TECHNICAL ASSISTANCE PREPARATION OF CLIMATE RESILIENCE DESIGN

GUIDELINES FOR THE PUBLIC ENTERPRISE FOR STATE ROADS IN NORTH MACEDONIA

PART C SUMMARY OF ENGINEERING MEASURES AND PROJECT LEVEL NON-ENGINEERING MEASURES

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1 Climate impact and adaptation options

1.1 Introduction

To ensure that road assets perform satisfactorily over their design life they must be designed to resist the range of destructive impacts that will exist during that life. These impacts may be a one-off impact such as torrential flood flows or a steady environmental degradation of a side slope. The design should be adapted at the design stage to take cognisance of the anticipated future climate that will affect the assets over their design life. The obvious adaptation measures are to design for example, culverts and bridges to accommodate the flows that will exist in the future, or the best estimate of these flows. For side slopes the design slope should be relaxed to a safe slope for the weakest materials identified by a comprehensive materials investigation.

Adaptation measures do not always need to be considered. Status-quo design recognizes that implementing no explicit adaptation measures is a valid response, provided that the QP documents the reason or reasons that this is done.

1.2 Road standards – adaptation

Climate and increased natural hazard resilience aspects should be reflected in road design standards.

The most important factors are the road levels (such as in flood plains), the surface and cross drainage of the road and erosion protection of the road and associated assets (e.g. culverts and bridges). These aspects are discussed further as follows:

- **The expected flood levels and flowrates** used to design road assets (e.g. river crossings and surface drainage) in any given location should include an appropriate uplift due to the projected climate effects (increased storm intensity).
- **Road elevations** must be designed at a safe level above the flood elevations. To our understanding, Macedonian standards require for the subgrade level to be at 0.3-0.5 m above the expected flood level. This is in order not to risk having the sub-grade saturated in water and hence weakened. This safety level will result in road elevations approximately one meter (as a minimum) above flood levels. Climate projections should be used to review whether current road elevations are sufficient at each particular location.
- The **cross drainage** of the road should be properly designed and sufficient for the predicted water after the climate change effects on peak precipitation (e.g. the likely return period for the maximum rainfall intensity for a given storm period – such as one hour) has been considered. Where a new road is planned, or major rehabilitation is planned for a road, the flow of water in the drainage system alongside the road should be fully investigated. The hydraulic capacity of existing structures should be determined. The type and size of cross drainage should be reviewed, with increased capacity, or alternative engineered or non-engineered solutions such as improved slope protection.
- **Erosion protection** should be constructed so that it is able to cope with accelerated and increased flows. It is especially important at the outlet of cross drainage structures and where there is expected to be major flow of water along embankments. Scour erosion can undermine a road very quickly. Equally, it can affect the stability of the toe of embankments (such as where a river runs close to the base of road embankment) or bridge abutments or river protection works. Similarly, flash flooding can

increase the risk of landslides as it adversely affects slope stability. Slope protection could include bio-engineering and/or engineered solutions such as retaining walls or improved drainage), both within and beyond the road corridor.

1.2.1 Landslide standard measures

The selection of the most appropriate mitigation measures to be adopted in specific situations take into account the following:

(1) the factors that affect the hazard, in terms of the type, rate, depth and the probability of occurrence of the movement or landslide, such as, for example:

– the physical characteristics of the terrain, including the lithology and the mechanical characteristics of the materials involved, the hydrological (surface water) and the hydro-geological (groundwater) regime;

– the morphology of the area;

– the actual or potential causative processes affecting the system, which can determine the occurrence of movement or landslides;

(2) the factors that affect the nature and the quantification of risk for a given hazard, such as the presence and vulnerability of elements at risk (roads), both in the potentially unstable area and in the run-out area; and

(3) the factors that affect the feasibility of specific mitigation measures, such as, for example:

- the phase and rate of movement at the time of implementation;
- the morphology of the area, accessibility and safety of workers and the public;
- environmental constraints, e.g. archaeological, historical and visual values;
- pre-existing structures and infrastructure that may be affected directly or indirectly;
- capital and operating cost, including maintenance.

The decision scoring matrix proposed in Table 1 and Table 2 provided different structural mitigation measures depending on landslide mechanism and material, depth of movement, velocity, surface and groundwater conditions[1]. The scoring factors shown in Table 1 and Table 2 are provided as default values, but may need to be changed by PESR. Values between 1 and 10 were used, depending on suitability, in order to make the scoring for these measures comparable to that for the mitigation measures where the scoring factors have been quantified.

For the criteria on reliability, aesthetics and costs (maturity of technology, reliability of performance, reliability in terms of uncertainty in design, reliability in terms of uncertainty in implementation, safety during construction, service life required (durability), aesthetics and typical cost), relative scoring factors between 1 and 10 were also established and entered in the toolbox as default values, as per listed in

[1] SafeLand - Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies. 7th Framework Programme Cooperation Theme 6 Environment (including climate change) Sub-Activity 6.1.3 Natural Hazards, 2011. Grant Agreement No.: 226479

Table 3. As these scoring factors are based on local and personal experience, the user should consider changing these. The aesthetics criterion should be changed in all cases, since it depends on the local setting.

For some non-structural mitigation measures quantitative scoring was allocated, as well.

Table 3 lists the scoring factors suggested for the six non-structural mitigation measures. Relative scoring factors between 1 and 10 were established and entered in the toolbox as default values. These should be carefully considered by the user. In the toolbox, the scoring and ranking are treated separately from the structural measures, because the sum of the weighted factor ends up being different from that for the structural measures.

The scores are given on a scale of 1 to 10; the higher the grade, the most suitable is the specific method under consideration for the landslides with the given characteristics. Overall suitability for the specific case under study is obtained by a weighted average of these ratings, with toolbox default or user-defined weights. Zero rating means "not applicable".

Table 1 Decision support matrix for structural mitigation measures – technological criteria

Category	No.	Structural mitigation measure	Type of movement					Material			Depth of movement					Rate of movement at time of works				Groundwater				Surface water					
			Falls	Tonnles	Slides	Spreads	Flows	Earth	Debris	Rock	Superficial (< 0.5m)	Shallow (0.5 - 3 m)	Medium (3 - 8 m)	Deep (8 - 15 m)	Very deep (>15m)	Moderate to fast	Slow	Very slow	Extremely slow	Artesian	High	Low	Absent	Rain	Snowmelt	Localized	Stream	Torrent	River
1		**Surface protection and control of surface erosion**																											
	1.1	Hydroseeding, turfing, trees,..	0	0	8	0	6	8	7	2	8	4	0	0	0	2	5	8	10	8	8	5	5	7	5	3	0	0	4
	1.2	Fascines/brush	0	0	8	0	6	8	8	0	10	4	0	0	0	2	6	8	10	8	8	6	4	8	7	6	6	0	6
	135	Geosynthetics	0	0	7	0	0	8	6	0	8	4	0	0	0	4	6	8	10	8	8	8	8	8	8	6	6	2	6
	1.4	Substitution/drainage blanket	0	0	7	0	6	8	4	0	10	4	0	0	0	6	8	10	10	8	8	4	2	8	8	4	0	0	0
	1.5	Beach replenishment, rip rap	0	0	7	0	0	8	8	4	10	4	0	0	0	6	8	10	10	8	8	4	2	6	6	6	7	8	7
	1.6	Dentition	8	6	0	0	0	0	0	8	8	0	0	0	0	8	8	8	8	7	8	8	8	6	6	8	4	2	0
2		**Modifying the slope geometry and/or the mass distribution**																											
	2.1	Removal of (actual or potential) unstable soil/rock mass	4	4	6	0	2	8	8	4	10	6	4	2	0	2	6	8	8	2	4	8	6	6	0	0	0	0	0
	2.2	Removal of loose/potentially unstable blocks/boulders	8	6	0	0	0	2	0	8	8	2	0	0	0	0	0	8	8	0	2	8	10	6	8	4	0	0	0
	2.3	Removal of material from driving area	0	2	8	0	0	8	8	4	8	8	8	6	6	2	8	8	8	4	6	8	8	6	6	4	2	0	0
	2.4	Substitution of material in driving area with lightweight fill	0	0	6	0	0	8	6	2	6	6	6	4	0	0	2	6	8	6	6	8	8	6	6	6	2	0	0
	2.5	Addition of material to the area maintaining stability	0	2	8	0	0	8	6	4	6	8	8	6	4	2	8	8	8	8	8	8	8	6	6	4	2	0	0
3		**Modifying surface water regime - surface drainage**																											
	3.1	Surface drainage works (ditches, channels, pipeworks)	0	0	8	4	6	8	6	2	8	8	6	4	0	0	6	8	8	6	6	6	6	8	8	8	4	0	0
	3.2	Local regrading to facilitate run-off	0	0	8	4	6	8	6	2	8	8	6	4	0	2	6	8	8	6	6	8	8	8	8	8	4	0	0
	3.3	Sealing tension cracks	0	0	8	4	0	8	6	2	8	8	6	4	0	2	6	8	8	6	6	8	8	8	8	8	4	0	0
	3.4	Impermeabilization (geomem--branes, impervious facing)	0	0	8	4	0	8	6	2	8	8	6	4	0	2	6	8	8	6	6	8	8	8	8	8	4	0	0
	3.5	Vegetation-hydrological effect	0	0	8	0	6	8	6	0	8	8	6	2	0	2	6	8	8	8	8	6	6	8	8	6	4	0	0
	3.6	Hydraulic control works	0	0	8	0	8	8	8	0	8	8	8	6	4	0	0	6	8	6	6	8	8	6	6	8	8	10	8

Category	No.	Structural mitigation measure	Type of movement					Material			Depth of movement					Rate of movement at time of works				Groundwater				Surface water					
			Falls	Tonnles	Slides	Spreads	Flows	Earth	Debris	Rock	Superficial (< 0.5m)	Shallow (0.5 - 3 m)	Medium (3 - 8 m)	Deep (8 - 15 m)	Very deep (>15m)	Moderate to fast	Slow	Very slow	Extremely slow	Artesian	High	Low	Absent	Rain	Snowmelt	Localized	Stream	Torrent	River
	3.7	Diversion channels	6	6	8	6	6	8	8	8	0	0	4	6	10	8	8	8	8	8	8	8	8	6	6	6	8	8	8
4		**Modifying groundwater regime - deep drainage**																											
	4.1	Shallow trenches filled with free-draining material	0	0	6	0	4	8	6	0	8	8	4	0	0	0	8	8	8	2	6	2	0	8	8	0	0	0	0
	4.2	Deep trenches filled with free-draining material	0	0	8	2	6	8	6	4	8	8	8	4	0	6	8	8	8	4	8	4	0	6	6	0	0	0	0
	4.3	Sub-horizontal drains (conventional drilling)	2	2	6	2	4	4	8	4	0	2	6	6	4	2	6	8	8	4	6	8	0	4	4	0	0	0	0
	4.4	Sub-horizontal drains (directional drilling)	2	2	6	4	4	4	8	4	0	0	6	8	8	2	6	8	8	4	6	8	0	4	4	0	0	0	0
	4.5	Wells																											
	4.5.1	Small and medium diameter vertical wells (<800 mm)																											
	4.5.1.1	Relief of artesian pressure	0	0	4	2	4	8	4	4	0	6	8	8	6	0	4	8	8	20	0	0	0	2	2	0	0	0	0
	4.5.1.2	Underdrainage, perched aq'fer	2	2	6	0	0	6	8	4	0	4	6	4	4	0	4	8	8	0	8	0	0	2	2	0	0	0	0
	4.5.1.3	Pumps	0	0	5	3	0	5	6	4	0	0	5	8	8	0	2	8	8	6	8	6	0	2	2	0	0	0	0
	4.5.1.4	Siphons	0	0	6	2	0	6	6	4	0	4	6	8	4	0	2	8	8	6	8	6	0	2	2	0	0	0	0
	4.5.2	Medium diameter vertical well (1200-1500 mm), gravity drainage through base conductor	0	0	6	4	2	8	6	2	0	0	2	8	4	0	2	8	8	4	8	6	0	2	2	0	0	0	0
	4.5.3	Large diameter vertical wells (>2000 mm) - gravity drainage through base conductor	0	0	6	4	2	8	6	2	0	0	2	8	4	0	2	8	8	4	8	6	90	2	2	0	0	0	0
	4.5.4	Caisson (>5-6 m), with gravity drainage (and secondary sub-horizontal drains)	0	0	6	6	4	8	6	2	0	0	0	6	8	0	2	8	8	4	8	6	0	2	2	0	0	0	0
	4.6	Drainage tunnels, adits, galleries, with secondary drains or as outlet for wells	2	4	6	6	6	6	6	6	0	0	2	6	8	4	8	8	8	6	8	8	0	0	0	0	0	0	0
5		**Modifying the mechanical characteristics of unstable mass**																											
	5.1	Vegetation-mechanical effects	0	0	4	0	0	8	4	2	8	4	0	0	0	2	6	8	8	8	8	4	2	8	8	6	4	0	4

Category	No.	Structural mitigation measure	Type of movement					Material			Depth of movement					Rate of movement at time of works				Groundwater				Surface water					
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	5.2	Substitution	0	0	8	0	0	8	6	8	8	6	8	4	0	0	2	6	10	2	4	8	10	8	8	8	2	0	0
	5.3	Compaction from surface	0	0	4	0	0	6	4	0	6	2	0	0	0	0	0	2	8	0	2	8	8	6	6	2	0	0	0
	5.4	Deep compaction (vibro-compaction, vibro-displacement, vibro-replacement)	0	0	6	4	4	8	4	0	0	0	8	8	6	0	0	2	8	0	8	6	6	8	8	8	2	0	0
	5.5	Mechanical deep mixing with lime and/or cement	0	0	6	4	4	8	4	0	0	4	8	8	6	0	2	6	8	6	8	8	8	8	8	8	2	2	2
	5.6	Low pressure grouting with cementitious or chemical binder	6	4	6	6	4	6	8	6	0	4	6	8	8	0	0	2	8	0	6	8	8	8	8	6	0	0	0
	5.7	Jet grouting	0	0	6	4	4	6	8	0	0	0	6	8	8	0	2	6	8	6	8	8	8	8	8	8	2	2	2
	5.8	Modification of ground water chemistry (e.g. lime piles)	0	0	6	4	4	6	0	0	0	4	8	8	8	0	0	6	8	0	8	4	0	6	6	0	0	0	0
6		**Transfer of loads to more competent strata**																											
	6.1	Counterfort drains (trench drains intersecting shear plane)	0	0	8	0	0	8	4	0	8	8	4	0	0	0	4	8	8	4	8	6	2	6	6	4	2	0	0
	6.2	Piles	0	0	8	4	4	8	8	0	0	4	8	4	0	0	4	8	8	2	6	8	8	8	8	8	8	2	2
	6.3	Barrettes (diaphragm walls)	0	0	8	4	4	8	8	0	0	0	6	8	4	0	2	6	8	2	6	8	8	8	8	8	2	2	2
	6.4	Caissons - mechanical effect	0	0	8	4	4	8	8	0	0	0	4	6	8	0	2	6	8	2	6	8	8	8	8	6	2	0	0
	6.5	Soil nailing	6	6	8	0	0	8	6	0	8	8	6	0	0	0	2	8	10	0	2	4	10	8	8	4	2	0	0
	6.6	Dowels and harnessing	8	2	0	0	0	0	0	8	8	2	0	0	0	0	0	0	8	0	6	6	6	8	8	6	0	0	0
	6.7	Rock bolting	8	8	0	0	0	0	0	8	6	8	6	0	0	0	0	0	8	0	6	8	8	8	8	6	0	0	0
	6.8	Strand anchors	6	8	8	0	0	8	6	8	0	2	6	8	8	0	0	4	8	2	6	8	8	8	8	8	2	0	0
7		**Retaining structures (to modify slope geometry and/or to transfer stress to competent layer)**																											
	7.1	Reinforced soil structure	0	2	8	0	0	8	6	4	0	4	8	6	2	0	4	8	8	8	8	8	8	6	6	6	4	0	2
	7.2	Gabion walls	0	2	8	0	0	8	6	4	4	8	8	2	0	0	4	8	8	8	8	8	8	6	6	6	6	0	6
	7.3	Crib walls	0	2	8	0	0	8	6	4	0	8	8	2	0	0	4	8	8	8	8	8	8	6	6	6	0	0	0
	7.4	Drystack masonry walls	0	0	4	0	0	8	6	4	8	8	2	0	0	0	0	6	8	8	8	8	8	6	6	6	0	0	0
	7.5	Mass concrete/masonry walls	0	0	6	0	0	8	6	4	0	8	6	0	0	0	0	6	8	8	8	8	8	6	6	6	6	4	6
	7.6	Reinforced concrete stem walls	0	0	6	0	0	8	6	4	0	8	6	0	0	0	0	6	8	8	8	8	8	6	6	6	6	4	6

