



3.3 Detailed Site Inspections

3.3.1 Introduction

While a routine inspection is a rapid exercise to check the slopes along a length of road, a detailed site inspection is a special activity when a problem is found with a slope or structure. It involves a careful examination of a particular site, with the purpose of finding out what is wrong, so that the correct remedy can be decided on.

A detailed inspection (see 3.3.2) should therefore first be carried out on an identified problem site, to determine the cause and extent of the distress or failure, plus an assessment of its priority for remedial works (see 3.3.3) and a determination of the potential stabilisation measures that might be appropriate (see section 4). In many cases, the construction of these remedial works may be able to proceed with no further analysis, other than a site survey and the preparation of contract drawings.

However, if the failure is complex, the detailed site inspection may need to be followed by intermediate or detailed geotechnical ground investigations and stability analyses (see 3.4.1 and 3.4.2).

Investigations should preferably be carried out by an experienced civil engineer or engineering geologist, taking due account of the factors mentioned in 3.1. The main features of the distress or failure should be sketched with the aid of an abney level or clinometer (to measure slope angles) and tape measure or, in the case of larger or more complex failures, by topographic survey techniques.

For many of the smaller stability problems affecting the road network, a visual investigation may be appropriate given the steep topography and difficulty of access, the likely constraints on the availability of experienced staff and the lack of specialist equipment. However, the completion of the appropriate report forms (see 3.3.2) is strongly recommended.

3.3.2 Detailed Site Inspection procedure

Inspection Report Forms are given Appendix C at the back of this Manual and in the *Slope Maintenance Site Handbook*, section 5. These forms should be filled in as a matter of course, and will help to build up a database of the incidence of failure. However, the immediate objectives of the visual site investigation are to:

- determine the extent of the slope and/or wall problem;
- understand the mechanism(s) of movement.

A comprehensive procedure for landslide mapping is given in Appendix D. This is most likely to be of assistance to the user when assessing particularly large and complex failures.

The detailed site inspection should produce:

- a sketch map of the site and its surroundings; and
- notes on what seems to be happening and the reasons for the problem; and to
- decide upon the remedial measures required or the further investigations that are needed.

With this in place, it should be possible to reach a full diagnosis of the problem.

The aim of this, the second part of the detailed site inspection, is to determine exactly what is happening on the slope in terms of the possibilities shown in Figure 2-2. To assist in this process, Figure 3-2 lists the likely signs and engineering implications of each of the failure types.

Figure 3-2: Diagnosis of the slope instability problems shown in Figure 2-2

Problem	**Common evidence**	**Likely consequences**
Above the road		
Erosion of the cut slope surface	• Debris present in roadside drains. • Gullies have formed in the cut slope. • Signs of damage to the vegetation.	• Debris *will* block drains and adjacent carriageway and *may* damage the road surface. • Loss of mass on the cut slope *may* undermine the hill slope above and cause a failure.
Failure in cut slope only	• A cone of debris blocking the drain and extending on to the carriageway. • A landslide scar on the cut slope.	• Debris *will* block drains and *may* damage the road surface. • Water from the blocked drains *may* flow across the road and cause erosion down slope. • Traffic *will* be disrupted on at least one side of the road. • Loss of mass on the cut slope *may* undermine the hill slope above and cause a larger failure.
Failure in hill slope but above the cut slope	• Debris on or above the cut slope, possibly extending down as far as the side drain and road. • A landslide scar on the hill slope above the cut slope.	• Debris *may* block the side drain or cause damage and disruption to the road. • The cut slope *will* be surcharged by the additional weight of debris from above, and *may* fail as a result.
Failure in cut slope and hill slope	• Debris on the cut slope, probably extending into the side drain and road. • A landslide with the upper part of its scar on the hill slope and the lower part on the cut slope. • Entire failure of the slope above the road	• Debris *will* block drains and *may* damage the road surface. • Water from the blocked drains *may* flow across the road and cause erosion on the lower side. • Traffic *will* be disrupted on at least one side of the road. • The failure *may* block the road entirely.
Below the road		
Erosion of the fill slope surface	• Gullies have formed in the fill slope. • Signs of damage to the vegetation.	• If untreated, the erosion *may* cause a failure of the fill slope
Failure in fill slope only	• Tension cracks on the valley side of the road. • A landslide scar in the fill slope.	• The road *may* be partly or wholly cut off. • Traffic *may* be disrupted on at least one side of the road.
Failure in fill slope and original valley slope	• Tension cracks on the valley side of the road. • A landslide scar in the fill slope extending into the original ground beneath. • Evidence that the slope below and either side of the fill slope is moving (e.g. scars, tension cracks)	• Loss of mass on the slope *will* undermine the fill slope above and *may* cause a larger failure.
Failure in original valley slope but not in fill slope	• A landslide scar in the original hillside beneath the fill slope.	• Loss of mass on the slope *may* undermine the hill slope above and cause a larger failure.
Deep failure in the original ground underneath the road	• Indication that the entire road and possibly the slope above is failing	• The road *will* be damaged and *may* be partly or wholly cut. • Traffic *will* be disrupted.
Loss of support from below by river erosion	• Obvious active or periodic river scour.	• Loss of mass on the slope *may* undermine the hill slope above and cause a larger failure.

Note:

There may be more than one slope problem present.

3.3.3 Prioritisation by hazard and risk

Funds for the routine maintenance of the highway network are currently allocated on a per km basis. By contrast, funds for emergency restoration works (e.g. landslide clearance, slope stabilisation, wall construction) are allocated according to need, and may vary considerably from one Provincial Department to another. Since some locations will require much more urgent attention than others, how should the remedial works be prioritised?

Prioritisation normally requires an assessment of hazard and risk. However, for the purposes of this Manual, a simple approach is recommended. From the point of view of slope and wall instability, the term 'hazard' is taken to mean the probability that a slope or wall of a certain size will fail within a specified period and at a particular location, whereas 'risk' means the expected consequences of that failure in terms of loss of life or injury, damage to property or engineering structures, or disruption to economic activity. In the vast majority of cases, some movement of the slope or wall will have already occurred or is occurring (and hence the probability is equal to unity). As a result the main consideration will be that of the expected risk. The possible consequences for each type of failure given in Figure 3-2 need to be checked on the ground during the site investigation. Reference can then be made to Figure 3-3, which gives a suggested ranking.

Figure 3-3: Suggested remedial works risk ranking

Actual or expected consequences	**Risk ranking**				
	1	**2**	**3**	**4**	**5**
Road completely lost (or road subsidence greater than 1m) or occupied buildings damaged or destroyed	✓				
Road partially lost		✓			
Road completely blocked		✓			
Road subsidence less that 1 metre		✓			
Road partially blocked			✓		
Productive agricultural or forest land lost or destroyed				✓	
Walls damaged or slope drainage blocked or damaged				✓	
Roadside drainage damaged or blocked					✓
Continued erosion without destroying vegetation cover					✓
Ranking and priority					
1. Top priority, emergency measures required immediately; buildings may need to be evacuated. 2. High priority; realignment may be necessary. 3. Moderate priority, but some temporary remedial measures are required immediately, such as slip debris clearance, emergency road signing etc. 4. Low priority, but some actions are required quickly, such as slip debris clearance. 5. Least priority, but should be tackled as soon as possible under routine maintenance.					

In many cases the consequences will be known, since the slope will have already failed, the road blocked, or the wall collapsed. In others, the hazard may still need to be assessed, since although signs of distress will be apparent (i.e. location known), the precise timing of failure will be unknown. In these cases, engineering judgement will be necessary to determine whether the hazard is high or low. Figure 3-4 is intended to help in this determination.

Figure 3-4: Suggested hazard ranking

Hazard ranking	**Soil/highly weathered rock or colluvial slope**		**Rock slope, fresh to moderately weathered**		**Wall**
	Height (m)	Angle (deg)	Height (m)	Angle (deg)	Height (m)
High	> 15	> 35	> 12	> 70	> 8
Moderate	5-15	25-35	7-12	50-70	3-8
Low	< 5	< 25	< 7	< 50	< 3
Notes: For slopes, use height or angle to derive highest category Table based on average conditions					

Where failure has yet to occur but signs of distress are very apparent, it is suggested that high hazard slopes and walls are given moderate priority (Figure 3-3), with moderate and low hazard slopes and walls being given low priority. However, it is strongly recommended that all such slopes and walls are regularly monitored (see 3.5) to record and respond to rates and changes in the rates of movements.

The requirements for investigating the causes of distress and failure at a particular location and for deriving geotechnical design parameters for the remedial works will mainly depend on the magnitude and complexity of the problem. As an approximate guide, Figure 3-5 below gives suggested requirements.

Figure 3-5: Requirement for investigation

Risk/hazard priority	**Type of investigation**		
	Detailed site inspection only	Intermediate geotechnical investigation	Detailed geotechnical investigation
Risk rating from Figure 3.3			
1			✓
2		✓	
3	✓		
4	✓		
5	✓		
Hazard rating from Figure 3.4			
High			✓
Moderate		✓	
Low	✓		

3.4 Geotechnical Ground Investigations

3.4.1 Intermediate Ground Investigations

An intermediate investigation will include the completion of the relevant recommended Inspection Report Forms as well as one or more of the following.

Trial pitting

At the very least, the investigation of slope instability affecting the road network should include a shallow subsurface exploration using mechanical or manual methods. Due to the heterogeneity of the subsoils, exploration by trial pitting (rather than sinking boreholes) is often a more appropriate method of assessing the characteristics of the near-surface soils.

The limit of machine dug pitting is usually about 5 metres depending on the material. Great care must be taken when digging in unstable or waterlogged ground. Trial pitting is particularly useful to determine:

- the nature and composition of the near-surface soils
- foundation conditions for new walls
- the depth to shallow slip surfaces
- the presence of shallow water seepages

Probing

Probing can sometimes be used successfully to obtain an estimate of soil strength near the “starting” surface (existing ground or base of excavation). This is usually carried out by manually operated equipment, e.g. Mackintosh Probe or Dynamic Cone Penetrometer (DCP), but both are of limited use in gravelly or bouldery soils e.g. colluvium. Probably the most appropriate use of this type of equipment, but with the same limitation, is in the assessment of wall founding conditions at the base of an excavation (see 6.4.).

Figure 3-6: Dynamic Cone Penetrometer test

Figure 3-7: Site investigation using drill rigs

The basic principle of the DCP (Figure 3-6) is that the rate of penetration of a cone, when driven by a standard force, is inversely proportional to the strength of the material being penetrated. It comprises an 8 kg hammer freely falling a distance of 575 mm onto a rod attached to a hardened steel, 20-mm diameter, 60° cone. The number of blows per mm penetration is recorded. Continuous measurements can be made to a depth of 1.2 m. The equipment is relatively light and can be carried easily. Figure 6-2 gives an indication of foundation strength versus blows per mm.

The results of the trial pitting and probing must be properly recorded on appropriate logs or forms, with the test locations shown accurately on a plan as well as details of the ground levels at all the test locations, in accordance with standard site investigation practice.

Engineering Geological Mapping

Engineering geological mapping is usually very helpful in developing an understanding of the relationship between the failed area and the main geological features and an example is given in Figure 3.8. Further details on the mapping of land forms and geological structures can be found in most engineering geology textbooks.

3.4.2 Detailed Ground Investigations

A detailed investigation will include all the requirements for an intermediate investigation, together with the following.

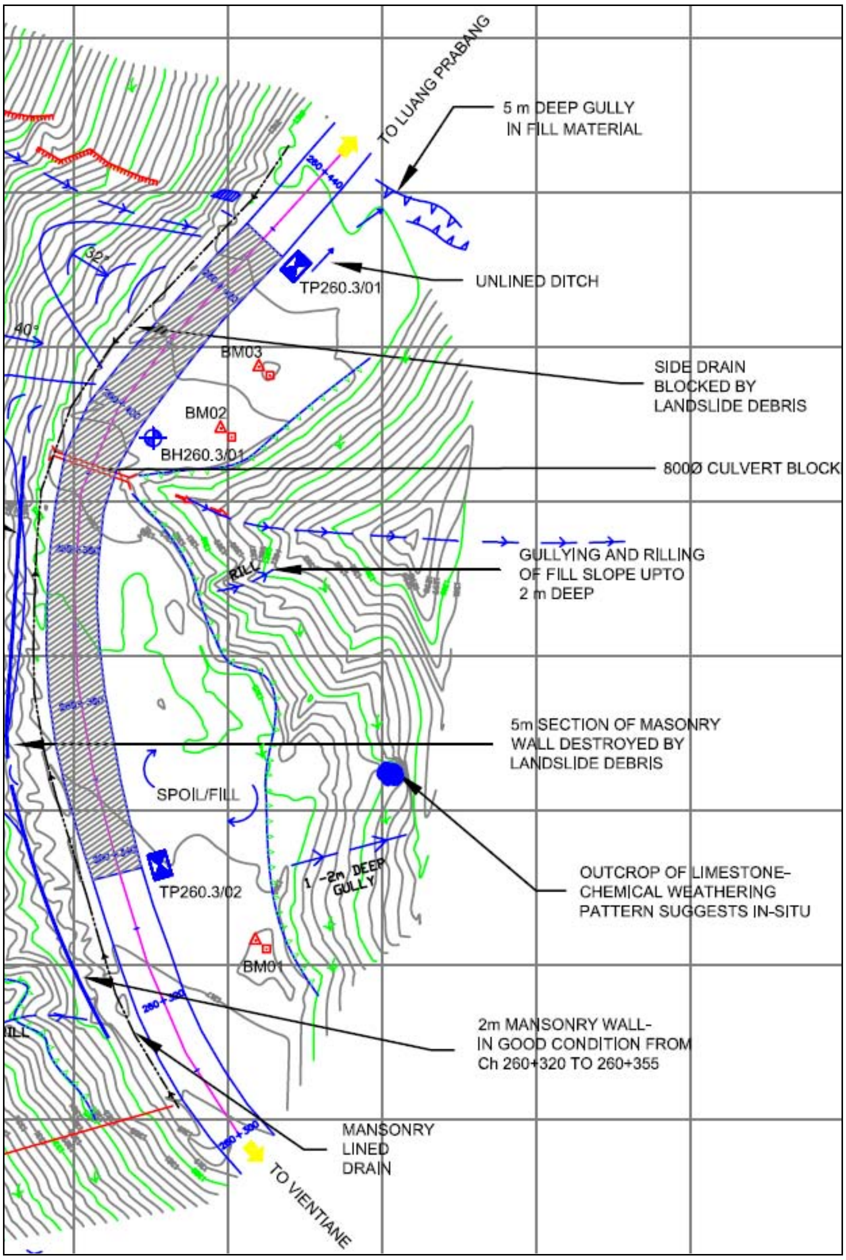
Drilling

Drilling or boring using a rotary or percussion rig is appropriate for investigations that are required to be too deep for trial pitting and where information on ground conditions at depth is critical to the design of high cost/risk structures, such as bridges and large retaining walls. In the context of the highway network, probably the most appropriate use of drilling equipment would be to carry out Standard Penetration Tests (SPT) in the overburden to obtain an approximate measure of the type of material and its strength, and to determine the depth to bedrock for founding purposes.

There are a few ground investigation firms in Laos that have the necessary drilling equipment. Careful consideration needs to be given to the problem of access to the proposed drillhole locations; the smaller type of rig usually being sled-mounted.

The results should be recorded on borehole logs prepared in accordance with recognised international standards.

Figure 3.8: Example of Engineering Geology Mapping



Laboratory testing

For the present, laboratory testing of soils for the investigation of slope and wall instability does not appear to be a regular feature of road maintenance activities in Laos. In some circumstances, it may be appropriate to carry out grading and classification tests to confirm soil types more closely, and possibly to estimate typical strength parameters; in other circumstances, where the costs of remedial works are likely to be high, it may be appropriate to carry out more sophisticated strength tests on undisturbed samples.

As noted earlier, the results of drilling and laboratory testing must be properly recorded in accordance with standard site investigation practice.

Geophysical testing

Geophysical testing methods may be appropriate to locate the depth below the ground surface to various underlying strata. There are two methods commonly used.

- Seismic refraction method. In this method a shock wave is generated by exploding a small charge or by striking a surface-mounted steel plate with a heavy hammer. The shock wave so generated is recorded by a number of geophones placed at intervals along the ground surface. By comparing the time taken for the shock wave to travel directly along the ground surface with the time taken for the shock wave to be refracted from the underlying layers, the depth to the underlying layer or layers can be determined.
- Electrical resistivity method. In this method, an electrical current is introduced into the ground and the electrical resistivities of the underlying layers are measured by an array of electrodes.

Both methods require specialist equipment and trained operators, and the interpretation of the data requires specialist skills. They can both give good results when the underlying strata are uniform and there are distinct changes in their properties. Interpretation can be very difficult when there are no distinct changes, where the upper layers contain a matrix of large boulders and soil, or where harder layers overlie weaker layers. However, geophysical surveys have been used in landslide studies in other countries where they have been successful in determining the depths to the slip surfaces and underlying bedrock. Geophysical testing usually requires associated boreholes for calibration.

3.5 Movement monitoring

Where total slope failure or wall collapse has yet to occur, it may be appropriate to set up a programme of movement monitoring, so that the magnitude and variation of movement with time can be determined (see Figure 3-9). The results of such a monitoring exercise can then be used to determine:

- if the movement is accelerating, and if so, whether it would be prudent to increase the prioritisation for remedial works; or
- if the movement is of such a small magnitude that remedial works can be postponed indefinitely.

Movements are most likely to occur during and after periods of prolonged and heavy rainfall (or during crop irrigation if that is the source of water initiating the movement). As a minimum, movement monitoring is therefore best carried out immediately prior to and after each wet season. However, in more serious cases, the frequency of monitoring may need to be increased substantially.

Slopes

Although sophisticated (and expensive) specialist equipment can be used to monitor such movements, the simple measures shown in Figure 3-9 are usually quite adequate.

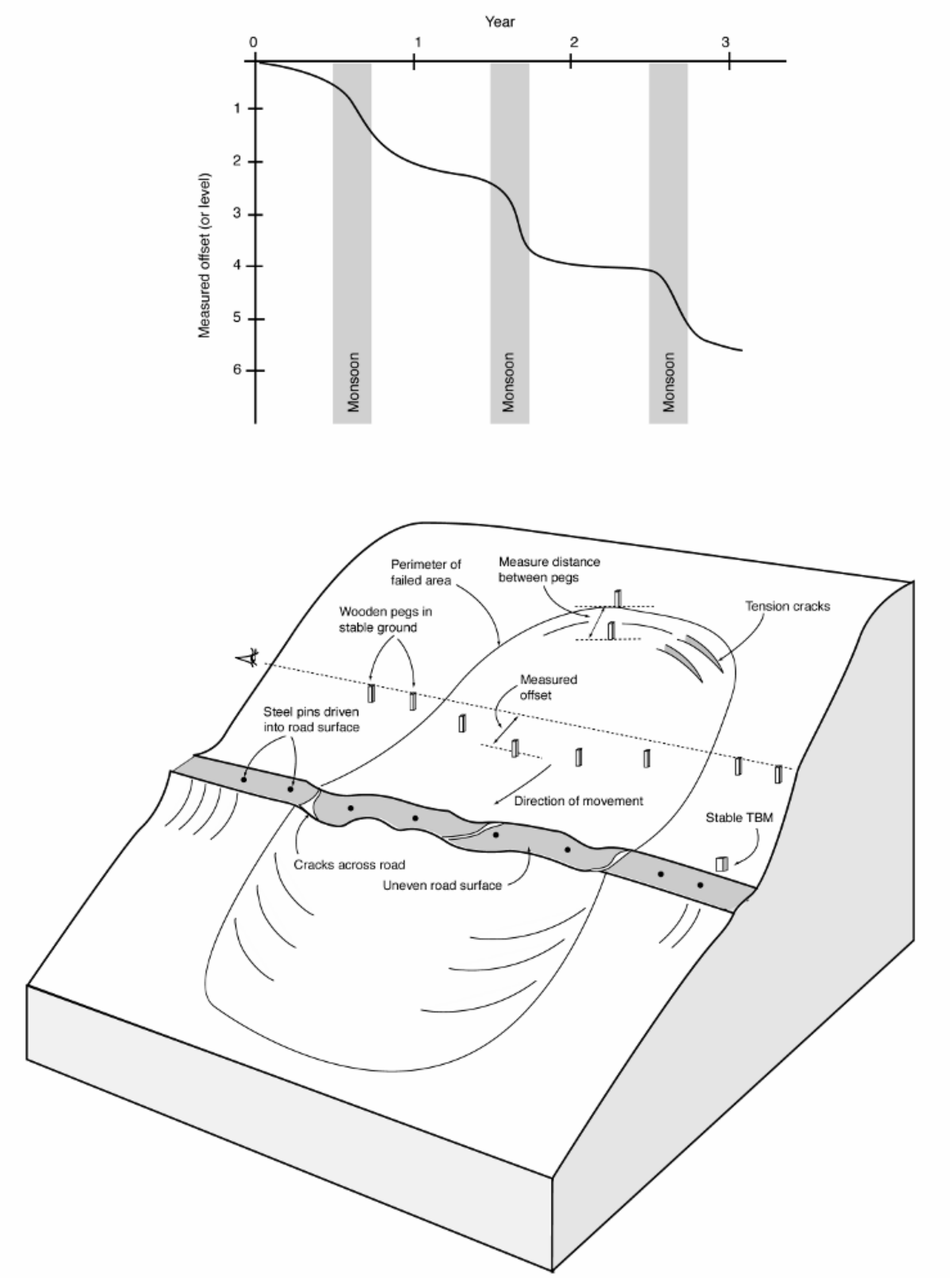
Slope movement monitoring can be carried out by driving a line of pegs or preferably stakes across the failed area and into stable ground on either side (see Figure 3-9). An observer then stands at one end of the line and observes the far end, whilst an assistant places a ranging rod beside each intermediate peg in turn. The ranging rod is then visually lined up, and the offset to the peg measured. However, the more common (and more accurate) method is to record the position of each peg using an electronic distance measuring (EDM) or total station survey instrument. Tension crack width at the crest can be monitored by driving pegs on either side of the crack and measuring the distance between them. For longer-term monitoring it is recommended that concrete monuments are used to discourage removal.

For 'sinking' areas (i.e. where the road itself is subsiding), steel pins can be driven into the road surface at intervals across the depressed length of road and into the stable areas on either side, and levels taken relative to a stable temporary bench mark.

Walls

With the exception of gabion walls, wall movements normally result in surface cracking or differential movements of construction joints. Movement monitoring should therefore be geared to the type of movement taking place, be it predominantly sliding, overturning, or settlement (see Figure 2-10). For the most part, simple measurements between pins or marks on the wall, or levels taken on horizontal surfaces, are all that is necessary so long as it is carried out in consistent manner.

Figure 3-9: Slope movement monitoring



4. DETERMINATION OF TREATMENT MEASURES

This section focuses mainly on slopes composed of soil or highly weathered rock (having many of the behavioural characteristics of soils), and on associated retaining walls. Consideration of rock slopes is given in section 4.7. The decision-making process in the determination of treatment measures is given in Figure 4-1.

4.1 Determination of remedial treatment for soil/weathered rock slopes

The detailed site inspection procedure (see 3.3.2), with or without ground investigations (see 3.4), reveals the nature of the problem that is faced. The specific forms of instability shown in Figure 2-2 have certain treatments that can be used to remedy them (see Figure 4-2). These take the following forms.

- Slope stabilisation. The arresting of structural and mass movements within a slope. In engineering terms this means either the reduction of driving forces (e.g. excess weight at the top of a section of slope) or the increase of resistance through an external force (e.g. a retaining wall).
- Slope protection. The prevention of surface degradation on a slope. This means strengthening the surface (e.g. with a rip-rap stone covering) or reducing the energy of runoff water (e.g. by interrupting flow with a vegetation cover).
- Slope drainage. The provision of either shallow drainage to remove mainly surface water or deeper drainage to remove mainly groundwater. This strengthens the slope by increasing the internal resistance (i.e. by reducing pore water pressures).

In addition to these, there are two other possible options.

- Avoid the instability, for example by realigning the road or removing an unstable slope mass (usually only possible for small volumes).
- Do nothing, or just keep the road open by regular clearance and repair operations. This can be the most cost-effective option on low traffic roads or on very large failures where continuing large scale instability is expected for several more years, and is beyond current economic justification.

Figure 4-3 provides the main possibilities for technical engineering solutions to slope instability. Some low-cost examples are shown schematically in Figure 4-4.

Slope stabilisation techniques seldom seen in Laos but worthy of consideration include:

- Slope drainage (see 4.4.3).
- Realignment. This is an expensive option, but sometimes the scale of the instability is such that the only practical option is to seek a new route elsewhere. However, it is still very important to establish the cause of the original instability so that the realignment truly avoids the problem, whether it be geological, topographical, or hydrological, in constructing the new length of road, and that the construction techniques themselves do not create further instability.
- Re-grading of slopes to a shallower angle. This is particularly applicable to existing cut slopes, but this is often impracticable. A shallower cut slope angle can result in a much higher cut face, a large volume of spoil to be disposed, and land acquisition issues. However, there may be locations that would benefit from re-grading, provided this was accompanied by bio-engineering techniques (see 4.6) to reduce surface erosion.
- Retaining wall construction other than in masonry or gabion (see 4.3).
- Construction using earth reinforcement techniques (see 4.3).
- Toe berm construction. This is effectively a toe embankment that acts as a buttress, preferably constructed using permeable materials such crushed rock, but weathered rock debris could be appropriate. However, a toe berm will occupy more space than a retaining wall and is rarely feasible in steep terrain.

The final selection is determined by feasibility, scale and cost. These issues are addressed in section 4.2.

