LAO PEOPLE'S DEMOCRATIC REPUBLIC
PEACE INDEPENDENCE DEMOCRACY UNITY PROSPERITY

SLOPE MAINTENANCE SITE HANDBOOK

MINISTRY OF PUBLIC WORKS AND TRANSPORT

SEPTEMBER 2008

Contents

About this Slope Maintenance Site Handbook

This Handbook was produced for the Ministry of Public Works and Transport as part of the SEACAP 21 Project, Slope Stabilisation Trials on Route 13N and Route 7. This was supported by the UK Department for International Development through its South-East Asia Community Access Programme, and implemented by Scott Wilson in association with LCG Consultants. It is intended for use by field staff at technical level for the maintenance of slopes immediately adjacent to the road network.

1. Definition of Maintenance for Slopes

1.1 Maintenance Activity Codes

The work involved in maintaining slopes is divided into three main categories under the MPWT's Road Management System:

- Routine Maintenance, which is required continually on every road because of progressive changes to the slopes, drainage and vegetation;
- Emergency Maintenance, which is needed to deal with emergencies and problems calling for immediate action when a road is threatened or closed; and
- Rehabilitation and Improvement, which is required to adapt the road to the changing nature of slopes and streams.

This Handbook provides guidance on the implementation of all of the main off-road problems with particular respect to slopes, but does not cover culverts or bridges

Routine off-road maintenance activities are listed under two headings.

MAC	Activity	Tasks	Section
Drainage and Erosion Protection			
131	Clearing of ditches by hand tools	Removing obstructions (rocks, fallen trees, soil heaps, debris etc.) on shoulders, slopes and in the ditch.	2.1
132	Clearing of ditches by machine	Removing obstructions (rocks, fallen trees, soil heaps, debris etc.) on shoulders, slopes and in the ditch. This is on a larger scale and for bigger areas than the item above.	2.1
133	Clearing of culverts	Removing of silt, sand and blockages by debris.	2.1
134	Repair of culverts	Repair of inverts, concrete and steel surfacing, and reconstructing or correcting levels and falls.	Not covered
135	Repair of erosion damage	Filling with selected and graded material to repair erosion damage, and the repair of erosion control devices.	2.2
136	Repair of retaining wall	Rebuilding collapsed walls, and repairing and replacing broken blocks or concrete.	2.3
137	Repair of ditch linings	Replacing broken linings and re-aligning the drain, and filling eroded areas with gravel material.	2.4
Roadside Maintenance			
161	Grass cutting	All grass to be cut within the road reserve, by hand or machine.	2.5
162	Bush cutting	All bushes to be cut and removed within the road reserve.	2.5
163	Bush cutting (thick vegetation)	All bushes to be cut and removed within the road reserve.	2.5
164	Cleaning of the right of way or road reserve	Cleaning of the road reserve and removing of debris.	2.5

Emergency maintenance activity categories mainly cover the resolution of external damage to the road.

MAC	Activity	Tasks	Section
311	Removing of landslides	Immediate attention to open the road and clear the roadway, while being aware of the possibility of additional landslides.	3.2
312	Emergency culvert repair	Replacing and backfilling damaged culverts as soon as possible.	Not covered
313	Emergency bridge repair	Attending to damaged bridges as soon as possible. A diversion should be considered but might be a problem due to the local surroundings.	Not covered
314	Erosion damage repair	Often resulting from heavy rain and flowing water. These are to be attended to and the cause for the water flow to be found.	3.3
315	Repair of collapsed road embankment	Finding the cause for the collapse and refilling with graded material.	3.4
316	Blasting	Drilling and the use of dynamite as an option to use when rocks are too big to be removed easily.	Not covered

Rehabilitation and Improvement activities in the MACs do not include the construction of new walls, but for completeness is included here.

MAC	Activity	Tasks	Section
431	Construction of new culverts with headwalls	Construction of new culverts as required, with attention to mitres and side drains, and inlet and outlet levels.	Not covered
432	Construction of box culvert	Construction of new box culverts as required, with attention to mitres and side drains, and inlet and outlet levels.	Not covered
433	Construction of new ditches	Where these are missing, with attention to ensure that the ditches have the correct inclination and that the water is directed to go in the desired direction.	4.1
434	Construction of scour checks	Features in ditches, cut off drains etc, where it is important to reduce the water velocity and possibility of erosion.	Not covered
No Code	Construction of new walls	Construction of new walls as required.	4.2
435	Erosion protection by gabions	Stabilising the base of a slope. A gabion retaining wall may be used, or any other protection structures to prevent erosion.	4.3
436	Erosion protection by rocks	Using rocks to protect slopes and materials which have a tendency to erosion.	4.3
437	Riprap, protection of banks or bed by stone	The use of stones, usually 5-50 kg, for protection of banks or beds, with or without grouting.	4.3
438	Erosion protection by vegetation	Slopes, shoulders or any surface area within the road reserve which are liable to erosion being protected by planting grass or any plant which provides a soil stabilisation effect.	4.4

1.2 Routine Site inspections

Why is it necessary to carry out routine site inspections?

There are comparatively few occasions when a large-scale failure of a slope or wall occurs without some early warning. In most cases (except for minor slips), there are usually warning signs.

What should I look out for?

Check the reasons why the drainage system is damaged or cracked. Do the cracks in the roadside drain extend across the road? Is the damage being caused by differential movements? Are the roadside drains being blocked regularly in a particular location? Is the slope above/below moving?

Cracking in roadside drain and road surface caused by large scale slope movements

Cracking in the shoulder caused by fill slope movements below the road

Check the retaining walls and slopes above and below the road on foot. Are they in good condition? Are movements taking place? Are there any worrying signs of undue erosion or ravelling occurring?

What if the situation looks serious?