Table 2 Decision support matrix for structural mitigation measures – performance and reliability criteria

Category	No.	Structural mitigation measure	Maturity of technology	Reliability of performance	Reliability - design	Reliability – implementation	Safety during construction	Service life required (durability)	Aesthetics	Typical Cost
1		**Surface protection and control of surface erosion**								
	1.1	Hydroseeding, turfing, trees	10	8	8	6	10	7	1	8
	1.2	Fascines/brush	10	8	8	6	10	7	1	8
	135	Geosynthetics	10	8	8	8	10	8	1	6
	1.4	Substitution/drainage blanket	10	8	8	8	10	8	1	6
	1.5	Beach replenishment, rip rap	10	8	8	8	10	8	1	6
	1.6	Dentition	10	8	8	8	10	8	1	5
2		**Modifying the slope geometry and/or the mass distribution**								
	2.1	Removal of (actual or potential) unstable soil/rock mass	10	8	10	8	5	8	1	6
	2.2	Removal of loose/potentially unstable blocks/boulders	8	8	10	4	5	8	1	8
	2.3	Removal of material from driving area	8	6	10	8	6	8	1	8
	2.4	Substitution of material in driving area with lightweight fill	6	6	10	6	8	8	1	6
	2.5	Addition of material to the area maintaining stability	10	10	8	8	8	8	1	8
3		**Modifying surface water regime - surface drainage**								
	3.1	Surface drainage works (ditches, channels, pipeworks)	10	8	8	10	8	6	1	10
	3.2	Local regrading to facilitate run-off	10	8	8	10	8	6	1	10
	3.3	Sealing tension cracks	10	8	6	10	8	6	1	10
	3.4	Impermeabilization (geomembranes, impervious facing)	10	8	8	10	8	6	1	10
	3.5	Vegetation-hydrological effect	6	6	6	8	8	6	1	10
	3.6	Hydraulic control works	8	8	4	6	8	6	1	5
	3.7	Diversion channels	6	6	6	6	8	6	1	2
4		**Modifying groundwater regime - deep drainage**								
	4.1	Shallow trenches filled with free-draining material	8	7	10	7	8	8	1	7
	4.2	Deep trenches filled with free-draining material	8	7	8	6	6	8	1	6
	4.3	Sub-horizontal drains (conventional drilling)	7	6	8	6	8	8	1	7
	4.4	Sub-horizontal drains (directional drilling)	6	6	6	7	8	8	1	6
	4.5	Wells								

Category	No.	Structural mitigation measure	Maturity of technology	Reliability of performance	Reliability - design	Reliability – implementation	Safety during construction	Service life required (durability)	Aesthetics	Typical Cost
	4.5.1	Small and medium diameter vertical wells (<800 mm)								
	4.5.1.1	Relief of artesian pressure	8	7	7	7	8	4	1	6
	4.5.1.2	Under-drainage, perched aquifer	6	6	7	7	8	4	1	6
	4.5.1.3	Pumps	7	6	6	7	8	4	1	5
	4.5.1.4	Siphons	5	6	4	7	8	4	1	5
	4.5.2	Medium diameter vertical well (1200-1500 mm), gravity drainage through base conductor	8	7	6	6	8	6	1	4
	4.5.3	Large diameter vertical wells (>2000 mm) - gravity drainage through base conductor	8	7	6	6	8	6	1	4
	4.5.4	Caisson (>5-6 m), with gravity drainage (and secondary sub-horizontal drains)	7	7	6	7	4	8	1	2
	4.6	Drainage tunnels, adits, galleries, with secondary drains or as outlet for wells	7	7	6	6	6	8	1	1
5		**Modifying the mechanical characteristics of unstable mass**								
	5.1	Vegetation-mechanical effects	8	8	8	8	10	8	1	8
	5.2	Substitution	8	8	10	8	10	8	1	8
	5.3	Compaction from surface	6	4	8	8	10	7	1	8
	5.4	Deep compaction (vibro-compaction, vibro-displacement, vibro-replacement)	6	8	6	6	9	6	1	4
	5.5	Mechanical deep mixing with lime and/or cement	6	8	6	6	8	8	1	4
	5.6	Low pressure grouting with cementitious or chemical binder	6	6	6	6	6	6	1	6
	5.7	Jet grouting	6	6	5	5	6	8	1	4
	5.8	Modification of ground water chemistry (e.g. lime piles)	4	4	4	8	7	6	1	6
6		**Transfer of loads to more competent strata**								
	6.1	Counterfort drains (trench drains intersecting shear plane)	8	8	6	6	8	6	1	8
	6.2	Piles	10	8	5	6	6	8	1	4
	6.3	Barrettes (diaphragm walls)	10	8	6	6	6	8	1	4
	6.4	Caissons - mechanical effect	8	8	6	6	4	8	1	2
	6.5	Soil nailing	6	6	6	6	6	8	1	6
	6.6	Dowels and harnessing	8	8	6	6	6	6	1	6
	6.7	Rock bolting	8	8	8	6	8	8	1	6
	6.8	Strand anchors	6	6	6	6	6	6	1	6
7		**Retaining structures (to modify slope geometry and/or to transfer stress to competent layer)**								
	7.1	Reinforced soil structure	8	8	6	8	8	8	1	6

Category	No.	Structural mitigation measure	Maturity of technology	Reliability of performance	Reliability - design	Reliability – implementation	Safety during construction	Service life required (durability)	Aesthetics	Typical Cost
	7.2	Gabion walls	8	8	8	8	8	8	1	8
	7.3	Crib walls	8	8	8	8	8	6	1	6
	7.4	Drystack masonry walls	6	4	6	8	8	6	1	8
	7.5	Mass concrete/masonry walls	8	6	6	8	8	6	1	8
	7.6	Reinforced concrete stem walls	8	6	8	8	8	8	1	6

Table 3 Decision support matrix for non-structural measures

No.	Non-structural mitigation measure	Maturity of technology	Reliability of	Reliability - design	Reliability - implementation	Safety during construction	Service life required (durability)	Aesthetics	Typical Cost
a	Early warning systems	8	6	7	5	0	8	6	6
b	Restricting construction activities	8	8	8	8	0	6	8	10
c	Discouraging construction activities	8	8	8	8	0	6	8	10
d	Increasing resistance or coping capacity of elements at risk	5	5	6	10	0	10	10	4
e	Relocation of elements at risk	4	10	10	10	0	10	10	2
f	Sharing of risk through insurance	4	6	8	6	0	10	10	5

1.2.2 Flood adaptation measures

Similarly the flood adaptation measures are based on the below criteria and are presented in the Table 4 below:

- PREPAREDNESS – Activities in preparation of an extreme event to reduce consequences; and activities just before an extreme event: activities in this stage aim to support evacuation.
- PREVENTION: activities in this stage aim to eliminate vulnerability, e.g. raising a road above the High Water Level. The objective of this stage is to enable smooth and safe traffic.
- PRO-ACTION: activities in this stage aim to rule out the possibility of an extreme event, e.g. flood defenses to prevent flooding. The objective of this stage is to enable smooth and safe traffic.
- RESPONSE – During an extreme event: activities in this stage aim to minimize damage, e.g. shutting down systems; and activities just after an extreme event to guide emergency transport, e.g. restricting heavy traffic on saturated roads. The objective of this stage is to provide access for repairs and humanitarian aid.

Table 4 Flood protection measures for the road network

	Type of flooding			Asset type					Category of measure								
	Flooding due to failure of flood defense system of rivers and canals	Pluvial flooding	Flooding from snow melt	All road infrastructure	Drainage of earthworks and pavements, sewers	Geotechnics, including landslips and rock falls, cuts	Geotechnics, including landslips and rock falls, cuttings	Mobility services	Capacity building	Legislation, regulations	Maintenance and replacement	Monitoring	Planning	Research	Resilient construction	Robust construction	Traffic management
STRUCTURAL MEASURES																	
PREPAREDNESS																	
Clear natural blockages such as shrubs and weeds	x	x	x		x						x						
Cleaning out watercourses and structures of flood prone areas ahead of predicted heavy rainfall		x	x		x						x						
Drainage of road embankment for fast lowering of groundwater table after flood retreats	x	x	x		x										x		
Inspect and clean drainage systems regularly					x						x						
Keeping the road drainage in good condition		x			x						x						
Prevent the clogging of pipes/culverts on connecting roads		x			x						x						

	Type of flooding			Asset type					Category of measure								
	Flooding due to failure of flood defense system of rivers and canals	Pluvial flooding	Flooding from snow melt	All road infrastructure	Drainage of earthworks and pavements, sewers	Geotechnics, including landslips and rock falls, cuts	Geotechnics, including landslips and rock falls, cuttings	Mobility services	Capacity building	Legislation, regulations	Maintenance and replacement	Monitoring	Planning	Research	Resilient construction	Robust construction	Traffic management
Remove large obstructions (such as fallen trees or rubbish which restrict flow	x	x	x		x						x						
Remove recent accumulations of debris which create obstructions to flow	x	x	x		x						x						
Remove recent accumulations of debris and ice which create obstructions to flow			x		x						x						
Remove snow and ice from the road			x		x						x						
Resize drainage systems to meet threats	x	x	x		x										x		
Shelter locations with facilities and life supplies, evacuation routes	x			x											x		
Use geosynthetics for improving slope stability and erosion protection	x	x	x			x									x		
Use vegetation for improving slope stability and erosion protection	x	x	x			x									x		
PREVENTION																	
Cover slope with vegetation		x				x									x		
Vertical or Horizontal realignment (raise or move infrastructure)	x			x												x	

	Type of flooding			Asset type					Category of measure								
	Flooding due to failure of flood defense system of rivers and canals	Pluvial flooding	Flooding from snow melt	All road infrastructure	Drainage of earthworks and pavements, sewers	Geotechnics, including landslips and rock falls, cuts	Geotechnics, including landslips and rock falls, cuttings	Mobility services	Capacity building	Legislation, regulations	Maintenance and replacement	Monitoring	Planning	Research	Resilient construction	Robust construction	Traffic management
Rebuild stretches of the road on safe ground	x	x	x	x												x	
PRO-ACTION																	
Build dams, reservoirs and retaining ponds to buffer the water	x					x										x	
Build flood walls to protect the road from flooding	x	x	x			x										x	
Construct detention storages		x	x		x											x	
Dredge to increase depths and/or straighten the stream	x	x	x	x												x	
Mangroves restoration to reduce wave run-up and shore erosion				x												x	
Organize weirs/overflow towards storage facilities		x			x										x		
Physical reinforcement of the coast line to protect against wave action					x											x	
Sand nourishment to reduce wave run-up and shore erosion						x										x	

	Type of flooding			Asset type					Category of measure								
	Flooding due to failure of flood defense system of rivers and canals	Pluvial flooding	Flooding from snow melt	All road infrastructure	Drainage of earthworks and pavements, sewers	Geotechnics, including landslips and rock falls, cuts	Geotechnics, including landslips and rock falls, cuttings	Mobility services	Capacity building	Legislation, regulations	Maintenance and replacement	Monitoring	Planning	Research	Resilient construction	Robust construction	Traffic management
Wetland restoration as part of a strategy of multiply lines of flood defenses	x	x	x			x										x	
RESPONSE																	
Construction of (temporary) flood barriers along road	x			x												x	

Table 5 Flood protection non structural measures

	Type of flooding				Asset type					Category of measure								
	Flooding due to failure of flood defense system of rivers and canals	Pluvial flooding	Inundation of roads in coastal areas, combining the effects of sea level rise and storm surges	Flooding from snow melt	All road infrastructure	Drainage of earthworks and pavements, sewers	Geotechnics, including landslips and rock falls, cuts	Geotechnics, including landslips and rock	Mobility services	Capacity building	Legislation, regulations	Maintenance and replacement	Monitoring	Planning	Research	Resilient construction	Robust construction	Traffic management
NON-STRUCTURAL MEASURES																		
PREPAREDNESS																		
Install sign posts warning for flooding in threatened areas																		
Inspect blue spots areas adjacent to heavy rainfalls																		
Inspect blue spots areas adjacent to snow melt																		
Inspect watercourses regularly																		
Revised standards for road design, avoiding buildup of water level differences																		
Reviewing design storm return periods in the light of new weather information																		

PREVENTION																		
Make strategies for temporary rerouting	x	x	x	x					x					x				
Prepare Traffic Management Plans	x	x	x						x									x
PRO-ACTION																		
Avoid deforestation in the catchment area	x	x					x									x		
Carrying out risk assessment of identified areas	x	x	x	x			x							x				
Develop plans and routines for the priority of securing areas prone to flooding	x	x	x	x	x									x				
Establish a guideline for standardized inspection of drainage system		x				x					x							
Integration of infrastructure development and land use planning	x		x		x									x				
Keeping in-house GIS up to date	x	x	x	x	x									x				
Keeping records of flooding events and locations	x	x	x	x	x								x					
Mapping areas prone to flooding (Blue spot analysis)	x	x	x	x	x								x					
Prepare and educate road users for flooding	x	x	x	x	x					x								
Prepare and educate staff for flooding	x	x	x	x	x					x								
Prepare contingency / emergency plans	x	x	x	x	x									x				
RESPONSE																		
Access restriction	x	x	x	x					x									x
Carriageway cross-over	x	x			x													x

Lane closure	x	x	x		x													x
Modal shift		x							x									x
Preventive information	x	x	x	x	x										x			
Real time traffic information		x			x													x
Real time weather and traffic forecast		x			x													x
Reroute the traffic	x	x	x	x					x									x
Rerouting and guidance	x	x	x						x									x

1.3 Climate Resilience Measures

The matrices in the foregoing guidelines provides guidance on a full range of engineering interventions and the means for their prioritisation to address hotspots within the road network. This section of the guidance provides a greater definition of the interventions that relate to improving the climate related resilience of road infrastructure and a context for their use on the road network.

In order to reduce the impact of future climate change effects, physical engineering interventions can be used to avoid damage being caused to the road infrastructure by the most common natural hazards, flood related events and landslides. These physical interventions are suggested as ways in which the road managers can avoid severe damage to roads, road structures and bridges. Obviously, amendments to existing infrastructure will incur a cost and there must be a demonstrated return on the investment in any intervention.

The most cost effective approach to climate resilience is to ensure that all new roads, or upgrading works are designed in accordance with International good practice and standards, and especially those that incorporate resilience. Within the design processes there may be the need to incorporate an appropriate uplift to all climate related design parameters to compensate for near term and, as appropriate with the longer design life for the element, longer term future climate change.

Climate resilience measures are intended to be applied to existing infrastructure to enable them to accommodate the impacts of climate change without serious failure. Some such measures are designed to allow a short term operational (safe) failure while protecting the infrastructure of the road from a destructive failure. The measures described may anyway be incorporated into the ongoing design and construction of roads, as good practice.

From an inspection of the road network and a recent history of climate events that impacted the road network the most common risk is due to damage to or obstruction of the road network from landslides, flooding or failures of the drainage systems. Although the causes of landslides are not solely climate related, the assessment of the causes of landslides in North Macedonia in Part B of the guidelines identified a strong relationship between precipitation event and landslide propagation. In suggesting the most suitable climate resilience measures for slope stabilisation the priority has been given to those that control or reduce the flow of water over or into slopes.