Figure 4-1: Decision- making process for treatment measures

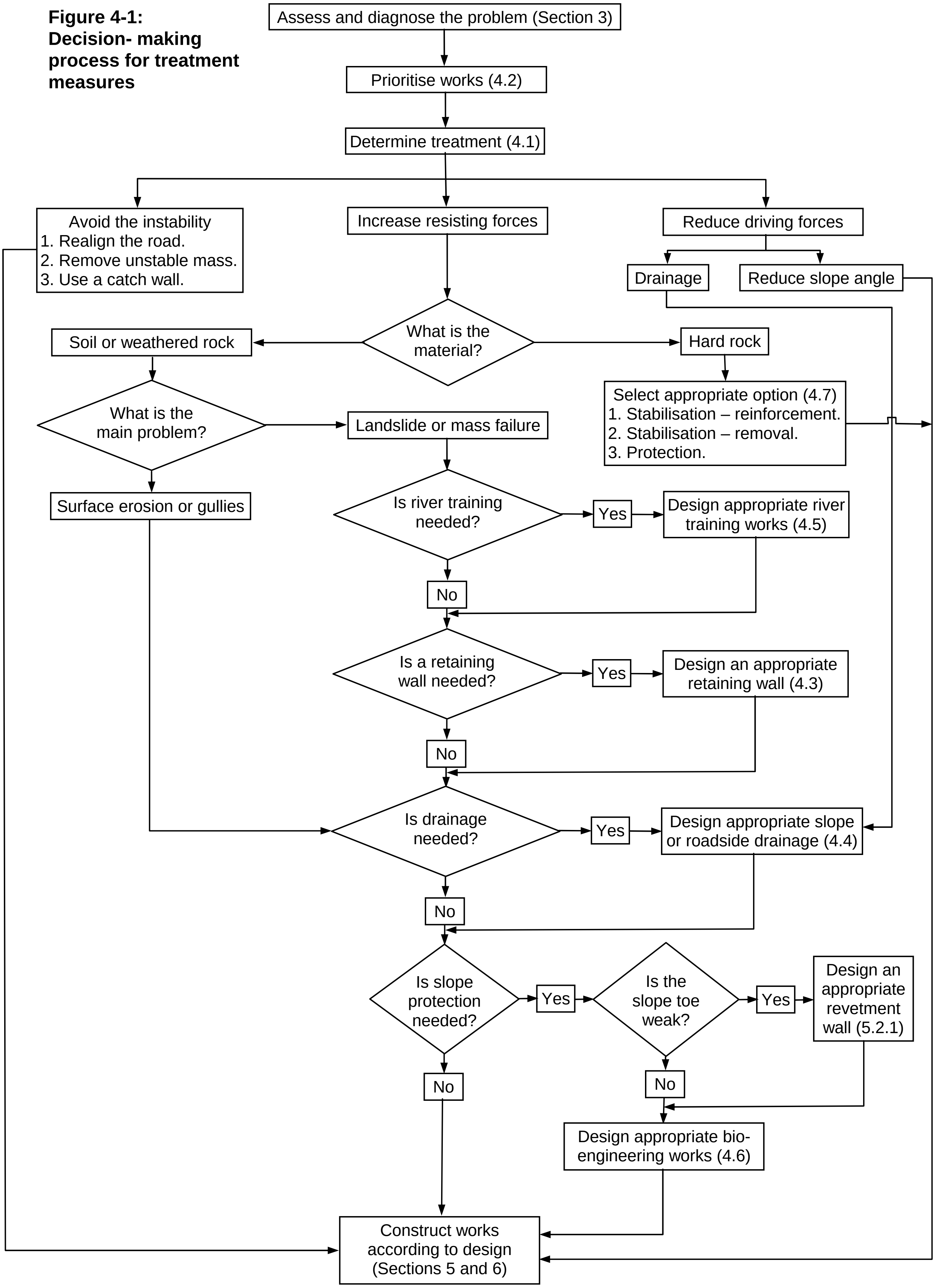


Figure 4-2: Engineering solutions for slope stability (excluding bio-engineering)

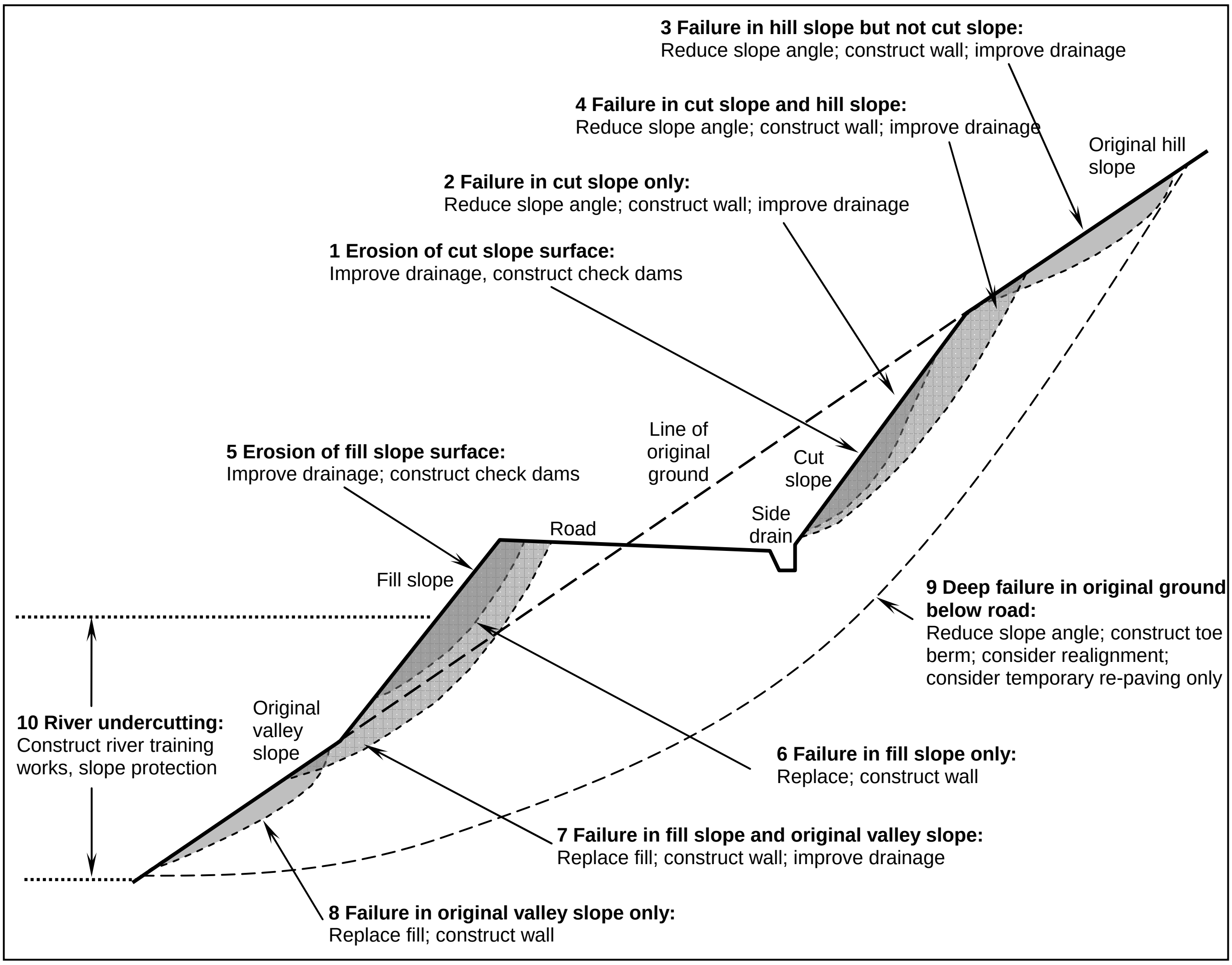


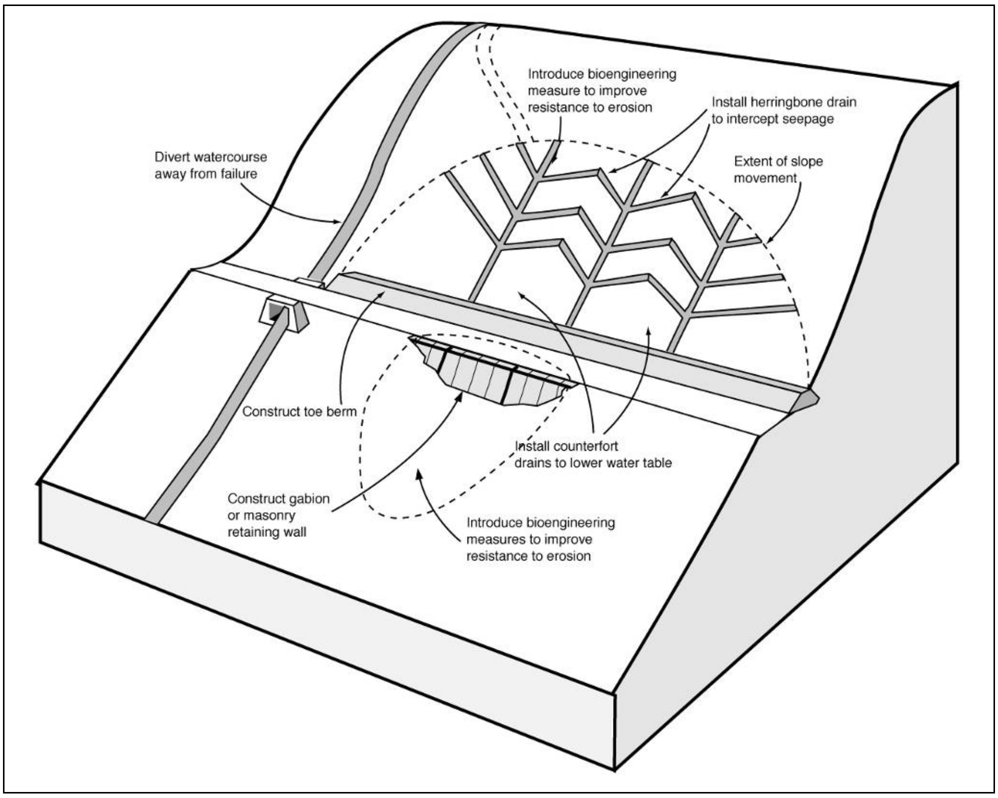
Figure 4-3: Technical treatment requirements for different failure types shown in Figure 4.2

Instability	Stabilisation options	Drainage options	Protection options
Above the road			
1 Erosion of the cut slope surface	• None.	• Usually none. • Occasionally a cut-off drain above the cut slope can reduce water runoff; however, these are difficult to maintain and can contribute to instability if blocked or otherwise disturbed.	• In most cases, bio-engineering is adequate, usually grass slip planting. • Where gullies are long or slopes are very steep, small check dams may be required. • Sometimes a revetment wall at the toe helps to protect the side drain.

Instability	**Stabilisation options**	**Drainage options**	**Protection options**
2 Failure in cut slope only	• Reduce the slope grade if this is feasible, then add erosion protection. • A retaining wall to retain the sliding mass. • For small sites where the failure is not expected to continue, a revetment might be adequate.	• A subsoil drain may be required behind a wall if there is evidence of water seepage. • Herringbone surface drains may be required if the slope drainage is impeded.	• Bio-engineering is usually important to prevent surface erosion and increase the resistance of the surface soil.
3 Failure in hill slope but not cut slope	• Reduce the slope grade if this is feasible, then add protection. • A retaining wall to support the sliding mass, as long as foundations can be found that do not surcharge or threaten the cut slope.	• A subsoil drain may be required behind a wall if there is evidence of water seepage. • Herringbone surface drains may be required if the slope drainage is impeded.	• Bio-engineering is usually important to prevent surface erosion and increase the resistance of the surface soil.
4 Failure in cut slope and hill slope	• Reduce the slope grade if this is feasible, then add protection. • A retaining wall to retain the sliding mass. This may need to be quite large, depending on the depth of the slip plane	• A subsoil drain may be required behind a wall if there is evidence of water seepage. • Herringbone surface drains may be required if the slope drainage is impeded..	• Bio-engineering is usually important to prevent surface erosion and increase the resistance of the surface soil.
Below the road			
5 Erosion of the fill slope surface	• None.	• Ensure roadside drainage is controlled.	• Bio-engineering is usually important to prevent surface erosion and increase the resistance of the surface soil.
6 Failure in fill slope only	• Re-grade or remove, replace and compact fill. • Before replacing fill, cut steps in original ground to act as key between fill and original ground. • A new road retaining wall may be the only option	• Ensure roadside drainage is controlled	• Bio-engineering is usually important to prevent surface erosion and increase the resistance of the surface soil.
7 Failure in fill slope and original valley slope	• Re-grade or remove, replace and compact fill. • Before replacing fill, cut steps in original ground to act as key between fill and original ground. • A new road retaining wall may be the only option	• Ensure roadside drainage is controlled.	• Bio-engineering is usually important to prevent surface erosion and increase the resistance of the surface soil.
8 Failure in original valley slope	• Re-grade if sufficient space between road and valley side. • A new road retaining wall may be the only option	• Ensure roadside drainage is controlled	• Bio-engineering is usually important to prevent surface erosion and increase the resistance of the surface soil.

Instability	Stabilisation options	Drainage options	Protection options
9 Deep failure in the original ground underneath the road	• Consider re-alignment of road away from instability • If slow moving, short-term option may be to re-pave or gravel the road.	• Ensure roadside drainage is controlled	• Bio-engineering is usually important to prevent surface erosion and increase the resistance of the surface soil.
10 Removal of support from below by river erosion	• May need extensive river training works to prevent further erosion.	• None.	• Slope protection (walls and rip-rap etc) may be necessary.

Figure 4-4: Examples of low cost soil/weathered rock slope stabilisation techniques



4.2 Works prioritisation and cost

In section 3, a scheme for classifying slope instability according to hazard and risk was proposed (see Figure 3-3). These factors can now be compared with cost. The aim should always be to maximise the use of resources so as to satisfy the following criteria:

- Safety of people living near the road and people using the road.
- Keeping the road open.
- Maintaining the best possible standard of road quality.

Because budgets are usually limited, it is frequently necessary to prioritise investments. In doing so, it may be useful to bear in mind the following considerations.

- The largest hazards that are the most expensive to remedy are not necessarily those that pose the highest risk.
- It may be best to concentrate spending on stabilising the slopes along the road, rather than on improving the road surface.
- Drainage structures, if they are required, should be given high priority, as they are usually very important in achieving stability.

The more common techniques for resolving slope instability are set out in Figure 4-5, against an indication of the potential cost implications. This is provided to assist the user in considering comparative costs, once the site inspections have identified the key stabilisation needs. Detailed analysis will make it possible to create initial estimates of the quantities of the different structures that are required, and from those to derive costed comparisons.

Figure 4-5: Soil/Weathered Rock Slope Stabilisation Techniques

Option	Implications
Avoid the instability	
Realign road	High cost; may create similar problems; slow to implement.
Completely or partially remove unstable material	Low cost; only feasible for minor, shallow slips; may create further instability.
Construct catch wall	Moderate cost: must be enough space so that the wall is capable of containing slip debris and access for clearance; slip may become more extensive upslope.
Reduce driving forces	
Reduce slope angle	Low cost; unlikely to be feasible in steep terrain, cut surface will need erosion protection.
Drain surface	Low cost; will only reduce surface infiltration, therefore combine with other techniques.
Drain sub-surface (see Table 4-6)	Moderate cost; assumes that the water table is above the slip surface; more effective when sliding mass is relatively permeable.
Increase resisting forces by application of an external force	
Construct retaining wall (see Figure 4-5)	Moderate cost; must be founded below slip surface; may need to be combined with other techniques.
Construct toe berm	Low cost; usually requires significant space at toe
Install anchors	High cost; specialist installation equipment needed, potential corrosion/monitoring problems.
Increase resisting forces by increasing internal strength	
Drain sub-surface (see Table 4-6)	Moderate cost; assumes that the water table is above the slip surface; more effective when sliding mass is relatively permeable.
Install soil nailing (see Figure 4-5)	High cost; specialist installation equipment needed.
Use bio-engineering (see 4.6 and 5.4)	Low cost; not suitable for very steep slopes and deep-seated failures.
Protect the surface	
Construct revetment or rip-rap	Moderate cost.
Use bio-engineering (see 4.6 and 5.4)	Low cost; not suitable for very steep slopes or hard, compacted soils.
River training works	Usually high cost, but only required in particular locations.

4.3 Determination of remedial treatment for walls

For the rehabilitation of an existing wall undergoing distress or even failure, there will only be a few circumstances, particularly in respect of masonry walls, where repair will be appropriate rather than total reconstruction, see Figure 4-6 below:

Figure 4-6: Recommended stabilisation measures for existing walls

Wall Type	Distress due to:	Recommended measure	Additional action
Masonry	Sliding	Redesign and reconstruct if wall becomes unserviceable	Determine cause of movement and, if appropriate, carry out measures to reduce load on wall (e.g. earthworks)
	Overturning		
	Differential movement	Reconstruct on stable foundation if movement due to bearing capacity failure	Wall may be redundant if movement due to deep-seated slip
Gabion	Sliding	Rebuild distressed gabion baskets if wall becomes unserviceable. Redesign may be necessary.	Determine cause of movement and, if appropriate, carry out measures to reduce load on wall (e.g. earthworks)
	Overturning		
	Differential movement		Wall may be redundant if movement due to deep-seated

			slip

In the majority of situations where slope failure has occurred, some form of structural retention will be required. Figures 4-7 and 4-8 give details of some retaining structures commonly used around the world.

Reinforced concrete walls have the advantage of being able to utilise tensile forces to provide resistance to movement and can therefore be designed to be much more slender than masonry walls. Where space is limited, this can be an important factor. However, such walls require the use of skilled labour, imported steel, mechanised equipment to produce crushed aggregate and quality concrete, and are costly. Their use may therefore often be difficult to justify in economic terms.

Figure 4-7: Features of Retaining Structures

System	Function	Type	Advantages	Limitations
Externally stabilised	Gravity walls	Masonry	Technique well known	Unable to accommodate movement without distress
		Mass Concrete	Simple to construct	Large quantities of concrete required
		Reinforced Concrete - Cantilever	Generally occupies less width	Requires reinforced concrete construction; good foundations; generally uneconomic above 8m height
		Reinforced Concrete - Counterfort	As above	As above, but can be constructed to greater heights
		Gabion	Technique well-known; can accommodate limited movement without distress; permeable	Moderate durability; not recommended as retaining walls below and immediately adjacent to paved road surface due to flexibility
		Crib	Attractive, environmentally-friendly appearance	Possible problems of durability if timber cribs are used
	In-situ walls	Sheet pile	Occupies very limited space, no temporary excavation works required	High cost; requires specialist installation equipment; impermeability may create problems
		Slurry walls		
		Bored-in-place piles		High cost; requires specialist installation equipment
Internally stabilised	Reinforced soil	Strips and grids	Can accommodate limited movement without distress; easy to construct	Occupies large space behind wall face
		Soil nailing	Used extensively when steepening existing cut slopes	Requires specialist installation equipment

Most retaining structures in Laos are constructed in masonry or gabion, since the construction techniques are well-known and are of relatively low cost. Of all the forms mentioned in Figure 4-7, probably the only other types worthy of consideration for use in Laos at the present time for standard applications are:

- crib walls. Provided a large number of walls were to be constructed, then a manufacturing operation for precasting concrete cribs could be set up, thus providing economies of scale. Crib walls have the advantage of being permeable, of having limited flexibility, are rapid to construct, and stocks could be held for emergency works. Alternatively the cribs could be made out of timber, but environmental and durability considerations may rule this out.
- anchored retaining walls. A special mention must be made about anchored retaining walls (Figure 4-9). Anchored walls have been constructed successfully in other countries on a number of road projects, either with composite reinforced concrete/gabion or with reinforced concrete walls. Situations can arise where the importance of the road and the instability problem are so great that a conventional solution is not appropriate. However, the main problem with anchored retaining walls is that not only do they require specialist installation equipment to install the anchors, but that the anchors themselves must be adequately protected against corrosion for the design life of the structure. More details are given in Section 5.
- Earth reinforced walls. Although these are used extensively around the world, they have rarely been used in Laos in the past. The most likely reasons for this are the need for technical

expertise and the need to import reinforcing strips or geogrids, the requirement for good compaction, and the difficulties in working in confined spaces and non-uniform sites. Earth reinforced walls utilising geogrids would appear to be a potential option for Laos, particularly for new road construction where the limitations on working space are not so stringent as those for existing roads.

- buttressed walls. Masonry buttressed walls have not been constructed in Laos, as far as is known (see Figure 4-9). They may be appropriate to provide additional support to a wall undergoing minor distress, provided a good founding layer can be located for the buttresses. They may also be designed to act as supports to reinforced concrete road slabs, thus providing additional road width in critical locations.

Figure 4-8: Some common forms of retaining structures

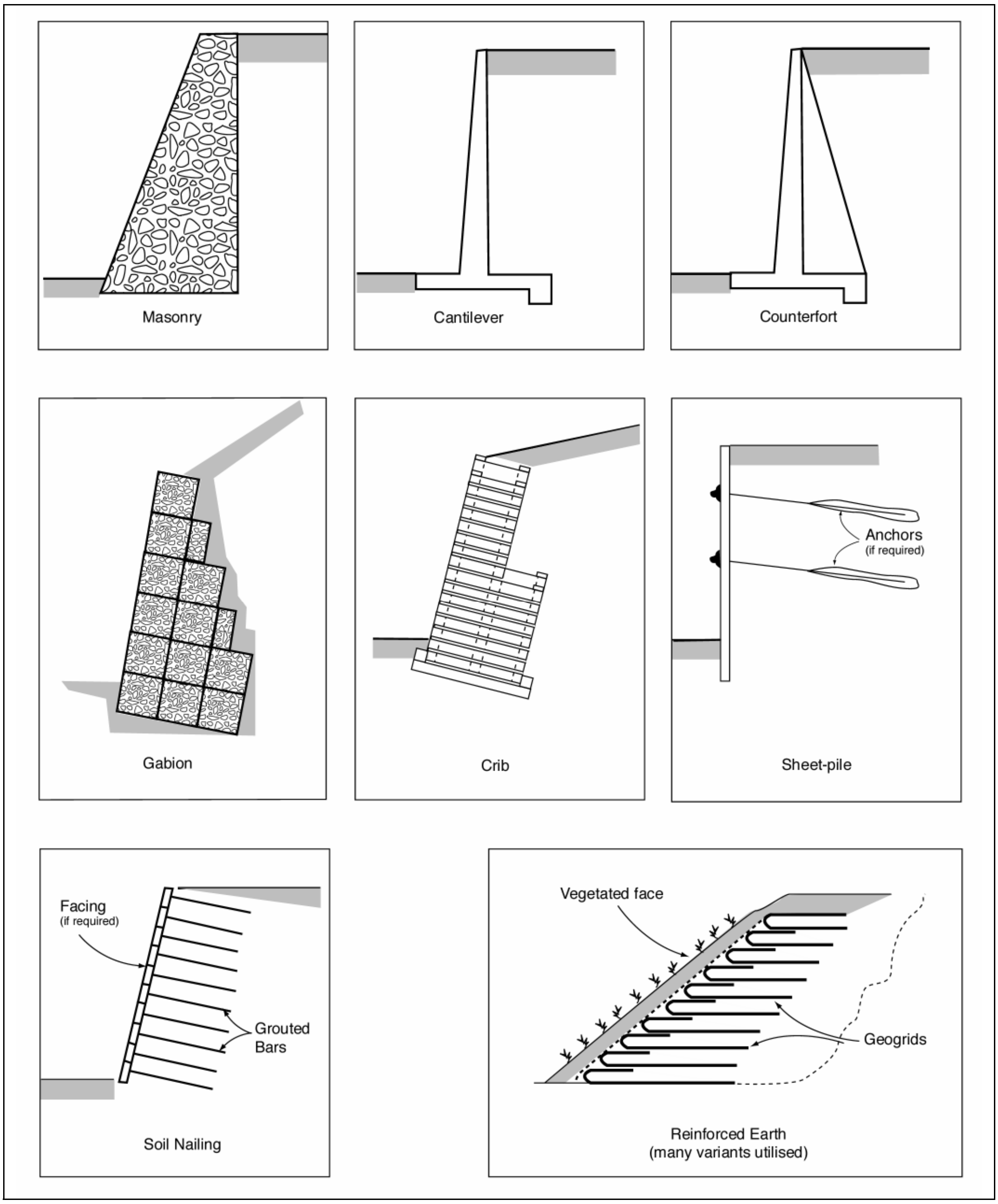
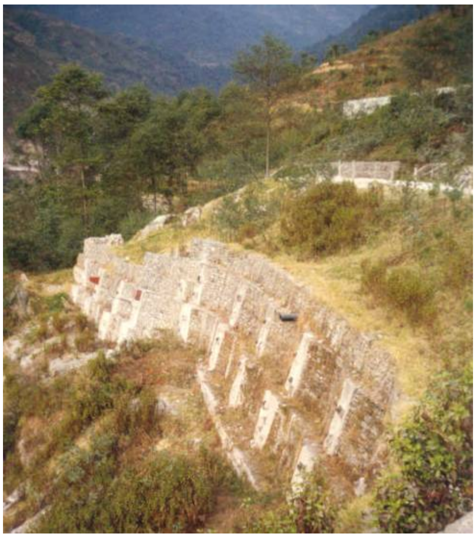


Figure 4.9: Examples of other wall types used in the region

Concrete Crib Wall

Anchored Wall



Buttressed mortared masonry wall

Buttressed masonry wall with reinforced concrete road slab

Revetments (see 5.3.5 and Figure 5-6) are not classified as retaining structures and have not been included here.

4.4 Drainage improvements

Since the principle cause of slope instability is the uncontrolled presence of water, a well-designed and properly functioning drainage system is of paramount importance.