Report it to your supervising engineer. As best as you can, fill in a Landslide or Wall Report (see Section 5).

1.3 Detailed Site inspections

What is a detailed site inspection trying to do?

Detailed site inspections are required when there has been a landslide or a retaining wall distress or failure. The most important question that a detailed site inspection is trying to find the answer to is – why did the failure or distress happen? Sometimes the reasons are very simple, but sometimes they are very complex and difficult to understand.

Who should carry out the inspection?

A full inspection should preferably be carried out by an experienced engineer, but an initial inspection can be carried out by a competent technician.

What details need to be recorded?

It is recommended that a Landslide and/or Wall Report be completed (see Section 5), even for an initial inspection. The main features of the failure should be accurately recorded with the aid of a tape measure and preferably an abney level or clinometer (to measure slope angles). A camera is also important.

Take plenty of pictures as you inspect the site!

2. Routine Maintenance of Slopes

2.1 Clear drains and culverts

Why is it necessary to clean drains and culverts?

The roadside drains and culverts are required to direct rainwater away from the road surface and into existing streams and gullies. If they become partially or totally blocked, then the water flow will become uncontrolled and may cause erosion and damage.

Where should the material that has been cleaned out be placed?

Ensure that the removed material is placed in a location where it won't be washed back into the drainage system during heavy rain; for example on a flat stable area on the opposite side of the road. The removed material should be levelled out and not left in loose piles.

Cleared material from a roadside drain being removed by wheelbarrow to the other side of the road.

What else needs to be done?

Ask the labourers to look out for any damage or cracks to the drainage system and point these out to you. This may be an indication of unstable ground. Any such damage or cracks will need to be repaired under Routine Maintenance. Look out for places where scour or ravelling or slope movements are taking place. If the road seems to be at risk, then it may be necessary to carry out Emergency Maintenance.

2.2 Erosion

What should be done if erosion is occurring?

Erosion taking place below the road is usually due to a concentrated flow of water from the road finding its way onto an erodible slope or gully. This often happens when the roadside drains have been blocked, or where the surface water is able to run down the lower side of the road. In these cases the blockage should be cleared, or a temporary earth bund constructed on the edge of the road to prevent the water from running down the slope. The problem also often occurs at the lower end of road supporting retaining walls. Eventually, the temporary earth bund should be replaced with a concrete upstand or kerb, to make sure that the water flow is redirected to a suitable location where it will not cause further erosion.

Severe shoulder erosion at the end of a retaining wall caused by road surface run-off.

Erosion also commonly takes place in streams and gullies above and particularly below the road. In this case it might be necessary to construct a check dam or non-erodible lining, for example out of gabion or mortared masonry.

If the erosion is occurring above the road, then the source of the water needs to be determined. If it is the result of human activity, for example rice irrigation, housing etc, then the appropriate village authorities should be notified. If it is the result of natural causes, then bio-engineering techniques may solve the problem (see Section 4.4).

2.3 Wall repair

What repairs should be carried out?

An advantage of gabion walls is that they are flexible and while still remaining structurally sound. Therefore minor movements can be tolerated. However, if individual gabion baskets are actually damaged – by falling debris, by vandalism or by larger movements, then steps should be taken to repair the affected gabion baskets. If it is necessary to dismantle the affected baskets and replace them, then the cause of the distress must be determined since other additional stabilisation measures may be necessary.

This damaged gabion basket should be repaired, and the boulder broken up and removed.

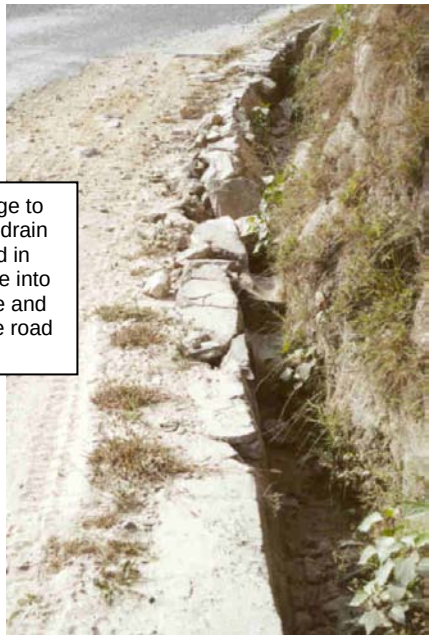
Masonry walls are not designed to be flexible and minor movements will result in the wall becoming cracked and may lead to structural failure. Simply filling the cracks with a sand/cement mortar will be ineffective unless the movement can be stopped by other means as well. If the movement is due to overloading of the foundation, then additional support to the wall by buttressing or underpinning may help. If the cause of the movement is due to undermining of the foundation by scour, then underpinning together with the removal of the cause of scour may be appropriate. If the movement is due to large-scale slope movements, then it is likely that the entire wall may have to be replaced as a *Rehabilitation and Improvement* activity.

This masonry wall is damaged too badly to be repaired, and must be rebuilt.

2.4 Drainage repair

Why is it important to carry out repairs to the drainage system?

If water can penetrate through a lined roadside drain or the walls of a culvert or cascade or stream lining, then it may create further scour and damage. If the crack is due to slope movements, then a concentrated flow of water may enter the failure zone and create further movements.



Traffic damage to this roadside drain has resulted in water seepage into the road base and damage to the road itself

What repairs are necessary?

The section to be repaired should be broken out and replaced with mortared masonry or concrete. If the slope is slowly moving, the repairs may have to be repeated many times until the entire slope is stabilised under Emergency Maintenance.

2.5 Vegetation management

Why is it necessary to manage vegetation?