The climate resilience measures to address landslide and flood risks are shown in the **Table 6** below, along with an indication as to which of the projected climate change effects in North Macedonia they are most useful to combat.

Table 6 Overview of Potential Resilience Measures

	Category/Resilience Measure	Flooding	Flash flood	Landslide
1	**Outside of Road Corridor**			
1.1	Realignment (vertical or horizontal)	X	X	X
1.2	Watershed/catchment management	X	X	
2	**Cross-drainage/structures**			
2.1	Culverts and box culverts improvements	X	X	
2.2	Roadway Swale	X	X	
2.3	Permeable embankment	X	X	
2.4	Debris stopper	X	X	X
2.5	Bridges	X	X	

3	**Road Drainage**			
3.1	Road pavement drainage	X	X	
3.2	Longitudinal road drainage	X	X	
3.3	Scour checks	X	X	
3.4	Cascade/spillways	X	X	X
4	**Erosion Protection**			
4.1	Retaining and façade walls	X	X	X
4.2	Gabion mattresses and boxes	X	X	X
4.3	Rock protection		X	X
4.4	Bioengineering measures	X	X	X
5	**Slope Stabilisation**			
5.1	Cut off drains		X	X
5.2	Slope protection vegetation and drainage			X
5.3	Soil reinforcement and geotextiles	X	X	X
5.5	Rockface scaling			X
5.5	Debris and rockfall netting			X
5.6	Catch ditches and fencing/walls			X
5.7	Reinforced sprayed concrete			X
5.8	Ground Anchors and Rock Bolts			X
5.9	Warning systems			X
5.10	Reprofile slope (non-Rock material)			X
5.11	Rock Shelters			X

Source: IMC

Note: Flooding generally relates to a long term build-up of water in flood plains alongside a road.

Further details of each of these potential resilience measures are discussed as follows.

2 Outside road corridor

Planning a new road should start with wider consideration of the land and climate impacts outside of the existing or proposed new road corridor.

The improvement of the flood resilience of a road should consider catchment management options before cross-drainage and road drainage improvements within the road corridor itself are considered. In a similar way the prevention of landslide risks can require erosion protection and/or slope protection measures (see specific sections below) applied outside of the road corridor. Both of these may require land acquisition or ownership agreements to be considered so that the issues may be addressed. For a new road, where land must be acquired, addressing these issues at the earliest possible stage will be more economic than not so doing and attempting to do so later when a failure has occurred.

2.1 Realignment (vertical or horizontal)

The realignment of the road may be required to deal with an existing hazard, or to reduce future vulnerability. This could include a new horizontal road alignment (e.g. around a flood or landslide prone location) and/or new vertical alignment (e.g. raising a road/road embankment level to reduce flood risk).

ROAD REALIGNMENT
Technical and Design Horizontal realignment. Realignment of the road can be a best solution to limit identified climate impacts on a proposed route. The cost of construction over a new route may well be lower than the long term hazard maintenance and upgrading cost of the existing road. This is most likely for roads located close to rivers that are frequently flooded, roads close to or passing through landslides zones where remedial maintenance is more frequent and climate events cause road damage. Realignment may be planned in advance of a proposed highway intervention or be an option considered after a flood or landslide event. It is important that any new road or proposed relocation is located away from the flood risk area(s) and/or landslide zone(s) as far as is practicable. For the planning of new roads alignments the impacts of flash-floods, wildfires and snow/ice over the alignment should be taken into consideration as factors of importance. Realignment of existing roads for these hazards are likely to be less appropriate than mitigation of the risk at specific locations. It should be noted that any new road alignment must preserve connection to local communities in a similar manner. Vertical realignment. For flooding higher risk locations raising the road level is one solution to adapt to climate change. The road surface level can be raised to an elevation higher than the new predicted design flood level be it from overland flooding or flash flooding through a bridge. This will reduce the risk of road damage and the likelihood of a road becoming inaccessible during a flood event. It is important to remember that a raised road can block flood water flowing from one side of the road to the other. It is important therefore, that proper cross-drainage through the road is designed into any intervention, so that a flood embankment does not act as a dam. Thus, in addition to raising the road level the amount of cross drainage (e.g. number/size of culverts) may need to be increased. When raising the road elevation, it is important to use suitable construction materials and to ensure that these materials are compacted in a good manner. Compactions of layers of embankment, sub-base or base must be in accordance with SRPS (SRPS-EN), or specific-designed requirements. Embankment protection should be considered to avoid a risk of erosion of the embankment at culverts and bridges due to the increased velocities and disrupted flows near the structures' inlets under flood conditions. These are discussed under Resilience Measure 2.3 and Category 4 below.
Policy and Institution Purchase of existing land will likely be required. For an existing road, environmental legislation must be complied with as for a new road.
Maintenance and Operation A road realignment, designed to international good practice, will require less preventative maintenance than a threatened road alignment.
Expertise/Inputs required: As for the design of any new road
Resilience Type: Preventative; Robust Construction

2.2 Watershed/catchment management

In a new road design or when one is being improved or upgraded the current status of each watershed/catchment should be assessed and the future potential for developments therein that could affect the design flows considered for a structure under the road. Development of stream catchments has been identified as a causation for past flood events. It is possible using drones or satellite imagery to assess changes in a stream catchment, especially clearance of forest or natural vegetation. The effects of these changes should be assessed when a drainage structure exist within any road section’s design.

Management of the watershed/catchment using ‘upstream’ measures should be considered before attempting to address flood risk within the road corridor using the resilience measures (categories 2-4 below). The management could include a range of Sustainable Drainage System (SuDS) measures to retain water in the catchment and then to slow and reduce the rate at which water arrives at the road from the catchment. These would however have to be undertaking in conjunction with the landowners and other interested Institutions and government departments and may require a range of approvals.

The forgoing limitations may restrict the use of this resilience measure but it can prove to be cost effective in the long term and benefit more than the road’s operation by reducing flooding both upstream and downstream of the road structure.

RSuDS
Technical and Design- "RSuDS comprise individual or multiple linked component structures replicating natural processes, designed to attenuate water flow by collecting, storing and improving the quality of run-off water within rural catchments. The simple definition is that they are measures that primarily intercept run-off or drainage pathways"[1]. The RSuDS measures include bioengineering measures such as tree planting to reduce run-off rates across a catchment (re-forestation), and retention basins and check dams to reduce the peak hydrograph in the stream/river itself. Additionally, land-use planning should be introduced to avoid land clearance or built-up development with hardstandings that increase run-off rates.
Policy and Institution Legislation to prevent the development of river catchments or to ensure they are managed so as to prevent flooding downstream. Access by authorised bodies, with prior notice to inspect the catchments and require the implementation of controls e.g. reforestation. Catchment Management Plans
Maintenance and Operation Agreements will be required with the landowners and others to maintain the RSuDS works and their operation. Access to the land for maintenance by PESR or other entities will be required
Expertise/Inputs required: Hydrologist and Environmental expert
Resilience Type: Preventative

<u>References</u>

1. Rural Sustainable Drainage Systems (RSuDS), Published by: Environment Agency, Horizon House, Deanery Road, Bristol, BS1 5AH 2012

CHECK DAMS/RETENTION PONDS

Technical and Design-

Check dams are an element of an RSuDS scheme to control the flows exiting from a catchment and the design must consider the whole catchment. The dams are placed at intervals in the streams contributing to the flow out of the catchment. A typical spacing might be 6 to 10m but the number and positioning will be defined by the slopes and the size of the stream.

The dams can be constructed from a variety of materials. The example alongside uses concrete but alternative materials such as tree logs or rock filled gabion baskets can also be placed across the stream to form a leaky dam. Rock mounds in the stream bed or rock dams can also be constructed.

Retention ponds are existing low or lowered areas of land within a catchment. These are available to retain excess water flows. Water may be diverted into them by a higher level diversion channel from a main stream channel. Alternatively, low lying land can be used to retain water. The water flowing over the catchment ground surface is control and directed to the land using check dams, or similar low earth mounds.

Policy and Institution

Agreement of the land owners or rights to operate and maintain these structures will be required, unless legal statutes impose the requirements on the catchment owners e.g. Catchment Management Plans. Catchments with check dams and retention ponds should be identified in RAMS

Maintenance and Operation

Dependent upon the access arrangements of each catchment. There should be a yearly visual inspection visit of each series of check dams/retention ponds to check for damage and satisfactory operation. The timing of the visits should be before the period of the year with the greatest risk of torrential rainfall.

Expertise/Inputs required:

Hydrologist and Environmental expert

Resilience Type: Preventative

3 Cross-drainage/ structures

The climate resilience measures in this section should be considered alongside those set out above for measures outside of the road corridor. Although future year mean annual precipitation is anticipated to reduce in NM climate change is likely to increase a short period storm's intensity. This will increase the risk of existing structures overflowing and/or a local destruction of a road.

New roads and new drainage structures should be designed in accordance with NM technical standards and international good practice for the specified design year storm, see Figure 1 - Drainage structure design storm frequency (ref. Civil Engineering Faculty NM).

, but uplifted to incorporate future climate change predictions, see Flood Section of the guidelines above.

	Dreinage Structure Type (Typical) Тип на дренажен објект	Frequency In Years Фрекфенција во години	Design standard Проектен Стандард
1	Gutters and Inlets (urban) Олуци и сливници	10 for highway/10 за автопати 5 for national, regional, local road/ 5 за магистрални, регионални и локални патишта	JUS.U.C4.20 од 1982 МКЦ.У.Ц4.20
2	Roadside Ditches Странични канали	10 for for highway 5 for national, regional, local road	JUS.U.C4.20 од 1982 МКЦ.У.Ц4.20
3	Ford/Low-Water Bridge	100	(искуствено)
4	Culver, pipe less than 2 m diameter Пропусти, цевки со дијаметар < од 2m	100	(искуствено)
5	Culver, 2 m<span<6 m Пропусти, 2 m<распон<6 m	100	(искуствено)
6	Short Span Bridges, 6 m<span<15 m Кратки мостови, 6 m<распон<15 m	100	(искуствено)
7	Medium Span Bridges, 15 m<span<50 m Средни мостови, 15 m<распон<50 m	100	(искуствено)
8	Long Span Bridges, spans>50 m Долги мостови, распон>50 m	100	(искуствено)
9	Check/Review Flood		

Figure 1 - Drainage structure design storm frequency (ref. Civil Engineering Faculty NM).

It is noted that a 100 year design year for smaller cross drainage structures 3, 4 and 6 in the table is in excess of the values used in the EU. As such, these structures already have had a climate uplift provided by comparison to elsewhere. However, if these structures are >20 years old approximately, the 100 year storm used in their design has already outdated by an updated, prior to this report's publication, to reflect the climate change impacts from the nineties onwards.

The capacity of older cross drainage structures on existing roads, mainly culverts and bridges should be investigated and modified if needed. This is particularly necessary when a road is to be rehabilitated or widened. Changes in the watershed/catchment conditions for an existing drainage structures needs also to be considered along with the use of the most up to date storm data and making an allowance for near future year climate change in.

When considering cross drainage, it is important to avoid water upstream of the road reaching levels so high as to damage or erode the road embankment or overtop the road pavement. It is also important to investigate the areas downstream of the outfall to avoid erosion of the area due to an increased flow's volume and velocity or overtopping of the stream banks causing localised flooding.

Where an existing structure is unable to carry the future design year storm, the capacity of the structure may be increased, or other resilience measures incorporated to restrict the likelihood of damage to the road or the structure.

3.1 Culverts and box culverts improvements

Culverts are normally pipe culverts or box culverts. Having assessed a culvert to have inadequate capacity to accommodate the catchment’s flows (based on flood hydrographs incorporating future climate impacts) a number of resilience measures may be required.

1. The existing culvert is retained and the inlet and outlet modified to accommodate the new design volume without damage being caused to the structure or the embankment. Erosion control measures may also need to be installed
2. An existing culverts is increased in size or a new culvert(s) added alongside
3. The existing culvert is retained and a swale/spillway installed in the road surface to allow excess volumes to pass over the road embankment. See 2.2 below.

A final solution is that the existing culvert is replaced by a bridge but this is generally not necessary, unless significant changes within the catchment have occurred to increase the design flows, or the original design of the culvert was inadequate.

INCREASING THE AVAILABLE CAPACITY OF A CULVERT.
Technical and Design A culvert is originally designed so that the water flow does not rise to or a specified distance above the soffit of the culvert's inlet, or a similar capacity condition restriction. Where a culvert's near future flow is estimated to be surcharged by a backwater, above the restriction defined, the capacity can: a. be increased by improving the shape of the inlet structure to improve the inlet flow and the culvert's capacity or b. by accepting that the backwater can rise above the limit but does not threaten the road surface, typically on higher embankments. In both cases the consequences for both the road embankment and the land and properties upstream must be considered. For the design of improved inlets under point a., reference should be made to the HEC 13 Hydraulic Design of Improved Inlets for Culverts. For lower backwater levels introducing a bevel (either a plane or rounded surface) at the face of a square edged culvert inlet provides the first level of improvement in performance by 5% to 20%, followed by a side tapered inlet. In regard to the flooding of the embankment, the saturation of the fill material may result in weakening of the embankment and potential fill slippages, especially as the water draws down after the flood. In the location of the inlet the embankment is at risk of erosion due the flow velocity as the water enters the culvert. The embankment slopes must be protected from erosion around the inlet structure. See options under Category 4. Likewise, the outfall will be subject to higher flows and velocities so that erosion of the stream bed and side may result. Again, erosion protection may be necessary. Again, see options under Category 4
Maintenance and Operation See below
Expertise/Inputs required: Hydraulics Engineer; Structural Engineer
Resilience Type: Robust construction

References

Hydraulic Design of Improved Inlets for Culverts HEC 13 August 1972; https://dsda.org.il/uploads/n/1525855067.4295.pdf

ENLARGING THE AVAILABLE SIZE OF A CULVERT.
Technical and Design For a culvert the existing culvert capacity can be enlarged by: a. tunnelling or thrust boring under the embankment an additional new culvert alongside the existing, or b. by tunnelling a larger culvert along the line of the existing culvert. This may be necessary where inadequate space exists for an additional culvert. The risk of this option is having to deal with the ongoing flows in the existing culvert during construction by pumping or other means. Where an embankment is shallow the works may be undertaken by cut and cover rather than boring through the embankment.
Policy and Institution All new or upgraded culverts to be included in RAMS
Maintenance and Operation See below
Expertise/Inputs required: Hydrologist and hydraulics Engineer; Thrust boring or tunnelling experts
Resilience Type: Robust construction

MAINTENANCE OF CULVERTS.

Technical and Design

The maintenance of culverts is an essential element of the ongoing protection of a road from climate impacts. The guidance provided is intended to guide PESR to balance the risk of deferred maintenance with inspection frequency, based on practices used by similar agencies.

For example, very small culverts may not warrant inspection and well-performing installations may allow reduced frequency of inspection. Developing a schedule for inspection frequency should carefully consider culvert location, ownership, waterway hydraulics, installation age, and consequence of failure (e.g embankment height, annual daily traffic carried).

<u>Clearing and Cleaning of Culverts and Drains</u>

Culverts and drains must be maintained regularly in order that no debris will block the flow of water. This is especially important close to forest areas where branches and other debris from trees can be brought by the water.

In areas with slow water flow, the culverts can easily be blocked by soil deposits that can considerably reduce the flow area of the culvert. In order to facilitate cleaning of culverts, cross drainage structures smaller than 1.2m diameter should <u>Not</u> be used.

<u>Repair of Erosion Protection and Scour Checks</u>

Erosion protection and scour checks have to be inspected and repaired regularly and especially after the rainy season and heavy rainfall.

Maintenance of erosion protection is important in order for it to work as expected. If no maintenance and repair is made of the erosion protection, the road might be damaged and the cost of repair will later be much higher.