4.4.1 Cross drainage

Conservation of the pre-existing drainage system is a prime goal in the successful design of new mountain roads, although this is an ideal that is never fully achieved. Since the road is effectively creating a barrier to natural surface drainage, it is important that adequate cross drainage is provided without unduly overloading the natural drainage courses and thus creating the conditions for excessive scour and erosion.

4.4.2 Roadside drainage

In common with most hillside roads, the crossfall of the main road network is generally towards the mountain side of the road, except where there would otherwise be an adverse crossfall at re-entrant bends. Continuous roadside drains on the mountain side of the road therefore collect most of the surface runoff, and these usually discharge into cross-drainage catchpits and culverts.

There are several types of roadside drain in use in Laos; unlined and lined, (see Figures 4-10 and 4-11).

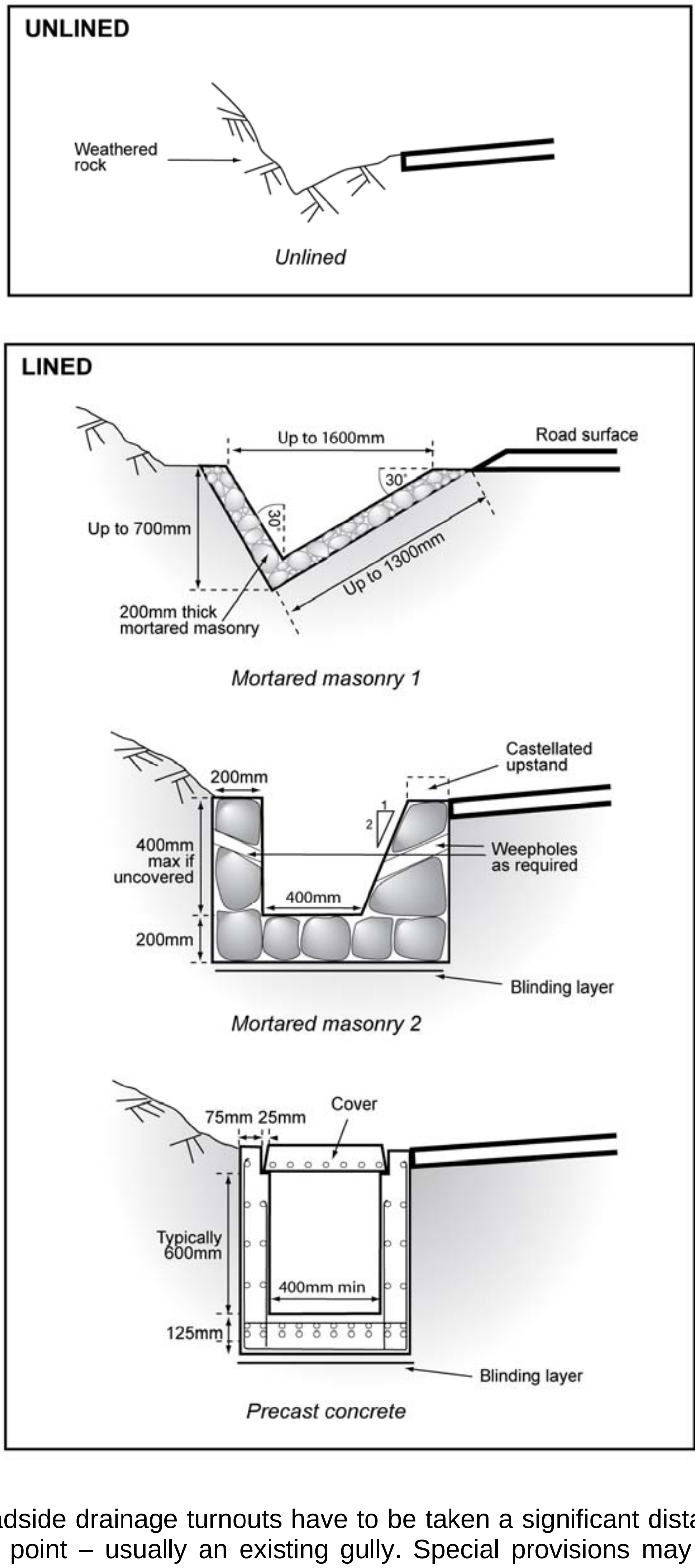
Figure 4-10: Roadside drains

Type	Construction	Advantage	Limitation
Unlined	Ditch	Inexpensive	Use only on flat gradients unless invert in erosion resistant material, e.g. rock
Lined	Dry stone masonry (V-shaped)	Relatively inexpensive	Permeable; roadside wall often unable to take traffic load
	Mortared masonry	Impermeable; high capacity; roadside wall better able to withstand traffic load	Invert must be well constructed to reduce potential for cracking, leakage and erosion
	In situ concrete	As above; strong; easier to clean	More costly; walls sometimes in mortared masonry, invert sometimes reinforced in soft ground
	Precast concrete	Quality and workmanship easier to control, very strong	Expensive; requires mechanical aid for handling, careful attention to laying and joints

- Unlined drains. These are particularly common where the longitudinal gradient of the road is shallow, or where the drainage invert is erosion resistant (e.g. rock). In the vast majority of cases, these drains work quite satisfactorily and present no risk to slope stability, although in some cases their permeable invert can promote infiltration into an existing or potentially sliding mass, and this needs to be considered in selecting these drains. It is recommended, however, that wherever a slope remedial works are undertaken and an unlined roadside drain is present, consideration be given to constructing a lining throughout the affected length of road. In this manner, any seepage from the drain into the potentially unstable area can be minimised.

- Lined drains. These are normally constructed in mortared masonry and concrete, and less commonly in dry-stone masonry. Trapezoidal or U-shaped lined drains are usually located in urban areas and sometimes in areas where the road has a gradient greater than 5% (Figure 4-10). They have the advantage of a greater flow capacity, but the disadvantage of presenting a potential traffic hazard. This hazard can be reduced by introducing an upstand (with openings at maximum 1m intervals) or a heavy-duty cover. However, whilst withstanding traffic loading, the cover must also be designed to be capable of being lifted by hand. The base of the U is preferably flat-bottomed with a minimum width of 400mm to ease the task of manual clearing, and a maximum uncovered depth of 450mm (although a depth of 300mm is often preferred for traffic safety reasons). In rural areas, V-shaped drains are common.

Figure 4-11: Roadside drainage



At hairpin bends, roadside drainage turnouts have to be taken a significant distance from the road to a suitable discharge point – usually an existing gully. Special provisions may be necessary at the discharge point to prevent undue erosion (e.g. check dam, apron).

Where the crossfall of the road is directed to the valley side, or where the gradient of the road is such that concentrated runoff is likely to occur along the edge of the valley side shoulder, then in the absence of a standard roadside drain it is recommended that a small kerb be constructed along the edge of the road pavement (see Figure 4-12). This is often important when the road crosses re-entrants, to avoid scour occurring at the ends of retaining walls as shown in Figure 4-13. Openings or lined discharge points can then be constructed at suitable intervals.

Figure 4-12: Kerb to road edge

Figure 4-13: Erosion adjacent to wall

4.4.3 Slope drainage

Figure 4-14: Slope drainage

Function	Type	Advantage	Limitation
Interception of surface run-off above slope	Unlined cut-off drain	Inexpensive	May create line of instability beyond crest; may be prone to erosion; usually not maintained
	Lined cut-off drain	Less prone to erosion and leakage	Requires frequent inspection for damage/blockage; inspection access may be difficult
Interception of surface runoff on slope	Slope surface drain	Less prone to leakage	Rigid mortared masonry construction incapable of withstanding small movements
	Branch drain	Inexpensive. Often used with bio-engineering	Dry stone pitching less rigid than slope surface drain
Interception of high/perched water table	Herringbone drain	Able to intercept water up to approx 1.5m depth below slope face; good for intercepting surface seepage or springs; can accommodate some slope movement	May only have limited effect on overall slope stability for deep-seated failures
	Counterfort drain	Able to intercept water up to 3-4m depth below slope face; can act as a stabilising buttress if base below slip surface	Usually needs to be machine dug; difficult to construct in bouldery material
Interception of deep water table	Horizontal drain	Only feasible method of intercepting groundwater at depth	Comparatively costly; drilling equipment required; may not always be successful
Diversion or improvement of watercourse or gully	Lined channel or Cascade	May be necessary if existing watercourse is direct cause of instability	Usually very expensive and often difficult to construct. If diverted, may overload new watercourse.
Reduction of erosion in gully	Check dam	Relatively cheap, often necessary below culvert outlets	Effective only for a limited length of gully in steep terrain

As detailed in Section 5, one of the most important factors to take into account in the design of stabilisation measures is water. Failures inevitably occur due to the unwanted presence of water and, if this cannot be properly controlled, then other stabilisation measures may well prove to be ineffective. Slope stability analyses can be performed using an assumed groundwater table following the installation of drainage, but it may prove to be prudent, following construction, to check that the drawdown assumptions are correct, and if not, to introduce further drainage measures (see Figure 4-14):

- Cut-off Drain. Two typical types of cut-off drains are shown on Figure 4-15. In the context of slope stability and erosion control, cut-off drains are sometimes used to reduce surface runoff at the crest of a cut slope or slope failure. In order to reduce the likelihood of continuing slope movements breaching the drain, they are sometimes located many tens of metres above the failure crest. More robust cut-off drains can be constructed, but they can become very costly. The problem with cut-off drains is that unless they are regularly maintained, they can create their own instability problem (e.g. due to a blockage or breach). Since they are usually situated in relatively inaccessible locations and cannot be seen from the road, maintenance is easily forgotten. On balance, it is not recommended that cut-off drains be constructed unless regular maintenance can be assured.
- Slope surface drain and branch drain. Often used with bio-engineering to control surface erosion, but the former in particular should only be used on stable slope surfaces (see Appendix E, Drawing 005).
- Herringbone drain. Herringbone (or chevron) drains are constructed herringbone fashion on slope faces to collect surface seepages and surface runoff (Figure 4-15). They are often quite shallow (about 1m deep), but can be much deeper. In order to function as intended, it is recommended that the upslope face is lined with a geotextile, that the lower face and invert is lined with heavy-duty polythene, and that the drain itself is filled with free-draining gravel. Care needs to be taken to ensure that the construction of the drain does not lead to further instability, and to ensure that the drain can still function in the event of minor downslope movements. In the event of large anticipated flows a perforated high-density polypropylene pipe may be necessary at the base of the drain (see also Appendix E, Drawing 005).
- Counterfort Drain. Counterfort drains are used to depress a high water-table. These drains are constructed at right angles to the toe of the slope and are often dug to a depth of 3 metres or more at intervals of 3-10 metres depending on the permeability of the subsoil. Ideally the sides should be lined with a geotextile and the invert with polythene. A perforated high-density polypropylene pipe is likely to be necessary for large flows.
- Horizontal Drain. Horizontal drains are used to intercept groundwater and seepage at depth. They require the use of plastic pipes and specialist drilling equipment that may not always be available, and they are not easy to install. The drains usually comprise minimum 40mm diameter polyethylene pipes up to 40 metres long (but usually less) installed in fan-shaped pre-drilled holes inclined 5° upwards. The pipes are perforated and wrapped in a geotextile to reduce the likelihood of clogging. In theory if not in practice, they should be capable of being flushed with water and eventual removal and renewal. The biggest problem with this type of drain is that it is costly to install and not always successful unless the subsoils are very permeable or it intercepts a seepage path. Additionally, it is only able to cope with very minor continuing slope movements. Although there are situations where such drains perform very successfully, in general they are not recommended for use on the road network except in conjunction with other measures at major landslide sites.
- Lined Channel or Cascade. Although really beyond the scope of this manual, lined channels or cascades are likely to be necessary if a watercourse or gully is a direct cause of the instability in the first place. A lined channel may be necessary to divert an existing watercourse from the failed area, or to train the watercourse within defined limits. The lining itself may be impermeable (mortared masonry and/or concrete) or permeable (gabion). The structure may comprise cascades, chutes (see Figure 4-16) and check dams (see below). As a general rule, gabion structures are preferred since they are flexible and allow water ingress provided they are located below the wet season groundwater table. Check dams. Check dams are necessary where undue scour would otherwise occur from the stream flow of water. They are often particularly necessary in eroding gullies and below valley side retaining walls where an earlier failure has created a preferred drainage path.
- Check dams are preferably constructed in gabion and must be properly keyed into the gully sides. The extremities should be raised at least 250 mm to minimise the possibility of end scour. The dams should be backfilled, and an apron or mattress provided at the toe to dissipate the flow energy.

Figure 4-15: Slope drainage

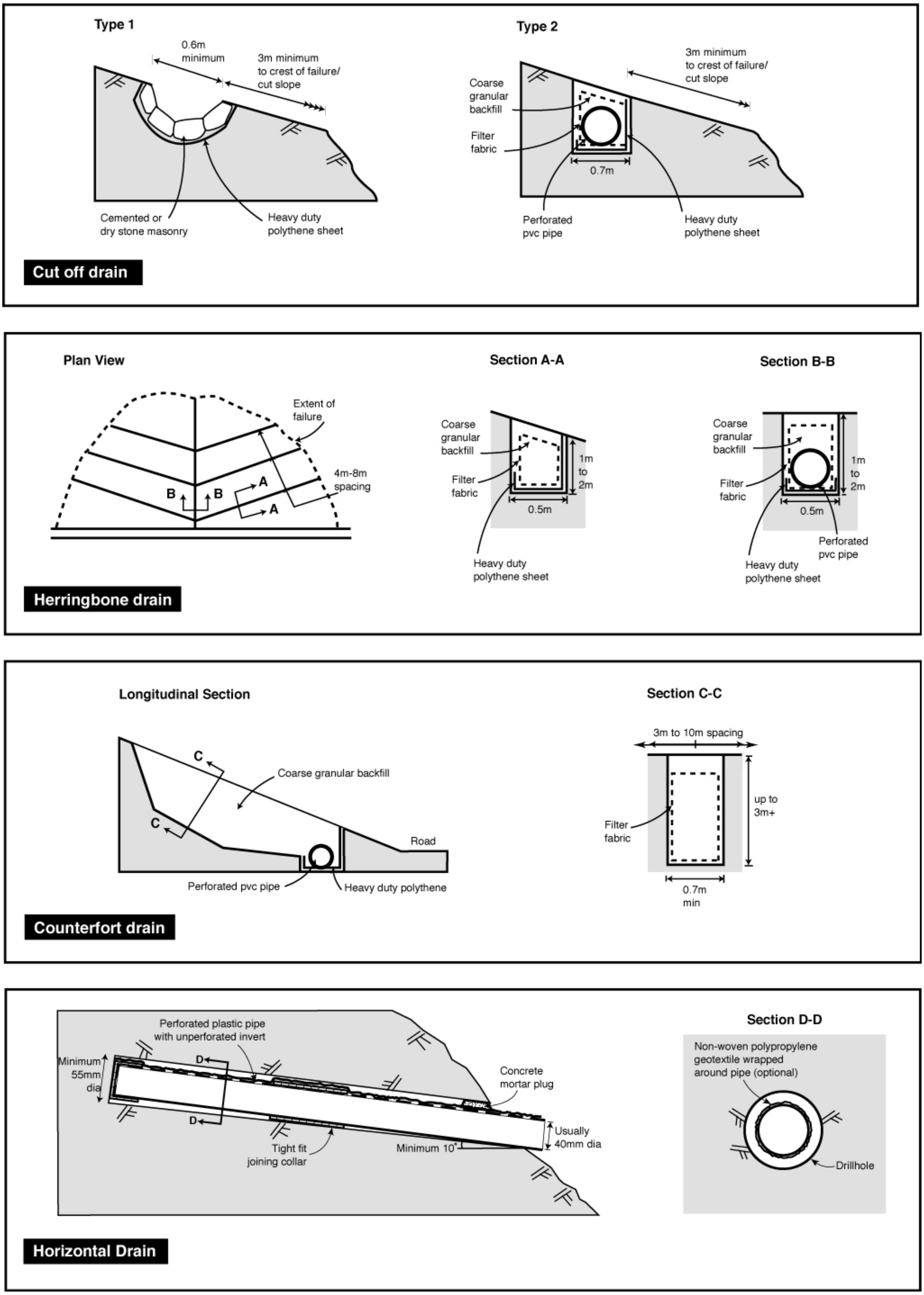


Figure 4-16. Typical gabion chute

4.5 River Training and Scour Protection

The scour to river banks and valley side slopes in streams and rivers can be an important factor in triggering landslides on adjacent slopes. Scour takes place either through down-cutting or lateral erosion, both of which tend to steepen adjacent slopes and remove support to the hillsides above. Roads located on these hillsides become vulnerable to the development of landslides triggered by these processes. Scour protection is therefore a key factor in the prevention or control of landslides on lower valley side slopes.

The ideal properties of materials used for riverbank protection are:

- flexibility
- free draining
- durability
- easily repaired or replaced
- provide protection in all seasons.

Other important factors in the choice of material include:

- cost
- performance
- safety
- environmental impact
- appearance.

Not all materials can provide all the desirable properties and the choice is driven by circumstances, cost, the location and nature of the stream and river channels to be protected. Some of the materials in common use are described below. A filter or geotextile is essential for several of the methods in order to prevent the migration of fines from backfill and adjacent slope materials.

Rip-Rap

Rip-rap is a layer of heavy stone which protects the softer materials of the riverbed and bank from eroding. The stone must be heavy enough so that it is not moved by the water flow. Therefore heavier stone is required for faster flow velocities. It should be laid over a filter material or a geotextile to protect the underlying material.

Rip-rap has all the required properties and advantages over most other materials in many circumstances because:

- it is flexible and as a mass is not impaired by slight movements resulting from settlement
- local damage is easily repaired
- no special equipment or construction practices are necessary
- appearance is natural
- additional thickness can be provided at the toe to offset possible scour
- vegetation will often grow through the rocks, or may be planted to do so

The major disadvantage of rip-rap is that over time there is often a loss of stone by washing away and this must be replenished. Also where flow velocity is high, large size stone is needed which can be difficult to quarry and transport and makes the protection layer very thick.

Numerous guidelines, charts and specifications have been produced for the selection of the stone size for rip-rap. These all require estimation of the flow velocity so the designer must obtain this from direct measurement or calculation.

Gabions

Gabions are stone filled wire baskets (see also 5.2.2 and 6.3) constructed as a wall, groyne, surface covering or other form of barrier to river scour (Figure 4.17). In most instances however, gabions are used as walls for river bank protection (see Appendix E). Gabions must always be laid over a filter, geotextile filter fabrics are best.

Figure 4-17. Typical gabion river training works

Gabions have all the required properties, very similar to rip rap with the possible exception of durability and size:

- they are flexible and their effectiveness is not impaired by slight movement resulting from settlement
- local damage is easily repaired
- no special equipment or construction practices are necessary
- appearance is natural
- a gabion apron or mattress can be provided at the toe to offset possible scour
- vegetation will often grow through the gabions, or may be planted to do so

Gabions have additional advantages over rip-rap because the wire basket holds the stones together:

- preventing it being moved away by water velocity
- ensuring the desired thickness of protection at all times by preventing loss of stone

For a given level of protection a layer of gabions is about only 40% of the thickness of the equivalent layer of rip-rap. This gives a saving in real cost. Also there is a significant benefit in terms of environment and sustainability in that less quarried stone is required.

A gabion basket is made of steel wire mesh in a rectangular box shape (see Appendix E, Drawing 008). It is strengthened in the corners by heavier wire and by mesh diaphragms that divide it into compartments. The wire is galvanised, and sometimes PVC coated for greater durability.

The baskets usually have a double twisted hexagonal mesh. This is important because it allows the gabion to deform without the box breaking or losing its strength.

There are two distinct types of gabions with two different uses:

- gabion boxes are the heavier more rigid form with larger stones used in bank protection walls, stiff aprons and such like, usually 1.0 metre high boxes are used but sometimes 500 mm boxes are used for rigid aprons.
- gabion mattresses are thinner using smaller stones and mesh and therefore more flexible so that they will fold down to protect scour holes, for this purpose the maximum thickness is 300 mm.

The size of stone is important, small stones which can fall through the mesh must not be used. Too large stones must not be used in mattresses because they will reduce flexibility.

There is sometimes confusion over this terminology when 500 mm boxes used as aprons are referred to as mattresses. The definitions above are the correct generic terms.

One disadvantage of gabions is that high bed loads can damage the wire, but this is only usually a problem in upland watercourses where sediment transported is of a large size. Measures to protect the gabions include mastic grouting (which retains some flexibility) or facing with concrete (used on Road 11 where gabions are founded on rock).

In many riverside locations, the key issue is the potential under-scour of the gabion structures. Mattresses and aprons can assist in protecting the wall foundation but it may be necessary to take additional steps, such as much deeper foundations and foundation strengthening with concrete where practicable. A typical application is shown in Appendix E, Drawing 008.

Mortared masonry

This common and popular method of protection can work well in road drains but is in general totally unsuitable for use in natural rivers and difficult flood conditions. This is because it lacks two of the required properties: it is rigid and difficult to drain, and will fail from the toe unless protected.

It is important to understand the problem of drainage. During a flood the ground behind the slope protection becomes saturated with water. When the water on the river side drops, water must be allowed to drain from behind the wall through a filter layer and weep hole (drainage pipes). But such drainage is seldom properly provided, and even when it is it will tend to block up over time. If back drainage is poor there will be a high hydrostatic force pushing outwards from behind the lining, which can literally blow apart, as is illustrated in Figure 2-14.

Concrete

Concrete protection can be formed of mass or reinforced concrete. They have the same disadvantages as mortared masonry except that the concrete is much stronger and will accommodate minor failure but still protect the slope. It can be used for bank slopes and river walls, provided that the toe is adequately protected against scour and that there is effective back drainage.

4.6 Determination of bio-engineering techniques

Role of vegetation in engineering

Bio-engineering is the use of plants to undertake light engineering tasks. Certain types of plant, arranged in particular configurations, can be used to control erosion and reduce the likelihood of shallow landslides.

Bio-engineering techniques provide cost effective methods of surface protection for soil slopes. This is achieved through providing a surface cover of vegetation that armours the surface against erosion. Different types of plants and planting materials give rise to a variety of rooting patterns, with the result that the surface layer of soil will be bound together and have its resistance to deformation increased.

The poor predictability of vegetation growth means that it cannot be guaranteed to provide an immediate solution. Furthermore, there are situations in which vegetation can actually reduce slope stability if used wrongly. As a result of this, the following general rules should be adopted.

- Trees should not be allowed to grow to more than 10 metres in height, or large bamboo clumps permitted to grow, on steep or fragile slope areas. This means that these big plants are appropriate in the following locations: (a) on slopes of less than 1V:1.5H; (b) in the bottom 2 metres of slopes steeper than 1V:1.5H; or (c) more than 5 metres from the top of slopes steeper than 1V:1.5H.
- Maintaining a line of large trees or bamboo clumps at the base of a slope can help to buttress the slope and reduce undercutting by small streams.
- Grasses that form large, dense clumps generally provide the most robust slope protection in tropical areas where rainfall can be particularly intense. This type of plant is usually best for erosion control. However, most grasses will not grow under the shade of a tree canopy.
- Shrubs (i.e. woody plants with multiple stems) and small trees (i.e. woody plants with single stems) can often be grown from cuttings taken from their branches. Plants propagated by this method tend to produce a mass of fine, strong roots. These are often better for soil reinforcement than the natural rooting systems developed from a seedling of the same plant.
- In most cases the establishment of a full vegetation cover on unconsolidated fill slopes can be achieved in one to two wet seasons.
- Likewise, in most cases the establishment of a full vegetation cover on undisturbed cut slopes in residual soil may take 3 to 5 wet seasons. Less stony and more permeable soils will have faster plant growth rates, and drier locations will lead to slower rates.
- There is no single species or technique that can resolve all slope protection problems.
- Plant roots cannot be expected to contribute to soil reinforcement below a depth of 500 mm.
- Plants cannot be expected to reduce soil moisture significantly at the critical periods of intense and prolonged rainfall when they are most likely to fail.
- Grazing by large numbers of domestic animals can devastate a planted site if it occurs before the plants are properly established.
- Once established, plants are flexible and robust. They can recover from significant levels of damage (e.g. flooding and debris deposition) although this may not occur fully until the following wet season.

These rules do not avoid the lack of predictability that is the drawback in engineering designs. There are numerous published studies world-wide that show how stability analysis can be adapted to incorporate vegetation, but they generally assume “average” growth. In reality, the growth on any particular site is rarely comparable. This is because the numerous environmental factors either cannot be assessed readily (e.g. soil nutrition and rooting conditions) or are fully variable over time (e.g. rainfall and temperature). For these reasons, plant growth remains dependent on indeterminable factors. These are counteracted to some extent by using the most robust species available in a locality, and by using experience to predict likely growth characteristics on different sites.

The practical approach that has to be adopted, therefore, is that:

- the stabilisation and drainage of a slope need to be addressed first; and

- bio-engineering measures need to be designed to protect surfaces in ways that enhance the stability and drainage of the slope.

In many cases the structural integrity of a slope is already good enough, and so the only works required are protection through bio-engineering with only minor additional physical engineering details.

Figure 4-18: Typical bio-engineering measures to prevent surface erosion

The techniques recommended in this Manual are chosen so that they will always improve slope stability and, in certain situations, enhance drainage as well. For this reason, it is “safe” for them to be added to any other design of slope treatment.

Technique selection

Bio-engineering measures have been used in many parts of the world. As a result, there are numerous methods, adapted to different environments and specific site requirements. Only some of these are appropriate to roadside slopes in Laos, since others have been developed for wholly different environments, such as old colluvial Alpine slopes or river banks in North America. The incorporation of natural elements means that greater care must be taken in adapting methods from one place to another than with purely physical engineering measures.

Figure 4-19 summarises the available techniques that have already been introduced to Laos and tested in field trials. Between them they provide a range of options that allows slope protection works to be undertaken in all situations found in the road network.