The roadside slopes are mainly covered in vegetation. This helps to control erosion on soil slopes. However, the plants grow rapidly and need to be controlled regularly to stop them from extending out into the road. They become dangerous to traffic when they hide pedestrians, cause vehicles to be driven in the middle of the road or reduce drivers' sight lines

How should vegetation be controlled?

Plants should be cut back several times a year, according to need. Smaller plants can be cut with a machete. Plants must never be pulled or dug out by roots, and must never be burnt.

Where should the material that has been cut be placed?

Ensure that the cut plant material is placed in locations where it won't be washed into the drainage system during heavy rain; for example on a flat area on the opposite side of the road. The removed material should be left in tidy piles but not burnt.

Vegetation is being cut on the lower cut slope to improve drivers' sight lines. Once the cutting is finished, the material will be removed from the drain and piled on the other side of the road.

What else needs to be done?

Ask the labourers to look out for any damage or cracks in the ground and point these out to you. This may be an indication of instability, especially on the lower side of the road. Any such damage or cracks will need to be repaired under Rehabilitation or

Emergency Maintenance. Make sure that the labourers do not light fires to burn vegetation, especially at the end of the day.

3. Emergency Maintenance of Slopes

Most slopes and walls that have or are in an imminent state of collapse will require Emergency Maintenance. Some of these procedures are described in more detail in the *Slope Maintenance Manual*, but the key practical points are given here.

3.1 Safety

Who should first be informed?

Where a slope or wall failure has occurred or is about to occur, the first consideration must be to warn people who could be placed in danger by the failure. This will normally include persons travelling along the road or working or living above or below the failure. Where appropriate, the police, the DPWT and other civil authorities should be given the necessary details.

What else should be done?

If the failure is affecting the road then traffic warning signs or easily visible physical obstructions should be set up immediately at a suitable distance on either side of the failure.

Crest of failure protected by an earth bund and marked by easily visible concrete posts.

3.2 Removal of landslides

Where should the material blocking the road or roadside drain be dumped?

Slip debris should only be dumped in locations where it will not cause more stability problems nor create land-use, environmental or safety issues. In decreasing order of preference, these are:

- on level ground;
- on the tops of spurs;
- at steeper locations protected by resistant bedrock; or
- at locations as far away from the edge of the road as possible.

Where should the material NOT be dumped?

Slip debris should not be dumped:

- on the valley side of a "sinking" area; it should be taken away at least beyond the boundary of the sinking area;
- on top of existing watercourses, as this may create major erosion problems; or
- over retaining walls, unless it is obvious that the wall is founded on non-erodible material; in particular, dumping over gabion retaining walls is likely to prevent water escaping from the gabions and cause the foundations to soften or erode.

Anything else?

Dumping small amounts in a number of locations may be better than dumping it all in one location, to reduce the risk of slope overload.

Be careful not to damage the road surface during the clearing operation.

Tidy up afterwards. Remove or reshape and compact unsightly heaps of debris on the side of the road. If appropriate, carry out bio-engineering to reduce the risk of erosion.

If the slip is very minor, there may be no other further requirements. If it is obvious that further movements are going to occur, or water is continuing to seep into the failed area, or the road itself has partly fallen away, then additional measures will be required. These are likely to include:

- additional drainage;
- retaining wall construction; and
- bio-engineering.

Damage caused to a slope below a road by bad tipping practice.

3.3 Temporary drainage measures

Why are temporary drainage measures required?

If the failure is located below the road, immediate steps should be taken to prevent water from the road surface or drainage system from entering the crest of the failure and creating further instability. It may be necessary to dig catchpit bypass channels to prevent roadside drainage water from entering a culvert. The upstream roadside drain may need to be blocked and water directed across the road away from the failure by an earth bund to a more suitable temporary discharge point.

If the failure is located above the road with debris 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.

A temporary drain dug in debris that has fallen from above the road.

Emergency work following the collapse of a culvert on a national highway.

3.4 Embankment repairs and protection

What does this involve?

Embankments are engineered earth structures. They are not hard, and so are particularly liable to damage from heavy flows of water and river cutting. They need to be treated carefully to ensure that repairs provide the maximum possible strength.

How are embankment slopes repaired?

If an embankment is damaged, the first priority is the safety of the traffic on the road (see section 3.1). Make sure that the failure is marked and that traffic will not cause further damage to the edge of the failure.

Once the cause of the failure (e.g. a flood) has passed, use an excavator to clear away any weak material, or any soil containing clay or organic matter.

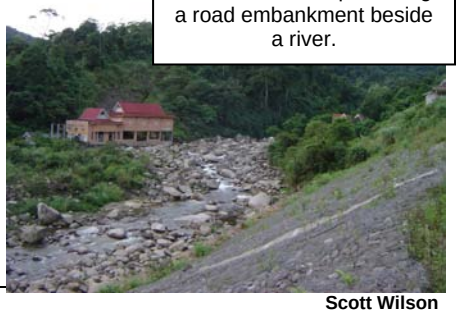
Replace the lost material by filling with graded material according to the specifications. Compact the material in layers using a plate compactor or small roller.

Place too much material on the slope so that compaction extends beyond the final slope line. Once the gap in the embankment has been completely filled, use an excavator to regrade the side slope by removing the excess material. Embankment side slopes should be finished to a maximum grade of 1V:1.5H.

How can embankments be protected?

The usual way to protect embankment slopes is with stone pitching or rip-rap placed on a suitable geotextile to reduce sub-surface erosion (see also Section 4.3). Rocks of as large a size as possible are laid on the slope, starting from at least 2 metres beyond the foot of the embankment. The size to be used must be large enough that it cannot be moved by the maximum expected water flow. It is usually necessary to have enough rocks so that they are three or four thick. The rocks should be angular to give good interlock.