<u>Structural Condition Checks Through Visual Inspection</u>

Regular inspections of larger culverts and small bridges should be inspected for their structural condition on a regular frequency. One possible example is given below.

Table 1 – Inspection Frequency (Routine Inspections)

Barrel Size (S)	Inspection Frequency (Ratings ≤ 2)	Inspection Frequency (Ratings ≥ 3)
New Installation (S > 1 ft)	Inspect annually for the first 2 years after construction.	N/A
S ≤ 1 ft	No routine inspection required. Inspect during roadway maintenance activities.	No routine inspection required. Inspect during roadway maintenance activities.
1 ft < S ≤ 4 ft	Every 10 years or prior to routine roadway maintenance activities, whichever is less.	At least every 5 years and with routine roadway maintenance activities.
4 ft < S ≤ 10 ft	Every 5 years or prior to routine roadway maintenance activities, whichever is less.	At least every 2 years and with routine roadway maintenance activities.
S > 10 ft	Every 2 years	At least every 2 years and with routine roadway maintenance activities.

Policy and Institution

Instigate and fund adequate inspections and repair of all culverts and small bridges

Maintenance and Operation

Undertake regular inspections of all drainage structures following a prioritised schedule based on the flows carried, size of culvert and their importance to the road and its physical structure.

Expertise/Inputs required:

Road Maintenance experts

Resilience Type: Preventative

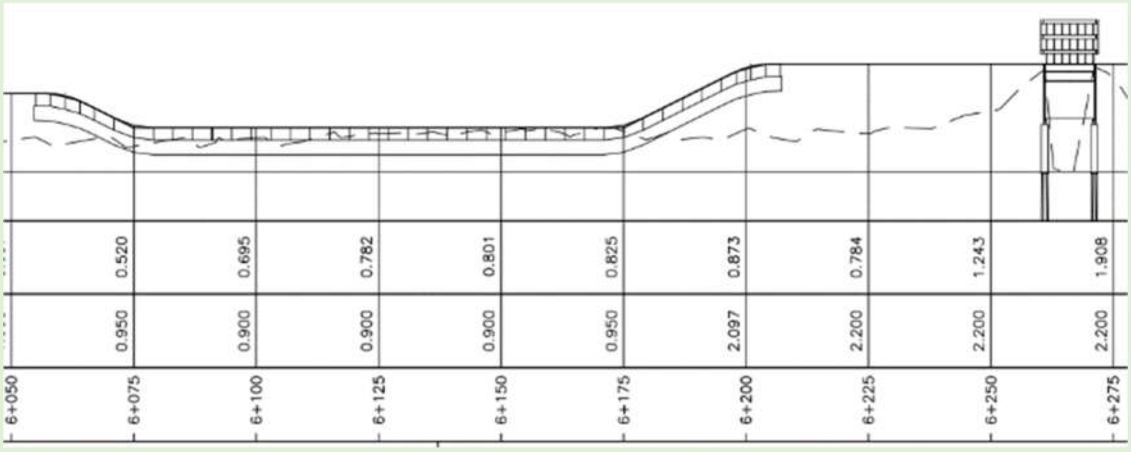
3.2 Roadway Swale

Swale and Spillways are a means to accommodate flows in excess of an culvert's capacity where the improvement of the culvert as in 2.1 above, is not practicable or cost effective. It is not generally an option to be used on a new road except in exceptional circumstances with low traffic volumes. The approach used is that, when water flows in excess if those that can be carried by the existing drainage structure, the flows are allowed to cross over the road pavement via the swale, in a designed and controlled manner.

ROADWAY SWALE

Technical and Design

The swale length and depth will be designed such that the maximum depth of water passing across the swale is not more than say 0.25m, so that the road is passable during flood events. See an example below of a swale to carry excess flood water at a bridge (note that the vertical scale is exaggerated).



Swale under construction with stone filled mattress protection to embankment visible.

Policy and Institution

Amendment to standards to allow for safe failure

Maintenance and Operation

Road pavement maintained to be carried out as for other concrete roads; Swale and associated embankment protection measures to be inspected and repaired as required after each flood event. A maintenance inspection to be carried out before the start of the snow melt (if appropriate) and before the high storm intensity period.

Expertise/Inputs required:

Hydraulics Engineer; Pavement Engineer.

Resilience Type: Safe failure

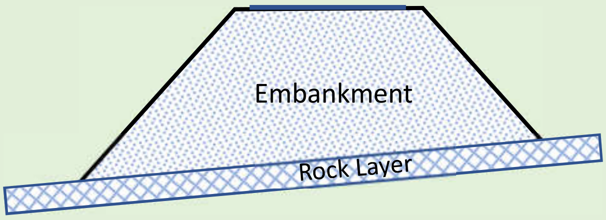
IMC worldwide 2014

3.3 Permeable embankment

This measure is most appropriate where a new road is being constructed but it is anticipated that the road will be subjected to flood inundation. Alternatively, it will be appropriate when the road has to be constructed following the road being washed out.

Where a road is subjected to inundation from flood waters on one or both sides it needs to be constructed of a resilient material such as rock or granular fill that can be stable when flooding occurs and is then generally permeable. However, a specific case is the use of this is a Roadbed Rock Mattress.

This option, also known as Rock Sandwiches or French Mattresses and are normally used in extremely wet areas or wet land. A layer consisting of clean rock wrapped in geotextile fabric is placed as the first embankment layer on the ground. The water is then supposed to pass through this layer from one side of the road the other. The rock layer will be a support foundation for the road during wet or muddy conditions.

ROADBED ROCK MATTRESS. ALSO KNOWN AS ROCK SANDWICHES OR FRENCH MATTRESSES
Technical and Design The option allows the flood water on one side of an embankment to drain through the layer to the downstream side. It is most useful in low lying wet areas where flooding of the ground is common. A layer consisting of clean rock wrapped in a geotextile fabric is placed as the first embankment layer on the ground. The water is then supposed to pass through this layer from one side of the road the other. The rock layer will also be a support foundation for the road during wet or muddy construction conditions. The fabric layer needs to be designed to match the likely soil materials to be transported during flood conditions to reduce the likelihood of the material being blocked. 
Policy and Institution Locations of embankments with permeable layer included in RAMS
Maintenance and Operation Inspection after each flood event to assess the operation of the blanket
Expertise/Inputs required: **Geotechnical expertise for design of the geofabric**
Resilience Type: Preventative

3.4 Debris stopper

Debris might be a problem, in some areas, during period of more intense rains. Floating or submerged debris like tree logs, twigs, or leaves can obstruct the waterway entrance of culverts or block culverts or cause damage to drainage structures. In urban environments the debris may be human rubbish or trash such as plastic bags. A debris stopper at the end of a culvert is a way of stopping it from getting blocked with debris.

Where torrential flows are able to transport large debris such as rock and boulders which could damage bridges and large culverts down streams debris dams made need to be constructed.

It is important, especially before the rainy season, to inspect and, if needed, repair the debris stoppers and dams.

DEBRIS STOPPER/SCREEN

Technical and Design

Debris stoppers can consist of metal grids or vertical bars to collect the debris. They are most commonly used on culverts that can be blocked by general rubbish and such debris carried in the flow. The pictures shows a screen to a small pipe culverts.

Tree branches or trunks are a different problem in wider stream beds and structures. These may require a stronger structure as shown in the photograph here. The photo also shows one of the problems of screens. As the debris is captured it can block the entrance to the culvert causing the water level to rise and over flow the top of the screen as can be seen by the debris deposited at the top of the screen. It is recommended that the screen incorporates has a horizontal section before the culvert inlet to allow for water to pass up and over the screen top and enter the culvert.

As mentioned the spacing and strength of the grid components will depend upon the likely materials that need to be intercepted, and the force of the water generated when the debris is captured. In the worst cases the stopper bars may need to be substantial girders projecting up out of the stream bed able to resist rock and trees carried by the flood water.

For the design of the screens refer to following:

Trash and Security Screen Guide 2009 published by Environment Agency UK

The UK Highways England DMRB Vol. 4 Section 2 Part 7 – HA 1078/04 Chapter 8, and examples in Appendix A

Policy and Institution

Location of all debris stoppers included in RAMS

Maintenance and Operation

Debris stoppers must be regularly cleared through the year, and more intensively during the peak flow season in the stream. Damage to the structures to be repaired before the peak flow season.

Expertise/Inputs required:

Hydraulics Engineer; Structural Engineer

Resilience Type: Preventative

DEBRIS CHECK DAMS
Technical and Design  Debris dams are essentially substantial porous check dams. Their purpose is to retain heavy debris brought down a stream within a torrential flow, such as rocks boulders and trees. In normal flows they allow the passage of water through the structure or over the lowered lip. Under torrent flows the boulders etc. are stopped on the upper stream side. Such dams must be designed taking account of the flow predicted as well as the volume of debris flows to be carried and the types of materials. In some cases it may be necessary to provide more than one dam. As the dams need to be cleared of debris which may include large boulders, it is necessary for access ways to be available to bring to the site heavy lifting equipment.
Policy and Institution These dams will be placed some distance upstream of a bridge or large culvert. The approval of other authorities will be required to construct these protective measures, Location of all debris dams to included in RAMS
Maintenance and Operation Debris dams must be regularly cleared through the year, and more intensively during the peak flow season in the stream. Damage to the structures to be repaired before the peak flow season.
Expertise/Inputs required: Hydraulics Engineer; Structural Engineer
Resilience Type: Preventative

3.5 Bridges

Bridges themselves are a resilience measure when well designed, as they enable a road to remain passable in a period of flood flow and will have a greater capacity than a culvert/box culvert. Bridges are generally expensive to extend or replace when found to have inadequate capacity. Additional capacity can be provided by installing additional culverts to the approach embankments. See Resilience Measure 2.1 above. Swales over the approach embankments can be introduced the accommodate extreme flows of water at the bridge sites. See Resilience Measure 2.2.

Bridges also need to be protected themselves to ensure that they are resilient to the range of hazards. Bridge approaches need to be protected from both landslides and flooding. Specific measures to improve bridge resilience are discussed below

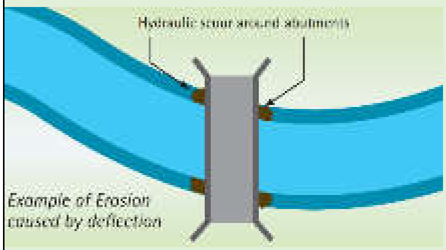
- Provision of adequate freeboard/deck raising.
- Abutment and foundation erosion protection

PROVISION OF ADEQUATE FREEBOARD/DECK RAISING.
Technical and Design The design of a new structure or the assessment of an existing structure should ensure that the design flood, making due allowance for climate change impacts, can be passed without the water level reaching the underside of the superstructure or a stated clearance thereto. A clearance below the underside of the superstructure may be required to provide for navigation or to allow the passage of large floating debris such as uprooted trees. A freeboard of some 3m would be required. In flood conditions where the freeboard is inadequate the and water rises to the road level on the bridge the flood waters can commonly flow around the back of the abutments as bridges are commonly designed with the approach embankments rising towards the bridge. As a consequence the flow around the abutment washes away the backfill and the embankment behind. The loss of the material can actually save the bridge which will often end up as an island in the river. The use of Swales on the approaches can prevent the loss of the road connection in such cases. Where an existing bridge's freeboard is inadequate, or when the design of a new bridge is provided with a lesser freeboard for economic or other constraints due to the current uncertainty of the flood projections raising of the bridge deck is a solution. In the case of a new bridge the future deck raising can be incorporated into the design of the foundations and sub-structure at relatively little cost. The design of the deck itself may need to more carefully considered. Options for jacking up of the bridge deck can be incorporated into the deck's and abutments' design, The deck may need additional strengthening. An alternative design solution may be the use of steel girders and a concrete deck slab. The deck slab can be broken out and the steel beams removed and refurbished, and then reinstalled on the raised abutments. For an existing bridge the option of raising the deck is more complicated. However, it is a possibility depending upon the foundations' design and the abutment layout. More likely, the deck will require substantial demolition. However, for a cost it will be generally practicable and potentially less disruptive than total demolition and replacement with a new bridge.
Policy and Institution A Bridge Maintenance and Management System to be installed in association with the RAMS to store information regarding each bridge's structure and foundations as well as the state of the erosion protections measures. The BMMS should also identify the inspection schedule for the bridge in regard to erosion and other impacts, and hold the inspections reports digitally such that changes in the quality and capability of these to resist erosion are reported. All rivers should have installed remote flow monitoring and range recording devices reporting to a central database, linked to the BMMS. Recording of flood levels to be carried out at bridge sites following high flow events
Maintenance and Operation Bridge inspection procedures shall be implemented before the peak flow season within North Macedonia. The inspections should ensure that no blockage to the free flow in the vicinity of the bridge exists, e.g. silting or other depositions.
Expertise/Inputs required: Hydraulics Engineer; Structural Engineer
Resilience Type: Adaptive design

ABUTMENT AND FOUNDATION EROSION PROTECTION

Technical and Design

A common failure for bridges is in extreme flow conditions as a consequence of climate change. This may consist of scour of the river bed around a bridge pier or the of river bank under the abutments. The result is the erosion of the foundations under or around the bridge's sub-structure. Existing scour and erosion protection may exist but be damaged or be unable to resist the flows.



A similar failure results from the erosion of the river bank upstream of the bridge resulting in the river eroding the approach embankment. Bridges on bends in the river or stream are especially prone to such failures.

The climate resilience approach is to provide hardening of the foundations by implementing one of the following depending upon the design flows calculated and the natural resistance of the natural materials.

Each location will require a detail review of the existing flow regime at the bridge, the existence of any existing erosion or sedimentation, establishment of the bed and bank materials and their resistance to erosion which may include geotechnical investigates on site. Thereafter a preliminary and detailed design will be prepared considering which of the following options, on their own or in combination will provide the most efficient and cost effective solution.

- Sheet piling to foundations, river banks and abutment toes, etc.
- Gabion basket and mattress erosion protection to riverbeds, banks and abutment foundations and approach embankments
- Rock armour or rock rip rap protection to river beds and banks
- Erosion protection to river banks using geotextiles and/or vegetation

Policy and Institution

A Bridge Maintenance and Management System to be installed in association with the RAMS to store information regarding each bridge's structure and foundations as well as the state of the erosion protections measures. The BMMS should also identify the inspection schedule for the bridge in regard to erosion and other impacts, and hold the inspections reports digitally such that changes in the quality and capability of these to resist erosion are reported.

All rivers should have installed remote flow monitoring and range recording devices reporting to a central database, linked to the BMMS.

Maintenance and Operation

Bridge inspection procedures shall be implemented in accordance with International Standards to ensure that erosion and scour damage or damage to the protection measures is identified and remedial measures undertaken, before the peak flow season within North Macedonia. The inspections should include the river banks above and below the bridge.

Expertise/Inputs required:
Hydraulics Engineer; Soils and Materials Engineer

Resilience Type: Robust Construction

4 Road drainage

A good road drainage system, which is properly maintained, is vital for all type of roads.

A good drainage system conveys water from the surface of the road, as well from the different layers of the road structure, to a safe exit (stream or cross drainage structure). The drainage system also intercepts surface water flowing towards the road and ensures that any water that flows across the road does so in a controlled fashion.

The destructive power of water increases exponentially as its velocity increases. Therefore, water must not be allowed to develop sufficient volume or velocity to cause excessive wear along ditches, at culverts or along exposed running surfaces, cuts or fills. Velocities over 1 m^3/sec may require erosion protection measures.

The presence of excess water within the roadway will adversely affect the properties of the materials with which it was constructed. Cut or fill failures, road surface erosion and weakened subgrades followed by a mass failure are all products of inadequate or poorly designed drainage.

It is suggested that all the drainage of the roads is surveyed and inspected on a regular basis including small scale CCTV inspection for pipework

Other categories aim to improve the resilience of the road corridor from flooding originating from outside of the road corridor. In addition, it is important to ensure the road is resilient to flooding (mainly flash flooding) due to extreme rainfall on the road itself. This is covered in this section. Different types of drainage measures relating to the road drainage itself are discussed below.