Figure 4-19: Bio-engineering techniques appropriate to Laos

Technique	What it offers	Limitations
Recommended techniques		
Grass planting: rooted slips of	• The best and quickest way to	• Requires a slope with at least

Technique	What it offers	Limitations
large grasses are planted in lines across a soil slope. Slips are made by splitting out the clumps to give a small section of both root and shoot. Lines are usually horizontal or diagonal, depending on material.	create a surface vegetation cover on a bare slope. • Effective on almost all soil slopes up to 2V:1H. • Robust protection and shallow reinforcement of the surface soil.	30% soil. • Slow to establish on rocky cut slopes. • Where contour lines are used on less permeable materials, slowed runoff can increase infiltration to cause shallow slumping. • Where diagonal lines are used on very weak, non-cohesive materials, small rills may develop.
Direct seeding: the seeds of shrubs and small trees are inserted into crevices in slopes composed of moderately weathered rock.	• The best way to establish vegetation on rocky slopes.	• Slow to provide a coverage good enough to resist erosion.
Brush layers: woody cuttings from shrubs or small trees are laid in shallow trenches across slopes formed in unconsolidated debris. These can be installed on slopes up to about 1V:1.25H.	• Instant physical barrier that interrupts runoff. As the plants root and grow, they provide strong protection and soil reinforcement. • Stronger than grass. • Often successful on stony debris, however loose. • Most shrubs will tolerate some shade, so this method can often be used under tree canopies where grasses will not grow.	• Can only be installed on slopes of 1V:1.25H or less, on unconsolidated materials. • Construction causes considerable disturbance to the slope.
Fascines: bundles of long woody cuttings are laid in shallow trenches across slopes formed in unconsolidated debris. These can be installed on slopes up to about 1V:1.25H. After burial in the trenches, they put out roots and shoots, forming a strong line of vegetation. It is sometimes called live contour wattling.	• Provide surface protection and shallow root reinforcement. Once established, they can also catch debris. • In certain locations, fascines can be angled to provide drainage.	• Brush layers are quicker and easier to construct than fascines. • Can only be installed on slopes of 1V:1.25H or less, on unconsolidated materials. • Construction causes considerable disturbance to the slope.
Palisades: woody cuttings are planted in lines across the slope, usually following the contour. This can be done on a wide range of sites up to about 1.75V:1H.	• Form an immediate barrier that traps small debris moving down the slope; after some time, a small terrace will develop. • Less disturbance to the slope than brush layers, so they can be installed on steeper slopes. • In certain locations, palisades can be angled to act as drains.	• Materials that are poorly drained and are subject to high rates of small-scale slumping should be avoided. • Not as strong as brush layers.
Truncheon cuttings: big woody cuttings from trees are inserted upright at intervals in slopes formed in deep or poorly stabilised and unconsolidated debris.	• Relatively strong plant material on slopes that are still unstable. • Withstand damage from moving debris.	• Takes a long time to establish a complete cover. • Needs a lot of planting material.
Live check dams: small check dams with structural elements made from the woody cuttings of trees are placed at intervals in erosion gullies.	• Low cost, flexible structures to reduce erosion where water flow is concentrated. • Relatively limited disturbance to the slope, particularly on weak, unconsolidated materials.	• Not as strong as check dams of gabion or masonry. • Require careful supervision.
Tree planting: potted seedlings from a forest nursery are planted at intervals across a soil slope.	• Restoration of a forest mix of trees in the long term.	• Takes a relatively long time (5 years or more) to contribute significantly to slope strengthening or establish a complete cover. • Seedlings are vulnerable to grazing, so care and protection are required in the first 3 years.

Technique	What it offers	Limitations
Large bamboo planting: a section of the stem and root of a large bamboo is planted, usually at the base of a slope, a stream bank or above a river training wall. It is about 2 metres in length and has to be excavated from the mother clump carefully.	• Large bamboos support the base of a slope or strengthen river banks by installing a very strong line of plants. Once they are well established, they are highly flexible, immovable barriers. • With their multiple stems, they catch debris moving down the slope.	• Bamboos take about 5 years to contribute significantly to slope strengthening. • Cannot be used in hot, dry sites, since most bamboos require cool, moist sites. • Bamboos planted in steep upper slope situations develop deep roots slowly and so are prone to slumping some years (7 or more) after planting.
Other techniques		
Random grass planting: grass slips are planted at random, usually with a specified number of plants per square metre. This is usually in association with a temporary geogrid surface covering.	• Rapidly forms a strong and complete surface covering. As with the other grass systems, the roots provide strengthening to the surface soil layers.	• This should not be used where the specific erosion control or structural advantages of line planting patterns are important.
Downslope grass lines of planted slips: grass slips are planted in lines running straight down the line of maximum slope.	• This arrangement provides the maximum amount of surface drainage by channelling runoff and minimising infiltration. • It still protects against erosion and reinforces the surface.	• In drier sites, grass plants can suffer from drought due to the increased drainage. • On some weak materials, rills can develop down the side of the plant line, damaging the grass slips and reducing their growth.
Grass seeding: seeds of grass plants are spread across a soil slope. On slopes steeper than about 1V:1.5H, a mulch or other temporary surface covering is usually required.	• Creates an even cover over bare slope surfaces. • Fully protects and reinforces slopes after a few years of growth. Reinforcement depends on the character of the plant used.	• This technique gives none of the structural advantages of grass slip planting. • Plants take longer to develop from seeds than from slips. • Very heavy rain in the days immediately after sowing can lead to seeds being washed off the slope, or to damage to the very small seedlings.
Vegetated stone pitching: stone pitching is where small rocks are hand-laid to protect a soil slope surface; they can be vegetated by inserting grass slips or woody cuttings between them.	• A very strong surface protection in gully beds or other locations where periodic water flows may occur. • Stronger than purely dry stone pitching but more flexible than if the pitching is mortared.	• Relatively more costly than other forms of surface protection.
Geotextile coverings: permeable coverings are spread on the surface and used as an aid to starting vegetation growth. These may be of natural fibres (e.g. jute or coir) or synthetic (e.g. proprietary products such as *Enkamat* or *Terramesh*).	• Immediate surface covering to reduce erosion while vegetation gets established. • Some types help vegetation to establish, allowing bio-engineering to be undertaken on very harsh or very steep slopes.	• A significantly greater cost than simply using vegetation. • It can be hard to place geotextiles on uneven ground, and specialist supervision is needed. • Some coverings can lead to worse problems in some situations.
Wattle fences: fences made of woven branches or bamboos are used to retain small volumes of debris, forming mini terraces.	• A rapid temporary measure on slopes with loose surface debris.	• Only a temporary measure, as the vegetation does not grow but gradually degrades. • Wattle fences built in the dry season are liable to collapse in the wet season, when the pressure from retained debris increases.

Technique	What it offers	Limitations
Hydro-seeding: a mixture of seeds, binder, mulch and fertiliser is sprayed on to the slope surface. Various proprietary systems are available.	• Rapid surface covering of vegetation over large areas.	• Highly capital intensive, relying on imported machinery and supplies, and specialist skills. Therefore greatly more expensive than hand-planted works. • Seed mixes of locally appropriate species can be difficult to obtain. • Adhesion of spray material can be poor on steep roadside cuts under intense tropical rainfall, leading to incomplete coverage. • Some systems using thick mulch applications lead to a shallow discontinuity in the rooting structure, leading to rapid early plant growth, followed by a sudden decline or shallow mass failure.

4.7 Rock slope stabilisation

The usual techniques of stabilising an otherwise unstable rock slope are detailed in Figure 4-20 and illustrated in Figure 4-21.

Major expenditure on rock slope stabilisation on the road network Laos is rarely economically justified except for the busiest roads. However, low-cost techniques worthy of consideration include:

- buttresses. These can be constructed in masonry and are likely to be appropriate where cavities are formed in the exposed face previously occupied by blocks that have fallen out. They may help to prevent further degradation and instability of intermediate weathered strata. Where they are designed to support larger rock masses then concrete buttresses will be necessary.
- scaling. Although this is a labour-intensive operation and may require workers using ropes secured at the crest of the rock face, it can very effectively reduce the incidence of ravelling and spalling.
- catch ditch. A very inexpensive method of reducing the incidence of rock falls blocking the road, although space considerations rarely permit this.
- mesh. Usually used in conjunction with scaling to prevent further ravelled and spalled material from reaching the road. Purpose-made mesh is normally utilised.
- barriers. These can range from chain link fences to large gabion catch walls, depending on the size and quantity of potentially unstable material. However, space limitations may be a limiting factor in the construction and maintenance of these structures.

Figure 4-20: Rock slope stabilisation techniques

Requirement	Technique	Where?	Limitation
Stabilisation - Reinforcement	Rock bolting	Any potentially unstable block that can be bolted and tensioned back to stable material	High cost; installation using specialist equipment; long term corrosion/creep problems
	Dowels	Any potentially unstable block that can be kept in place by passive dowel	Use usually restricted to blocks 1-2m thick
	Tied-back walls	Where multiple rock bolting is required to provide load spread	Same as for rock bolting
	Shotcrete	Closely fractured or degradeable rock face	Specialist equipment required
	Buttresses	Cavity on rock face	Potential access problems
	Drainage	Any rock face where water pressures in fissures create instability	Drilling equipment necessary for drain holes
Stabilisation – Removal	Resloping	Instability at crest of rock face	Potential access problems
	Trimming	Overhangs	Controlled blasting techniques required
	Scaling	Loose rock on surface	Labour intensive; potential access and safety problems
Protection	Catch Ditch	Base of slope where space permits	Shape of ditch dependent on height and slope of rock face
	Mesh	Loose/weak rock on surface	Will not retain major blocks; good anchorage required at top of face
	Barrier	Base of slope where space permits	Needs to be robust to halt movement onto road
	Shelter	At base of high unstable face where other measures not feasible	High cost
	Tunnel	If relocation only solution	High cost

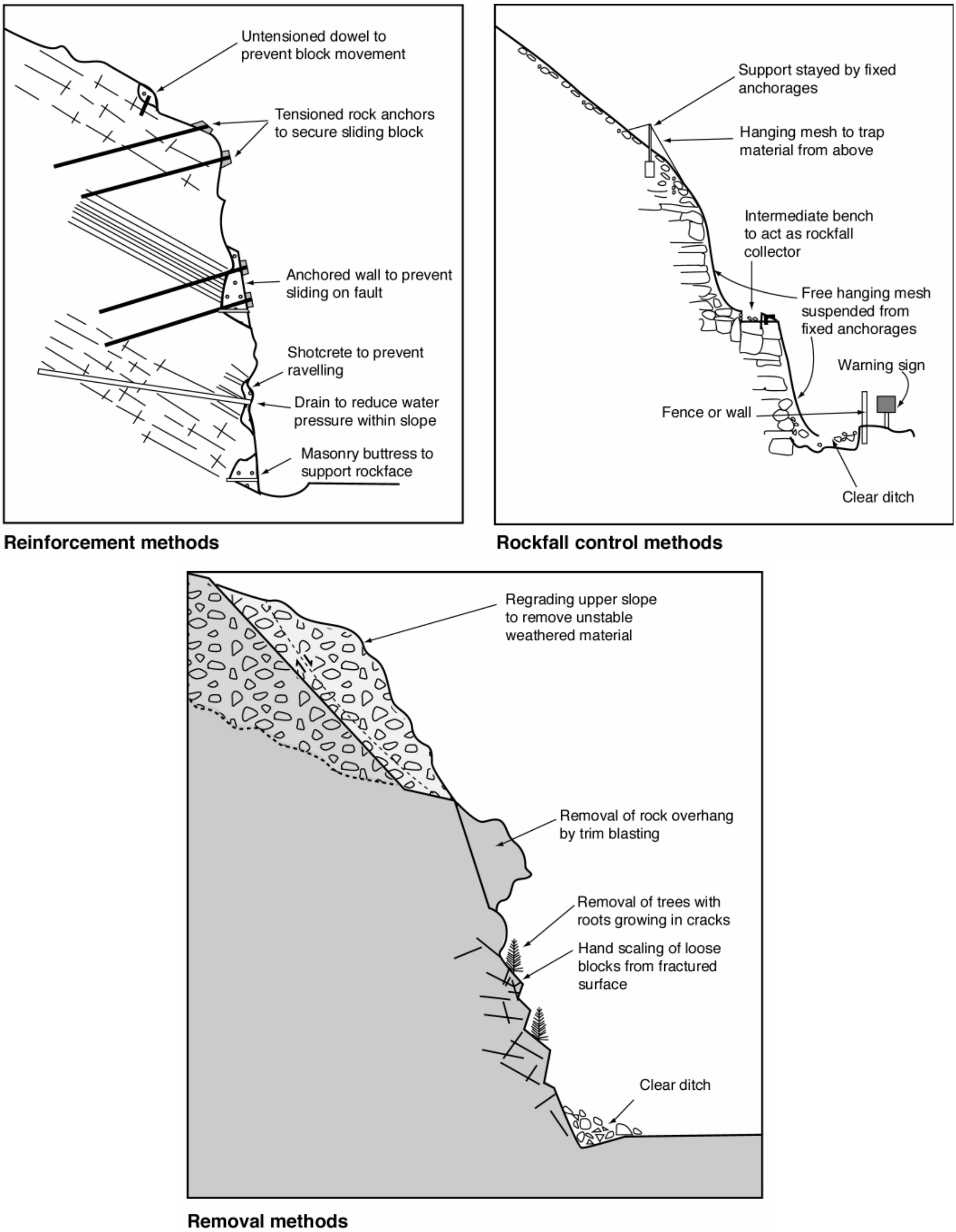
Design

A prerequisite to any rock slope stability design is the mapping of the rock face. Parameters normally measured include the orientation of the discontinuities, their persistence, the spacing and presence of any infilling (see 3.1).

Design is then fundamentally a two-part process; the first step is to determine if the orientation of the discontinuities could result in further instability, the second step is then a stability analysis to compare the forces resisting failure with the forces causing failure. The first step is normally analysed using stereonet projections, the second using standard limit-equilibrium methods.

The design will usually require the services of an experienced engineering geologist, particularly if it becomes desireable or necessary to install rock dowels or rock bolts.

Figure 4-21: Rock slope stabilisation techniques



Based on Fookes and Sweeney (1976).

5. REMEDIAL WORKS - DESIGN

There are many standard textbooks on the design of slopes and retaining walls, and it is not the intention to provide a comprehensive treatise here. Rather, it is the intention to highlight some of the more important aspects with particular reference to the typical conditions (physical and economic) found in Laos.

5.1 Soil/Weathered Rock Slopes

For most minor slope failures the design of any remedial works will usually rely solely on engineering judgement. Whilst this may be acceptable for many situations, there will be occasions when this will not be sufficient, particularly for major slope failures. In these cases engineering design must be carried out based on site survey and ground investigation, where necessary.

The one certainty about a failed slope is that at some point it reached and passed the point of limiting equilibrium i.e. its factor of safety has fallen below 1.0. In assessing the cause of slope instability it is usually most appropriate to carry out a back analysis of the failure using a proprietary slope stability computer program. In establishing the conditions at which failure occurred however, the major difficulties usually lie in the definition of the failure surface and the configuration of the groundwater table or slope drainage condition at the time of failure.

Back analysis will usually require the following information:

- the shape of the ground surface prior to failure. This can often be deduced with reasonable accuracy by comparison with the unfailed areas immediately adjacent.
- the assumed failure surface. This can sometimes be reasonably deduced by reference to the exposed failure surface, to the rear scarp, to the shape of the slumped material at the toe, and the interpretation of the failure mechanism, e.g. planar, rotational etc.
- the shape, sequence and depth of the underlying strata, at least down to the failure surface. With the exception of major investigations, it is very likely that, for analytical purposes, a single homogenous layer can be assumed above bedrock (e.g. soil, colluvium or weathered rock). Although this will be a simplifying assumption, it will usually be sufficiently accurate for most of the landslides affecting the road network.
- an initial assessment of the shear strength parameters for each stratum or soil layer. Ideally these are determined either from a comprehensive laboratory testing programme on undisturbed samples obtained from the site, or by insitu field tests. In practice, for the vast majority of landslides, the shear strength parameters or range of parameters are usually assumed on the basis of experience and observation of natural slope angles in the similar materials.
- the phreatic surface. This can be defined as the water pressure exerted on the assumed failure surface, expressed as an equivalent depth of water. Again, for the majority of back analyses for landslides affecting the road network, it will be sufficiently accurate to assume a groundwater table. Factors to take into consideration in assessing the water table level will include the presence and location of seepages after failure, and the point(s) of potential ingress of water (e.g. surface rainfall, stream course, roadside drainage).

A back analysis of slope stability can then be carried out (see Appendix B), with further refinements to the assumed strength parameters and groundwater conditions, until a plausible combination (or combinations) results in a factor of safety of 1.0. A further sensitivity analysis is recommended to check the susceptibility of the stability of the slope to variations in parameter values. Sophisticated techniques utilising pore pressures and suctions are not considered appropriate.

Further analyses are then undertaken with these derived parameters, examining the effect of various potential slope stabilisation measures on the factor of safety. In order to obtain the most effective combination of measures, the choice of design factor of safety will depend upon the reliability of the assumed parameters and the consequences of further failure. It is suggested that where the consequences of failure are high (e.g. disruption to heavy traffic flows), then a factor of safety of 1.2 is likely to be appropriate. Where the consequences of failure are low (e.g. a rural feeder road), then a factor of safety of 1.1 might be reasonable.

5.2 Gravity Walls

There are several factors to consider in the stability design of traditional gravity walls:

- the wall shape. Overturning and bearing capacity considerations will normally dictate the wall height to base width ratio. However, there are probably two other main variables to take into consideration; the inclination of the front and rear faces of the wall and the inclination of the base, all of which have advantages and disadvantages (see Figure 5-1).
- the forces acting on the wall (see Figure 5-2). The standard assumptions will normally apply; i.e. active pressure and wall friction (if appropriate) on the rear face, passive pressure on the embedded portion of the front face, skin friction on the base. Hydrostatic pressures may need to be included if there is a significant risk of a water table developing behind the wall. Seismic loads are not normally taken into account in the case of conventional retaining walls on low volume roads; traffic loads, if applicable, usually are.
- the required factors of safety. In general the minimum requirements are 2.0 against overturning, 1.5 against sliding, and 3.0 against bearing capacity failure. These values can be reduced slightly if some settlement/rotation of the wall is acceptable.
- the wall type. The advantages and disadvantages of the various types of wall are discussed in 4.4 and further amplified later in this section.
- shear strength parameters. These will often be a matter of engineering judgement. For a cohesionless granular backfill, shear strength parameters of $c' = 0$ kN/m^2, $\phi' = 30°$ to $35°$ are likely to be appropriate. For the residual soils or weathered rock encountered by the road network, shear strength parameters are likely to be in the range of $c' = 0$ to 10 kN/m^2, $\phi' = 20°$ to $35°$ depending on the degree of weathering and plasticity. Colluvium, because of its granular composition (up to large boulder size) is likely to be less cohesive and more frictional, and shear strength parameters of $c' = 0$ to 5 kN/m^2, $\phi' = 30°$ to $38°$ are usually more appropriate. However, all these figures should be used with caution. It should also be borne in mind that for a reactivated failure, the shear strength along the pre-existing failure surface could be significantly lower than the material immediately above and below.
- bearing capacity. The bearing capacity of the ground beneath the base of a wall can be estimated from the results of probing (Section 3.4) or by visual examination of trial pitting or foundation excavations.
- if rock is absent, masonry walls may be founded on a 300mm concrete base, often reinforced where foundation conditions are marginal. In order to provide additional frictional resistance between the wall and the concrete base, the top of the base is sometimes inclined towards the back of the wall (Figure 5-3) or the wall base itself inclined (see Appendix E, Drawing 001). A reinforced concrete shear key is also sometimes added at the rear of the base to improve overall sliding resistance (Figure 5-3).
- apart from the upper 500mm, backfill to the wall should be free-draining and, preferably, well-graded, and non-plastic (Appendix E, Drawing 001). The upper 500mm, by contrast, should be as impervious as possible to minimise the ingress of water from the exposed surface. For mortared masonry walls, the addition of a free-draining filter layer immediately behind the wall is recommended, at least 300mm thick, preferably comprised of well-graded gravel with a maximum size of 40mm. For composite and dry stone masonry and gabion walls, this free-draining filter layer is not always necessary if the retained material is mainly non-cohesive, although it may be prudent to install a geotextile immediately behind the wall to prevent the loss of fines from the backfill. This is particularly important for road-supporting retaining walls, where the backfill might otherwise settle.
- geotextiles are not recommended in fine soils where a gabion wall is continually subject to the flow of groundwater because of the potential for clogging. This could eventually result in wall failure due to excessive hydrostatic pressure.
- in wet locations or locations where significant water infiltration may be expected, it may be advisable to provide a suitably lined interceptor drain at the base of the wall (Appendix E, Drawing 001)).
- walls that are curved concave in plan into the hillside will have a much greater resistance to sliding and overturning, particularly if the ends are founded in strong material.

Figure 5-1: Comparison between different wall shapes

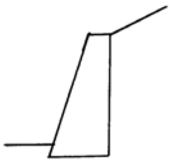
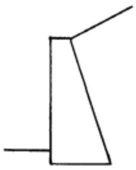
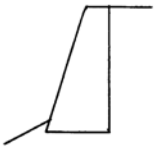
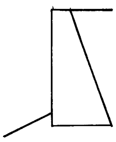
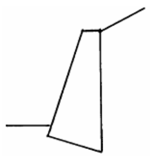
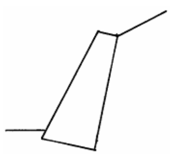
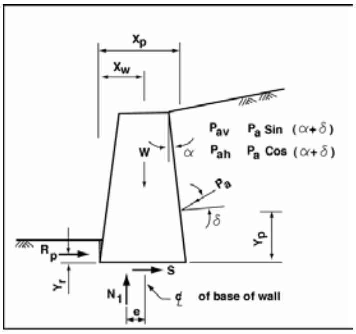
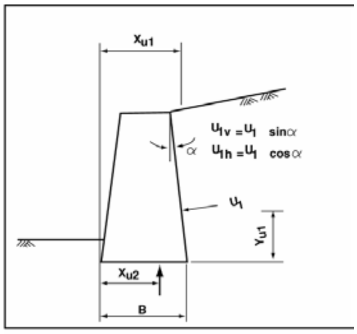
Shape and location	Advantages	Disadvantages
	Lower toe pressure, greater resistance to overturning	Greater wall height for a fixed retained slope angle
	Smaller wall height for fixed retained slope angle	Lower resistance to overturning, higher toe pressure
	Lower toe pressure, greater resistance to overturning	Greater wall height for fixed height of retained soil
	Smaller wall height for fixed height of retained soil	Higher toe pressure, greater extent of excavation into road – more disruption to traffic
	Greater resistance to sliding	Shape not suitable for gabion construction, increased volume of excavation, positive drainage required at heel to prevent ponding and foundation softening.
	Greater resistance to sliding and overturning, ground bearing pressures evened out	Tilted shape more difficult to construct in gabion, increased volume of excavation, compaction behind wall more difficult, positive drainage required at heel to prevent ponding and foundation softening

Figure 5-2: Forces acting on a gravity wall



Forces on retaining walls
(water forces not shown)



Water forces on retaining wall

Sliding Failure

Activating force $F_a = P_{ah} + U_{1h}$

Resisting force $F_r = N_1 \tan \delta_b + R_p$, where $N_1 = W + P_{av} + U_{1v} - U_2$

Overturning Failure

Overturning moment $M_o = P_{ah}y_p - P_{av}x_p + U_{1h}y_{u1} - U_{1v}x_{u1} + U_2x_{u2}$

Resisting moment $M_r = Wx_w + R_py_r$

Eccentricity $e = B / 2 - (M_r - M_o) / N_1$

Bearing Capacity Failure

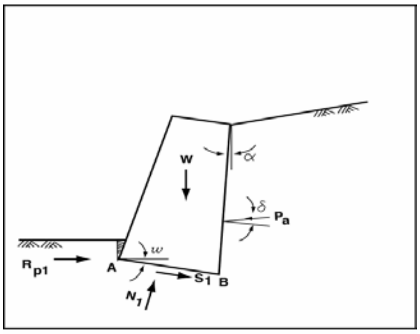
Effective normal load Q_n and shear load Q_s imposed on the foundation are given by $Q_n = N_1$ and $Q_s = F_a$ respectively.

Notes:

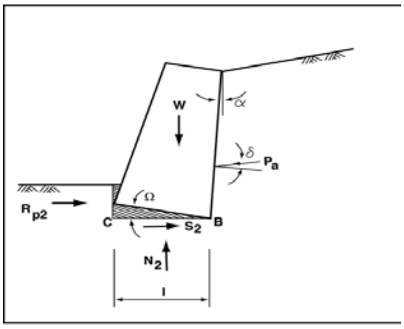
(1). The total weight W equals the weight of the wall plus the weight of the hatched portion of soil.

(2). The possibility of excavation in front of the wall should be considered in evaluating passive resistance. Where excavation is likely, a minimum trench depth of 0.5m should be allowed for in the calculation.

(3). Zero wall friction should be assumed for the vertical plane in soil on which the passive resistance acts.



Mechanism 1: Sliding along
soil/structure interface AB



Mechanism 2: Sliding along
a foundation soil surface CB

Mechanism 1, resolve forces parallel and perpendicular to base AB of the retaining wall to obtain S_1 and N_1 respectively. Passive resistance R_{p1} in front of the wall should be calculated down to point A.