Where heavy water flows are possible, such as near rivers, gabion mattresses should be used. These are specially made gabion boxes of only 300 mm thickness. In this case rounded stones can be used since the mattress is designed to fold into scour holes. Structures designed to prevent scour are usually termed ‘aprons’ and usually comprise 500 mm thick gabion mattresses formed in angular rock.



Gabion mattress protecting a road embankment beside a river.

4. Rehabilitation and Improvement

4.1 Additional drainage

When are additional drainage measures required?

When it is obvious that the existing drainage system is not working properly or is overloaded. When the failure is clearly due to excessive water within the failure, either coming in from the outside or from within (for example surface seepages or minor streams).

Who will decide what additional drainage measures are necessary?

The supervising engineer will normally decide.

What measures are likely to be required?

There are two broad categories – slope drainage and road drainage.

Slope drainage may consist of the following.

- Herringbone drains on the slope face to collect water from any seepages and groundwater close to the slope surface.
- Counterfort drains on the slope face to intercept groundwater at deeper levels.
- Drilled horizontal drains to intercept groundwater at some depth below the slope surface.
- Lined channels or cascades to improve or divert existing streams or gullies.
- Check dams to reduce stream or gully erosion.
- Where it is obvious that a lot of water runs on to the slope from above, cut-off drains can be built above the crest of the failure to collect this run-off before it enters the failed area. But note that these can be difficult to maintain and soon get blocked.

Road drainage may be as follows.

- New roadside drains to replace or upgrade existing drainage to control surface run-off.
- New culverts to replace damaged culverts or to take the flow of diverted stream courses.

Further details can be found in the *Slope Maintenance Manual.*

4.2 Construction of new walls

What are the main types of walls?

There are three main types of wall constructed in Laos: masonry, gabion and reinforced concrete. Masonry walls can be composite or fully mortared.

Mortared masonry wall

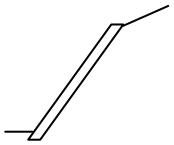
Composite masonry wall

Gabion wall

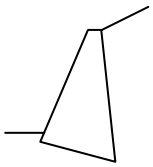
Reinforced concrete wall

Retaining walls may be constructed below or above the road. They retain the ground behind them. Revetments may also be constructed above the road.

From the road, Revetments and Retaining Walls can both look the same. The difference is that Revetments are very thin (usually only 300mm thick) and only prevent erosion and shallow sliding from occurring at the base of the slope. They are not very strong, and they do not act as retaining structures.



Revetment Wall



Retaining Wall

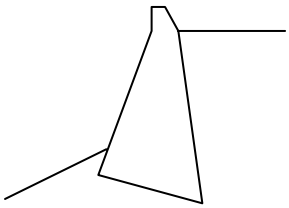
What are the advantages and disadvantages of the main types of walls?

Type	Advantages	Disadvantages
Composite masonry	Fairly cheap.	No flexibility.
	Dry stone panels very permeable	Not as strong as full mortared masonry.
Mortared masonry	Very durable.	Expensive.
		No flexibility – should always be constructed on good foundations.
		Limited permeability, weep holes should always be provided.
Gabion	Flexible – good where founding conditions are variable.	May be too flexible for road supporting retaining walls.
	Very permeable	Usually requires geotextile on back face to reduce fines seeping through wall.
	Cheaper than cemented masonry	Foundation may be softened by water percolating through wall.
		Less durable than mortared masonry.
		Difficult to construct if foundation uneven, although this can be overcome by using a mortared masonry layer at the base.
		More difficult to construct in curves in plan.
Reinforced Concrete	Very durable if good quality construction	Most expensive option
		No flexibility – should always be constructed on good foundations.
		No permeability, weep holes should always be provided

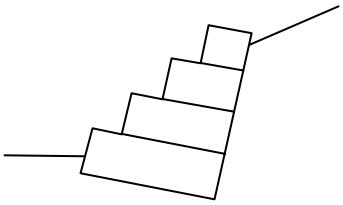
From considerations of cost, durability, appearance and strength, cemented masonry walls are generally recommended except where foundation conditions are soft or expected to move over time. In those cases, gabion walls are recommended.

What wall shape should be used?

The *Slope Maintenance Manual* discusses a number of wall shapes and their advantages and disadvantages. For simplicity, two basic wall shapes are recommended – one for mortared masonry walls and the other for gabion walls.



Mortared Masonry wall



Gabion wall

Should mortared masonry or gabion bases be tilted or horizontal?

There are advantages in tilting the base of the wall slightly backwards into the hillside, since this helps to even out the bearing pressures on the base and increase the resistance against the wall sliding out of the hillside. However, where this might also encourage the accumulation of water in the foundation, it is recommended that either drainage measures be incorporated to keep the foundation dry or the base be kept horizontal.

Should the wall be founded on a concrete base?

Gabions are usually founded straight on to the excavated ground.

For masonry walls founded on rock or residual soil, it is recommended that the foundation be blinded with 50 mm of sand-cement mortar prior to construction.

For masonry walls founded on varying ground, it is recommended that a concrete base, minimum 300 mm thick, be constructed first. If the ground is very weak in places, it may be advisable to reinforce the base.

What is good construction practice?

Checklists for the safe construction and quality control of walls are given in Section 5. Some additional points to look out for are illustrated here:

The mix for this mortared masonry wall is much too dry and being applied too sparingly. The exposed face of the wall needs to be properly finished and smoothed.

Gabion walls. Remember that gabion walls are permeable to water. Any water permeating through the gabions down to foundation level must be allowed to escape easily. This means that any surplus spoil placed in front of the wall during excavation must be removed to prevent ponding.

Water seeping through these gabions is unable to drain away due to the uncleared debris dumped in front of the wall.