4.1 Road pavement drainage

Road pavements should be designed to be avoid water ponding on the road surface. The design of the road pavement should be linked to the provision of resilient design solutions for roadside drainage.

ROAD PAVEMENT CROSSFALLS
Technical and Design Road pavements shall be designed to ensure that water is efficiently and effectively removed from the road surface through sealed surfaces that resist water ingress, and by having crossfalls adequate to ensure surface water flows to the road edge. Recommended crossfalls vary in international practice but a minimum crossfall of 3% on roads constructed from bituminous materials is recommended for roads in North Macedonia. Although lower values are used in other countries, 3% makes an allowance for the likelihood of rutting and localised settlement of road surfaces as identified on the roads in the country. Likewise, in steeper terrain a larger crossfall assists in ensuring water move to the road edge rather than running down the road itself. Where roads are to be reconstructed or widened, the crossfalls should be a minimum of 3%
Policy and Institution Incorporate minimum crossfall in laws
Maintenance and Operation None above existing requirements
Expertise/Inputs required: Road Geometry Engineer; Pavement Engineer
Resilience Type: Preventative

4.2 Longitudinal road drainage

Longitudinal road drainage includes a range of different measures to capture the water flowing from the road's surface and evacuate it to a suitable discharge point. An additional purpose is to capture surface water from the embankment toe and discharge it to a suitable stream or outfall.

Climate resilience - the main concern in regarding ensuring resilience is, as for culverts and other drainage structures, to ensure that the drainage system can remove the increased design year storm flows that will exist in the near future and without damage to the drains or the outfalls.

The types of drainage used, which will be appropriate in different circumstances, can be summarised under the following headings:

- Over-edge drainage
- Ditches, gutters (road surface water drainage);
- French drains (sub-surface drains to dewater the surrounding ground); and
- Underground drains (gulleys or pipes).

The design year for longitudinal road drainage is 1 in 5-10 years which is much less than for culverts, at 1 in 100 years in North Macedonia etc. These requirements are generally in excess of the standards across the EU providing some resilience against future climate impacts.

However, at these design years, it is to be expected that the longitudinal drains will overflow in the near future, resulting in generally acceptable flooding on the road surface. It is however important that the overflow does not enter into and cause damage to the road's underlying structure. Water ingress can precipitate land sliding in embankments and especially those constructed in sidelong ground. See ???Landslides?

Over-edge drainage is used in many cases on lesser category roads road it is common for pavement runoff on embankments to pass off of the road pavement directly onto the roadside grassed verge/embankment top. Although this is not uncommon on roads in elsewhere, this approach requires that the roadside verge must be efficiently maintained to remove silt and debris, and grass at the road edge to prevent a dam forming at the road pavement edge. If maintenance is inadequate, water does not pass into the verge but is channelled to a low point or similar where it flows off of the road in a stream eroding the verge and resulting a wash out of the embankment.

Ditches or drains are often constructed alongside the road pavement when the road passes through cut areas. The size and shape of the ditch can vary depending on the amount of water anticipated. The ditch shall have a longitudinal slope towards an exit point, where the water can be safely discharged.

Ditches can also be constructed at embankments to lead water from the embankment slopes and from surrounding land areas towards an exit point.

Ditches might be protected by stone riprap or concrete and can also be combined with embankment protection depending on the amount of water expected. Ditches with steep longitudinal slopes are more vulnerable for scour and in need of protection. According to SRPS ditches with slopes lower than 0.3% or steeper than 3%, are made of concrete or non-erosional material.

In sidelong road construction unsealed ditches at the toe of the cut slopes can allow saturation of the underlying soils possibly resulting in slumping or sliding of the embankments. Where fill the material is moisture susceptible the ditch should be constructed with a concrete liner

Gutters can be and are used at the toe of cut slopes instead of ditches. In North Macedonia these are typically a concrete slab sloped more steeply than the road pavement with the outside edge formed by a concrete kerb or other upstand. Outfalls are usually provided to culverts carrying cross drainage flows. It is unclear on inspection if any design is applied to the provision of the outfalls or the height of the rear upstand.

Particular care is required in cuttings where the subgrade materials are moisture susceptible to ensure that the drainage system does not overflow due to an inadequate rear upstand kerb height and result in saturation of the road's foundations of the embankment materials In sidelong road construction saturation of the subgrade can result in a landslip failure of the embankment.

French drains or underdrains are mainly used to remove water from the structure of the road and to hinder ground water from surrounding areas to reach the road structure. It is important to construct the drain with proper longitudinal slopes towards a safe outlet of the drain. The end of the drain can be a culvert or an embankment area where the elevation of the land is lower than the drain.

Underground pipe and road pavement inlets consist of a carrier drain under the road edge and inlets set alongside the road pavement too capture the flows direct from the pavement (gulley pots) or the outflow from a gutter system.

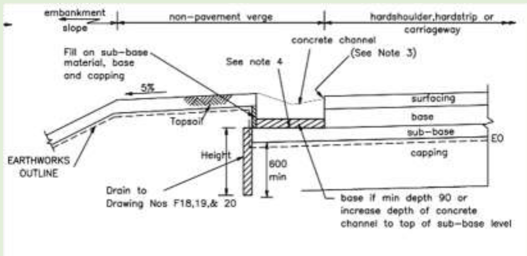
OVEREDGE ROAD DRAINAGE

Technical and Design

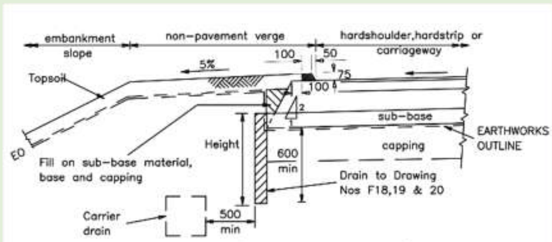
With the anticipated increase in storm intensity greater volumes of water will need to be removed over the road edge. As a result Overedge Road Drainage can result in the washout of road embankments.

Overedge drainage requires that the road edge is efficiently maintained to remove any build up of debris that can prevent drainage over the edge, and instead, channel an increasing volume of water to a low spot. See example in the photograph alongside taken on the road network. At the low spot excessive water volume will then over flow to erode the embankment slope, and in a short time cut it back to the road edge. The problem is increased where roads are upgraded by widening.

Where roads are to be reconstructed or widened the road edge drainage should be improved to provide a concrete channel with a rear upstand, a gutter. An example of good practice from the UK Standards for Highways, Construction Details are given below.

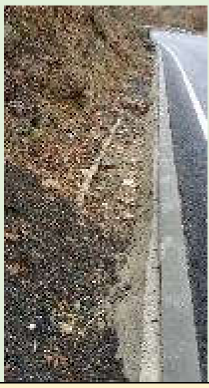


TYPE 23C
(Channel formed on first base layer)



Type 21A (Flexible carriageway).

It is noted that in the Balkans, a standard approach to road edge restraint is to form a 200mm high kerb at the road edge, as a lesser alternative to corrugated beam safeguard railing. A study in the UK likewise showed that a 150mm kerb reduces the incidences of run off accidents. The use of a 200mm kerb upstand in the Type 21A detail above on road embankments, would provide both a climate resilience and a safety improvement for embankments.



Care must be taken in cuttings to ensure that water is not trapped behind the rear of the gutter and that water from the cut slope can reach the gutter. See on the photo alongside how the new gutter is above the toe drain, which should have been raised during the overlay works

Outfalls to the embankment toe will be required at intervals using cascades/spillways (see Measure 3.5) or drop inlets to culvert barrels. Alternatively, on long embankments a carrier drain may be installed with intermittent outlet connections to the road edge.

Policy and Institution

Amend standards to remove over edge drainage on road embankments for certain road classes

Maintenance and Operation

Over edge drainage systems must be regularly maintained by cutting the grass and removing the accumulated debris that can form a dam preventing water flowing off the road pavement if they are to be climate resilient. Regular clearance of the concrete drainage system is to be undertaken
Expertise/Inputs required: Hydrologist to predict flows and Hydraulics expert to design channel flows and outfall frequency.
Resilience Type: Preventative

References

UK Standards for Highways available to use under the Open Government Licence

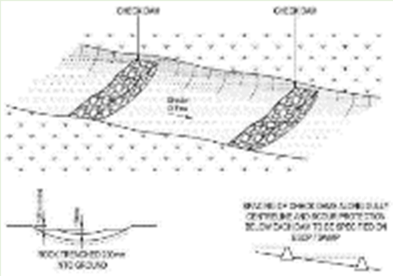
http://www.standardsforhighways.co.uk/ha/standards/mchw/vol3/section1/b_series.pdf

4.3 Scour checks

Scour checks are considered, in ditches, when the longitudinal slopes are steep enough to cause erosion in the natural soils, which is commonly more than about 5%. Scour checks will reduce the speed of the water so as to prevent erosion. They are constructed across the width of the ditch.

SCOUR CHECKS

Technical and Design



Scour checks are provided to open ditches and drains formed on steeper gradients, to prevent the bed of the drain from being eroded. The checks are intended to encourage the deposition of material on the upstream slope. The normal construction is similar to check dams (see Watershed/catchment management - Check dams) using concrete or stone masonry, although tree trunks can also be used.

Drain Gradient (%)	Scour Check spacing (m)
4 or less	Not required
5	20
6	15
7	10
8	8
9	7
10	6

Source: ILO, Building Rural Roads, 2008.

Policy and Institution

To be incorporated into the standards

Maintenance and Operation

Yearly inspections required or after extensive rains

Expertise/Inputs required:

Drainage Engineer

Resilience Type: Preventative

4.4 Cascades/Spillways

Drainage system outfalls may need to traverse down steep slopes of erodible soils e.g. at the cut/fill line; as outfalls for road gutters and the like on embankments; and down or around cutting slopes as outfalls for cut-off drains.

Cascade formed using stepped precast units.

Spillway / Cascade Structures

Reinforced Concrete Spillway to Landslide repair

Cascade using stepped precast units

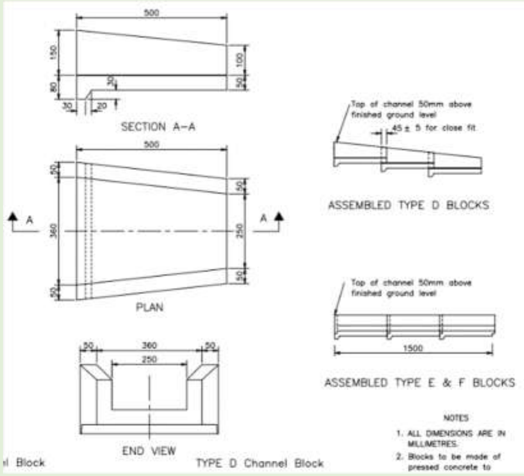
Note that the base of the structure must be protected from erosion both by disruption of the flow in the structure at the toe using baffle blocks or similar, and by erosion protection in the natural ground at the toe as shown.

CASCADES/SPILLWAYS

Technical and Design

Spillways or cascades must be designed to accommodate the volumes of water presented from the outflow of the upstream drainage systems. These systems may be cut-off drains above a cut slope; berm drains on a stepped cut or embankment slope; outflows from a road side gutter or channel drain or similar.

As the cascades or spillways will be typically at a steep gradient the capacity of the inlet works and the outlet at the toe will be the main consideration in assessing the allowable flows. The means of preventing erosion at the toe using baffle blocks, stilling basins and rock armour as shown in the photo above must be carefully considered. Due consideration of the effects of the possibility of flooding and of erosion on the land below the toe. The effectiveness of measures to control erosion and flooding will need to be at their highest for agricultural land or land occupied by buildings



A further concern is the longer term erosion of the materials used to form the spillway or cascade slope. The materials will most commonly will be concrete, either as cast in situ lining to a formed ditch, or as a formed spillway as shown above. Precast units for accommodating outflows from road edge gutters and the like are shown alongside. The drawings are extracted from the Highways England standard construction drawings. Alternatively, grouted rock riprap may be used to form the spillways, using rocks of a size capable of resisting removal by the flow velocities.

Policy and Institution

Incorporate into standards; record all locations in RAMS system

Maintenance and Operation

The spillway or cascade shall be inspected at the same frequency as other drainage structures; The erosion measures at the toe should be inspected during this inspection. Additional damage inspections should be carried out after major storm events.

Expertise/Inputs required:

Hydraulics Engineer; Structural Engineers, Geotechnical Engineer

Resilience Type: Robust Construction

4.5 Erosion protection

Erosion protection is required for different infrastructure elements, that will be exposed to different natural hazards. This could include protection of a slope from flash flood erosion, or protection of an embankment from river erosion, including in the approach to a bridge, or at a stream or river bed of a bridge or a culvert.

Erosion is expected to be a major problem. Flows in streams and rivers may increase as a result of the expected increase in precipitation storm intensity due to climate change. Similarly the river and stream catchments may become less able to retain water flows due to loss of vegetation due to the increased temperature and more frequent drought type conditions predicted.

Measures to prevent increased erosion might be an important adaptation option to climate change particularly in vulnerable locations. Different approaches to erosion protection are set out below, which also overlap with the slope stabilisation measures set out under Category 5.

5 Retaining and façade walls

Retaining walls are used to protect the toe of a slope, as well as being used for river training works. It is important to not only design the wall itself, but ensure appropriate design of the back-of-wall drainage. The use of retaining walls and their design is in common practice in NM.

Retaining walls will mainly be used as a Climate Resilience measure at the toe of an embankment where a major stream of water or a river, flows close by or immediately alongside the road and erosion is a concern due to increased flood flows in the near future.

Retaining walls (typically of concrete) constructed along the road will take the form of a reinforced concrete wall or as an unreinforced (mass) concrete wall. This is an expensive option, especially where large stretches of road have a similar level of vulnerability. Gabion rock mass retaining walls are discussed in 4.2 below.

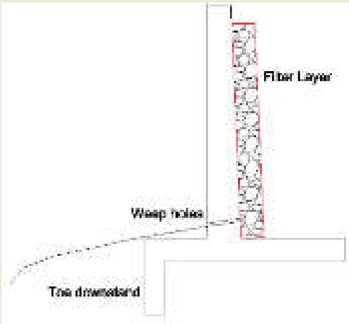
These retaining walls may also be used to support the toe of unstable slopes.

A Façade wall is a wall placed against the side of a usually steep slope to help protect and stabilise the slope but is strong enough to stand up when support is partially lost.

RETAINING WALLS

Technical and Design

Retaining structures will be designed by a competent structural engineer to resist the overturning forces of the supported earth. The design will follow the local codes and standards for NM. Careful design of the foundations and their depth will be required to ensure erosion does not result in toppling of the wall.



The foundations will need to be designed to resist erosion directly, using piles, or a down stand toe and side wall to a spread footing as shown alongside. Alternatively, indirect protection using rock armour, gabion mattresses or similar will be required in front of the wall and over the foundations. See details below.

It is important that provision is made to allow water pressures behind the wall to be dissipated under normal conditions by providing a vertical free draining filter layer behind the wall and adequate weep holes through the wall, again as shown.

Policy and Institution

Location and wall type to be inserted into RAMS

Maintenance and Operation

Yearly inspections to be made to check for erosion in front of, or rotation or sliding of the wall.

Expertise/Inputs required:

Structural Engineer; Hydraulics Engineer to design erosion profile

Resilience Type: Robust construction

FACADE WALLS

Technical and Design

A façade wall is typically a thin wall structure built against a slope face. The slope protected is generally stable. The purpose of the wall is to control surface erosion and protect from shallow slope instability. Such structure structures will be designed by a competent structural engineer to resist the forces of the supported earth. The design will follow the local codes and standards for NM. Careful design of the foundations and their depth will be required to ensure erosion does not result in loss of the foundations.