Activating force $F_a = S_1$

Resisting force $F_r = N_1 \tan \delta_b + R_{p1} \cos \omega$

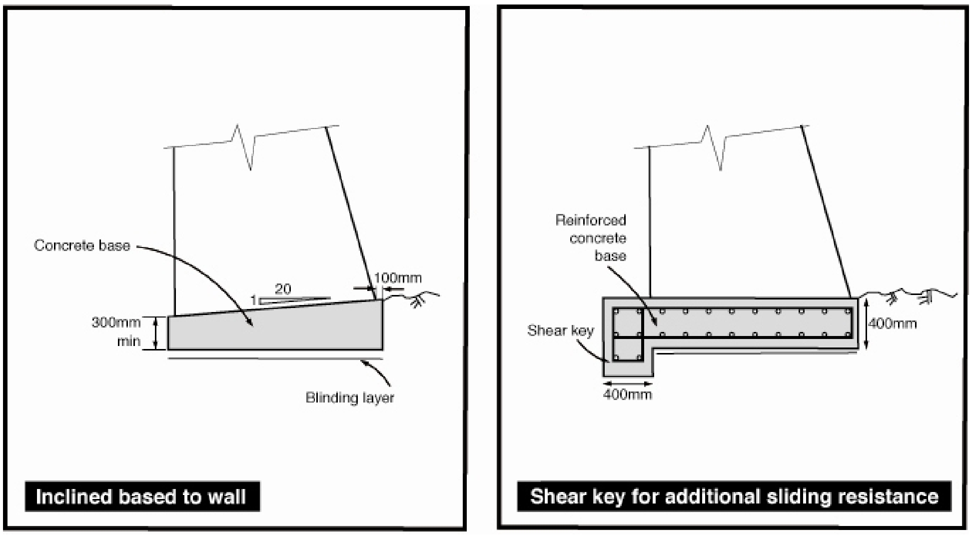
Mechanism 2, resolve forces parallel and perpendicular to selected foundation soil surface CB to obtain S_2 and N_2 respectively. Passive resistance R_{p2} in front of wall should be calculated down to point C.

Activating force $F_a = S_2$

Resisting force $F_r = N_2 \tan \varnothing ' + c'l + R_{p2}$

The value of Ω should be varied to obtain the worst design condition.

Figure 5-3: Retaining wall details



5.2.1 Wall uses

Retaining Walls

Retaining walls are here defined any walls that are designed to retain the material behind them. They may be located adjacent to the road and primarily support the road bench or the base of the hillside above (see Figure 2-12), or they may be located some distance above or below the road and support part of the hillside. In Laos, retaining walls are generally constructed in mortared masonry or gabion.

The base of roadside retaining walls should never be higher than the invert of the roadside drain.

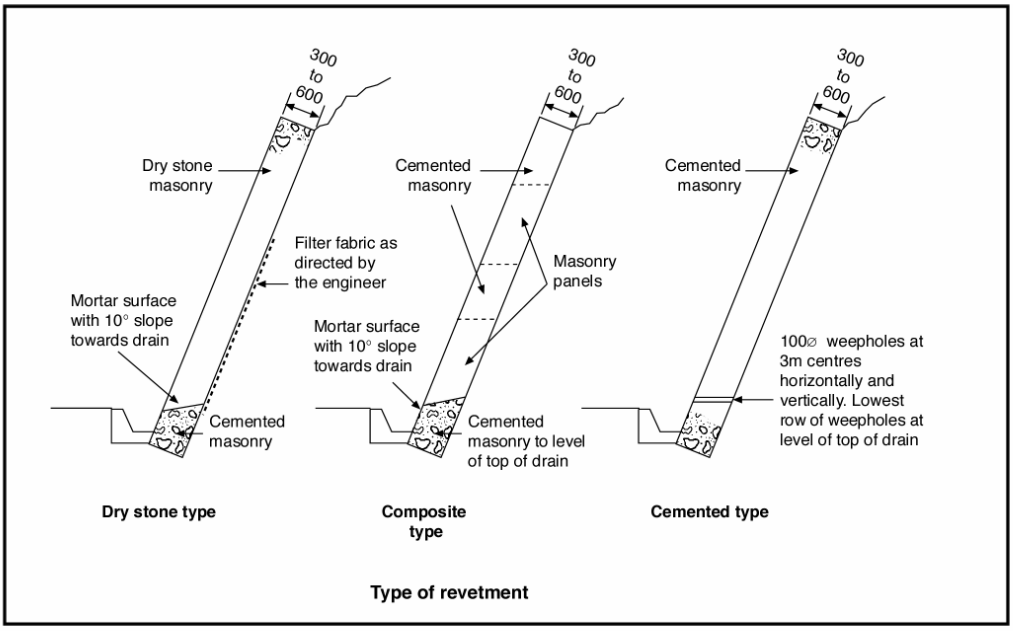
Revetments

Some walls adjacent to the road and located at the base of the hillside are designed as revetments. Although revetments (see Figure 5-4 and Appendix E, Drawing 003) are included here, revetments are not designed to offer slope support; they act merely as slope protection and are usually only appropriate to protect residual soils or weathered rock. Viewed from the front, revetments are identical in appearance to masonry retaining walls and are often mistaken as such. However, revetments tend to be inclined backwards at a greater angle than retaining walls; they can be as little as 1m high although they are commonly constructed 3-4m high. They are particularly beneficial in reducing seepage erosion at the toe of cut slopes, with the subsequent softening and leaching of materials that might otherwise lead to progressive erosion and failure of the entire cut slope. They can also provide a convenient back wall to the roadside drains.

Catch Walls

In some cases of above-road slope instability where the base of the failure is comprised of predominantly steep intact rock, but where further limited slips near the crest could occur, it may be possible to construct a catch wall at the toe of the slope. The essential feature of a catch wall is that there is sufficient space behind the wall for slipped material to accumulate without overtopping the wall. Sometimes this will mean that the existing slipped debris at the toe will have to be removed prior to wall construction, and possibly that the road itself will have to be realigned away from the toe. In most instances there will be insufficient room to achieve such space, in which case a catch wall is not appropriate. Ideally, the wall is best constructed in gabion, since this type of wall is capable of absorbing some dynamic load without structural damage. For obvious reasons it is preferable that the slipped debris accumulating behind the wall is removed each dry season.

Figure 5-4: Revetments



5.2.2 Wall types

Composite Masonry

Composite masonry walls are mortared masonry walls but with dry stone panels (see Figures 5-5 and 5-6).

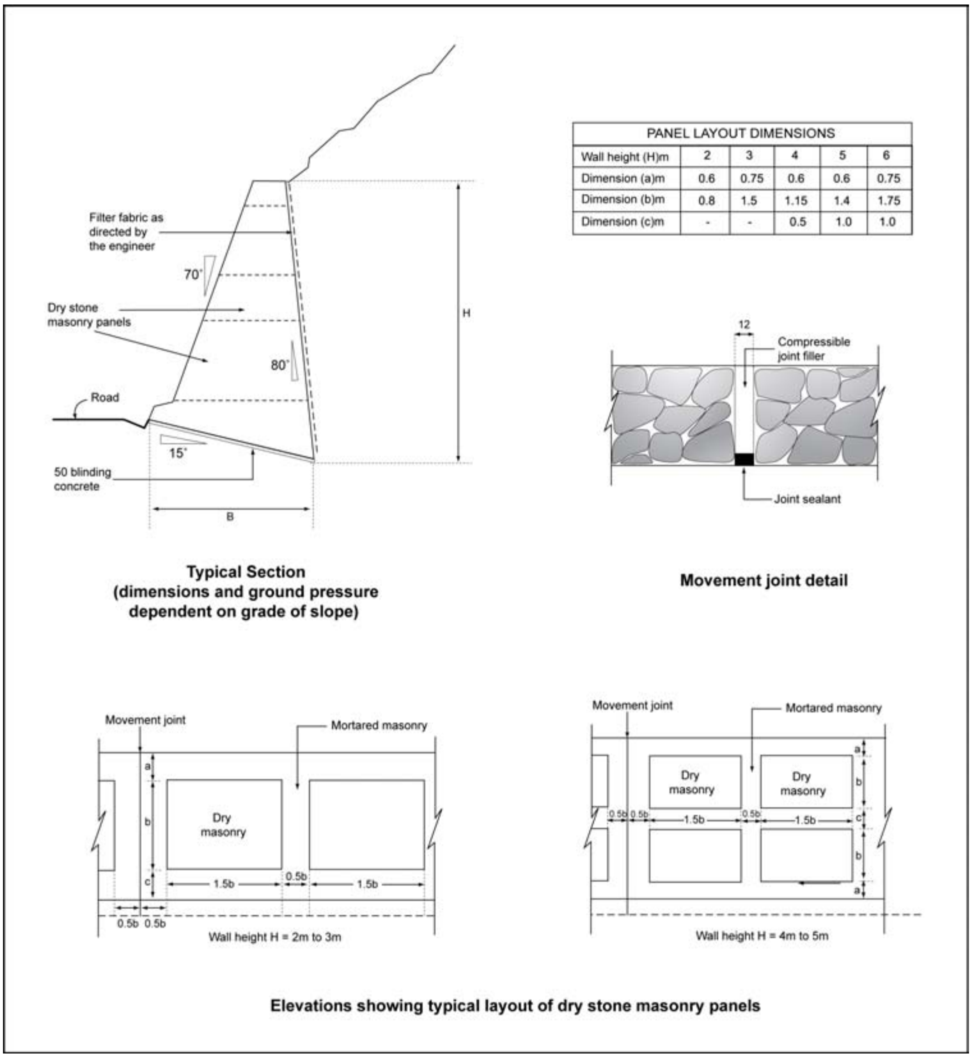
Typically the walls are provided with movement joints at regular intervals (usually around 5-7 metres) so that if one section of wall is overstressed, the entire length of wall is not at risk of collapse. The joints should be lined with a resilient jointing material about 10-20 mm thick and sealed with a proprietary jointing compound.

Composite masonry walls offer the benefit of being stronger than dry stone walls, but still provide a relatively unrestricted passage for seepage. Care is usually taken for the panels to be protected from the ingress of cement mortar during construction, the dry stone panelling being constructed at the same time as the mortared “frame” and not inserted afterwards. The mortared frame consequently offers a limited degree of flexibility, but large movements are still likely to cause collapse.

Although composite masonry walls have been used in Laos, it is suggested that unless there are significant cost savings or that heavy seepages are likely to occur over extended periods (e.g. wet colluvial slopes), the preferred choice should be either for fully mortared masonry or gabion walls.

Figure 5-5: Typical composite masonry wall

Figure 5-6: Composite masonry walls



Mortared Masonry

Mortared masonry walls are the most durable of the low-cost wall options (see Figures 5-7 and 5-9 and Appendix E, Drawing 001). They are especially suited to uneven founding levels, and where adequate founding conditions exist, as retaining walls supporting the road.

Figure 5-7: Typical mortared masonry wall

Figure 5-8: Cracking of masonry wall due to differential movement

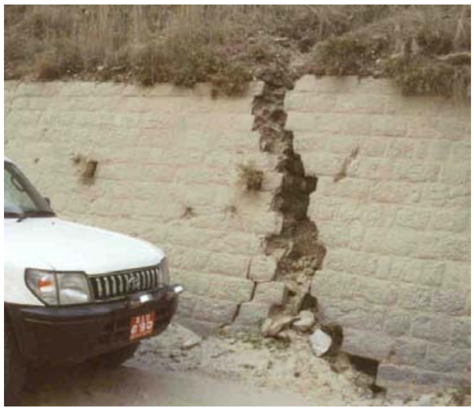
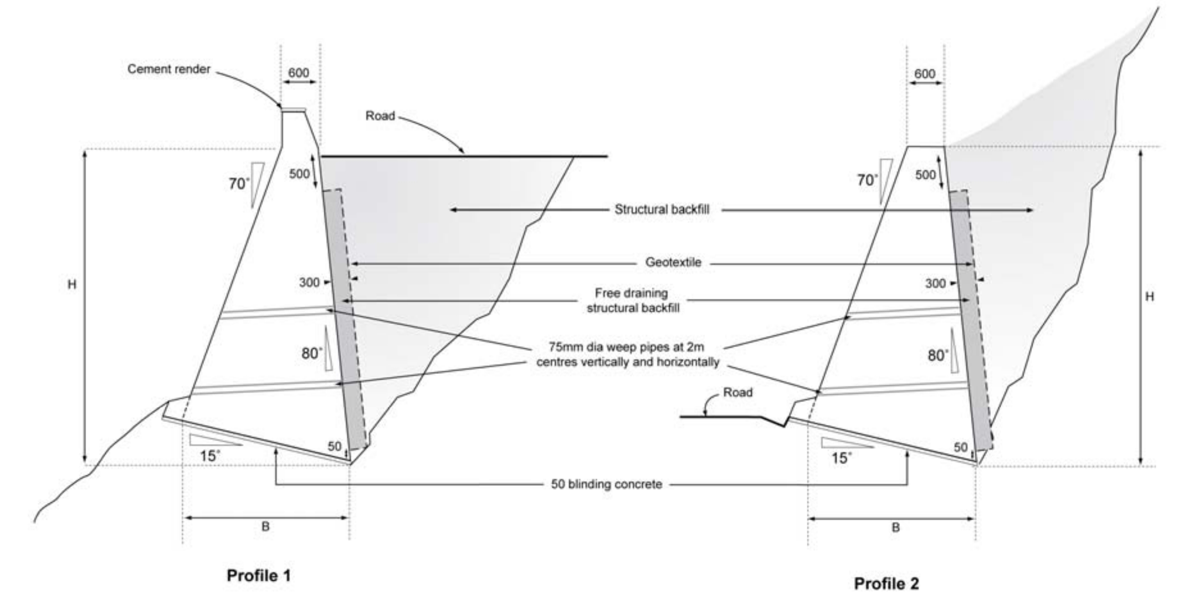


Figure 5-9: Mortared masonry walls



Base Widths and Typical Ground Pressures										
Wall Height (H) m		2	3	4	5	6	7	8		
Profile 1	Base Width (B) m	1.6	2.1	2.6	3.1	3.6	4.1	4.6		
	Max Pressure kN/m^2	30	50	70	90	110	130	150		
Profile 2	Base Width (B) m	1.6	2.1	2.6	3.1	3.6				
	Max Pressure kN/m^2	40	60	90	120	150				

The width to height ratio usually lies between 0.5 - 0.75:1. If the wall foundation is stepped along its length, movement joints should preferably be positioned to reflect the differing wall heights, so that limited differential movements can be accommodated.

The maximum ground pressures given in Figure 5-9 are based on a number of assumptions and should be used with caution. For high risk locations, individual stability calculations are strongly recommended.

Rounded river stone can be used provided that it does not exceed a recommended one third of the total stone used, although dressed stone should always be used on the exposed faces.

Where confidence blocks (castellations) are to be provided on the top of valleyside retaining walls, these should be constructed as an integral part of the wall and not added on later. To ensure that durability is not compromised it is important to ensure that the stone is of good quality and is not significantly weathered, that the cement mortar conforms to a strength criterion, and that the wall does not contain uncemented voids. Further details are given in the *Slope Maintenance Technical Specifications*.

As with composite masonry, movement joints are recommended for mortared masonry walls, normally at 5 – 7 metre intervals.

The disadvantages of mortared masonry walls are that they are the most costly and least permeable of the low-cost options, and that they are unable to tolerate differential settlement (Figure 5-9).

To some extent, the permeability of the wall is improved by providing weepholes, but there is always the risk that these will become clogged with fines over time. Weepholes should in any event generally be provided at 1-2 metre centres vertically and horizontally, inclined forwards at a slope of 1 vertical: 20 horizontal, preferably using a 75mm polythene pipe with a geotextile 'sock' placed over the upper end.

Criteria for filter materials behind the wall using a geotextile or graded stone are given in the *Slope Maintenance Technical Specifications*.

Gabion

Gabion walls (see Figures 5-10 and 5-12 and Appendix E, Drawing 002) are usually preferred where the foundation conditions are poor or variable, the retained soils are wet, and continued slope movements are anticipated.

Figure 5-10: Typical gabion wall

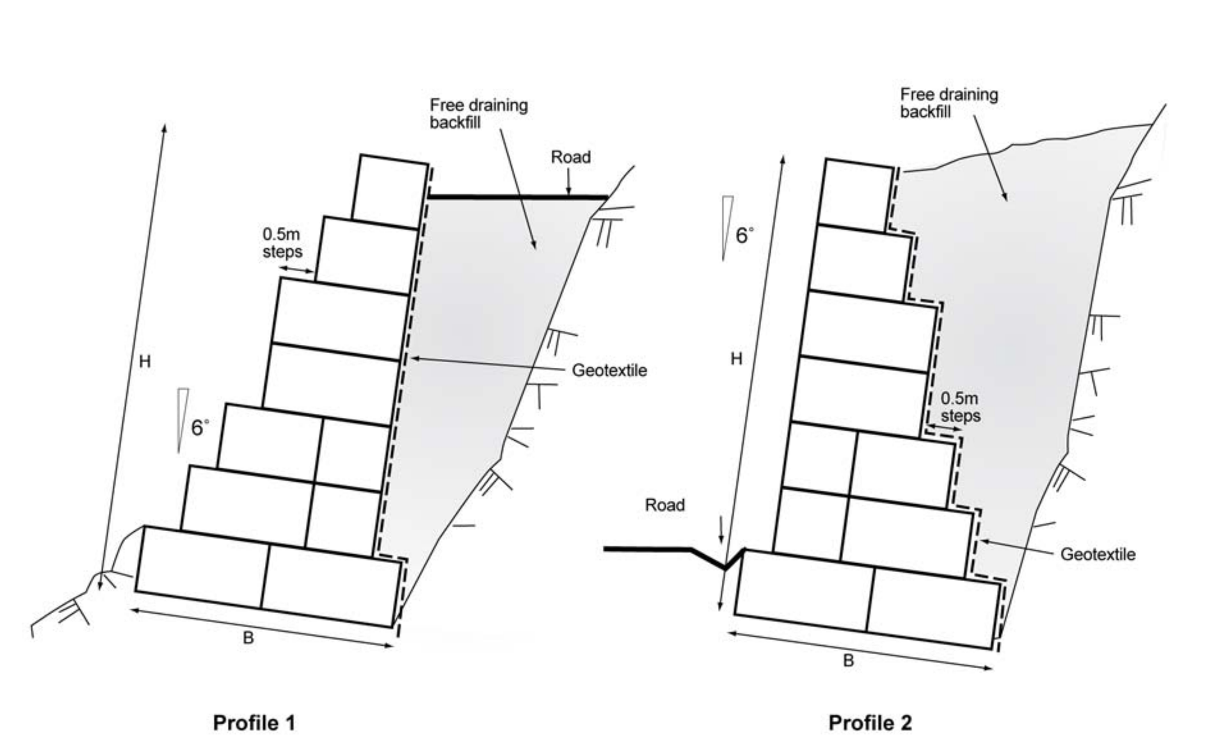
Because of their inherent flexibility, they are not preferred as road support retaining walls immediately adjacent to sealed roads due to the likelihood of movement of backfill behind the wall and subsequent pavement cracking. However, in many cases (e.g. "sinking" areas) there is no practical alternative.

Where gabion walls are nevertheless used as retaining walls to support a sealed road, care should be taken to locate the base of the wall on a good foundation to reduce the potential for movement. If the road surface runoff is directed towards the wall, it is recommended that a small bitumenous upstand or fillet is formed at the edge of the road to prevent excessive amounts of water entering the back of the wall and weakening the foundation (see Figure 5-11).

Where the nature of the foundation is such that severe weakening could take place if it was saturated, the gabions should be founded on an impermeable membrane (i.e. heavy duty polythene sheet) or thin (max 75mm) concrete screed.

Figure 5-11: Bituminous upstand to gabion road supporting wall

Figure 5-12: Gabion walls



Base Widths and Typical Ground Pressures										
Wall Height (H) m		2	3	4	5	6	7	8		
Profile 1	Base Width (B) m	1.5	2.0	2.0	2.5	3.0	4.0	4.0		
	Max Pressure kN/m^2	45	50	90	105	115	115	130		
Profile 2	Base Width (B) m	1.5	2.0	2.0	2.5	3.0				
	Max Pressure kN/m^2	70	130	170	270	300				

The maximum ground pressures given in Figure 5-12 are based on a number of assumptions and should be used with caution. For high risk locations, individual stability calculations are strongly recommended.

Figure 5-13: Gabion retaining wall – still functioning despite major slope movements

Gabion walls have the following advantages:

- they can accommodate significant movement without rupture (see Figure 5-13),
- they allow free drainage through the wall,
- the cross section can be varied to suit site conditions,

- the boxes can take limited tensile forces to resist differential horizontal movement

Gabion walls have the following disadvantages:
- their high degree of permeability can result in a loss of fines through the wall. For road support retaining walls this can result in potentially problematic settlement behind the wall, although this can largely be prevented by the use of a geotextile between the wall and the backfill,
- they are less durable than mortared masonry walls. In certain aggressive conditions, e.g. fast flowing rivers) gabion mesh can corrode quite rapidly, although there are also many instances of gabion mesh up to 20 years old in excellent condition,
- unless well packed good quality stone is used, wall heights may have to be limited to prevent crushing of the lower courses,
- they are not really suited to uneven foundations, although this can usually be overcome by the use of a mortared masonry levelling course (see Figure 5-14),
- they are not so well suited to a varying wall height since the standard baskets require minimum 1.0 metre steps, although for example the top row of gabions can be modified to follow the road gradient (see Figure 5-14).
- they are more difficult to construct on curves and may require specially shaped baskets.

Figure 5-14: Gabion wall on stepped masonry base

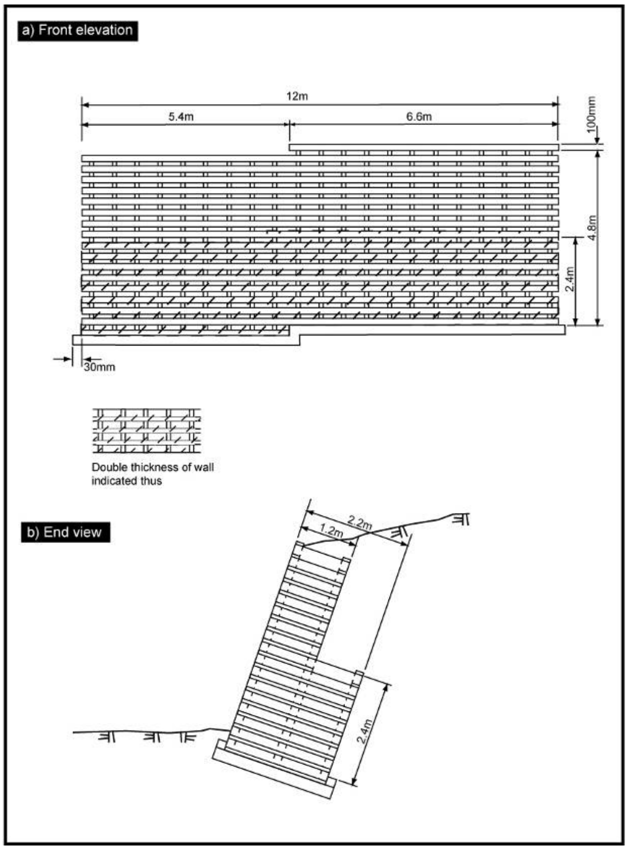
5.3 Other Walls

As noted in Section 4, other types of gravity wall worthy of consideration include reinforced concrete walls, crib walls, and earth reinforcement:
- reinforced concrete walls. The main types of reinforced concrete walls are described in Figures 4.7 and 4-8 and Appendix E, Drawing 003. A cantilever wall is generally economical for retained heights up to 8 metres, thereafter the thickness of the stem becomes excessive and a counterfort wall is more appropriate. A shear key (Figure 5.3) is sometimes provided below the base slab to improve sliding resistance. For free-standing walls, the wall together with the backfill up to a vertical plane above its heel (i.e. the virtual back) can be treated as a single block for the purpose of checking against sliding, overturning and bearing capacity failures. Active earth pressures may be assumed behind the wall. Vertical expansion/contraction joints should be provided at approximately 5 – 7 metre intervals.
- crib walls. Figure 5-15 shows an example of a typical reinforced concrete crib wall. The cribs are usually precast off-site and can be limited in size so that they can be placed manually, although mechanised placement will allow more rapid construction. The crib structure is usually founded on a 150 mm concrete base tilted at a batter of up to 1V: 4H. Filling within the wall should take place as erection of the wall proceeds. The filling should be durable, inert, and free-draining. Crib

walling is normally built in straight lengths although special members can be cast to permit curvature.

- Earth reinforcement. The reinforcement used in these structures can vary widely from galvanised steel strips to polymeric geogrids. The front face can also vary from pre-cast vertical reinforced concrete panels to sloping soil and vegetation. The most appropriate system for Laos is probably either gabion mesh (as used on Road 8) or geogrids. If gabion mesh is used, the front face can comprise vertical or stepped gabion baskets (Appendix E, Drawing 008), or a mesh/geogrid-wrapped sloping face. As backfilling proceeds, horizontal mesh is laid the length of the wall at selected vertical intervals, the mesh being securely connected to the front face. As a rough guide the width of this mesh is likely to be about 0.6H – 1.0H, where H is the retained height of the wall. Alternatively, geogrids can be used throughout. The backfill must be properly compacted and inert (particularly if gabion mesh is used) and preferably granular. If polymeric geogrids are used, care must be taken to reduce the possibility of damage due to vandalism and deterioration from ultraviolet light.

Figure 5-15: Typical concrete crib wall



5.4 Bio-engineering

Following completion of stabilisation measures, slopes are frequently left in a highly erodible condition. In order to prevent further environmental and engineering damage, it is essential that they are protected as soon as possible.

As explained in section 4, bio-engineering is the use of plants to perform surface protection and shallow soil strengthening. Bio-engineering techniques should therefore normally be used to control erosion or help to prevent or stabilise shallow slope movements where the depth to the sliding surface is up to 0.5 metre. If the depth to the sliding surface is greater than 0.5 m, then bio-engineering techniques should only be carried out in conjunction with other slope stabilisation techniques, typically with retaining walls.