Foundation level. Most small scale wall foundation levels can be determined by visual inspection. The use of a Dynamic Cone Penetrometer (DCP) may help in determining a suitable foundation level and further information on this device is given in the *Slope Maintenance Manual*.

The DCP comprises an 8 kg hammer falling a distance of 575 mm on to a rod to which a 20-mm diameter hardened steel cone is attached. The number of blows to drive the cone a measured distance into the ground gives an indication of its strength.

What about backfilling behind the wall?

Compaction of backfill behind road supporting walls must always be carried out in accordance with the specification to reduce the amount of future settlement of the backfill. Backfilling and compaction is best carried out in layers as the wall is constructed, and not after construction is complete. In difficult locations it is usually necessary to use vibrating plate compactors or pedestrian rollers to achieve the necessary compaction.

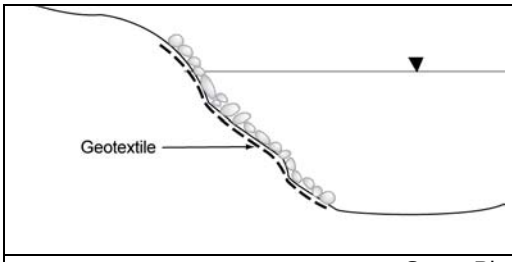
Compaction of free-draining fill behind a masonry retaining wall using a vibrating plate compactor.

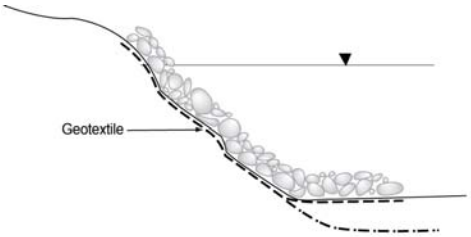
The material used for all backfilling should not contain any clay. A graded filter layer (usually a gravel-sand mix) should be placed against the wall to drain any water behind the wall. If a geotextile is specified for gabion walls, it should be fixed in a manner such that it does not get torn during backfilling operations, and is sufficiently loose so that if the wall flexes, the geotextile will not become taut. Geotextiles should not be exposed to sunlight for prolonged periods.

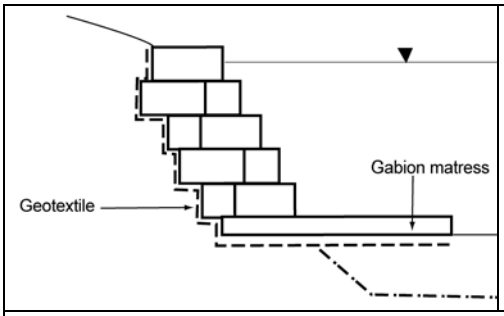
4.3 Erosion protection using structures

This section mainly concerns river bank erosion and is covered in greater detail in the *Slope Maintenance Manual*.

There are three main types of protection: stone pitching, rip-rap and gabion.

	Normally carried out on slopes that may experience significant surface run-off or are occasionally submerged during flood peaks. Stone pitching can be dry-stone, mortared or vegetated (by inserting mortar or plants in the gaps between the stones.
Stone Pitching	

	Rip-rap is a layer of heavy stone, sometimes with individual pieces weighing more than 2 tonnes, that protects the softer material in the river bed and banks from eroding. Rip-rap can be dry-stone or riprap but in streams and rivers it is not normally grouted. The stone must be heavy enough so that it is not moved by water flow. It should always be laid over filter material or a geotextile to protect the underlying material.
Rip-rap	

	Gabion is partly covered in Section 4.2. Gabions have many advantages over rip-rap but possibly do not have the same durability. Gabion baskets are more rigid and can be used to protect steep slopes or banks; gabion mattresses are thinner and more flexible with a maximum thickness of 0.3m. Sloping river banks can sometimes be protected with gabion mattresses.
Gabion	

4.4 Erosion protection using vegetation

Slope Preparation

What is soil slope preparation?

On roadsides, slopes composed of soil (or any weak material) need to be finished to an even grade. This is to improve stability, provide a sound basis for bio-engineering and improve the appearance. Slopes should be trimmed to a straight profile. There should never be a pronounced convex or concave profile, as these are prone to failure starting at a steep point.

Cut slopes should be finished to a slope angle of between 1V:1.5H (particularly at the tops of slopes which often comprise weak soils) and 2V:1H. In certain cases the angle may be steeper, but this should be carefully reviewed in each case.

Fill slopes should be finished to a grade of 1V:1.5H.

How are slopes finished?

Trim off steep sections of slope, whether at the top or bottom. In particular, avoid 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.

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

Where retaining walls are constructed on or at the base of slopes, the excavated material can often be used for backfilling. During backfilling, compact the material in layers, 100 to 150 mm thick by ramming it thoroughly with tamping irons. To a maximum finished slope of 1V:1.5H. This must be done while the material is moist.

What happens to surplus material?

Dispose of excess spoil carefully, in an approved tipping site. Tipping it over the slope below the road is bad practice. Much slope instability and erosion is caused in this way. Always include adequate provision in your estimates for haulage to an approved safe tipping area, and make sure it is used.

A well-trimmed cut slope, prepared for bio-engineering works.

Bio-engineering

What is bio-engineering? Bio-engineering is the use of plants to undertake light engineering tasks. Certain types of plants can be used to control erosion and shallow landslides. Often it is used in association with small-scale structures.

When should bio-engineering techniques be used?

Bio-engineering techniques should normally be used to control erosion or stabilise or prevent shallow slope movements where the depth to the sliding surface is up to 0.5 m and to protect slopes against erosion. 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 described in section 4.3.

What are the best bio-engineering techniques?

The table below summarises the best available techniques.