The walls may be constructed of modular block units or mortared rock masonry. An alternative approach is to construct a framework or grid of reinforced concrete ribs with the natural stable face showing and vegetated

It is important that provision is made to allow water pressures behind the wall to be dissipated. Opening in the blocks or missing out blocks to allow water to dissipate is one option. Alternatively providing a free draining filter layer behind the wall and adequate weep holes through the wall.

Policy and Institution

Location and wall type to be inserted into RAMS

Maintenance and Operation

Yearly inspections to be made to check for erosion or rotation or sliding of the wall.

Expertise/Inputs required:

Structural Engineer; Geotechnical Engineer for slope stability

Resilience Type: Preventative / Robust Construction

5.1 Gabion mattresses and boxes

This includes gabion mattresses, gabion boxes and groynes.

Gabion are rectangular woven or welded wire or geotextile mesh baskets filled with rock to form flexible, permeable, monolithic structures. The boxes are normally one or more 1m sided cubes and can be stacked and constructed as shown below to form a wall retaining structure.

Mattresses are similar in construction and are usually 6m or 3m long by 2m wide and have a thickness of 17cm through to 30cm. Mattresses are used as erosion control measures on their own or in front of gabion basket or other retaining walls.

Gabions can also be constructed in a similar manner to retaining walls, as groyne walls projection out into a river to prevent erosion.

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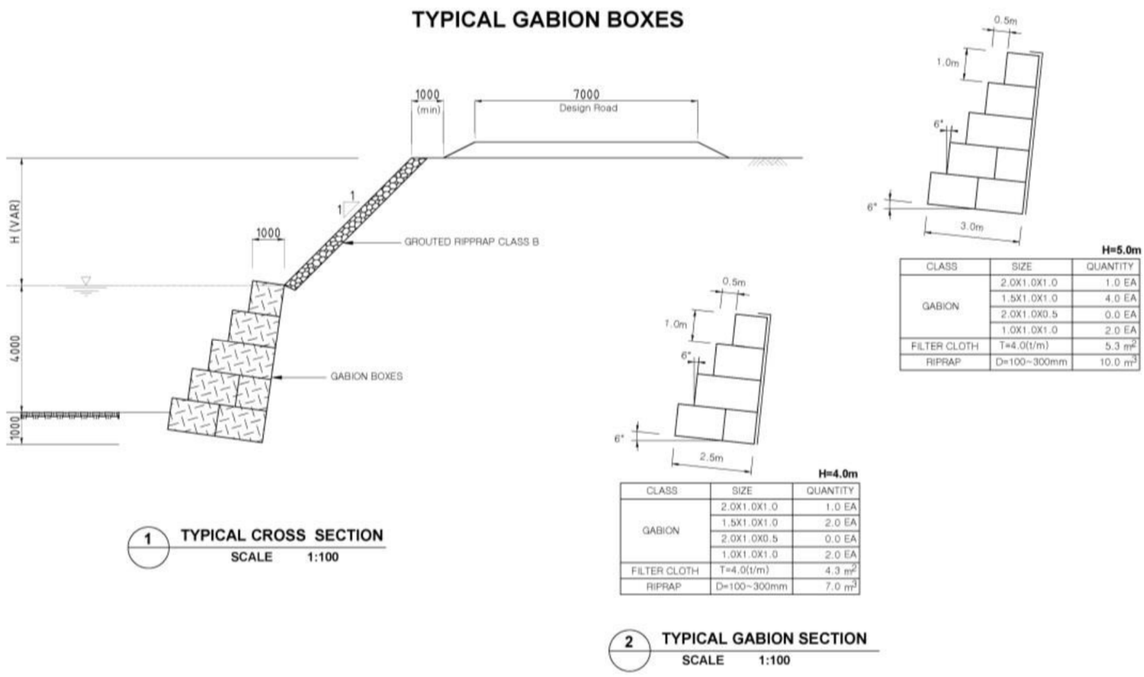


Figure 39 Examples of Gabion Boxes

GABION BOXES AND MATTRESSES

Technical and Design

Gabions mattresses are used in river and stream beds, and on sloped banks to prevent erosion under high flow conditions. Gabion walls are used to support slopes both where a river flows at or near the toe but also in other locations where a retaining structure is required.

Structural design programmes are available from, and specifications for the construction are provided by the manufacturers.

The mattresses are wired together in the river bed using the proprietary wire and fixings provided by the supplier to form continuous mats. Gabion boxes are designed as gravity retaining structures. Again the boxes are wired together with the correct fixings as for mattresses.

They are filled with strong rocks of a minimum dimension and defined shape. A filter fabric designed for the soil material being protected is installed behind the wall and under the mattresses.

Where walls are used to protect a river or stream bank, the wall's foundations can be sunk into the river bed to a depth that is below the predicted scour depth. Alternatively, the wall is constructed on a mattress at or about bed level.

The mattresses then extend out into the river bed a distance in front of the wall to provide the scour protection. The extended length of the mattress or mattresses in front of the wall is calculated based upon the scour depth. The intention is that the ends of the mattresses will sag into the scour hole as it initially forms, to eventual stop the erosion reaching the wall's foundations. Alternatively the mattresses may continue across the stream bed to the opposite side and the supporting gabion wall.

Policy and Institution

Location and wall type to be inserted into RAMS

Maintenance and Operation

Yearly inspections

Expertise/Inputs required:

Hydraulic Engineer; Foundation Engineer; design programme output from the manufactures

Resilience Type: Robust Construction

5.2 Rock protection

This includes rip-rap, grouted rip-rap and rock armour.

ROCK PROTECTION

Technical and Design

Rip-rap is normally used as protection of embankments where water may flow over the surface such as at a culvert inlet or near a stream.

It consists of layer of angular stone about 0.25-0.4 m thick. The stones shall be hard, sound, durable angular field or quarry stones. The stones shall normally have a weight between 10 and 50 kg with shapes to allow for proper placing.

Rip-rap can be used as loose rip-rap where larger stones are placed on the slope and gaps are filled with smaller stones. Cement grouted rip-rap is more durable but is also slightly more expensive to construct.

Grouted rip-rap is rip rap constructed with a cement grout or mortar is placed between the stones. The intention is to leave the stones protruding, not attempt to make a concrete slab.

The surfaces of the stones must be cleaned from adhering dirt and clay before being placed. Grout/mortar shall be applied while the stone is moist and shall be worked into the interstices to fill the voids completely. After placement of the grout/mortar the surface shall thoroughly moistened with clean water after placement and maintained in a moist condition to cure the grout/mortar.

Rock Armour is formed of heavy rocks able to resist being lifted or disrupted by a flow of water over or around them. It will most normally be used on rivers with high velocity flood flows to protect the river banks or bridge piers/foundations. The armour size would require placement my machinery.

Maintenance and Operation

Yearly inspection and after extreme events

Expertise/Inputs required:

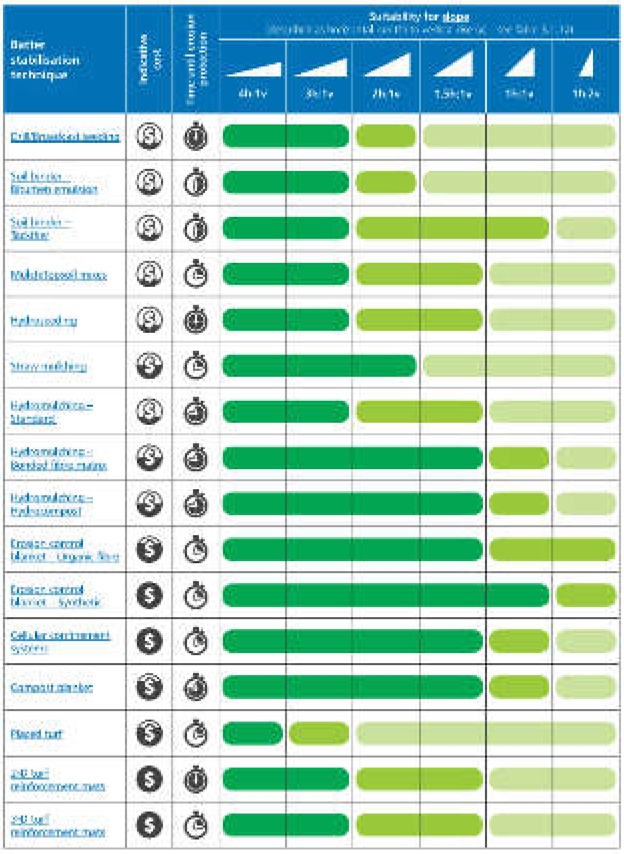
Hydraulic Engineer

Resilience Type: Robust construction

References

5.3 Bioengineering measures

There are a whole range of bioengineering measures which can be used to stabilise slopes and reduce erosion. This ranges from establishment of grass (e.g. hydroseeding or turfing) to more substantial vegetation establishment, such as shrub or tree planting. The aim of bioengineering through vegetation is to both reduce surface run-off as well as to better bind the slope materials together. Bioengineering measures may be used in combination with soil reinforcement and geotextiles (see below).



All slopes should be vegetated as soon as possible after construction to reduce erosion of the surface using grass seeding and maintenance thereafter by watering and cutting. Grass may die in the dry summer season, requiring regular re-seeding. The difference between simple grass seeding bioengineering is the specification and choice of the grass, or other vegetation applied to the slope. Grasses with a deep thick root is a plant for soil erosion control.

The suitability of any slope for Vegetation is dependent upon the steepness of the slope. The table shown is extracted from the document The Guideline for Batter Surface Stabilisation using vegetation published in 2015 by the New South Wales government in Australia. This indicates the difficulties of ensuring that vegetation can be established on steep slopes. The document is also a suitable refence for the vegetation of slopes. https://www.rms.nsw.gov.au/documents/about/environment/guideline-for-batter-surface-stabilisation-using-vegetation.pdf

BIOENGINEERING MEASURES

Technical and Design

All slopes should be vegetated as soon as possible after construction to reduce erosion of the surface using grass seeding and maintenance thereafter by watering and cutting. Grass may die in the dry summer season, requiring regular re-seeding. The difference between simple grass seeding and bioengineering is the specification and choice of the grass, or other vegetation applied to the slope. Grasses with a deep thick root system is the plant to be used for soil erosion control.

One reference document for the subject is the "Roadside Bio-engineering Reference Manual" published by the Department of Roads, Nepal on behalf of the UK Department for International Development and the Government of Nepal. The author John Howell is a recognised expert in bioengineering. Nepal does have some climatic and geological similarities with Macedonia.

In Bioengineering the aim is to create a stable natural vegetation community that uses plants adapted to the environment and climate. An ideal community of grasses scrubs and trees is desired. It has the following features:

Trees that root deeply. However, on slopes trees can surcharge a slope creating instability. Also as the tree canopy establishes it reduces the grasses ability to stabilise the soil by shading out sunlight. Maintenance(pollarding) is required to the trees to reduce problem

Shrubs that have strong woody roots but that are shallower than those of the trees. The shrubs form and understory below the tree canopy

Grasses that are large and clumping to provide a thick surface cover to prevent erosion and have a dense network of fibrous roots.

Bioengineering can be combined with other engineered erosion control measures. By example under Slope protection vegetation and drainage Slope Drainage, angled grass lines can be planted alongside the herringbone drains shown to increase their effectiveness.

The design of bioengineering measures is specific to any slope. The right balance of plants is required such that over time they can be managed to form a balanced community that maintain their desired engineering functions. A lot of work has been undertaken in Asia and especially Nepal. One reference is given below. Many of the plants suggested have similar species that exist in the Mediterranean region. However, the use of imported Asian species, e.g. Bamboo which was imported to many Caribbean island for slope stabilisation, is not recommended.

The species considered in a recent study[1] of soil root reinforcement were Lygeum spartum L. (a perennial herbaceous monocotyledonous), Atriplex halimus L. and Pistacia lentiscus L. (two dicotyledonous shrub species). These show that the root reinforcement exerted by L. spartum is stronger than the reinforcement exerted by P. lentiscus and A. halimus in the upper layers of the soil, while P. lentiscus presents higher reinforcement values in deeper horizons. A. halimus presents lower values than either of the other species studied.

Policy and Institution

Bioengineered slopes to be inserted into the RAMS system along with a maintenance procedure based upon the type of planting carried out.

Maintenance and Operation

Vegetation needs watering and reseeding in the early propagation stage and thereafter cutting twice in the growing season to encourage ground coverage. Thereafter as plants establish, trees should be pollarded to prevent a closed canopy forming and shading out scrubs and grasses and the trees surcharging the slope.
Expertise/Inputs required: Geotechnical Engineer; Bioengineering expert; Environmentalist; Arboriculture expert
Resilience Type: Preventative

<u>References</u>

1 Biotechnical characteristics of root systems of typical Mediterranean species; Plant and Soil Journal Vol. 278, No. 1/2 (December (II) 2005), pp. 23-32

5.4 Slope Stabilisation

Slopes in NM suffer from two different kind of landslide issues. Firstly, slopes need to be stabilised to limit (and limit the impact of) mass movements (slope failure). Secondly, slopes are needed to be stabilised to reduce the risk of rock fall, particularly from steep rock faces. Options for improving the resilience of slopes due to the impact of climate change are described here. Slopes may also be stabilised through incorporating many of the measures set out under Erosion Protection, above. These may include the inclusion of bioengineering measures, retaining walls etc. These measures can both control flood flow and vulnerability, whilst increasing resilience against landslides in slopes.

There are a number of options that can be used in order to increase the stability of a cut slope. These include:

- Flattening slopes
- Benching slopes
- Lowering the water table
- Structural systems such as retaining walls or reinforced slopes.

Changing the geometry of a cut slope is often the first technique considered when looking at improving stability. For flattening a slope, enough right-of-way must be available. the stability in purely dry cohesionless soils depends on the slope angle, while the height of the cut is often the most critical parameter for cohesive soils. Therefore, flattening slopes usually proves most effective for granular soils with a large frictional component. Benching will often prove more effective for cohesive soils. Benching also reduces the amount of exposed face along a slope, thereby reducing erosion. Benching of slopes is used extensively on new roads being constructed in NM, and not just in cohesive soils.

The prevention of water ingress into a slope of soft, or hard fractured material is a significant measure to improve its resilience to near future climate change. Storm events will increase the flows of water able to enter the slopes. However slopes may become less able to resist water flows due to a loss of vegetation as a consequence of the predicted increase in annual temperature and reduced annual precipitation leading to more frequent drought conditions.

The construction of road cuttings with steep side slopes results in the slopes being difficult to re-vegetate. Their instability also requires a greater use of cement based materials such as shotcrete. In recent works on the road network, shotcrete has been commonly used to stabilise steep slopes of friable materials, as well as for fragmented rock faces.

The use of cement based materials in preference to compensating for the loss of vegetation on the original ground surface by using flatter slopes, is to increase the amount of CO^2 emissions of the construction. If the original excavated vegetation was forest the emissions impact is even greater.

To help limit the impact of global warming, one small contribution would be to flatten road cuttings and embankments slopes so that they can be vegetated with a diverse mix of flora that can encourage small fauna and insects and provide environmental benefits, into the future. The reduction in cement usage would be an added initial benefit. The initial economic costs may be greater. Butt the cost of responding to slopes failures and other damages would, in the long term, compensate.

5.5 Cut-off drains

Cut off drains are intended to prevent the water flowing over the ground above the slope from the flowing over the slope face and either eroding or saturating the slope leading to instability. Cut off drains are used to intercept the flows. These could be in the form of a ditch, a swale or bund. It would normally take the form of a sealed ditch. To intercept shallow ground water flows an interceptor filter drain and pipe system can be installed.

A specialised form of cut-off drain is found when a benched side slope exists using a series of berms up the slope. Each berm catches the water flowing over the slope face above. A cut-off drain is required to capture the flow and direct it to an outfall point at the edge of the cut slope.

In reviewing the existing road network a number of locations were viewed where cutting slips have occurred yet there was no evidence of a cut off ditch being visible. It is possible that interceptor drains had been installed below ground but again these were not obvious in the failures. For all new cut slopes, where the land falls towards the top of the cutting, cut off drains, interceptors or berms should be installed with suitable outfalls.