The techniques listed in section 4 are appropriate for use in sites of different characteristics. Table 5-16 shows how an understanding of the characteristics of the site allows the recommended technique to be identified. An important feature of bio-engineering works is that the design should be at the sub-site level. For this reason, Figure 5-16 refers to components of a typical site rather than whole sites. The engineer should therefore expect to use a range of different techniques on the same site. This is because a "typical site" that may consist of, for example, cut slope faces, debris slopes and a landslide head scarp.

Figure 5-16: Determination of bio-engineering technique according to site characteristics

Site characteristics	Recommended techniques
Sites mainly above roads	
Cut slope in soil, very highly to completely weathered rock or residual soil, at any grade up to 2V:1H.	Grass planting in lines, using slip cuttings.
Cut slope in colluvial debris, at any grade up to 1V:1H (steeper than this would need a retaining structure).	
Trimmed landslide head scarps in soil, at any grade up to 2V:1H.	
Roadside lower edge or shoulder in soil or mixed debris.	
Cut slope in mixed soil and rock or highly weathered rock, at any grade up to about 4V:1H.	Direct seeding of shrubs and trees in crevices.
Trimmed landslide head scarps in mixed soil and rock or highly weathered rock, at any grade up to about 4V:1H.	
Sites mainly below roads	
Fill slopes and backfill above walls without a water seepage or drainage problem: these should first be regraded to be no steeper than about 1V:1.5H if this is possible.	Brush layers using woody cuttings from shrubs or trees.
Debris slopes underlain by rock structure, so that the slope grade remains between 1V:1H and 1.75V:1H.	Palisades using woody cuttings from shrubs or trees.
Other debris-covered slopes where cleaning is not practical, at grades between 1V:1.5H and 1V:1H.	Brush layers using woody cuttings from shrubs or trees.
Fill slopes and backfill above walls showing evidence of regular water seepage or poor drainage: these should first be regraded to be no steeper than about 1V:1.5H.	Fascines using woody cuttings from shrubs or trees, configured to contribute to slope drainage (e.g. in a herringbone pattern).
Large and less stable fill slopes more than 10 metres from the road edge (grade not necessarily important, but likely eventually to settle naturally at about 1V:1.5H or less).	Truncheon cuttings (big woody cuttings from trees).
The base of fill and debris slopes.	Large bamboo planting; or tree planting using potted seedlings from a nursery.
Other sites	
Stream banks where minor erosion is possible.	Large bamboo planting.
Gullies or seasonal stream channels with occasional minor discharge.	Live check dams using woody cuttings of shrubs and trees.
Gullies or seasonal stream channels with regular or heavy discharge.	Stone pitching, probably vegetated. Gabion check dams may also be required.
Other bare areas, such as on the land above landslide head scars, on large debris heaps and stable fill slopes.	Tree planting using potted seedlings from a nursery.

5.4.1 Selection of the appropriate plant species

The main factors to be addressed when selecting the particular species for use in bio-engineering works are covered through the following steps.

1. The plant must be of the right type to undertake the bio-engineering technique that is required. The possible categories are:
   - a grass that forms large clumps; or
   - a shrub or small tree that can be grown from woody cuttings; or
   - a shrub or small tree that can grow from seed in rocky sites; or
   - a tree that can be grown from a potted seedling; or
   - a large bamboo that forms clumps.
2. The plant must be capable of growing in the location of the site.
3. There must be enough soil material available for the plant at the site.

Figure 5-17 lists the plants that have been shown to be successful for bio-engineering work in Laos.

Figure 5-17: Bio-engineering species by type of plant

Lao name	Other name	Botanical name	Comments
Grasses that form large clumps			
Nyar khaem, dok khaem	Broom grass	*Thysanolaena maxima* or *T. latifolia*	Appears to grow on a wide range of sites, but it prefers damp locations with a fine-textured soil. Readily colonises landslide scars in the Attamite mountains. The most widely used NTFP, hence valuable to farmers.
Nyar kha		*Imperata cylindrica*	A tough, invasive, very common grass. Seen as a troublesome weed in shifting cultivation although forest cover appears to be able to re-assert and eventually shade it out after 10 to 20 years.
Nyar phaek		*Themeda triandra*	Clumping grass, not as big as Imperata.
Nyar khaem lao		*Themeda arundinacea*	A tall clumping grass with coarse, sharp-edged leaves. A common coloniser.
Nyar khaem lao		*Saccharum spontaneum*	Identification uncertain: listed as a common weed in shifting cultivation, but South Asian *S. spontaneum* has not been seen in northern Laos; this is a riverine grass and would not colonise upland fields.
Nyar phaek, fek hom	Vetiver	*Vetiveria zizanioides*	Use only on fill material, not on cut slopes. Be wary of extravagant claims for this grass, which are generally based on lowland rather than upland trials. Available from the Huayson Huaysua Agriculture Development and Service Centre (20 km north of Vientiane).
Shrubs and trees that can be grown from woody cuttings			
Mak koh	Chestnut	*Castanopsis* sp.	Grows only above 700 metres elevation.
Korbai leuam	Chestnut	*Castanopsis* sp.	
Posa	Paper mulberry	*Broussonetia papyrifera*	Fibres collected from bark for paper etc.
Mak nhiao	"Diesel nut"	*Jatropha curcas*	Large shrub. Performs well in brush layers. Grows in hot, sunny locations. Grows slowly on rocky sites.
Kook, kork, mark	Hog plum	*Spondias pinnata* (or *S. mangifera*)	Medium-sized fruit tree. Performs well in truncheon cuttings and live check dams.
Peuak meuak, toutiang		*Boehmeria malabarica*	Straggly shrub; valued for its bark, which is used to make paper.
Khee nok, khee hen, ngen	Simali	*Vitex* spp.	Not certain that the common Lao *Vitex* spp. propagate from cuttings like the South Asian *V. negundo*.
Mai mook		*Euphorbia hirta*	Not certain that this propagates from cuttings; found by roadside near R13N, km 375.
Thorng		*Erythrina*	Medium-sized tree. Good for truncheon cuttings.
Shrubs and trees for direct seeding			
Khileckdong		*Cassia garrettiana*	
Koun	Amaltas	*Cassia fistula*	Showy yellow flowers; grows in hot, sunny sites
Khathin		*Leucaena leucocephala*	Widely planted, fast-growing, small leguminous tree from Central America Seems to perform well in Laos
Tiou dam		*Cratoxylon prunifolium*	
		Crotalaria anagyroides	Legume; performed well in agricultural trials in northern Laos
Pohou		*Trema orientalis*	Seed difficult to collect; grows well on hot, rocky sites
		Flemingia congesta	Legume; considered by NAFRI to be suited to Lao conditions and to be of strong potential
		Calliandra calothyrsus	Legume
Hookatai		*Tephrosia vogelii*	Legume; small shrub that allows natural regeneration under its canopy.
Thua hae pa		*Acacia*	Yellow-flowering acacia(?). Gives spectacular early growth when seeded on harsh, stony sites. Small, non-edible seed.
Phak nao		*Acacia pennata*	Small thorny acacia, sometimes used to make hedges.

Lao name	Other name	Botanical name	Comments
Som poi		*Acacia concinna*	Fast-growing woody shrub that grows well in dry, open places.
Phak thon		*Albizia procera*	Fast growing deciduous tree capable of growing among dense grasses.
Trees for planting as nursery-raised potted seedlings			
Mai nhom hin		*Chukrasia tabularis*	Timber tree
Mai dou		*Pterocarpus macrocarpus*	Timber tree; light canopy
Mai ham ngoua	Mahogany	*Swietenia* spp.	Timber tree; light canopy
Mai champa pa		*Paramichelia baillonia*	Timber tree; shade tolerant
Mai te kha		*Afzelia xylocarpa*	Veneer timber tree
Mai sako		*Anthocephalus chinensis*	Light canopy; shade tolerant
Mai kadao sang		*Melia azedarach*	Light canopy; grows on bare, hot sites
Mai khilek ban		*Senna siamea*	Firewood tree; light canopy
Magdua	Milky sap	*Ficus neriifolia*	Small edible figs and animal fodder
Mak bok		*Irvingia malayana*	Popular large tree that successfully colonises bare ground.
Phak kadao	Neem	*Azadirachta indica*	Medium-sized tree capable of growing in hot, open ground.
		Ficus semicordata	Small edible figs and animal fodder; natural coloniser of rocky slopes
Large bamboos			
Bong	Bamboo	*Bambusa* spp.	A large number of large species of this genus are available in Laos
Hok	Bamboo	*Dendrocalamus* spp.	A large number of large species of this genus are available in Laos

A number of plants are considered undesirable in certain circumstances. In some cases this is because they give too much shade and hence inhibit the growth of other plants (e.g. trees with a dense canopy that stop grass from forming a surface cover). Other plants can be invasive of neighbouring land and become weeds. Figure 5-18 gives a list of plants that should not be used on roadside bio-engineering sites.

Figure 5-18: Plants that should NOT be used for bio-engineering

Lao name	Other name	Botanical name	Comments
Species NOT to be used in bio-engineering			
	Teak	*Tectona grandis*	Provides too much shade and excludes other plants
	Ban mara	*Eupatorium adenophorum/ Chromolaena odorata*	Not clear if this is the same species Very invasive, weedy herbaceous plant with weak roots but shading out other more vigorous plants
Thua hae	Pigeon pea	*Cajanus cajan*	Apparently not robust enough for hard slopes, or suffers in competition
		Sesbania sesban	Appears to fail when planted in combination with other species
Mai vick		*Eucalyptus spp.*	Excludes other plants
Mai pek song bai		*Pinus merkusii*	Provides too much shade and excludes other plants
Mai pek sam bai		*Pinus kesiya*	Provides too much shade and excludes other plants

5.4.2 Timing of bio-engineering works

Bio-engineering work should only be undertaken in the first half of the wet season: in practice this means between April and June. The slope should be moist when the planting is done. If it does not rain within 24 hours of the work being done, the plants should be watered by hand every day until it does rain. Planting work should not be done later, since there may not be long enough for the plant roots to development adequately for it to survive the subsequent dry season

6. REMEDIAL WORKS - CONSTRUCTION

6.1 Safety

The first consideration at any location where slope or wall failure has, or is about to occur, must be safety; the safety of persons travelling along the road or working or living above or below the failure. Where appropriate, the police and other civil authorities should be given details of the actual or impending danger.

If the failure is affecting the road, then traffic warning signs or physical obstructions should be immediately set up at a suitable distance on either side of the failure. If the failure is likely to affect persons living or working above or below, particularly in occupied buildings, then appropriate warnings must be given to them.

Where the failure is located within and below the road, immediate steps should be taken to prevent water from entering the crest of the failure from either the road surface (see Figure 6-1) or the roadside drains. If necessary the roadside drain upstream of the failure may need to be blocked and the water directed across the road by means of a temporary bund to a more suitable discharge point.

Figure 6-1: Failure below road protected by earth bund and marker posts

Where the failure is located above the road such that the slipped debris is blocking the roadside drain, then immediate measures should be taken to prevent the water from crossing the road and discharging at random down the valley slope.

If the road blockage is the result of a rockfall or the displacement of an individual boulder, then a rapid visual inspection should be made to assess the likelihood of further falls or displacements.

6.2 Soil/weathered rock slopes

6.2.1 Slip debris disposal

Usually the requirement to open the road in the shortest possible time is of primary importance, with the result that the slip debris is dumped downslope immediately opposite the failure site using a front-end loader or dozer. This is, of course, quite likely to create a further instability problem downslope.

It is of the utmost importance to select a suitable disposal location as close to the failure site as possible, but at the same time one that is acceptable when taking into account land use and environmental considerations. In decreasing order of preference, these are:
- on level ground or terraces
- on tops of spurs
- at steeper locations protected by resistant bedrock
- at a location that is as far away from the edge of the road as possible

Wherever possible, the following recommendations should be observed:

- never place slipped material downslope in a 'sinking' area; at the very least remove it to the boundary of the area before side casting,
- try to use a number of suitable disposal locations rather than a single location, to reduce the risk of slope overload,
- avoid the disruption of natural water courses, since this may result in major erosion,
- avoid tipping slipped material over retaining walls, unless it is quite obvious that the wall is founded on non-erodible material,
- be careful not to damage the surface of the road, particularly if it is sealed.

On completion of slip clearance, every effort should be made to compact the removed debris if at all possible, reshape if necessary, and carry out appropriate bio-engineering methods to encourage increased resistance to erosion.

6.2.2 Temporary drainage

The problems associated with slip clearance have already been dealt with in Section 4.2. The action of clearance of an above-road slope failure will often cause further movement of the failed mass and the gradual migration of the scarp upslope, creating even more problems. As a consequence, particularly for above-road failures, it is usually preferable to tackle the upper portion of the failure before moving downslope to the base. This is particularly important in cases where water is entering the failure crest. Unless this water is prevented from entering the failure, or preferential drainage paths are constructed to lead the water out of and away from the failure, the slippages are likely to continue to occur. However, if the remedial works involve the construction of a wall, then it is usually more appropriate the construct the wall first.

In areas where the road itself is part of the failed slope, it is essential to ensure that the roadside drains are not feeding water into the failure. As noted in 4.1, it may be necessary to block the roadside drain at each edge of the failed section and create temporary drainage channels across the road. These need to be located carefully so that they can discharge safely downslope away from the failed area.

Failures below the road are often caused by concentrated runoff of surface water from the road itself. Again, it is essential to divert the runoff temporarily to a safe discharge point before commencing slope stabilisation work.

Excavation for slope drainage works should always be carried out in short sections to avoid creating local instability – this is very important from the safety point of view if hand labour is being used. Each section should be backfilled with free-draining material before proceeding with the next adjoining section.

6.2.3 Cut slopes

The remediation of cut slope failures will usually require the removal of failed material from the road and side drain and any overhangs and potentially unstable masses. A decision has to made as to whether a solution can be found based principally on earthworks, or whether a retaining structure will be required. In some cases the entire removal of slip debris could serve to undercut the slope above causing further failure. In such cases a gabion or masonry retaining wall might be constructed to support the slope. Most cut slope failures are shallow and the most common forms of treatment comprise removal, trimming and bio-engineering, with or without a revetment.

6.2.4 Fill slopes

For fill slope failures it may be more difficult to ascertain where the failure surface is at depth. Careful site inspection is therefore required. Failed fill material will need to be excavated and stockpiled while the ground beneath is prepared. Fill will then need to be replaced and compacted in layers until the final slope profile is achieved. Planting and drainage may be necessary.

6.3 Wall Construction

The foundation excavation for a wall can in itself initiate further instability, creating a hazard for those carrying out the excavation and causing further clearance problems. In order to minimise such problems, it is always recommended that, whenever possible, wall construction is carried out in the dry season, and preferably in alternate bays. Construction of alternate bays, rather than the whole wall in its entirety, does mean that at least some support is maintained to the area of instability throughout the wall construction activity.

The depth to a suitable founding level can often only be decided during construction, particularly for road-supporting retaining walls. The most important factors to take into account are:

- the origin of the material in the base of the excavation. Is it fill from the original road excavation (an indication is often to look at the ends of the excavation for any signs of the original sloping ground) or is it more obviously original ground? If it is original ground, is it colluvium or is it non-transported material such as weathered bedrock?
- the type of material in the base of the excavation. Is it soil or weathered rock, or a mixture of soil and boulders?
- the consistency of the material in the base of the excavation. Is it hard or soft, loose or intact, wet or dry?
- the probability of a better foundation at a greater depth. Is it likely that there is harder or less variable material at a short depth below the surface of the excavation?

Obviously it is better to found a wall in material that is in-situ rock or residual soil, and not too variable in strength, so that a masonry wall can be constructed. In some cases this is not possible, in which case a gabion wall may be necessary. Probing the base of the excavation using a Dynamic Cone Penetrometer (DCP) may help in the decision-making process and the following simplified table may be used as guidance:

Figure 6-2: Allowable bearing pressures

No of blows for 300mm penetration	Equivalent mm per blow	Allowable bearing pressure (kN/m2)	
		2m width foundation	4m width foundation
5	60	90	70
10	30	140	100
20	15	200	160
30	10	270	220
40	7.5	340	290
50	6	400	350

The table should be used with caution; in gravelly soils a single large stone could significantly distort the blow count. For most moderate size walls, a consistent DCP blow count of at least 20 blows per 300mm should indicate a satisfactory founding stratum.

Walls founded on smooth bedrock should either be keyed or dowelled into the bedrock.

Compaction of backfill is also important for road-supporting retaining walls to reduce the possibility of long-term settlement of the road pavement. Care needs to be taken not to cause overloading of the wall during the compaction process, and ideally small pedestrian rollers or plate compactors should be used to compact the fill immediately adjacent to the wall.

The ends of walls should be keyed into intact material by gradually reducing the height of the wall or by constructing an angled return into the hillside (see figure 6-3). This will also help to reduce ravelling and scour.

Figure 6.3: Retaining wall with angled return

In Laos, current gabion construction involves the use of mechanically prefabricated gabion baskets. These comprise:

- mild steel wire galvanised with a heavy coating of zinc
- 3.0mm dia hexagonal mesh with a normal mesh size of 80mmx120mm, although this can be adjusted to suit the size of stone being used
- triple-twisted connections (i.e. twisted together in three half-turns) to reduce slippage and increase strength
- panel frames (selvedge) made up from 3.9mm dia wire
- wire for binding and connecting one basket to another to be 2.2mm dia wire

Further details may be found in the *Slope Maintenance Technical Specifications*. In good practice, gabion wall construction is usually made up of 1 metre x 1 metre baskets with a maximum length of about 2 metre (see Figure 6-4), although more often the end panels are prefabricated separately. The baskets are then staggered, as in brickwork, and with some gabions placed front to back. In this manner, the overall flexibility of the wall and the propensity for bulging or tearing apart is significantly reduced.

It is also important to ensure that:

- the end panels are properly wired in;
- bracing wires are fixed to hold the sides of the basket when it is one third and two thirds full to prevent the basket from bulging;
- in long baskets, properly wired in vertical cross panels are introduced within the basket preferably at 1.0 metre intervals to reduce distortion and stone migration;
- all baskets are wired together;
- all basket lids are properly wired down.

In some circumstances where additional corrosion resistance is required, the use of PVC coated mesh and binding wire may be appropriate.

The stone used to fill the gabions should be carefully packed by hand, of even tabular size, of a size double the mesh, and of good quality. Rounded river stone should be limited to a third of the total stone in any one basket, the remainder preferably dressed; long flat stones should be oriented from front to back.

Figure 6-4: Gabion basket detail

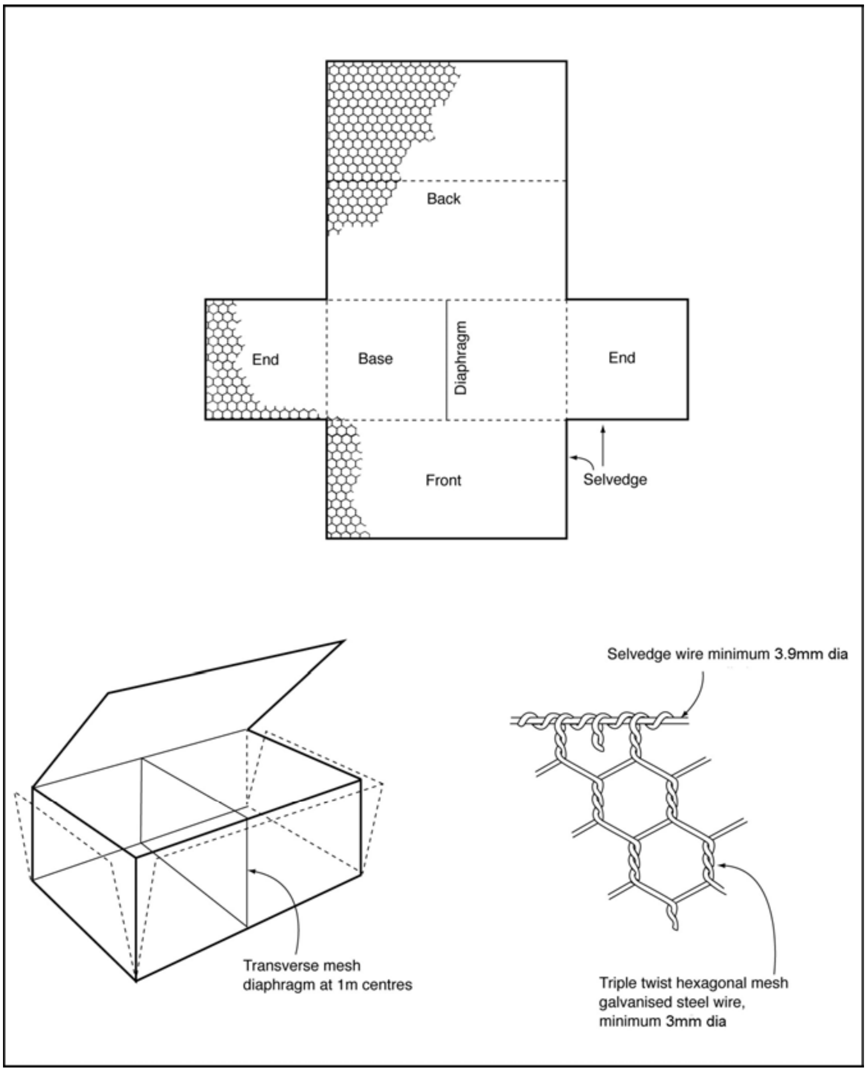


Figure 6-5: Examples of good and poor stone filling

For mortared masonry walls it is important to ensure that the stone used is of the appropriate quality and size and that the mortar has the correct consistency and strength. The *Slope Maintenance Technical Specifications* give the necessary details. In particular the finished mortared masonry should contain no voids and the exposed surface of the mortar joints should have a smooth appearance.

6.4 Bio-engineering

The construction of bio-engineering techniques has two main steps, covered by the sub-sections below. These are:

- final slope preparation;
- preparation of plant materials; and
- construction of the bio-engineering works.

6.4.1 Final slope preparation

Before civil engineering structures can be put in place and bio-engineering treatments applied, the site must be properly prepared. The surface should be clean and firm, with no loose debris. It must be trimmed to a smooth profile, with no vertical or overhanging areas. The object of trimming is to create a semi-stable slope with an even surface, as a suitable foundation for subsequent works.

Trim soil and debris slopes to the final desired profile, with a slope angle of between 30° and 60° (in certain cases the angle will be steeper, but review this carefully in each case). Trim off excessively steep sections of slope, whether at the top or bottom. In particular, avoid slopes with an over-steep lower section, since a small failure at the toe can destabilise the whole slope above. Remove all small protrusions and unstable large rocks. Eradicate indentations that make the surrounding material unstable by trimming back the whole slope around them. If removing indentations would cause an unacceptably large amount of work, excavate them carefully and build a prop wall.

Remove all debris and loose material from the slope surface and toe to an approved tipping site. If there is no toe wall, the entire finished slope must consist of undisturbed material.

Where toe walls form the lower extreme of the slopes to be trimmed, the debris can be used for backfilling. Where this is done, compact the material in layers, 100 to 150 mm thick, by ramming it thoroughly with tamping irons. This must be done while the material is moist.

6.4.2 Preparation of bio-engineering materials

The ways in which materials are prepared depends on the type of plant that is being used, and this is determined in turn by the technique that is chosen. The paragraphs below describe the construction steps involved for each category of plant. The drawings in Appendix E show how this is done.

Figure 6-6: A prepared grass slip

Grass slips are small sections of a grass plant, made by splitting up a large clump (see Figure 6-6). The stems are cut down to a height of 100 to 200 mm and the roots cut back to 40 to 80 mm. There should be 2 or 3 stems per slip.

(i) Fully rhizomatous grasses such as nyar khaem or dok khaem (broom grass or *Thysanolaena latifolia*): slip cuttings with 100 to 150 mm of two or three stems and 50 to 80 mm of rhizome.
(ii) Semi-rhizomatous large grasses such as nyar kha (*Imperata cylindrica*): slip cuttings with 100 to 200 mm of two or three stems and 50 to 80 mm of rhizome.
(iii) Semi-rhizomatous smaller grasses such as nyar phaek or nyar khaem lao (*Themeda triandra, Vetiveria zizanioides* and *T. arundinacea*): slip cuttings with 100 to 150 mm of two or three stems and 40 to 60 mm of rhizome and root.

Woody or hardwood cuttings are taken from the branches of certain types of small trees (see Figure 6-7). The diameter should be between 20 and 40 mm in diameter. Shoots and leaves are trimmed off. Lengths are as follows.

(i) 500 mm for use in palisades.
(ii) 450 to 600 mm for use in brush layers.
(iii) 1 to 2 metres for use in fascines.
(iv) 2 metres for the horizontal elements in live check dams.

Figure 6-7: Freshly prepared woody (hardwood) cuttings

Truncheon cuttings are made from the branches of large trees. They should be about 2 metres in length and 50 to 80 mm in diameter.

Logistics. It is very important that plant materials for bio-engineering are kept cool and damp when they are being moved and prepared. For this reason, the materials must be gathered and prepared only on the day that they are to be planted on site. This gives rise to a need for careful logistical planning, to ensure that there are sufficient labourers available on the site to undertake the collection, preparation and planting works simultaneously.

6.4.3 Planting work implementation

This sub-section provides details of the construction steps to be followed in the implementation of the various bio-engineering techniques. These are summarised below. Details of design are given in section 5.3 and in the typical drawings in Appendix E. The accompanying Technical Specifications for Slope Maintenance also provide full technical information.

- Grass planting: rooted slips of large grasses are planted in lines across a soil slope.