Location	Technique	Advantages	Disadvantages
Cut slope in soil Road edge or shoulder in soil	Grass planting in lines, using rooted slips.	Rapid and complete surface cover.	Requires a soil slope without too many stones. Slow to establish on hard cut slopes.
Cut slope in mixed soil and rock	Direct seeding of shrubs and trees in crevices.	The best way to establish vegetation on rocky slopes.	Slow to provide a coverage good enough to resist erosion.
Fill slopes and backfill above walls	Brush layers using woody cuttings from trees or shrubs.	Instant physical barrier that interrupts runoff. Stronger than grass. Often successful on stony debris.	Can only be installed on slopes of 1V:1.25H or less, on unconsolidated materials.
Large and less stable fill slopes	Truncheon cuttings (big woody cuttings from trees).	Relatively strong plant material on slopes that are still unstable; withstands damage from moving debris.	Takes a long time to establish a complete cover. Needs a lot of planting material.
Gullies or seasonal stream channels	Live check dams using woody cuttings of trees.	Low cost, flexible structures to reduce erosion where water flow is concentrated.	Not as strong as check dams of gabion or masonry. Require careful supervision.
Other bare areas	Tree planting using potted seedlings from a nursery.	Allows a long term forest mix of trees to be restored.	Takes a long time to establish a complete cover. Seedlings are vulnerable to grazing

			for a few years.

What are the materials for these techniques?

Grass slips are small sections of a grass plant, made by splitting up a large clump. 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.

Woody cuttings are taken from the branches of certain types of small trees. They are cut to be between 450 and 600 mm long, and the diameter should be between 20 and 40 mm in diameter. Shoots and leaves are trimmed off. For live check dams, cuttings are needed that are 2 metres in length.

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.

It is very important that plant materials for bio-engineering are kept cool and damp when they are being moved and prepared.

Which species of plants should be used?

The table below lists the plants that have been shown to be successful for bio-engineering work in Laos.

Species for grass slips	Species for woody cuttings	Species for direct seeding
Nyar khaem, dok khaem (broom grass) Nyar kha Nyar phaek Nyar khaem lao (2 different species) Nyar phaek, fek hom (vetiver)	Mak koh (chestnut) Korbai leuam(chestnut) Posa (paper mulberry) Mak nhiao (“diesel nut”) Peuak meuak, toutiang Khee nok, khee hen, ngen (simali) Mai mook Thorng	Khileckdong Koun Khathin Tiou dam Pohou Hookatai Phak nao Som poi Phak thon

Almost any type of tree can be brought from a nursery as a potted seedling.

How is grass planting done?

Grass slips are planted in lines across the slope. The best results usually come from lines that are at 45^{o} to the maximum slope. Start from the top and work downwards.

Mark out the lines on the slope and then plant the grass slips to the original depth and gently firm the soil back around them.

How is brush layering done?

Mark out horizontal lines every 2 metres down the slope. Start from the bottom and work upwards. Dig shallow trenches along the lines, 350 to 450 mm wide.

Lay the cuttings across the trenches with the bottom inwards and 80 to 100 mm of the top protruding from the slope. The cuttings should be 50 mm apart. Place a small amount of soil over the cuttings and then lay another line of cuttings. Replace all the soil and firm it down gently.

How are truncheon cuttings planted?

Use a crowbar to make a vertical hole that is about 20 mm wider than the cutting and at least 1 metre deep. Place the cutting in the hole and gently fill around it with loose soil. Truncheon cuttings are usually planted 1 metre apart on deep debris slopes.

Truncheon cuttings after one season of growth.

How are live check dams built?

Select the places on the gully to be stabilised where interruptions to the water flow are most likely to stop erosion from occurring.

Dig a horizontal trench right across the gully, 100 mm deeper than the gully bed and extending at least 300 mm into the gully sides. Place truncheon cuttings at a spacing of 200 mm, in two lines 200 mm apart, throughout the trench.

Weave long woody cuttings in and out between the truncheon cuttings. Start from the bottom and weave the woody cuttings on alternate sides. You will need 25 to 40 cuttings, 2.0 m long, per metre of check dam height, for each line of weaving.

Carefully fill between and around the check dam with soil and stones, and firm it down gently. Weave cuttings higher between the posts at the ends, so that the middle of the check dam is lower for water to flow through.

A small live check dam a few weeks after construction.

How is direct seeding done?

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. Start at the top and work downwards.

How are potted tree seedlings planted?

A hole is dug that is at least 300 mm in diameter and 300 mm deep. The pot is removed from the seedling and the seedling is planted in the hole, with care taken to fill soil gently but firmly around the root mass. This is repeated at 1.5 metre centres across the slope.

Anything else?

Bio-engineering work should only be done in the wet season. The slope should be moist when the planting is done. If it does not rain within 24 hours of the work being done, water the plants by hand every day until it does rain.

Finishing works

What finishing works are necessary?

Check all construction and bio-engineering details. Make sure that they have been completed as instructed. If necessary, instruct repairs.

Finally, the site should be inspected during or immediately after a period of heavy rain to see if the run-off is going where it is intended and without any erosion, and if not, to carry out any additional works to ensure that it does.

Before and after treatment

Road 13 North, km 316.
A revetment wall and various types of bio-engineering works were used to protect the slope.

5. Inspection Report Forms and Checklists

How should the forms be completed?

Copies of inspection report forms are given on the following pages. Enlarge these by photocopying them on to A4 sheets. Recommendations on their completion are below and examples given on pages 31 and 32. If possible, use photographs to help.

Landslide Report

- The location of the failure should be recorded, preferably using the chainage.
- Boxes should either be ticked or the required measurement inserted.
- Assess the consequences of no remedial works being carried out. Will the failure continue to occur? Will the road be completely blocked or cut off? Are there any houses nearby that could be damaged or destroyed?
- Try to arrive at a probable cause of failure, particularly if this will involve special remedial measures (e.g. water course diversion, realignment etc).
- Draw a plan view and cross section of the failure, noting down all the relevant measurements.
- If the failure is also affecting a retaining wall, complete a Wall Report as well.
- Use additional sheets of paper if necessary. Further notes on the underlying geology and the land use etc will usually be helpful.