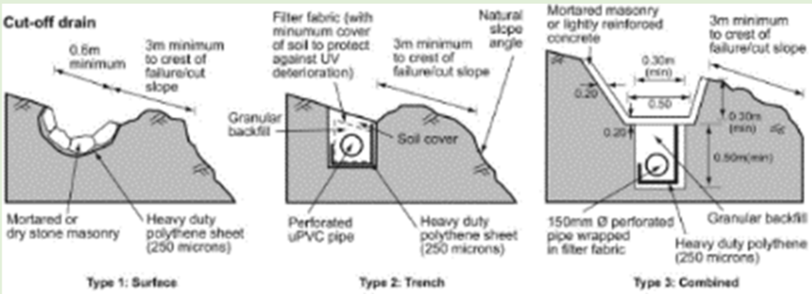
Access to the drain will be required during the construction. However the design must also make provision for adequate future access for maintenance and repair, including heavy equipment, either direct from the road right of way, or through a right of access over adjoining land.

It is important to ensure that the slope drains outfall to the drain that are provided around the slope edge. If this is not possible outfalls, must be provided down the slope face which is less satisfactory

CUT OFF DRAINS TO CUT SLOPES

Technical and Design.

A cut off drain can be formed in a number of ways depending upon the soil conditions, as shown below. A typical approach is to use a ditch profile with a sealed base as type 1. Generally a concrete lining if preferred. In rock material a berm/low dam can be formed to direct the water flow away from the top of the face.



Where it is necessary to intercept groundwater flow as well, a granular filter drain as type 2 or a combination drain as type 3 can be used.

The size of the drain is related to the potential overland flows down the slope from a near future year design storm, uplifted as necessary to consider climate change. Having established the flow to be captured the drain size and type can be established based upon available outlet locations and flow rates in the drain.

The design must make provision for adequate future access for maintenance and repair. The distance from the drain to the right of way fence needs to be of the order of 5m or greater depending upon the slope. This is to allow for the transport and operation of equipment to operate to repair and maintain the drain. In addition access to the right of way at the top of the slope either direct from the road or through a right of access over the adjoining land will be required.

Where a slope's stability is potentially impacted by water ingress the cut off drain must be sealed. Typically this will be by a concrete lining, reinforced to prevent cracking.

Outfalls from the cut off drain can usually be carried down the slope interface towards the cut/fill line

as in the photo. However care must be taken to ensure that any low points in the bench drains profile are designed out or an additional outlet may need to be provided down the slope face.

Such an outlet will need to be formed as a spillway or cascade as

Cascades/Spillways -

Cascades/Spillways. The outfalls for both outlet drains will need to have provision for erosion control e.g. stilling basins at the outlet points.

Policy and Institution

The location and type of all cut off drains and their outfalls, and their means of access, should be recorded in the RAMS system along with a maintenance and inspection schedule.

Maintenance and Operation

Access to the drain is required for inspection and debris clearance on a regular schedule, targeted to be before snow melt and high storm frequencies periods in NM.

Expertise/Inputs required: Hydrologist to establish the design storm and climate uplift; Hydraulic expert to design the drain shape, profile and outfalls. Structural engineer to design spillways and cascades, and drain linings. Geotechnical Engineer to review slope stability under the structures and erosion measures.

Resilience Type: Robust Construction

CUT OFF DRAINS TO CUT SLOPES BENCHES/BERMS

Technical and Design

On the high and steep slopes seen in NM on the existing and especially on new road construction the cut slopes are formed using berms at a regular spacing up the slopes face. The purpose of the berms are to help stabilise the (over) steep slopes and to intercept the surface water flowing down the slopes face.

The photo shows a large and high darker cut face using berms, during construction. Erosion gullies are clearly visible in the cut slope indicating that the berms do not slope towards the cut face.

Drainage of the berms is critical to prevent erosion of the slope face and saturation of the slope material at the back of the berm. With the increased storm intensities related to climate change the potential for slope failures due to water build-up on the berms, is increased.

Berms should be constructed with a backslope to the slope face and a drain provide at the rear to capture and remove the water from the slope.

Access to the drain will be required both during the construction and to make provision for adequate future maintenance and repair. The distance from the drain to the slope edge should to be of the order of 5m or greater. This is to allow for the transport and operation of equipment to repair and maintain the drain.

Outfalls from the cut off drain can usually be carried along the slope interface towards the end of the berm. It is important to ensure, either by the design of the berm or of the drain’s invert, that an adequate fall exists to the outfall point. At either side of the cutting an outfall drain is required to carry the flows to a suitable natural stream or other outlet. This outfall drain needs careful design due to its potential steed gradient. See CUT OFF DRAINS TO CUT SLOPES above

In addition, access to both ends of the berm is required either direct from the road or through access over the adjoining land. On a large slope as shown in the photograph an access road around the periphery of the slope is a necessity for future maintenance.

Policy and Institution

The location and type of all berm drains and their outfalls, and their means of access, should be recorded in the RAMS system along with a maintenance and inspection schedule.

Maintenance and Operation

Access to the drain is required for inspection and debris clearance on a regular schedule, targeted to be before snow melt and high storm frequencies periods in NM.

Expertise/Inputs required: Hydrologist to establish the design storm and climate uplift; Hydraulic expert to design the drain shape, profile and outfalls. Structural engineer to design spillways and cascades, and drain linings. Geotechnical Engineer to review slope stability under the structures and erosion measures.
Resilience Type: Robust construction

5.6 Slope protection vegetation and drainage

The prevention of water ingress into slopes is important. Ingress into slopes can cause a loss of strength in or erosion of the slopes. The increased intensity of storm events due to climate change will increase the frequency of such failures.

Firstly slopes should be vegetated at the earliest possible time following construction and the vegetation then maintained until self-sustaining. This will improve slope stability through the prevention of erosion of the slope surface and assist dewatering of the slope's surface materials. In addition the root structure once established can also increase soil strength and stability.

Slope drainage is normally added to a slope that has shown instability and investigations have identified water ingress into the slopes as being the cause. Other means of water removal may have been omitted at the original construction or provided and failed. The purpose of the drains is as a remedial measure to remove or control the water and lower pore water pressures, especially in clay type soils.

SLOPE VEGETATION

Technical and Design

It is to be noted that the establishment and long term viability of vegetation is more complex and expensive when slopes are steeper than 1 in 2 (V/H). Many of the slopes seen on the road network, both existing or under construction are steeper.

Slopes may be vegetated with a variety of grasses and low scrubs, using varieties and species that are common to the Balkans. The use of deeper rooting grass species along with a mix of other varieties is recommended. The use of trees or deep rooting shrub vegetation can be of benefit and, trees have been used on flatter slopes (see Bioengineering measures. Bioengineering measures). Trees on steep slopes and rock faces should <u>not</u> be used as they can encourage failures. Using a mix of flowering grasses and similar, to form wild habitats on the road side slopes can increase biodiversity and offer environmental benefits.

The near future climate change will cause more severe storm events but the temperature will rise and the overall annual rainfall reduce. This will place the vegetation under stress. It is therefore important that the vegetation is resilient and that the slope of the ground is flat enough the allow precipitation to be captured by the vegetation and the soil, rather than as runoff.

For slopes over 1 in 2 the use of more costly hydra seeding and geotextiles or other means, to stabilise and maintain the young vegetation on the slope will be required. If this is not practicable options such as shotcrete or concrete or similar retaining structures must be used, adding unnecessarily to CO^2 emissions.

Policy and Institution

none

Maintenance and Operation

Regular twice yearly grass cutting in the growing season during the early propagation stages. Thereafter as necessary to ensure sightlines, access to drains etc.

Expertise/Inputs required:

Horticulture specialist and Geotechnical engineer

Resilience Type: Remedial resilience measure

SLOPE DRAINAGE

Technical and Design

Herringbone and slopes drains are commonly inserted into side slopes to reduce the pore pressures in the slopes. The drains are designed to meet the specific requirements of the slope and its stability. See photograph of drains inserted into an unstable slope.

The drains are usually formed in the direction of the slope and may be 600mm or more wide and excavated to a depth appropriate to the problems encountered at the slope. The trenches are filled with a free draining granular material to soak water from the soils. Typically this a 50mm single sized coarse rock or stone grading granular material. If this material is used, the drains can also perform as rock ribs to buttress a slope.

The invert is most commonly formed using an impermeable base material upon which is placed a slotted plastic pipe to extract the water from the fill materials and pass it to the outfall at the base of the slope. It the high point of each of the drain pipes access points should be provided to allow rodding and clearance of the drain pipes.

For further information refer to the available reference document at https://trl.co.uk/sites/default/files/PPR341.pdf

Policy and Institution

The use of slope drainage systems in slopes should be recorded in the RAMS system to enable maintenance to be scheduled

Maintenance and Operation

Maintenance to inspect the satisfactory function of the system and to ensure clearance of the outfalls. Rodding and clearance if the pipes may be necessary on an ad hoc basis. Removal and topping up of the filter material may be necessary if inspections indicate blockage and flows being channelled down the drain surface.

Expertise/Inputs required:

Hydraulics engineer and Geotechnical engineer

Resilience Type: Remedial resilience measure

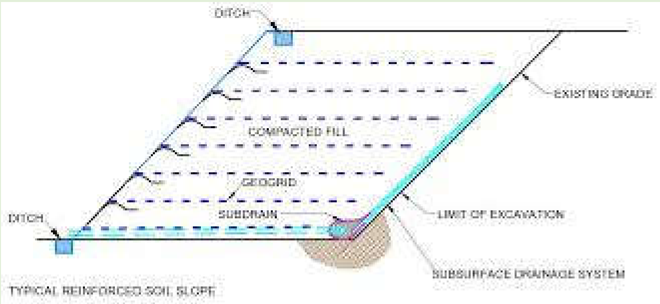
Published Project Report PPR341 Drainage of earthworks slopes TRL UK for the Highways Agency 2008

5.7 Soil reinforcement and geotextiles

This includes a range of measures both to construct artificial slopes and stabilise existing slopes. This will include nailing geotextiles to a slope face.

SOIL REINFORCEMENT

Technical and Design



The construction of new slopes can be reinforced by the use of geotextile layers placed between each layer of compacted material forming the slope. The resulting constructed slope can be used to buttress the base of an existing slope failure. Alternatively it can be used to rebuild an embankment slope where insufficient space exists to provide a natural stables side slope. The slope face should can be vegetated. Alternatively a facia can be provided usually of precast concrete but also metal

Policy and Institution

Location should be recorded in the RAMS system with warnings regarding deeps excavations that may sever the geotextile causing localised failure.

Maintenance and Operation

Once constructed inspections will be required as for any other structure.

Expertise/Inputs required:

Geotechnical Engineer; The design of the slope also requires the expertise of the geotextile manufacturer specifically related to the choice of their materials.

Resilience Type: Robust Construction

GEOTEXTILES

Technical and Design

The construction of new slopes can be reinforced by the use of geotextile layers placed on the surface, and nailed into the slope with soil nails.

In the example shown the geotextile has been overlaid by a wire mesh retained by the nails. Other proprietary systems exist.

The aim of the systems are to stabilise the slope and to prevent erosion of the face until vegetation is established as in the extract.

Maintenance and Operation

Once constructed inspections will be required as for any other structure.

Expertise/Inputs required:

Geotechnical Engineer; The design of the slope also requires the expertise of the geotextile manufacturer specifically related to the choice of their materials.

Resilience Type: Preventative.

5.8 Rock face scaling

NM has considerable lengths of all classes of road that pass through mountainous areas where cuttings are formed of near vertical rock faces. Much of the rock has been fractured due to past tectonic or seismic forces, and has been weathered and weakened by water ingress and freeze thawing cycles.

As a consequences fretting or ravelling of the rock faces is an ongoing maintenance problem requiring clearance of debris from the road. Additionally further weaknesses in the rocks structure can lead to larger rockfalls or slippages, with these commonly reported in the press.

The near future climate change impacts are unpredictable but more extreme freeze thaw events may result as well as higher intensity storm events. These may well increase the frequency and size of the rock falls.

One proactive measure is Rock Face Scaling to reprofile the face by removing potential failures that are present on a slope. Scaling and controlled removal are particularly suited to treating discrete and clearly defined individual potential failures, including ravelling failures. For slopes that have intrinsic large-scale stability problems or numerous discrete potential failures reprofiling is more suited. This reprofiling is not considered as a climate resilience measure

ROCK FACE SCALING

Technical and Design

Scaling involves the removal of superficial, loose or unstable material from rock slopes by either Light Scaling (manually, with hand tools) or Heavy Scaling (power-tools, small explosive charges, excavators). It is possible to remove many potential failures at relatively low cost by scaling. However, the work must be correctly specified and executed as well as supervised by Geotechnical Engineers to prevent creating further instabilities.

Rock face scaling can be undertaken from scaffolding, hydraulic or telescopic boom access platforms, cranes, and by rope access techniques. However, in many locations the use of most of these techniques is not practical due to difficult topography or lack of working space. In such cases rope access techniques may be the only feasible means of access for scaling.

Rope access techniques provide a cost effective and safe means of undertaking scaling work, when carried out properly. All rope access workers should be qualified to the relevant recognised safety standards, for example IRATA (Industrial Rope Access Trade Association) standards or similar.

In many scaling operations it may be necessary to provide some protection or containment measures to prevent falling rock from causing damage to persons or property, for example road surfaces. In many cases this can be achieved using straw bales, balks or sheets of timber, temporary catch fences. Some scaling operations will take place in locations where the quantity of material to be scaled is large, or the locations are within close proximity of persons or property that could be damaged. In these cases scaling will be by controlled removal.

Controlled removal utilises the same techniques discussed above but the main difference is the manner in which the removed mass is lowered in a controlled manner. A typical means of control is the use of rockfall netting as described in Debris and rockfall nettingDebris and rockfall netting Debris and Rockfall Netting. Scaling can be effectively employed to remove unstable material from superficial deposits which typically overlie rockhead. Typically this application will target the larger (>250mm diameter) undermined blocks. Scaling removes existing potential failures, but it may not be a permanent solution as it does not remove the geological controls that have created the potential for failure. Natural weathering and degradation processes will continue to exploit the geological conditions after the scaling operation.

Policy and Institution

Location and physical inspection frequency included in RAMS

Maintenance and Operation

Continued visual inspections at defined frequencies dependent upon face stability. Physical inspections using rope access at 5 year intervals or less as defined by the face stability.

Expertise/Inputs required:

Geotechnical engineer; Trained rope access Operatives

Resilience Type: Reactive, Preventative

5.9 Debris and rockfall netting

One reactive resilience measure is the use of rockfall netting and debris deflectors or catch fencing to retain the lost material on or within the rock face. An additional measure is catch ditches and fencing/walls placed at the cutting base to prevent material falling onto the adjoining road traffic lane. See Debris and rockfall netting below. Both or these measures are in use in NM with debris deflectors used over the tunnel portals on the recently completed (2018) section of the A1 Expressway Upgrade south of Demir Kapija

Other preventative measures consist of retaining the loose material within its original location using sprayed concrete over reinforcing mesh attached to the face (gunite) or for potential larger block failures rock bolts and anchors to physically anchor the blocks to the rock face. See 5.5 and 5.6 below. Gunite has been used across the network and has been extensively used on the recently completed A1 Expressway. Rock bolting was not identified as having been used.

Maintenance measures consist of the regular preventative removal of loose material under controlled conditions, usually by experts using rope access techniques from the top of the cut face and pry bars. See 5.7 scaling. Rockfall patrols and warning system are a final resilience measure under maintenance. See 5.8

The photograph is an indication of a typical problem for roads in North Macedonia's mountainous terrain where fractured rock results in general rock face spalling, and some larger slippages.

This newly rehabilitated road section has dealt with many such locations using rock netting, and here, a catch wall. Under Category 1 above, an option of re-alignment was discussed. This option was used but in a limited way at this location. Any more extensive realignment required a construction permit. The award of a permit was not viable within the construction period. Consideration to the use of realignments needs to be filly considered in the design stage and permits obtained.