- Direct seeding: the seeds of shrubs and small trees are inserted into crevices in slopes composed of moderately weathered rock.
- Brush layers: woody (or hardwood) cuttings from shrubs or small trees are laid in shallow trenches across slopes formed in unconsolidated debris. These can be installed on slopes up to about 1V:1.25H.
- Fascines: bundles of long woody cuttings are laid in shallow trenches across slopes formed in unconsolidated debris. These can be installed on slopes up to about 1V:1.25H.
- Palisades: woody cuttings are planted in lines across the slope, usually following the contour. This can be done on a wide range of sites up to about 1.75V:1H.
- Truncheon cuttings: big woody cuttings from trees are inserted upright at intervals in slopes formed in deep or poorly stabilised and unconsolidated debris.
- Live check dams: small check dams with structural elements made from the woody cuttings of trees are placed at intervals in erosion gullies.
- Tree planting: potted seedlings from a forest nursery are planted at intervals across a soil slope.
- Large bamboo planting: a section of the stem and root of a large bamboo is planted, usually at the base of a slope, on a stream bank or above a river training wall. It is about 2 metres in length.

Planting method for lines of grass

Grass slips are planted in lines across the slope (see Figure 6-8). The best results usually come from lines that are horizontal or at 45^{o} to the maximum slope.

- Sites should be prepared well in advance of planting. All debris is removed and surface irregularities either removed or filled in so that there is nowhere for erosion to start. If the site is on backfill material, it should be thoroughly compacted, preferably when wet.
- Grass planting should always be started at the top of the slope and work progressed downwards.
- The planting lines are marked out with string, using a tape measure and spirit level. Care must be taken to make sure that the lines run exactly as required by the specification.
- The grass plants are split out to give the maximum planting material, but ensuring that there will be 2 or 3 stems in each cutting. Long roots are trimmed off, and the shoots cut off at about 250 mm above ground level. Slips should then be made according to the grass type (see details of bio-engineering material preparation above).
- With a small steel bar, a hole is made in the soil that is just big enough for the roots. The grass is placed into the hole, taking care not to tangle the roots or have them curved back to the surface. The soil is filled in around them and gently firmed with the fingers. Care must be taken to avoid leaving an air pocket by the roots.
- If compost or manure are available, a few handfuls should be scattered around the grasses. This is especially important on very stony sites, where compost or manure can help to improve early growth. It may be necessary to incorporate it into the surface material to prevent it being washed off.
- If it looks rather dry and there is no prospect of rain for a day or two, the plants should be watered by hand.

Method for direct seeding

Where there is not enough soil for planting, the seeds of shrubs and small trees are inserted into crevices in slopes composed of moderately weathered rock. A small hole is made in the slope surface using a steel bar, between stones and soil. Next, 2 seeds are inserted to a depth of about 20 mm. They are then covered with 5 to 10 mm of soil and firmed in. This is repeated at 50 to 100 mm centres across the slope. The work should be started at the top and continued downwards.

Figure 6-8: Planting lines of grass on a trimmed landslide head scarp

Planting method for brush layers

Woody (or hardwood) cuttings from shrubs or small trees are laid in shallow trenches across slopes formed in unconsolidated debris (Figures 6-9 and 6-10). These can be installed on slopes up to about 1V:1.25H.

- The lines to be planted are marked out using string, starting 500 mm from the base of the slope.
- Brush layers should always be installed from the bottom of the slope, working upwards.
- A small terrace is formed, with a 20% fall back into the slope. The terrace should be 450 mm wide. If the brush layering is on a gravel-filled road embankment a 50-mm thick layer of soil should be laid along this terrace to improve rooting conditions.
- The cuttings used should be made from woody material that is 6 to 18 months old. They should be 20 to 40 mm in diameter and 450 to 600 mm long. The tops should be cut at right angles to the stems and cut the bottom at 45º: it is then clear as to which way each cutting should be inserted. The cuttings should be taken the same day that they are to be planted.
- The first layer of cuttings is laid along the terrace, with a 50-mm interval between the cuttings. At least one bud and up to a quarter of each cutting should be left protruding beyond the terrace edge, and the rest of the cutting inside. The growing tips must point towards the outside of the terrace.
- A layer of soil 20-mm thick is laid between the cuttings to provide a loose cushion.
- A second layer of cuttings is laid on top of this, staggered with the first layer. On a gravel-filled embankment slope, an 80-mm layer of soil should be laid over the cuttings before backfilling.
- The terrace is partly backfilled with the excavated materials. This should not be more than 50 mm thick.
- Subsequent lines are marked at the spacing specified from the first brush layer, and the string set for the next layer.
- The process is repeated with the next line. As the next terrace is cut, the bench of the brush layer below is filled with the material excavated from above, and firmed down by gentle foot pressure.
- Good site supervision is essential to ensure that lines run along the contours and do not concentrate runoff; also to make sure that cuttings are not allowed to dry in the sun. Well-buried cuttings have a higher survival rate.

Figure 6-9: A freshly completed section of single-row brush layer

Figure 6-10: A brush layer about 3 months after planting

Planting method for fascines

Bundles of long woody cuttings are laid in shallow trenches across slopes formed in unconsolidated debris. These can be installed on slopes up to about 1V:1.25H.

- The lines are marked on the slope where the fascines are to be installed. Workers should be supervised carefully to ensure that the lines follow the contour or desired angle precisely.
- Fascines should always be constructed from the bottom of the slope, and work continued upwards.
- About five metres of trench should be dug at a time, and the cuttings laid in as the work progresses across the slope. This ensures that the soil in the trench is exposed only for a short period, thereby minimising the loss of residual soil moisture. The trench should be about 100-mm deep and 200-mm wide.
- The cuttings used should be made from woody material that is 6 to 18 months old. They should be 20 to 40-mm in diameter and at least 2 metres long. They must be made on the same day that they are to be planted.
- The cuttings are laid together in a bundle, filling the trench and with their ends overlapping so that they form a single cable right across the slope. Four cuttings per bundle is normal, but eight per bundle should be used if there is a lot of material available or if the site is critical.
- The fascines can be bound as they are installed by first laying strings across the trench and then tying them when the cuttings are in place. This helps to keep the cuttings together during backfilling but is not essential.
- The trench is backfilled as soon as possible, lightly covering the cuttings, and the soil tamped down firmly around it.
- If the slope angle is more than 25º, the fascines should be pegged. This can be done by placing a large cutting at right angles into the slope immediately below the fascine. One peg should be used per 500-mm run of fascines.

Planting method for palisades

Woody cuttings are planted in lines across the slope, usually following the contour (Figure 6-11). This can be done on a wide range of sites up to about 1.75V:1H

- The lines to be planted are marked out with string.
- Work should always be started at the top of the slope and progressed downwards.
- The cuttings should be made from woody material that is 6 to 18 months old. They should be 20 to 40 mm in diameter and 500 mm long. The tops should be cut at right angles to the stems and the bottom cut at 45º: it is then clear as to which way each cutting should be inserted. Cuttings must be made on the same day that they are to be planted.

- Using a pointed bar, a hole is made in the slope that is bigger than the cutting and deep enough to take at least three-quarters of its length.
- The cutting is carefully placed in the hole, so that at least three-quarters is buried. The soil is firmed around it, taking care not to damage the bark. Ideally, only one node of the cutting or about the top 100 mm should protrude from the soil. On steep, unstable sites, however, a greater protrusion helps to raise the delicate new shoots above the zone of moving debris, and to catch more debris.
- Good site supervision is essential to ensure that lines run along the contours and do not concentrate runoff; also to make sure that cuttings are not allowed to dry in the sun. Cuttings buried completely have a higher success rate than those planted with the tops partially exposed. Under extreme conditions, cuttings can be hammered into the slope. However, this is likely to cause physical damage and reduce the chances of success.

Figure 6-11: A palisade about 2 months after planting

Planting method for truncheon cuttings

Big woody (or hardwood) cuttings from trees are inserted upright at intervals in slopes formed in deep or poorly stabilised and unconsolidated debris (see Figure 6-12).

- The cuttings should be made from woody material that is at least a year old. They should be 50 to 80 mm in diameter and 2 metres long. The tops should be cut at right angles to the stems and the bottom cut at 45º: it is then clear as to which way each cutting should be inserted. Cuttings must be made on the same day that they are to be planted.
- Using a crowbar, a vertical hole is made that is about 20 mm wider than the cutting and at least 1 metre deep.
- The cutting is carefully placed in the hole so that at least half is in the ground. The gaps around it are then gently filled with loose soil.
- Truncheon cuttings are usually planted 1 metre apart on deep debris slopes.

Figure 6-12: A line of truncheon cuttings about 3 months after planting

Live check dam construction method

Small check dams with structural elements made from the woody cuttings of trees are placed at intervals in erosion gullies (Figures 6-13 and 6-14).

- First it is necessary to select the places on the gully to be stabilised where interruptions to the water flow are most likely to stop erosion from occurring.
- At the selected locations, a horizontal trench is dug right across the gully, 100 mm deeper than the gully bed and extending at least 300 mm into the gully sides.
- The cuttings to provide vertical support should be of the biggest and strongest materials, in the form of truncheon cuttings (2 metres long and 30 to 80 mm in diameter). They should be made from material that is at least a year old.
- The cuttings used for the horizontal elements should be made from woody material that is 6 to 18 months old. They should be 20 to 40-mm in diameter and at least 2 metres long.
- All cuttings must be made on the same day that they are to be planted.
- Truncheon cuttings are placed at a spacing of 200 mm, in two lines 200 mm apart, throughout the trench. These are the main vertical elements of the check dam. See the section above for the method to plant these. They should protrude 300 to 500 mm above the ground surface.
- Long woody cuttings (2 metres in length) are then woven in and out between the truncheon cuttings.
- Work is started from the bottom and the cuttings woven between the vertical posts, passing on alternate sides. It will require 25 to 40 long cuttings per metre of check dam height for each line of weaving.
- Soil and stones are carefully filled between and around the check dam, and firmed down gently.
- The horizontal cuttings must be woven higher between the vertical posts at the ends of the check dam, so that the middle is lower for water to flow through.
- Care must be taken to ensure that the horizontal members are fully keyed into the sides of the gully.

Figure 6-13: A live check dam on a soil slope, about 2 months after completion

Figure 6-14: Live check dams about 3 months after completion, on a mixed debris slope

Planting method for potted tree seedlings

Potted seedlings from a forest nursery are planted at intervals across a soil slope.

- The desired quantity of potted seedlings, plus a 10% contingency, must be obtained from a well managed nursery. They must be healthy, undamaged and of a size appropriate to the specifications (usually 400 to 600 mm).
- When the ground is wet enough to support reasonable growth, the seedlings should be planted out.
- Pits should be dug that are at least 300 mm deep and 300 mm in diameter. The bigger the hole made, the better it is for the plant; but there must be a compromise between helping the plant and avoiding excessive disturbance to the slope.
- The pot must be removed carefully. If it is a polythene bag type, it should be sliced down the side with a razor blade, or torn carefully along the seam. Care must always be taken not to cut or damage the roots.
- The seedling is then planted in the pit, filling the soil carefully around the cylinder of roots and soil from the pot, and ensuring that there are no voids or cavities. The soil is firmed all around the seedling with gentle foot pressure.
- If available, a few handfuls of well-rotted compost should be mixed with the soil around the roots when backfilling the hole.
- Any weeds around the plant should be removed. Mulch should be added around the seedling, but with a slight gap so that it does not touch the stem.

Planting method for large bamboo planting

A section of the stem and root of a large bamboo is planted, usually at the base of a slope, on a stream bank or above a river training wall. It is about 2 metres in length.

- The method involves taking a very large rhizome and culm cutting, as is done for small grasses. Source clumps should be identified well in advance and an agreement reached with the owners.
- On the planting day, a suitable culm (stem) near the edge of the parent clump is selected and the rhizome (root) carefully dug out. The rhizome is cut where it branches from the main plant, to give at least 500 mm of rhizomatous root. Great care must be taken not to damage the buds and small roots. The culm is cut off about 2 metres above ground level.
- The root ball is wrapped in damp hessian jute and the big cutting transported to site for planting on the same day.
- A large hole (at least five times the size of the cutting's rhizome) is dug and the rhizome planted either upright or at right angles to the slope.
- The hole is carefully backfilled and the soil firmed as much as possible.
- The disturbed and surrounding soil is mulched well.
- A depression is formed around the roots to act as a water collection area. It should be watered thoroughly after planting and daily thereafter until rainfall is reliable.

APPENDIX A: SOURCES OF FURTHER INFORMATION

The references given below are just a few that the reader might find useful further reading with respect to slope stabilisation.

BS 8002:1994 *Code of practice for earth retaining structures*. British Standards Institution, UK

FOOKES, P.G, SWEENEY, M, MANBY, C.N.D, and MARTIN, R.P, 1985 *Geological and geotechnical aspects of low cost roads in mountainous terrain.* Engineering Geology, 21, 1/2 1 - 52.

GEOTECHNICAL CONTROL OFFICE 1984 *Geotechnical manual for slopes.* Civil Engineering Department, Hong Kong

GEOTECHNICAL CONTROL OFFICE 1993 *Geoguide 1. Guide to retaining wall design*. Civil Engineering Department, Hong Kong

GEOTECHNICAL ENGINEERING OFFICE 2000 *Highway Slope Maintenance.* Civil Engineering Department, Hong Kong

HOWELL, J.H, 1999 *Roadside Bio-engineering*. *Site Handbook and Reference Manual*. Department of Roads, Kathmandu, Nepal.

OVERSEAS ROAD NOTE 16, 1997. *Principles of low cost road engineering in mountainous terrain.* Transport Research Laboratory, UK.

SCHAFFNER, U 1987 *Road construction in the Nepal Himalaya. The experience from the Lamosangu - Jiri Road Project.* ICIMOD Occasional Paper No 8. International Centre for Integrated Mountain Development, Kathmandu, Nepal.

TURNER, A.K and SCHUSTER, R.L, 1996 *Landslides: Investigation and Mitigation*. TRB Special Report 247. Washington D.C. Transportation Research Board.

APPENDIX B: EXAMPLES OF SLOPE STABILISATION

Before considering typical applications, it is probably worth reiterating some points common to all types of failures

Firstly, the initial question that should be asked is - why has this particular location failed and not the adjoining sections? Usually, but not necessarily always, the answer involves water. It is therefore essential to locate the causes of the ingress of water into the failed area. If this arises from a drainage feature at or behind the crest of the failure, then the solution should incorporate every means to redirect the water away from the crest altogether or, if this is not practicable, to redirect the water down the edge of the failed area or to depress the water table within the failed mass using counterfort or drilled horizontal drains. If the water is causing more of an erosional problem due to seepage, then the solution might be to use herringbone drains or revetments or bio-engineering or a combination of these.

Secondly, thought then needs to be given to the two other most effective means of slope stabilisation; re-grading to reduce the steepness of the slope and toe weight - either by the construction of a toe berm or a retaining wall. Re-grading is usually only an option where the failure involves a cut or fill slope, but in steep side-long ground this may not be practicable. The construction of a toe berm, preferably using free-draining material, is a cheap option but not often possible due to lack of space. This then leaves the final option of a wall, and the advantages and disadvantages of the various types of construction are described in 4.3.

B.1 Failures above the road

B.1.1 Failures in colluvium

As noted in Section 2, one of the most common forms of slope instability is above-road planar failures in colluvium, usually with a failure surface limited by a competent underlying stratum such as bedrock, and daylighting adjacent to the road. Figure B-1 Case A shows a typical example in cross section, with an assumed failure surface and an assumed water table at failure, based on site observations (or perhaps in the case of a major failure, a ground investigation).

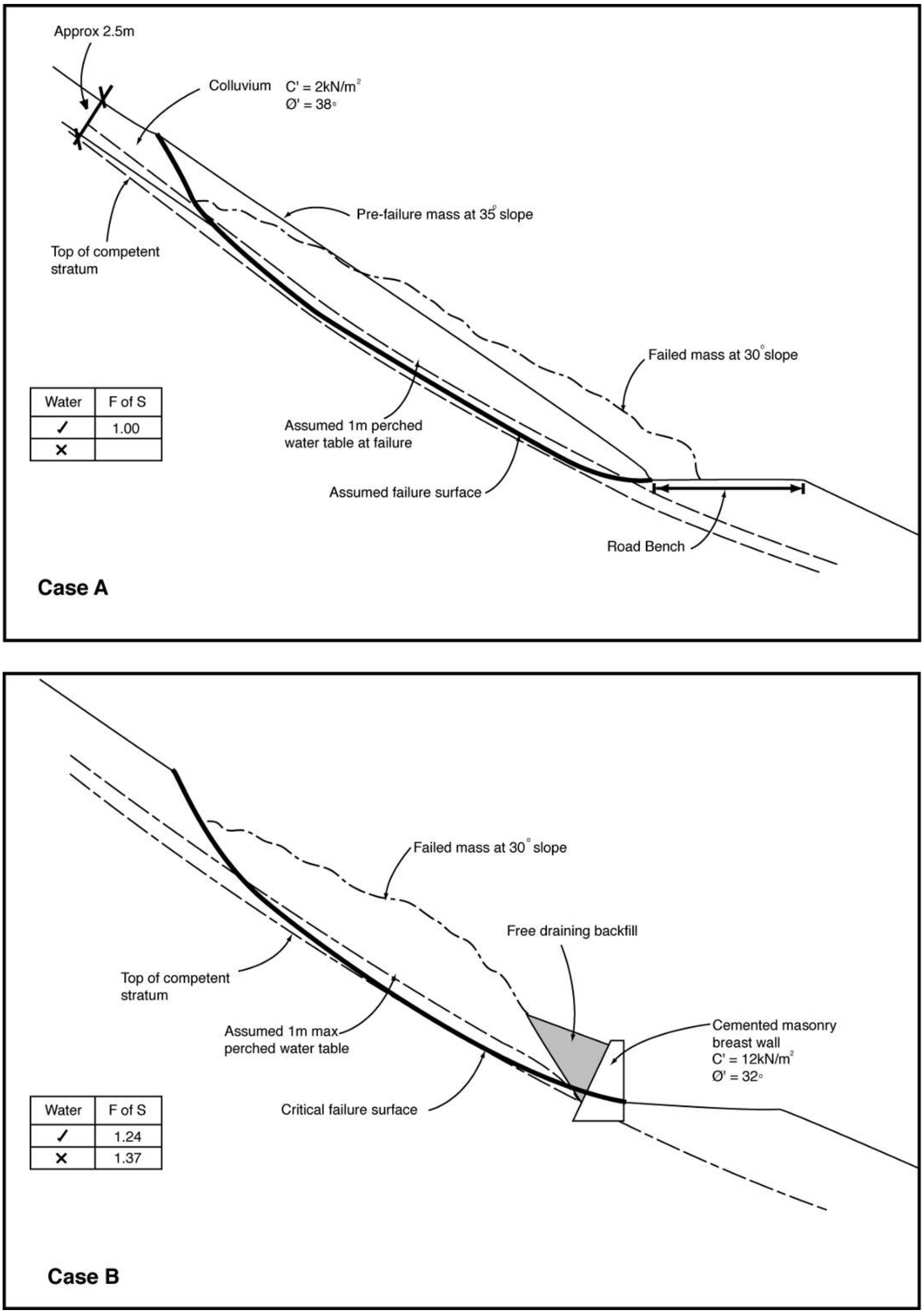
In the absence of reliable shear strength testing, shear strength parameters of $c' = 2$ kN/m^2 and $\phi' = 38°$ are assumed for the predominantly bouldery colluvium and by a process of trial and error with adjustments to the shape and depth of failure surface and the water table, a plausible mode of failure with a factor of safety of approximately 1.0 is obtained.

In view of the limited space at the base of the slope, the most appropriate stabilisation measures are likely to be water table lowering and a retaining wall at the toe.

With the assumed addition of a retaining wall, it is necessary to check the factors of safety for failure surfaces passing through or beneath the wall and, in this case, for a masonry wall, shear strength parameters of $c' = 12$kN/m^2 and $\phi' = 32°$ are considered appropriate (Case B). It can be seen that if the water table assumptions remain the same, this results in an increased factor of safety of 1.24. A separate analysis is necessary to check the stability of the retaining wall itself. If further measures are introduced to lower the assumed water table at failure by diverting the source of the water (if applicable) or by means of improved surface drainage (e.g. herringbone or horizontal drains), then the factor of safety of the slope could increase to as much as 1.37 depending on the effectiveness of the water table lowering measures.

Despite the many assumptions that this type of analysis requires in the absence of a detailed (and expensive) ground investigation and laboratory testing programme, it does provide a technical basis for the many engineering judgements that have to be made on site, and should be carried out wherever possible.

Figure B-1: Typical planar failure in colluvium



B.1.2 Failures in residual soils/weathered rock

Figure B-2 shows a feeder road in Nepal about five years after construction with cut slopes at 45° in residual soil and displaying no signs of instability or undue erosion.

By contrast, above-road failures in residual soils/weathered rock in Laos are very commonly seen where the cut slope has been formed at too steep an angle.

Figure B-2: Example of good cut slope construction

B.2 Failures below the road

B.2.1 Failures in loose fill slopes

As noted in section 2.1.2, road construction in Laos (and elsewhere) has often involved the formation of the road predominantly in cut and to dump the excess spoil as loose fill on the natural slopes below. Occasionally the road itself is formed partly on this loose fill, of which only the road formation itself might receive some form of compaction. Often the loose fill will consolidate and become covered in vegetation over a period of time, thus concealing its true nature, leading to below-road retaining walls inadvertently being founded within the fill layer. Sometimes the loose fill will continue to fail and erode, creating unsightly erosion scars and endangering the stability of adjacent road and the underlying natural ground, particularly if this comprises colluvium.

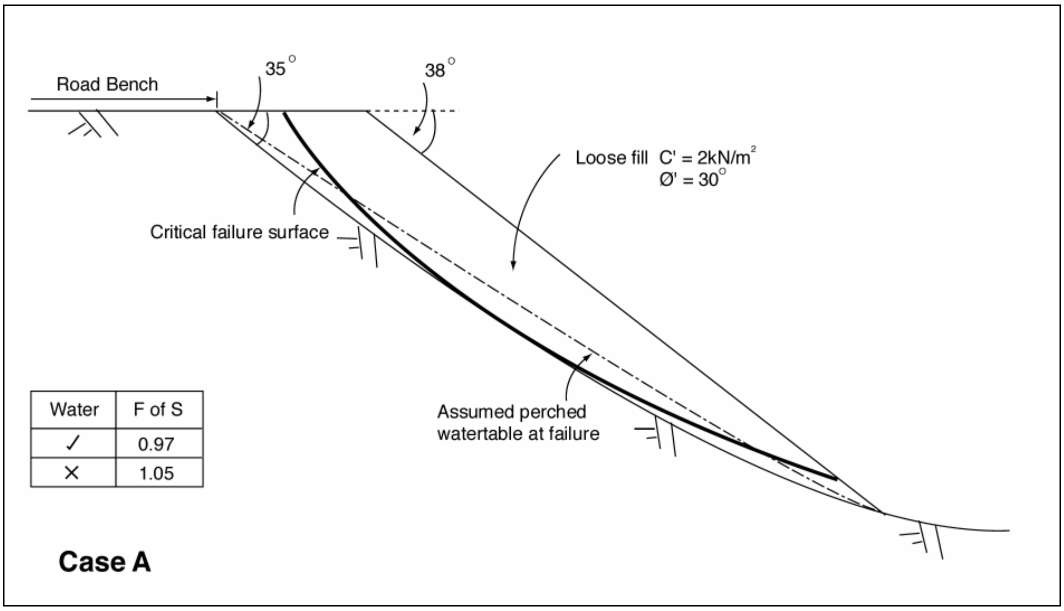
Figure B-3, Case A takes the case of a loose fill slope with an exposed slope angle of 38° (which is very commonly observed), overlying a natural slope of 35°. In its loose state, the shear strength parameters of the fill are assumed to be $c' = 2$ kN/m^2 and $\phi' = 30°$; in its compacted state these are assumed to increase to $c' = 2$kN/m^2 and $\phi' = 35°$.

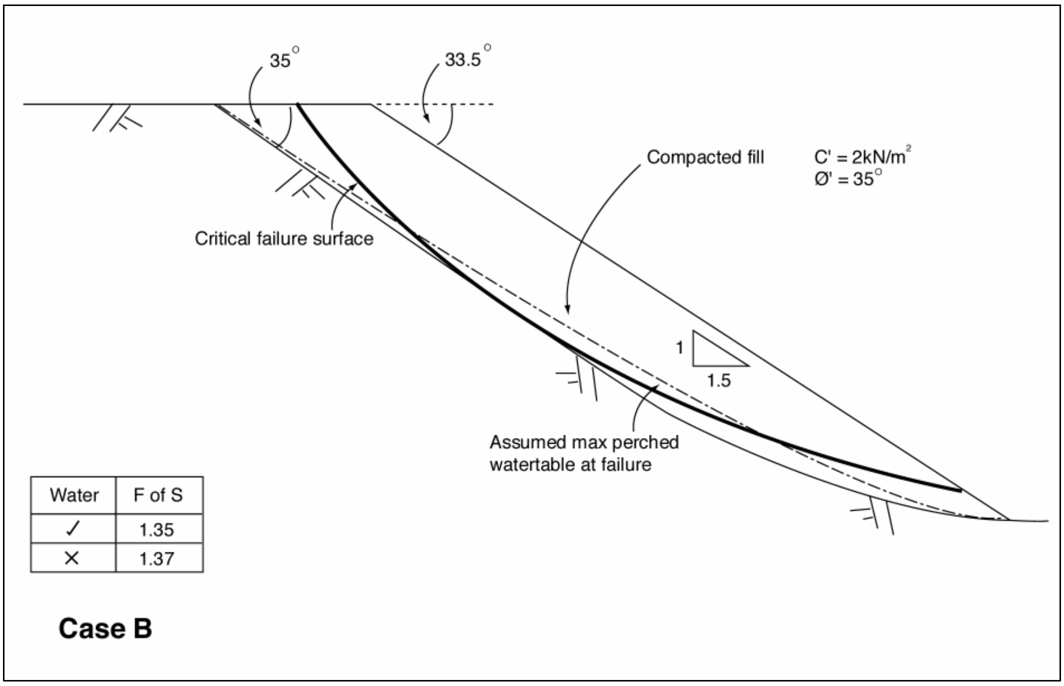
Due to its loose state, rainwater will rapidly percolate through the fill and possibly form a perched water table on the surface of the underlying natural ground. The factor of safety drops from just above unity to just below unity.