Wall Report

- Follow the guidance given above, plus the following.
- The location should also include the wall reference number, where applicable.
- Probable cause of failure or distress: it is important to determine whether or not the failure is associated with underlying slope movements, or whether the failure is simply due to weakness in the wall itself, or its foundations.
- Where the wall is retaining a slope, record the slope angle as well. If the slope is undergoing distress or failure, complete a Landslide Report as well.

Wall Construction Checklist – Main Features

- This checklist only gives the main features requiring checking during construction and is not a comprehensive checklist for all construction activities

Bio-engineering Works Quality Checklist

- This checklist can be used to check that the bio-engineering works have been completed to an acceptable standard. The list gives the main indicators.

Defects Liability Checklist – Main Features

- This checklist is intended for use during and close to the end of any construction contract Defects Liability Period.
- It is important to realise that defects may arise from the original design and changes in the site, as well as from the contractor's workmanship.

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 (m perpendicular to road)		Original slope angle	
Width (m parallel to road)		Failure angle	
Depth (m estimated)			
Estimated volume (L x W x D)		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)			Sloping	Vert	Horiz
Total length		Front face			
Width at base		Back face			
Height		Base			

Sketch of failure/additional notes:

Probable cause of failure:

Consequences if nothing done:

EXAMPLE OF A COMPLETED LANDSLIDE REPORT FORM

LANDSLIDE REPORT

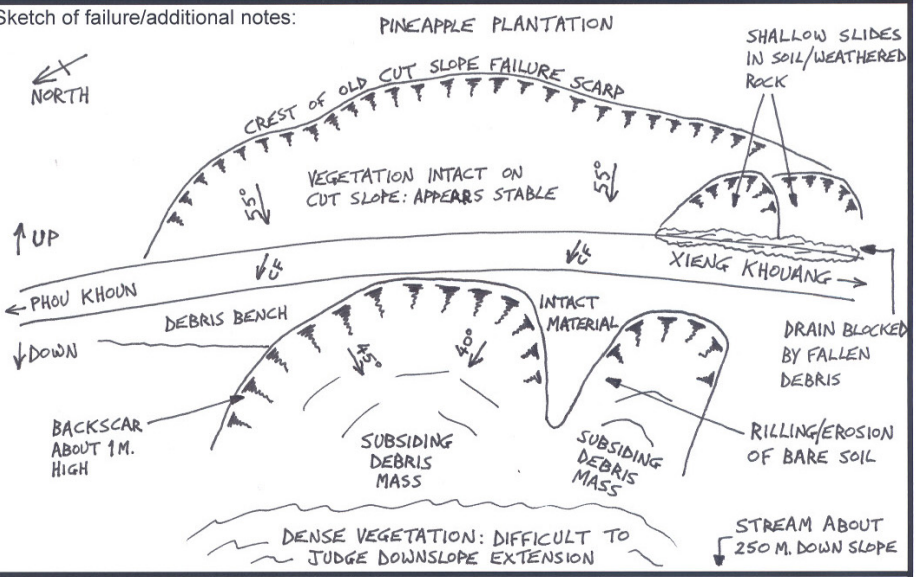
Location (road and km): NATIONAL ROAD 7, KM 6.1

Date of report: 11 OCT. 2006 | Reporter's name: A. FALANG

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 (m perpendicular to road)	40M	Original slope angle		35°
Width (m parallel to road)	50M	Failure angle	BELOW	40-45°
Depth (m estimated)	1-3M	" "	ABOVE	55°
Estimated volume (L x W x D)	3,000M³	Associated retaining wall		NONE

Sketch of failure/additional notes:



Probable cause of failure:

SMALL SLIDES IN CUT SLOPE SEEM TO HAVE OCCURRED DUE TO CULTIVATION AND RUNOFF FROM PLANTATION IMMEDIATELY ABOVE. THESE BLOCKED THE SIDE DRAIN. OVERFLOW FROM DRAIN RAN ACROSS ROAD AND SATURATED STEEP DEBRIS SLOPE BELOW, CAUSING IT TO SLUMP DOWN. WATER ALSO SCOURED EDGE OF ROAD.

Consequences if nothing done:

1. DEBRIS WILL CONTINUE TO SLUMP DOWN ON LOWER SIDE, LEAVING A HIGHER AND HIGHER BACKSCAR. 2. WATER WILL GO ON SCOURING THE EDGE OF THE ROAD SO THAT THE BACKSCAR EATS BACK INTO THE ROAD. 3. THE CUT SLOPE WILL KEEP FAILING SO THAT THE SIDE DRAIN IS CONSTANTLY GETTING BLOCKED.