ROCK NETTING

Technical and Design

Rock netting is in general use within Macedonia as a means to control the spalling of rock fragments from cut faces from entering the traffic lanes and is successful when correctly installed and used. It does require access to the top of the rock face or ledges thereon. It needs to be attached to solid rock.

It is to be remembered that it cannot prevent wholesale slippage of the rock face itself, as this will commonly undermine the fixings at the top of the slope, see photograph in the introduction above.

The nets need to be designed based upon the anticipated weights of falling rocks and be specified in the designs and technical specifications. The supporting steel cables will need to be sized to carry the combined dead weight of the net and of the rocks contained therein. The rock bolts or anchors and fixings will be designed to carry the cable loads calculated with a safety factor should one cable snap and the load be transferred. The installation of the netting is commonly designed in accordance with the manufacture's recommendations.

To ensure that the retained rock fragments do not overload the cables or eventually migrate onto the road's surface, the removal of the fallen material should be regularly carried out under the road's maintenance inputs. Regular removal can also inform the Network Manager of a potential larger rockfall. See Warning Systems and rockfall patrols under 5.7

Policy and Institution

Location of all installed rock netting incorporated into RAMS system with date of installation.

Maintenance and Operation

Visual inspection for damage to supporting cables and netting annually, or after a major rock fall. Inspections and physical testing of fixings at defined intervals, say 5 years.

Continual removal of rocks from the base of the nets is required under the routine maintenance activities.

Expertise/Inputs required:

Geotechnical engineer; Structural Engineer; Engineer trained in the specification and installation of rock netting

Resilience Type: Reactive, Preventative

ROCK CATCH FENCING
Technical and Design Rock catch fencing is commonly installed at the top of or on sloping rock faces to control rocks sliding or tumbling down the slope/face. As noted one such use is on the slopes above tunnel portals as on the A1 Expressway Upgrade. The fences are essentially the same rock fall netting as above supported on cables strung between steel I sections or posts inserted into the rock slope. As noted in the photograph the cables can be anchored into the rock slope itself to retain their tension and to resist the forces required when the fence is struck. Cables can also act as guy ropes to the supporting posts.  The design is more complex as an estimate must be made of the size and amount of the material to be retained during an event and the dynamic forces that the fence must resist. Two failure modes must be considered. One is that the cables yield tension is exceeded and the second is that the base of the supporting post fails as a plastic hinge. Using the foregoing the energy that the fence can resist can be identified.
Policy and Institution All locations to be included in the RAMS system with date of installation.
Maintenance and Operation Regular visual inspection of the fencing form the road, say weekly, or daily on the A1 tunnels, is required to identify if material has been arrested and how much. Any significant amounts of material captured will need to be removed to ensure that further falls of material do not overload the fence causing it to collapse. All falls should be recorded to identify the potential for a larger instability (see 5.9 Warning Systems)
Expertise/Inputs required: Geotechnical engineer; Structural Engineer; Engineer trained in the specification and installation of rock netting
Resilience Type: Reactive, Preventative

5.10 Catch ditches and fencing/walls

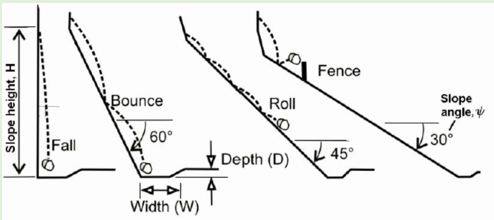
These are complementary measures to debris netting and rockfall netting, installed at the base of a cut slope.

Catch ditches are a space provided between the edge of the road construction and the base of a rock face, excavated to form a depression to 'catch' boulders and the like that fall out of the rock face. Catch fences can be combined with the ditches or used on their own to prevent fallen debris from reaching the road and are similar to Debris Fencing as 5.3 above. Catch walls are similar in purpose and are again set away from the face of the slope.

Alternatively as seen on the network permanent walls using concrete or gabion baskets are constructed at the slope toe, to firstly buttress the toe and are also high enough to catch debris.

CATCH DITCHES AND FENCING/WALLS

Technical and Design



Ideally a wide verge should exist at the base of any slopes. If the slope as the potential for rock falls a catch ditch is installed at the base of the slope between the slope and the road. A catch fence may or may not be installed. A double sided corrugated beam guard rail is one potential form of catch fence which also allows a deeper trench to be used without being a hazard to passing traffic.

If the road has been constructed in sidelong ground and the fill is moisture susceptible the trench should be lined to prevent water ingress into the fill material

Policy and Institution

Amend design standards to include for the provision of Catch Ditches in new roads where exposed rock faces will exist.

Maintenance and Operation

The ditch should be inspected regularly to record rockfalls, say weekly, and to arrange removal for the accumulated debris to avoid the ditch being slowly filled and reducing its catching ability.

Expertise/Inputs required:

Geotechnical Engineer to assess likelihood and type of rockfall; Road engineer to design ditch; Structural Engineer to design fence.

Resilience Type: Reactive; preventative

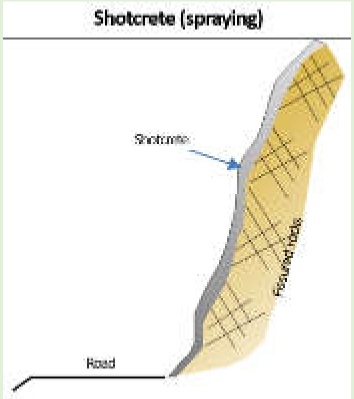
References: TRL UK Published Project Report PPR555; Rock engineering guides to good practice;: rock slope remedial and maintenance works. June 2000 https://trl.co.uk/sites/default/files/PPR555.pdf

5.11 Reinforced sprayed concrete

The use of reinforced sprayed concrete (gunite) is a climate resilience measure to prevent the ingress of water into rock faces. Its use is to limit the weakening effect of water on fractured rock faces and of freeze thaw cycles. It does also have a limited ability to control fretting of a rock face but the reinforcement and therefore the concrete itself is attached to the rock face.

Where a rock face is unstable or is heavily fractured the fixing points may not remain secure in the longer term. Rusting of the fixing points is another potential longer term weakness if water is able to enter in behind the concrete, either at the top or through fractures in the rock face.

It should be restricted to areas where other resilience measures cannot be deployed. This is because this measure is expensive, has a high embodied carbon (carbon emissions required to manufacture the materials used) and is not a flexible and adaptable solution. Its use should ideally be limited to rock faces (e.g. near vertical) that are to be stabilised to reduce rock fall risk.

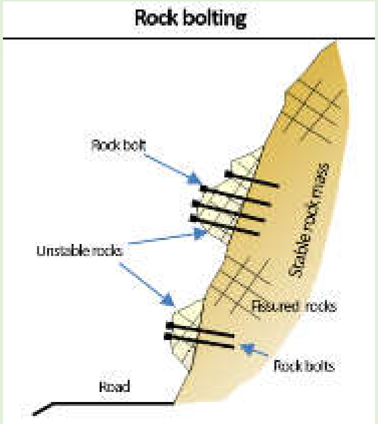
REINFORCED SPRAYED CONCRETE
Technical and Design  The NM standard technical specifications provides guidance the attachment of the reinforcing mesh to the slopes face and the application of the cementitious mix. The thickness is defined and is adequate for the prevention of water penetration to the rock face. An assessment of the rock face is required to establish secure fixing points. The fixing points themselves may need to be strengthened. The use of anchor bolts fixed to the stable points on the rock face may be required rather than the drilled and grouted wire fixings in the technical specifications. A greater spacing of the fixing points may require the thickness of the concrete to be increased to structurally bridge between the points.
Policy and Institution Upgrade the technical specifications to consider thicker layers and higher strength fixings
Maintenance and Operation Annual inspections to assess the structural integrity of the concrete and its fixings
Expertise/Inputs required: Geotechnical Engineer to assess the rock face and identify suitable fixing points; Structural engineer to assess the adequacy or not of the potential fixings and concrete thickness
Resilience Type: Preventative

5.12 Ground anchors and rock bolts

Where the road to be protected is very important, and other works cannot provide enough safety, ground anchors and rock bolts should be considered. Soil and rock anchors are used to apply a stabilising force to the rock face.

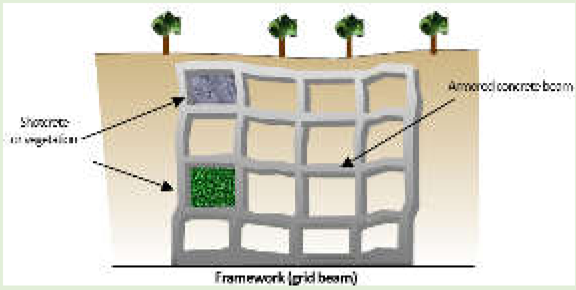
GROUND ANCHORS AND ROCK BOLTS

Technical and Design



Rock bolting is a shallow-fitting method, while ground anchoring is inserted deep into the slope. Rock bolts are applied to stabilize the slope face by exerting a force that compresses the joints and prevents loosening of the rock mass. The figure shows diagrammatically how unstable rock above a road can be stabilised by ground anchors and rock bolts.

Ground anchoring is applied to prevent a rockslide by tension, generally in association with sprayed concrete, or concrete or steel frame works.



Rocks bolts and ground anchors are designed so that the different type of forces acting on the rock structures are transferred as tensile force or comprehensive force or shear forces. Depending to the method of the stress transfer, the design of the anchor are carried out. Three main factors are considered in the design.

- Permissible bond stress between the steel and the grout
- Permissible bond stress between grout and rock
- Permissible tensile stress in the anchor or rock bolt
- Check for dislodging of the rock mass

Fuller details can be found in the Rock Engineering guide referenced below

Policy and Institution

Location of rock anchored or bolted sections included in RAMS

Maintenance and Operation

5 yearly inspections to assess the structural integrity of the fixings

Expertise/Inputs required:

Geotechnical Engineer for anchor locations; Structural Engineer for anchor design and framework design

Resilience Type: Preventative

References: TRL UK Published Project Report PPR555; Rock engineering guides to good practice;: rock slope remedial and maintenance works. June 2000 https://trl.co.uk/sites/default/files/PPR555.pdf.

5.13 Warning systems

Triangular Rockfall hazard signs are currently used to warn the public of the potential rockfall hazard posed by slopes, but are generally ignored.

Reactive warning systems are designed to give some warning of either imminent failures or failures that have just occurred. Warning systems can be set up for individual potential failures, or more widespread potential failures. The systems can consist of instrumented fences, trip wires or motion triggers. The instrumentation could consist of acoustic emission detection devices, accelerometers, extensometers, or electrical wires (to monitor continuity or resistance). Warning systems are usually set up to relay a warning to the manager of a network.

Most rockfall happens instantaneously and thus these warning systems give only minimal warning or reaction time. However they can provide a warning to prevent vehicles from driving into rock fall debris. A warning systems could also be set up to activate traffic signals, variable message signs or 'gates' on the road. This could be particularly important if the failure were on a section of road with poor sightlines.

In general the warning systems currently available are not generally practical or cost-effective. However, they may provide an interim measure while permanent solutions are designed or financed and such systems may prove beneficial for: Very infrequent large potential rockfalls. Rockfalls from large 'sources' above a road (for example natural mountain slopes). Where remedial works or relocation of the road is not practical or feasible.

"Rockfall patrols" can also be used as a 'warning' system. However, this approach may not be cost-effective in the long term. The patrols should be integrated in to larger rock slope management and emergency strategy for the road or section. Material can be removed from the road by the patrol. However the strategy should include that the location and nature of the rockfall should be recorded and passed on to the network manager. Frequently, large rockfalls can be preceded by small and seemingly innocuous failures, therefore the records may possibly give advance warning of active, potential failures.

5.14 Reprofile slope (non-Rock material)

Slope stability can best be improved by changing a slope's profile (supported as required by dewatering and strengthening of its structure – as noted above). A flatter slope will have a reduced risk of slope failure.

The use of berms to stabilise a slope is common practice internationally, but these berms require drainage features that must be maintained in perpetuity but are difficulty to access and costly to maintain. The slope under construction shows erosion down the face due to runoff from the berms indicating their cross-fall slope toward the road. Vegetation would reduce the erosion but on such steep slope would be unlikely to control it in the long term. Although a flatter slope would have taken more land, the potential for slope instabilities and the long-term maintenance costs of the drainage and slippages and their associated potential disruption may make it cost efficient

Flatter slopes are more able to sustain vegetation that will assist in stabilising the slope and resisting erosion, and water ingress. The safe angle of repose for a slope will depend on the weakest soil type in the slope.

REPROFILE SLOPE (NON-ROCK MATERIAL)

Technical and Design

Embankments - Where roads are affected by increased runoff due to climate change, the embankment side slopes should be adjusted from a steeper slope to 1:2 or flatter, to prevent flood damage and erosion from road surface runoff. Adjusting side slopes from 1:2 or less to 1:3 will additionally increase the safety traffic on the road. Similarly cut slopes should be constructed to a stable slope for the materials excavated, see below.

Adjusting side slopes normally requires more land, and if the existing right of way is not sufficient large during the design stage, it might be difficult to acquire additional land. If it is not possible to flatten the slope to 1:2 or better other measures could be considered, such as protection of embankment slopes with geofabrics combined with the removal of over-edge drainage systems.

Cut slopes – All new cut slopes, either for a new road or as a widening of an existing road should have been subjected to comprehensive geotechnical investigations in accordance with EU Codes of Practice. The slope's angle should have been designed for the weakest pre-dominant soil type that is anticipated to be exposed. It should be recognised that the steeper the slope, the more difficult it is to establish the vegetation that acts as a climate resilience measure.

Where an existing cutting has exhibited instability in the past, a long term climate resilience approach is to investigate the full length of the cutting to assess the possibility that flattening the slope which will reduce the instability. A typical example is shown alongside.

The down-hill cut's slope can be readily reduced, or removed completely. The uphill cut slope will however require a more complex solution but the slope could still be improved by flattening.

Policy and Institution

The design standards for slope design (for different soil types) across Macedonia should be reviewed in light of experience of failures and the threat of changes in the climate.

Maintenance and Operation

Inspect annually for erosion and slippages; special inspections after high intensity rainfall events.

Expertise/Inputs required:Geotechnical Engineer

Resilience Type: Robust construction

ROCK SHELTERS

Technical and Design

Rock or avalanche shelters are the final solution for a section of road that cannot be realigned or the rock falls prevented by stabilising the rock face. They are expensive but provide secure protection at the location where they are constructed. The photograph shows a rock shelter provided in the Scottish Highlands, protecting both a railway and a road.

They require that a thorough risk assessment is carried out associated with an economic cost versus benefits assessments to justify the cost. Where budgets are limited there is a need to justify the large expenditure at one location versus the same funds being expended on more cost efficient measures providing protection over a longer length of a road.

Rock sheds are most commonly designed using an almost flat sloping roof supported by columns in the wall furthest from the rock face. Construction is in reinforced concrete or steel with precast concrete beams as one means to construct the roof. The roof is designed to carry the worst case impact at the edge of the roof and must consider the stability of the wall foundations, as these may be founded on the edge of a steep slope or in uncompacted previous slide debris. Most important is a cushioning layer to absorb the impact of a boulder or similar. A gravel layer, which is heavy, or the more expensive alternative of reinforced styro-foam are typically used.

It is necessary to remember that the rock shed will allow debris to pass beyond the road and therefore consideration needs to be given to the impact of these debris. One consequence may be the blockage or diversion of river flows that may create an unintended problem elsewhere on the road.

Policy and Institution

The design standards for rock shelters need to be established or reviewed in NM so as to conform to best current international practice.

Maintenance and Operation

Inspect annually for damage or after exceptional events. Full structural inspection every 5 years

Expertise/Inputs required:

Geotechnical Engineer; Structural Engineer; Rock shed specialist with experience in specification and design or cushioning materials

Resilience Type: Robust construction