Had the fill been properly benched into the underlying ground and compacted throughout (Case B), then only considering a failure surface within the compacted fill indicates a factor of safety of more than 1.3, even with the assumption of a perched groundwater table - now very unlikely due to the greater impermeability of the compacted fill and the creation of benching to break up the interface between the fill and the natural ground. Of course, in considering the stability of the entire slope, further trial failure surfaces would need to be examined passing through the underlying natural ground. Nonetheless, this example does serve to demonstrate the importance of compacting fill slopes, and of the inherent instability of dumped loose fill.

In terms of stabilisation of existing loose fill slopes, there is very little that can be economically justified in terms of the road network If the road itself is being threatened, then the construction of a below-road retaining wall may be necessary, the wall foundation being taken down through the fill to a competent underlying stratum. Bio-engineering measures in the loose fill below the wall may also help to aid stability and reduce the prospects for erosion. If the road is not threatened, then bio-engineering measures alone, particularly for shallow fills, may be appropriate.

Figure B-3: Typical failure in fill





B.2.2 Failures in natural ground

Where failures occur in the natural ground, they are often due to a wider scale instability, such as that indicated in Figure B-4 or failures of greater complexity. Such failures may be above, below or encompass the road and may require very detailed investigation and analysis. However, some failures below the road may arise from uncontrolled road surface runoff.

In the latter case, such failures may not be appropriate for detailed analysis. The most important factor is to ensure that the uncontrolled disposal of water downslope is prevented in future. If uncontrolled roadside drainage cannot be guaranteed, then it might be appropriate to form an upstand at the valley side edge of the road to contain the water until it can be discharged safely downslope, preferably into a natural drainage course.

As far as any erosion scar itself is concerned, if the road is threatened then a roadside retaining wall may be necessary, the rehabilitation of the eroded surface downslope best tackled using bio-engineering techniques.

B.3 Failures cutting through the entire road bench

Figure B-4 Case A shows a typical example of a “sinking area” in cross-section. Essentially these failures are usually identical to the type of failure dealt with in B.1.1 except that they have a deeper failure surface, often 5-10 metres below ground level.

The main cause of failure can be twofold; either excess water entering the unstable area at its crest, or removal of toe support due to high level river stages or course changes at its base, or a combination of the two. This example assumes a moderate groundwater table and toe support removal and the same shear strength parameters as B.1.1. In practice, many of these large-scale, deep seated landslides are controlled by adverse geological structures.

If nothing is done to stabilise the slope, movement down slope will occur during the next period of prolonged heavy rainfall, the material accumulating at the toe being removed by the next high river stage. As a consequence any support at the toe will have to be designed to act as a stream/river scour protection as well as a gravity retaining wall. This type of failure is usually very costly to stabilise.

Figure B-4, Case B shows the effect of a major 8m high toe support gabion wall and the consequent increase in factor of safety to only 1.06. This small increase in factor of safety is not uncommon in this type of circumstance, primarily due to the large scale nature of the landslide. However, the prime effect of the wall is to prevent, or at least reduce the incidence of progressive failure, bringing about a gradual stabilisation of the entire slope and to prevent continuing river scour. Further increases in factor of safety will be brought about by additional measures to reduce peak groundwater levels.

Figure B-4 also highlights the difficulty of constructing a satisfactory retaining wall immediately above or below the road, so that the base of the wall is adequately founded in intact material below the failure surface.

There are likely to be similar cases where the scale of the failure is so large (e.g. affecting several hundred metres of road) and the potential cost of the stabilisation measures so high that remedial work cannot be contemplated for the immediate future. There will be other cases where some movement has occurred, but not to any significant extent.

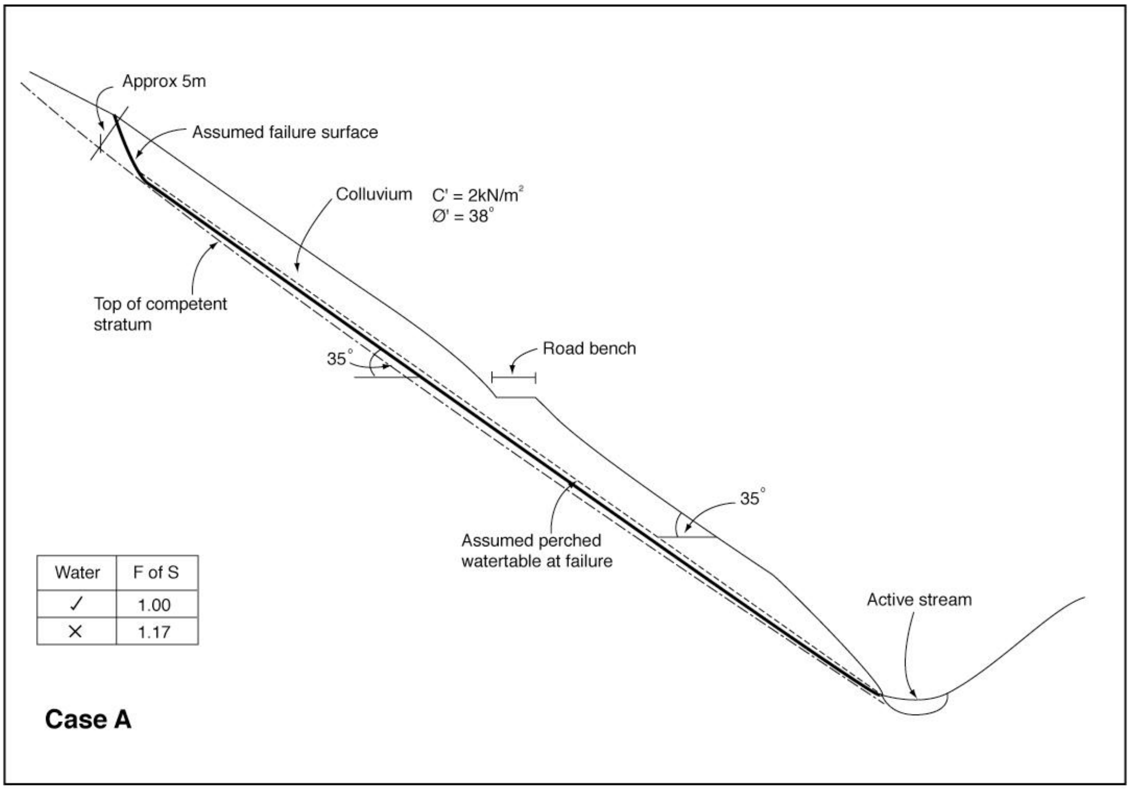
In both cases it is strongly recommended that road movements are monitored before and after each wet season to check whether the movements are accelerating or relatively static (see Section 3.5), so that future stabilisation measures can be properly assessed and prioritised.

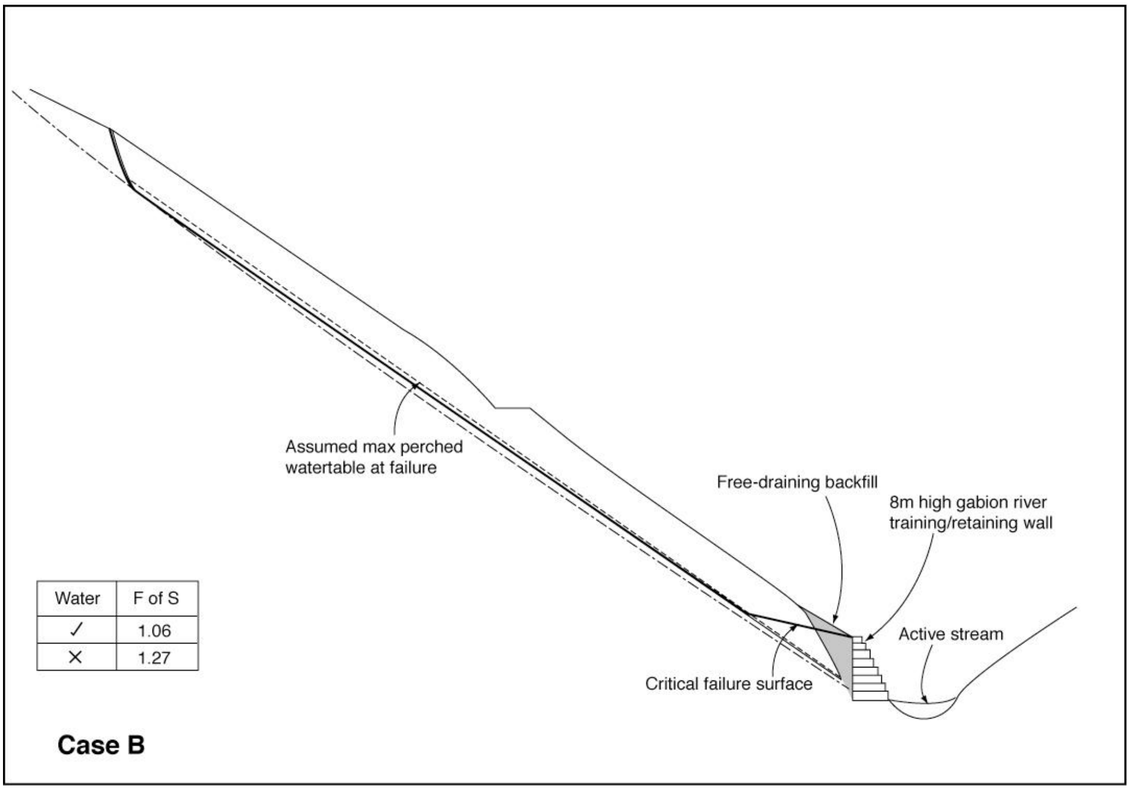
There will be instances where the scale of the failure is so large and the depth of movement so great that the only long-term economic course of action is to search for an alternative alignment and abandon the affected section of road. In these cases, the environmental and social consequences of abandoning the existing road need very careful consideration, and the new alignment carefully investigated, designed and constructed to ensure that the same problems are not encountered or initiated.

B.4 Wall failures

As noted in Section 2.3, wall failures due solely to an inadequacy of the structural integrity of the wall itself are comparatively rare in Laos. “Sinking” areas accepted, wall failures above the road are much more likely to be due to overloading from the retained ground, whereas wall failures below the road do appear to be the result of inadequate founding (e.g. the wall has not been founded on a competent stratum) or soil erosion (e.g. the toe of the wall has become exposed and under-scoured). In both cases the remedy will usually be to increase the depth of the foundation, either by underpinning or by total reconstruction.

Figure B-4: Typical translational or planar failure through road bench





APPENDIX C: SLOPE MAINTENANCE REPORT FORMS

C.1 Landslide Report Form

C.2 Retaining Wall Report Form

Examples of completed forms can be found in the Slope Maintenance Site Handbook

LANDSLIDE REPORT

Location (road and km):	
Date of report:	Reporter's name:

Situation		Material		Blockage		Failure	
Above road		Rock		Whole road		Whole road	
Below road		Debris		Part of road		Part of road	
Through road		Soil		Side drain only		Side drain only	

Geometry of slipped area		Topography	
Length (perpendicular to road) m		Original slope angle	
Width (parallel to road) m		Failure angle	
Depth (estimated) m			
Estimated volume (L x W x D) m^3		Associated retaining wall	

Sketch of failure/additional notes:

Probable cause of failure:

Consequences if nothing done:

WALL REPORT

Location (road and km):	
Date of report:	Reporter's name:

Situation		Type		Nature of distress		Distress due to:	
Above road		Mortared masonry		Cracking		Sliding	
Below road		Composite masonry		Tilting		Overturning	
		Gabion		Bulging		Sinking	
		Other (name)				Slope failure	

Geometry			Shape			
Affected length (parallel to road)	m			Sloping	Vert	Horiz
Total length	m		Front face			
Width at base	m		Back face			
Height	m		Base			

Sketch of failure/additional notes:

Probable cause of failure:

Consequences if nothing done:

APPENDIX D: LANDSLIDE MAPPING PROCEDURE

The procedure described below is a standard way of assessing the response to a slope failure. It describes the way in which landslides should be assessed in order to determine the seriousness of a failure. The forms given in Appendix C may be used with this procedure.

Procedure for the mapping of large and complex landslides

Procedural steps		**Action**
Stage 1	Initial observations of the geomorphology. Look at the general locality and situation of the site: • make a note of the exact location so that you can direct others to the site if necessary; • see if it is in a part of the landscape where instability would be expected; • see if the joint orientation of the rocks, outcropping on the hillside around the site, indicate that the cause of the failure may be due to rock structure, either as planes of weakness or movement of water along fractures; • look at other sites in the area: they may have a similar geomorphic situation and a similar life progression.	**Observe**
Stage 2	Sketch the site from the road or other good observation point	
(a)	Draw the main features: • concentrate on getting the general proportions correct; • estimate the length from top to bottom: record this on the drawing; • estimate the width across the base: record this; • sometimes the landslide may be very complex, and some additional sub-drawings may help.	**Draw**
(b)	Look for the landslide zones: • scar; • transport; • debris. Note that you cannot yet see whether there is a zone of cracking above the scar. You do not have to record these zones on the drawing, but the completed drawing should be sufficiently well illustrated and labelled to let another person recognise which zones are present and where they are.	**Draw**
(c)	Examine the material forming the original hill slope: • debris; • soft rock; • hard rock; • alternating hard and soft rocks. All of these could be present on one landslide. The drawing should show where they are. You will have to check your classes during the site walkover (Stage 3b).	**Describe and draw**
(d)	Sketch a slope profile of the site from top to bottom. Angles do not have to be precise, but should indicate relative steepness. It can be augmented with more detail (e.g. with slope measurements) as you walk up the slide. Note that slopes >35° can be unstable unless composed of solid rock.	**Draw**
(e)	Sketch the surface water drainage: • streams; • any springs that may be visible from where you are standing.	**Draw**
(f)	Sketch areas of rock outcrop.	**Draw**
(g)	Landmarks: note any obvious landmarks on the site, such as prominent trees. This will help you to keep your bearings as you walk over and around the site.	**Draw**

Procedural steps		Action
Stage 3	Walkover survey	
(a)	Walk up the centre of the slide to the crown (head of scar). Measure the angles of major slope units. If the slope is too steep or dangerous, walk around the edge, looking into the scar.	**Measure**
(b)	Rock: visit each rock outcrop. Measure any relevant rock planes or observe how the planes relate to the slope and failure planes. Make sure that the rocks observed are true outcrops (attached to solid rock beneath) and not simply large boulders partly buried on the slope. Check the weathering grade: • hard rock is from weathering grades 1 to 4 and often rings when struck with a hammer); • soft rock is in weathering grade 5 or greater, and gives a dull thud when struck with a hammer). Note the: • uniformity or layering (bedding) of the rock units; • degree of weathering (hardness and discoloration of minerals) of the rocks; • degree of fracturing/jointing, especially any open fractures/joints; • signs of water movement along fractures.	**Measure and describe**
(c)	Debris and slope: indicate the area of the slide that is occupied by debris: • location and extent of landslide debris; • composition of debris; • wetness of debris; • depth of debris / depth of failure plane; • location, orientation and size of any cracks in the debris or on the slope; • any back-tilted slope, where water may collect (if this is present, it indicates a deep-seated circular failure – a shear failure); • tilted trees: these can indicate subsiding ground; • disrupted engineering structures, e.g. masonry surface drains; • points of ground water seepage.	**Describe and draw**
(d)	Margins and top. Look for the following. • Cracks in the ground: cracks are most frequent above the head of a slide, but they often occur also around the sides. The presence of cracks shows that the ground is under tension and that it will probably fail, and soon. Note the location, dimensions and orientation of the cracks. This information tells you where, and in which direction, the ground is under tension. The area of cracking tells you the area over which failure is taking place; • Streams, springs, irrigation channels or drainage structures, especially masonry drainage ditches. These features may be sending water into the slide. They may either have caused it in the first place, or they may be contributing to further failure. Irrigation channels and masonry drainage ditches should be inspected closely for any signs of cracking and leakage; • Irregular topography, not due to rock outcrops. This may indicate the presence of an old landslide, in which case you will have to survey the whole of this, too. Continue walking up the slope above the landslide until there is no further evidence of instability. This may mean walking at least fifty metres higher than the landslide scar, and much further if necessary.	**Draw**
(e)	Base of the slide: describe the features and ground conditions at the base. Possibilities are as follows. • Intact road. Instability is from above only. The road may be buried but the road itself is not disrupted by the slide plane. Note: if the road is disturbed, the road cannot be at the base and the slope condition at the base must come under one of the three categories below. • Stable, undisturbed hill slope. • Unstable hill slope. Cracked ground, landslide or topography that collects water. • Stream, with a possible risk of bank erosion and undercutting of slope.	**Describe**

Procedural steps		**Action**
Stage 4	General assessment	
(a)	Causes and mechanisms of instability. Based on your observations, assess whether any part of the failure is due to the following causes. Mark them on your plan of the site. Surface water • Erosion, or soaking of surface to cause shallow sliding. • Effects of water infiltrating from surface. Causes shallow failures. Ground water • Ground water causes increased pore water pressure at depth. • Failure plane is often deeper than in surface water failure. Weathering • Rock shear strength is reduced by weathering. Rock strength is reduced as constituent minerals are broken down into weathering products and clay minerals. Physical bonds between rock constituents are weakened or broken. The rock can fail along weakened fracture planes or through its body (mass). Undercutting • Slope is undercut by a flowing stream or by the opening up of a road cutting. • Incision (downcutting) or lateral scour by streams is a major cause of slope failure. The initial failure can work rapidly up slope. Addition of weight • Weight added usually by landslide debris from above or by the dumping of spoil, or the construction of a road fill.	**Describe**
(b)	History and life progression of slide. Assess the likely evolution of the slide from its current condition into the future. Possibilities are as follows. • Stable slope formed, or will stabilise naturally • Single failure to stable rock plane or stable slope configuration. This is a relatively rare situation. • Further movement is expected, by a less serious mechanism. ‘Less serious mechanism’ means a movement at a depth shallower than that of the original failure. This means that the instability is going through post-slide adjustment. • Repeated movement expected, by the initial mechanism or another equally serious. • Further movement is expected, by a more serious mechanism. ‘More serious mechanism’ means a movement at a greater depth than that involved in the original failure, or a mass movement involving a different cause or mechanism.	**Describe**
(c)	Severity of instability Fill in the Check List for Assessing Severity of Slope Instability (see below). This does not quantify the severity (it is still impossible to do so in a way which permits meaningful comparisons) but allows you to assess the severity rapidly. On the check list, the criteria in each category get progressively larger, more difficult and harder to rectify. Therefore in assessing severity, you should look at how far down each list you have ticked each of the twelve categories.	**Check list**

Procedural steps		**Action**
Stage 5 Determination of site treatment		
You should now have as much information as you are able to obtain from a straightforward site investigation without specialist advice and equipment.		**Refer to diagnostic table below**
Question	**Functional implication**	**Action if the answer is "yes"**
Is the site subject to a deep-seated (several metres depth and usually failing through rock) shear or rotational failure?	Major reinforcing, anchoring or physical support required.	If the failure plane can be identified, use retaining walls to support the toe. Alternatively, it may be possible to remove weight from higher up the slope by debris removal/heavy trimming.
Is the slope very long (greater than about 30 metres), steep and in danger of a mass failure?	Reinforcing or physical support is required. Armouring is also required.	If suitable foundations are available, use retaining walls to break the slope into smaller, more stable lengths.
Is the foot of the slope undermined, threatening the whole slope above?	Strong physical support is required.	Consider the necessity of building revetment, toe or prop walls.
Is there a distinct overhang or are there large boulders poorly supported by a soft, eroding band?	Localised physical support or anchoring are required.	Consider prop walls or dentition work to support the overhang.
Does the slope have a rough surface; or is it covered in loose debris; or is it a fractured rocky slope; or does it have any very steep or overhanging sections, however small?	*Armouring is required, but only after the slope has been altered to stop it shedding loose material.*	Trim the slope as far as possible to attain a smooth, clean surface with a straight profile in cross-section.
Is there water seepage, a spring or groundwater on the site, or a danger of mass slumping after heavy rain?	Deep drainage is required.	Consider the advisability of a surface or sub-surface drainage system, depending on site conditions.
Is the slope made up of poorly drained material, with a high clay content?	Techniques used on this sort of material must be designed to drain rather than accumulate moisture.	There is a danger of shallow slumping. Investigate the need for a surface or sub-surface drainage system, depending on site conditions.
Is the site a major gully, subject to occasional erosive torrents of water?	Major drainage is already present; heavy armouring is required.	Use masonry check dams to reduce the scouring effect.
Stage 6 **Implementation of site treatment**		
It should now be possible to move to the detailed survey of the site, so that you can assess the exact position and quantities of the structures that you require. These can then be designed on the basis of the national standards, and the works tendered and implemented in the usual ways. It is recommended that all significant failures are examined by an appropriately qualified and experienced engineering geologist before stabilisation measures are scheduled and designed.		**Refer to standard engineering design drawings**

Check list for assessing severity of slope instability

Within each section of this check list, the conditions are described in order of increasing severity. A site that can be described by the first category in each section is relatively mild and straightforward to stabilise. A site that is described by the last category in each section is a very severe problem, often requiring large-scale civil engineering works to repair.

Road: .... **Chainage:** .... **Observer:** .... **Date:** ....

1 LOCATION OF SLIDE
☐ Off road alignment but within MPWT responsibility
☐ Above road - any distance
☐ Below road - any distance
☐ Between roads, *i.e.* above one road and below another
☐ Through road (slide is above and below road)

2 TYPE OF SLOPE AFFECTED
☐ Road cutting but not hill slope
☐ Hill slope but not road cutting
☐ Road cutting plus hill slope
☐ Embankment, fill or spoil slope

3 SLOPE CONDITIONS ABOVE SLIDE (above road, if road is at top of slide)
☐ Crest of ridge, or gentle slope (less than 35°)
☐ Stable, undisturbed hill slope
☐ Unstable hill slope. Cracked ground, another landslide or topography that collects water
☐ Cut-off drain or take-out drain

4 SLOPE CONDITIONS BELOW SLIDE (or below road, if road is at base)
☐ Stable, undisturbed hill slope
☐ Intact road at base of slide (road may be buried, but if it is disturbed, road is **not** at base)
☐ Unstable hill slope. Cracks, landslide or topography collecting water
☐ Stream

5 GENERAL TYPE OF FAILURE
☐ Erosion, rilling or gullying up to 2 m deep
☐ Gully more than 2 m deep
☐ Mass movement (slide, flow or fall)

6 MATERIAL FORMING ORIGINAL (FAILED) SLOPE
☐ Debris, colluvium or alluvium
☐ Soft rock (weathering grade 5 or equivalent)
☐ Hard rock (weathering grades 1 - 4)
☐ Alternating hard and soft rocks

7 FAILURE MECHANISM
☐ Erosion (rill, gully or pipe)
☐ Plane failure in rock (slide, fall)
☐ Collapse (fall with disintegration)
☐ Flow or shear failure (slump or slide)
☐ Undermining

8 CAUSE OF FAILURE
☐ Surface water. Erosion, or soaking of surface: shallow slide/flow
☐ Ground water, causing increased pore water pressure at depth
☐ Addition of spoil or landslide debris
☐ Weathering
☐ Undercutting of slope by stream or road cutting

9 DEPTH OF FAILURE

☐	Less than		25	mm	Erosion
☐	25	-	100	mm	}
☐	100	-	250	mm	} Slide, slump,
☐	250	-	1000	mm	} flow or fall
☐	More than		1000	mm	}

10 LENGTH OF FAILURE (top to bottom)

☐	Up to	15			m
☐		15	-	75	m
☐		75	-	150	m
☐	More than			150	m

11 HISTORY OF SLIDE
☐ Not moved within the last 5 years
☐ Moved within the last 5 years but not this year
☐ Moved this year for the first time
☐ Moves every year by initial mechanism - diminishing
☐ Moves every year by initial mechanism - constant or getting worse

12 LIFE PROGRESSION OF SLIDE
☐ Stable slope formed, or will stabilise naturally
☐ Further movement expected, by less serious mechanism (post-slide adjustment)
☐ Repeated movement expected, by initial mechanism or another equally serious

N.B. The above checklist is designed principally with bio-engineering measures in mind. Large and deep seated landslides will require review by a suitably qualified and experienced engineering geologist; river bank erosion will require review by a suitably qualified and experienced river engineer.

APPENDIX E: TYPICAL DETAILS FOR SLOPE STABILISATION, DRAINAGE AND BIO-ENGINEERING WORKS

The drawings that follow show suggested typical details for slope stabilisation, drainage and bio-engineering works that may form the basis of construction work in Laos on low volume roads. Since they show only typical details, they may require substantial revision to meet the requirements of a particular site.

Drawing No	Title
SMM/DWG/001	Masonry retaining wall
SMM/DWG/002	Gabion retaining wall
SMM/DWG/003	Reinforced concrete retaining wall
SMM/DWG/004	Slope protection
SMM/DWG/005	Slope and roadside drainage
SMM/DWG/006	Pipe culverts (1)
SMM/DWG/007	Pipe culverts (2)
SMM/DWG/008	Gabion earth reinforcement
SMM/DWG/009	Gabion check dams
SMM/DWG/010	Grass slips and grass planting lines
SMM/DWG/011	Shrub and tree planting
SMM/DWG/012	Hardwood cuttings
SMM/DWG/013	Brush layering, fascines and palisades
SMM/DWG/014	Large bamboo planting
SMM/DWG/015	Live check dam and vegetated stone pitching