EXAMPLE OF A COMPLETED WALL REPORT FORM

WALL REPORT

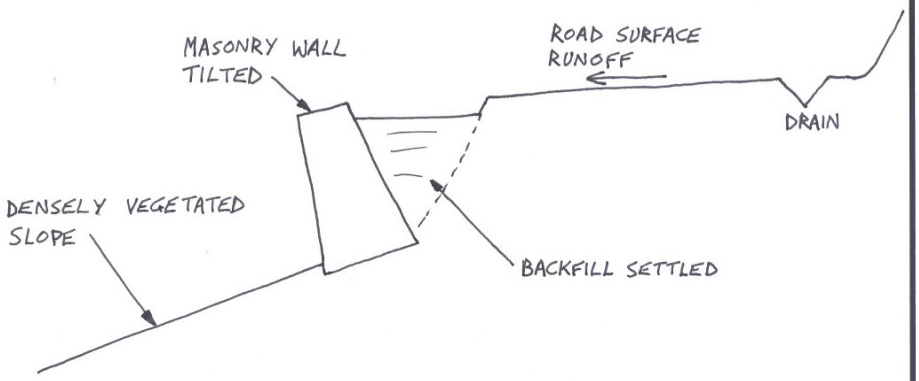
Location (road and km): ROAD 13 NORTH, KM. 326.9

Date of report: 11 OCT. 2006 | Reporter's name: A. FALANG

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			
			Sloping	Vert	Horiz
Affected length (parallel to road)	3M	Front face	✓		
Total length	10M	Back face		✓	
Width at base (ESTIMATED)	2M	Base	NOT	KNOWN	
Height	3M				

Sketch of failure/additional notes:



Probable cause of failure:

1. SURFACE RUNOFF FROM ROAD ENTERING BACKFILL BEHIND WALL AND CAUSING INCREASED LOAD ON TO WALL. 2. FOUNDATION OF WALL PROBABLY SOFTENED BY IN-FLOW OF WATER. 3. POSSIBILITY OF MOVEMENT IN SLOPE BELOW, BUT CURRENTLY OBSCURED BY THICK VEGETATION.

Consequences if nothing done:

1. WALL LIKELY TO CONTINUE TO TILT AND MAY COLLAPSE. 2. FILL BEHIND WALL WILL CONTINUE TO SINK. THIS IS CREATING A BACK SCARP THAT WILL EVENTUALLY REACH INTO THE ROAD.

WALL CONSTRUCTION CHECKLIST – MAIN FEATURES	
Safety	**Done?**
Have traffic warning signs been placed beside the road?	
Have barriers been placed alongside the excavation to mark out its extent? Are these clearly visible at night?	
All walls	
Have precautions been taken to prevent surface water on the road from entering the excavation?	
If excavating into the hillside, has this been done in alternate bays and the wall constructed in short lengths to prevent hillside instability?	
Is the excavated material being removed to a safe location and not dumped down the slope?	
Has the excavation level been taken deep enough to ensure that the wall is adequately founded? (The use of a DCP may help in this regard).	
Mortared and Composite Masonry walls	
Does the stone being used meet the specification for durability, size and shape?	
Is there sufficient cement in the mortar to meet the specified strength?	
Is the mortar sufficiently fluid to ensure that all the voids between the stones are completely filled?	
Have the marker blocks at the top of the wall been properly bonded into the rest of the wall?	
Gabion walls	
Is there adequate drainage from the lowest point of the excavation?	
Does the gabion wire conform to the specifications?	
Do the gabion baskets contain a transverse mesh at 1.0m centres?	
Are the stones durable and angular and with a minimum dimension not less than the gabion mesh?	
Have all the stones been carefully and densely packed into the basket?	
Have horizontal wire trusses (10 SWG or 3.25mm dia wire) been installed at 0.33m centres during filling to reduce bulging?	
Have the gabion baskets been properly connected to each other using 12 SWG (2.64mm dia) wire?	
Have the gabion baskets been staggered, as in blockwork, and with some gabions placed front to back?	
Reinforced Concrete walls	
Has the steel reinforcement been properly cleaned?	
Is there the specified cover between the reinforcement and the shuttering?	
Has the shuttering been properly secured to prevent movement during concreting?	
Does the concrete mix conform to specification?	

Has the concrete been vibrated to exclude all voids?	

BIO-ENGINEERING WORKS QUALITY CHECKLIST		
Type of works	**Sign of good works**	**Done?**
Whole sites	Has the site been completely treated, with no gaps or areas missed out?	
	Is the site evenly covered with the right plants?	
	Has the site been fully tidied up, with no loose debris on the slope?	
	Does the site show no signs of instability?	
	Is it stable enough to survive the early rains while plants get established?	
	Does it generally looking good, complete and healthy throughout?	
Individual plants	Are the plants of bright, healthy colours?	
	Do the plants show no signs of wilting?	
	Are they well proportioned (*i.e.* not stunted or very tall and thin)?	
	Are they growing fast, with a number of long new shoots?	
	Are the plants without signs of discoloration on the leaves?	
	Are they without signs of insect attack on the leaves or shoots (*e.g.* holes eaten in the leaves)?	
	Are they without any obvious signs of disease?	
	Are they undamaged?	
	Are the plants not yellowed (except in the later part of the dry season)?	
Grass lines	Are the lines complete, with plants at the spacing specified within the rows?	
	Is the distance right between the rows, according to specification?	
	Are the lines even, with no gaps or poor plants in them?	
	Are they straight, according to specification?	
Brush layers and live check dams	Are the works complete, with the right number of cuttings per running metre?	
	Is the distance right between the lines, according to specification?	
	Are the works even, with no gaps or dead cuttings?	
	Are they straight, according to specification?	

DEFECTS LIABILITY CHECKLIST – MAIN FEATURES	
Slopes	**Done?**
Are the slopes above the road showing any signs of instability, erosion or gullying?	
Are the slopes below the retaining walls showing any signs of erosion or gullying?	
Has all the loose material from the excavations been removed to safe locations?	
Road	
Does the road surface behind the retaining walls show any sign of cracking or deformation, indicating possible settlement of the back fill?	
Is the road fully sealed, right up to the new structures?	
Drainage	
Is the roadside drainage performing satisfactorily?	
Have the roadside drains been cleared of all vegetation and loose material?	
Are there any indications of scour along the edge of the road or at any of the drainage outlets?	
Walls	
Are the walls showing any signs of cracking or deformation?	
Bio-engineering	
Are there any gaps in the planting where plants have not grown or later died?	
Specific contract works details?	